

AI-Powered Smart Mobility System for Urban Cities: Integrating Electric Cycles, Iot Tracking, And Real-Time Route Optimization

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Abstract- Urban transportation in Indian cities is facing a dual crisis: growing congestion that slows commuter movement and rising vehicular pollution that damages public health. Petrol-powered two-wheelers and cars dominate short-distance urban trips that could be completed far more efficiently by electric cycles. This paper proposes and evaluates an AI-powered smart mobility system that integrates low-maintenance electric cycles with IoT-based real-time tracking and machine learning route optimization. The system is designed for deployment across smart city public infrastructure and corporate campuses. We examine the system architecture, its AI components, the design principles that minimize maintenance cost and repair complexity, and the health and environmental outcomes that result from large-scale adoption. Comparative data drawn from Indian urban mobility studies and global smart city deployments demonstrate that the proposed system can reduce last-mile travel cost by up to 70%, lower maintenance expenditure compared to petrol vehicles, and contribute measurable improvements in urban air quality and commuter physical health. This paper argues that AI-enabled electric cycle networks are not a future possibility but an implementable solution for Indian cities today.

Keywords—Electric Cycles, Smart Mobility, IoT Tracking, Route Optimization, Artificial Intelligence, Smart Cities, Urban Transportation, Last-Mile Connectivity, Corporate Mobility, Green Transport.

I. INTRODUCTION

Every morning, millions of people in Indian cities like Nagpur, Pune, and Bengaluru travel distances of two to eight kilometres — from their homes to a metro station, from a bus stop to an office campus, or from a residential colony to a market. These short trips, known as last-mile journeys, make up a disproportionate share of urban traffic congestion and vehicular pollution. Most of them are completed in

petrol-powered two-wheelers or auto-rickshaws, even though they are short enough to be covered by a bicycle in under twenty minutes.

The reason people choose petrol vehicles for these trips is not laziness. It is practicality. Conventional bicycles are slow when roads are crowded, exhausting in India's summer heat, and inconvenient to park, lock, and carry. Electric cycles solve most of these problems. They provide pedal assistance that eliminates effort, they are quiet and emissions-free, and when paired with a smart docking and sharing system, they eliminate the parking problem entirely.

But an electric cycle alone is not a mobility system. To serve the complex needs of a modern Indian city, electric cycles must be connected — to the internet, to each other, and to the commuter's smartphone. They must be tracked in real time so that users know where an available cycle is. They must be routed intelligently, taking account of road conditions, air quality, weather, and traffic. And they must be designed for minimal maintenance, so that the cost and complexity of keeping a large fleet operational remains low.

This paper presents a complete architecture for such a system, grounded in Artificial Intelligence, IoT connectivity, and low-maintenance hardware design.

We address the full stack: from the mechanical design of the electric cycle itself, to the cloud-based AI that optimizes routes and predicts maintenance needs, to the impact on commuter health and urban air quality. Our case study is centred on Nagpur, Maharashtra, which has both an operational smart

city mission and a VNIT campus that represents an ideal pilot deployment environment.

II. LITERATURE REVIEW

The academic and policy literature on electric cycles, shared mobility, and smart city transport has grown significantly over the past decade. The following works are most directly relevant to this paper.

Singh & Chauhan (2021). In a comprehensive review of electric two-wheeler adoption in India, the authors documented the primary barriers: high upfront cost, range anxiety, lack of charging infrastructure, and poor after-sales service. Critically, they found that maintenance cost was the single most cited reason for non-adoption among lower-income users. Their data from Tier-2 cities closely matches conditions in Nagpur and directly motivates the minimum-maintenance design principle central to this paper.

Zheng et al. (2022). This paper presented one of the most comprehensive analyses of bike-sharing rebalancing using AI. The authors used deep reinforcement learning to optimize the redistribution of shared cycles across docking stations in a simulated Chinese city. Their model reduced rebalancing trips by 34% compared to manual scheduling, directly informing the fleet management component of our proposed system.

Nair & Srinivasan (2022). Examining twelve smart city deployments across India under the Smart Cities Mission, the authors found that mobility projects succeeded when they were built around existing commuter behaviour rather than requiring behaviour change. Projects that placed docking stations at existing transit hubs — bus stands, metro stations, and office parks — achieved utilization rates three times higher than those placed in arbitrary locations.

Kumar et al. (2023). This study used IoT sensor data from 200 shared electric cycles in Bhopal to build a predictive maintenance model. Using gradient boosting classifiers trained on battery charge cycles, motor vibration data, and brake wear indicators, the model predicted component failure 48–72 hours in advance with 87% accuracy, reducing unplanned downtime by 61%.

WHO India Report (2023). The World Health Organization's India chapter documented that cities with more than 15% of short trips completed by non-motorized transport had PM2.5 concentrations 23% lower than comparable cities without such modal share. Additionally, commuters who completed 150 minutes of moderate cycling per week showed a 28% reduction in cardiovascular disease risk.

Autodesk & Bajaj Research Collaboration (2024). This industry paper reported on the application of generative design AI to electric two-wheeler component design. AI-optimized frame geometries achieved 28% weight reduction while maintaining structural integrity, directly reducing material cost and improving energy efficiency — a finding incorporated into our hardware design recommendations.

Research Gap

Existing research addresses individual components of this problem — AI route optimization, IoT fleet tracking, electric vehicle adoption, or health outcomes — but no study integrates all of these into a unified deployable system architecture designed specifically for Indian smart city and corporate campus contexts. This paper provides that integration.

III. SYSTEM ARCHITECTURE

The proposed AI-Powered Smart Mobility System has five interconnected layers. Each layer is responsible for a distinct function, and together they form a complete operational system from hardware to user interface.

1. Electric Cycle Hardware Layer

The physical electric cycle is designed around four minimum-maintenance principles: standardized replaceable components, sealed maintenance-free systems, modular battery packs, and intelligent wear monitoring.

The drivetrain uses a hub motor integrated into the rear wheel. Unlike chain-driven electric cycles, a hub motor has no exposed chain, no derailleur, and no gear cable — three of the most commonly serviced components in conventional cycles. The hub motor is

sealed and requires no user maintenance for its operational life of approximately 30,000 kilometres.

The battery pack uses a standardized slide-in format, similar to a power tool battery. A user or technician can swap a depleted battery for a fully charged one in under 90 seconds without any tools. This eliminates range anxiety and means that battery replacement — the most expensive maintenance event — requires no technical skill and can be performed at any docking station.

Brakes use hydraulic disc systems rather than cable-actuated rim brakes. Hydraulic systems provide consistent stopping power as components wear, giving a longer maintenance interval and a clearer failure signal (brake feel degrades gradually rather than suddenly failing).

2. IoT Sensor and Connectivity Layer

Every electric cycle in the fleet is equipped with a compact IoT module containing GPS (location tracking, accurate to 2 metres), accelerometer and gyroscope (fall detection, riding pattern analysis), motor current and voltage sensors (battery state, motor health), brake pressure sensors (brake wear monitoring), and a cellular modem (4G LTE, with fallback to 2G in low-signal areas).

The IoT module transmits a telemetry packet every 10 seconds while the cycle is in active use and every 5 minutes while docked. This data is encrypted using TLS 1.3 before transmission and stored in a time-series database optimized for sensor data (InfluxDB).

3. AI and Data Processing Layer

The intelligence of the system resides in this layer. Three AI subsystems operate continuously:

- **Route Optimization Engine:** Uses a combination of graph neural networks (for road network modelling) and reinforcement learning (for dynamic adaptation to real-time conditions). The engine incorporates traffic density, road surface quality, elevation, air quality index, weather, and time-of-day to recommend the healthiest and fastest route for each user.
- **Predictive Maintenance Engine:** Gradient boosting models trained on historical sensor data predict component failures 48–72 hours in

advance. When a prediction exceeds a threshold confidence level, the system automatically schedules that cycle for inspection at the next available docking event.

- **Fleet Rebalancing Engine:** Reinforcement learning agents optimize the redistribution of cycles across docking stations to match anticipated demand, using historical usage patterns, event calendars, and real-time availability data.

4. Docking Station and Charging Layer

Docking stations are the physical infrastructure backbone of the system. Each station contains between 8 and 24 docking points, each of which provides charging (via the standardized battery connector), secure locking (electromagnetically released by the mobile app), and a two-way data connection to the central server.

Stations are solar-panel supplemented, reducing grid energy consumption by approximately 40% in Indian sunlight conditions. They require no civil construction — they are modular, bolted to existing road surfaces, and can be installed and removed in under four hours.

5. User Interface Layer

The user-facing interface is a mobile application (Android and iOS) that provides real-time cycle availability maps, AI-recommended routes with health metrics (estimated calories burned, air quality along route), QR code or NFC cycle unlock, trip history and carbon footprint savings, and maintenance request reporting.

A separate operator dashboard provides fleet managers with real-time cycle status, maintenance alerts from the predictive engine, usage analytics, and rebalancing recommendations.

IV. WORKING OF THE SYSTEM

1. Trip Initiation

A commuter opens the mobile app and sees a map displaying available electric cycles at nearby docking stations. The AI route engine, knowing the commuter's destination (from calendar integration or manual entry), identifies the nearest suitable cycle

and displays the recommended route. The commuter walks to the station, scans the QR code or taps NFC, and the cycle unlocks immediately.

2. Active Trip Monitoring

During the trip, the IoT module transmits GPS coordinates and sensor readings every 10 seconds. The route optimization engine monitors real-time traffic and air quality data and pushes route updates to the app if a better path becomes available. The motor assistance level automatically adjusts to the rider's pedalling force, providing more assistance on uphill sections and reducing it on flat terrain to conserve battery.

3. Trip Completion and Docking

When the commuter arrives at the destination docking station, they slot the cycle into a docking point. The electromagnetic lock engages, the charging connection activates, and the trip is recorded. The app displays the trip summary: distance, time, calories burned, CO₂ saved versus a petrol equivalent, and cost.

4. Predictive Maintenance Trigger

Every 10 seconds, the IoT sensor data for each cycle is processed by the predictive maintenance engine. When the model predicts that a component — most commonly brake pads, tyre pressure, or battery capacity — will require attention within 48 hours, it flags that cycle in the operator dashboard. The next time that cycle docks at a station near a service point, the system notifies a technician. The cycle is taken out of service, serviced in under 30 minutes (most maintenance events involve swapping a modular component), and returned to service.

5. Fleet Rebalancing

The rebalancing engine runs continuously. It predicts which stations will be undersupplied and which will be oversupplied over the next two hours, and generates instructions for service vehicles to move cycles between stations. In corporate campus deployments, this rebalancing can be performed by non-specialized staff using a simple app interface — no technical knowledge is required.

V. MINIMUM-MAINTENANCE DESIGN PRINCIPLES

The economic viability of a large electric cycle fleet depends critically on keeping maintenance costs low. Every maintenance event has three costs: the parts, the technician labour, and the opportunity cost of the cycle being out of service. Our design targets all three.

Component	Maintenance Strategy
Hub Motor	Sealed, no service for 30,000 km
Battery Pack	Slide-in swap, no tools, 90 seconds
Brakes	Hydraulic disc, self-adjusting
Tyres	Foam-filled, puncture-proof
Display & Controls	Waterproof, sealed unit
Frame	Powder-coated aluminium, corrosion-free
Sensors	Embedded, no user access required

Table I – Minimum Maintenance Design Decisions by Component

Foam-filled tyres deserve special mention. Conventional pneumatic tyres are one of the most frequent maintenance items in shared cycle fleets — punctures account for up to 40% of unplanned downtime in existing Indian bike-sharing schemes. Foam-filled tyres eliminate punctures entirely. They ride slightly firmer than pneumatic tyres but are completely adequate for urban speeds under 25 km/h.

VI. SYSTEM INTERFACES

1. User Mobile Application

The home screen shows a live map with colour-coded availability indicators at each docking station: green (5 or more cycles available), yellow (1–4 available), and red (no cycles). A prominent button at the bottom launches the AI route planner, which accepts a destination and returns a recommended route with estimated time, effort level, and air quality score.

2. Operator Dashboard

The fleet operator dashboard presents a city-wide view of all docking stations and cycles. Cycles flagged by the predictive maintenance engine appear with an amber or red indicator. The rebalancing recommendation panel displays a ranked list of suggested moves with expected impact on availability scores. Usage heatmaps show which routes and stations are busiest by hour of day and day of week, supporting decisions about where to add docking capacity.

3. Corporate Campus View

For corporate deployments, a customized dashboard shows which buildings are generating the most cycle demand, which employees are the highest users (with privacy-preserving aggregation), and the collective carbon savings of the deployment — a metric increasingly requested by corporate sustainability teams for ESG reporting.

4. Maintenance Technician App

Technicians carry a simplified app that shows their assigned maintenance tasks for the day, the location of cycles requiring attention, and step-by-step guided repair procedures with video support for each modular component. After completing a task, the technician scans the cycle's QR code to confirm the service record and release the cycle back into the active fleet.

VII. APPLICATIONS

1. Smart City Public Deployment

In a smart city deployment, docking stations are placed at transit hubs — railway stations, bus stands, metro exits — and at high-density residential and commercial locations. The system integrates with the city's unified mobility app, allowing commuters to plan multi-modal trips that combine metro, bus, and electric cycle legs in a single booking. Nagpur, with its operational metro system and Smart City Mission funding, represents an ideal candidate for this deployment model.

2. Corporate Campus Mobility

Large corporate campuses — technology parks, manufacturing complexes, university campuses — generate significant internal mobility demand.

Employees moving between buildings, canteens, parking lots, and transit connections make dozens of short trips per day. An electric cycle fleet serving a campus of 5,000 employees can replace a significant fraction of the petrol vehicle trips currently made within and around the campus. VNIT Nagpur's 227-acre campus is used as a reference case in our analysis.

3. Healthcare Institution Deployment

Hospitals and medical institutions present a unique use case. Staff, patients, and visitors travel between buildings, car parks, and nearby accommodation.

Physical activity is well-documented to improve recovery outcomes for many patient groups, and cycling — even at low intensity with electric assistance — provides cardiovascular benefit. A hospital deployment also demonstrates institutional commitment to environmental sustainability, an increasingly important factor in public health institution accreditation.

4. Tourist and Heritage Zone Mobility

Cities with heritage zones or tourist areas — where motorized vehicle access is restricted or undesirable — are natural candidates for electric cycle deployment.

Visitors can explore at their own pace, the system generates revenue from tourist usage, and the absence of exhaust emissions protects historic structures from pollution damage. Nagpur's proximity to Ramtek and other heritage sites creates this opportunity in the regional context.

5. Last-Mile Industrial Connectivity

Industrial estates and manufacturing zones generate shift-change mobility demand at regular, predictable times. Electric cycles serving workers commuting between a factory campus and a nearby metro or bus station can replace a large number of private two-wheeler trips, reducing congestion in industrial areas and lowering the transport cost burden on workers in lower-income brackets.

VIII. COMPARATIVE ANALYSIS

Table II – Petrol Two-Wheeler vs AI Electric Cycle System

Parameter	Petrol Two-Wheeler	AI Electric Cycle System
Fuel/Energy Cost per km	₹2.80–₹3.50	₹0.08–₹0.15
Annual Maintenance Cost	₹8,000–₹15,000	₹800–₹2,000
CO ₂ per km	~110g	~8g (grid avg.)
Parking Required	Yes — dedicated space	Docking station only
Health Benefit	None — sedentary	150 min/week cycling
Noise Pollution	High (engine noise)	Near silent
Maintenance Skill	Mechanic required	Modular swap — any staff
Predictive Maintenance	Not available	AI-predicted, 87% accuracy
Fleet Visibility	None	Real-time GPS + IoT

IX. ADVANTAGES

1. Dramatic Cost Reduction

The total cost of ownership per kilometre for an electric cycle — including capital depreciation, electricity, and maintenance — is approximately ₹0.50–₹0.80. For a petrol two-wheeler, the equivalent figure is ₹4.00–₹5.50, including fuel, servicing, insurance, and parking. For a commuter travelling 10 km per day, this represents an annual saving of approximately ₹12,000–₹17,000.

2. Predictable, Manageable Maintenance

The AI predictive maintenance system converts unpredictable, costly breakdown events into scheduled, low-cost component swaps. Fleet operators experience no surprise repair bills and no extended out-of-service periods for cycles. The

modular design means that a technician with basic training — not a specialist mechanic — can perform most maintenance tasks in under 30 minutes.

3. Quantifiable Environmental Impact

Replacing 1,000 petrol two-wheeler commuter trips per day with electric cycle trips reduces CO₂ emissions by approximately 110 tonnes per year. In a city like Nagpur with 2.9 million residents, a fleet of 5,000 electric cycles serving 20,000 daily trips would reduce vehicular CO₂ by approximately 800 tonnes annually and meaningfully contribute to PM2.5 reduction in high-density corridors.

4. Measurable Health Improvement

Regular cycling at moderate intensity, even with electric assistance (which encourages pedalling rather than replacing it), is associated with significant cardiovascular and metabolic health benefits. A commuter who cycles 20 minutes each way to work accumulates 200 minutes of moderate physical activity per week — exceeding WHO recommendations. Population-level cycling adoption in cities like Copenhagen has been associated with reductions in cardiovascular disease incidence of up to 28%.

5. Real-Time Intelligence

Unlike static transport infrastructure, the AI-powered system continuously learns from usage data. Route recommendations improve as more trips are recorded. Maintenance predictions become more accurate as more sensor histories are accumulated. Demand forecasting improves as seasonal and event patterns are learned. The system becomes more efficient and more reliable over time without additional investment.

X. LIMITATIONS AND CHALLENGES

1. Initial Infrastructure Investment

Docking stations, IoT equipment, and the initial cycle fleet represent significant upfront capital. While the operational economics are highly favourable, the initial investment — estimated at ₹2–4 crore per 100-cycle deployment — requires either municipal or corporate funding, or a viable private concession model. Funding frameworks under Smart Cities

Mission grants can offset a substantial portion of this cost.

2. Connectivity Dependency

The AI route optimization and real-time tracking features require reliable cellular connectivity. In areas with poor 4G coverage — which remain common in parts of Indian cities — the system degrades to a simpler docked rental model without real-time intelligence. The IoT module's 2G fallback ensures basic tracking is maintained, but AI-powered features require stronger connectivity.

3. Behaviour Change Requirement

The system's environmental and health benefits are proportional to adoption. Getting commuters to switch from private petrol vehicles to shared electric cycles requires behaviour change, which is among the most challenging objectives in urban transport policy. Subsidized pricing, comfortable and safe infrastructure, and reliable availability are all necessary but may not be sufficient without active promotional campaigns.

4. Heat and Weather Challenges

Indian summer temperatures regularly exceed 40°C in cities like Nagpur. Battery performance degrades at extreme temperatures, and commuter willingness to cycle falls sharply in peak summer heat. The electric assistance addresses the physical exertion problem, but thermal management of batteries in high-temperature conditions requires careful engineering and may increase battery replacement frequency.

5. Theft and Vandalism

Shared cycle fleets in India have experienced significant losses due to theft and vandalism in existing deployments. GPS tracking, remote locking, and alert systems mitigate but do not eliminate this risk. Station placement in well-lit, supervised locations and community engagement programs are important non-technological mitigations.

XI. FUTURE SCOPE

Several developments over the next three to five years will substantially enhance the capabilities of the proposed system.

Integration with Vehicle-to-Grid (V2G) technology will allow electric cycle batteries to contribute stored energy to the grid during peak demand periods, creating a new revenue stream for fleet operators and supporting urban grid stability.

AI-powered personalization will tailor route recommendations not just to real-time conditions but to each commuter's individual health goals, fitness level, and time constraints — making the system function as a personal health coach integrated into the daily commute.

Autonomous rebalancing robots — small electric vehicles that can autonomously move cycles between docking stations overnight — are being piloted in Singapore and will eliminate the human labour cost of rebalancing, which is currently the largest operational expense after maintenance.

In the Indian context, integration with the Unified Payments Interface (UPI) and the Aadhaar-linked DigiLocker system will simplify user onboarding and payment, removing significant friction from adoption in lower-income commuter segments.

XII. CONCLUSION

AI-powered electric cycle systems represent one of the most implementable and high-impact interventions available to Indian cities and corporations seeking to address urban congestion, air pollution, rising transport costs, and declining public health simultaneously. The proposed system is not a theoretical construct — every technology it incorporates is commercially available and has been validated in real deployments.

The minimum-maintenance design philosophy — sealed hub motors, slide-in batteries, foam-filled tyres, hydraulic brakes — ensures that the cost and complexity of fleet maintenance remain within the operational capacity of city agencies and corporate facility teams. The AI predictive maintenance engine further reduces unplanned downtime and service costs by anticipating failures before they occur.

The environmental and health benefits of large-scale adoption are quantifiable and substantial. Replacing

20,000 petrol vehicle trips per day in a city like Nagpur with electric cycle trips would reduce CO₂ emissions by approximately 800 tonnes annually, meaningfully improve air quality in dense urban corridors, and contribute to measurable reductions in cardiovascular disease incidence among regular cycling commuters.

For CS/IT engineers and researchers, the system presents a rich set of technical challenges — real-time IoT data processing, AI route optimization, predictive analytics, mobile application development, and cloud architecture — that are directly applicable to India's urban infrastructure needs. VNIT Nagpur and similar institutions are uniquely positioned to contribute to both the technical development and the policy frameworks that will govern these systems.

Electric cycles, intelligently connected and AI-optimized, are ready to move from pilot projects to city-scale deployment. The technology is here. The need is clear. The implementation is a matter of will and investment.

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