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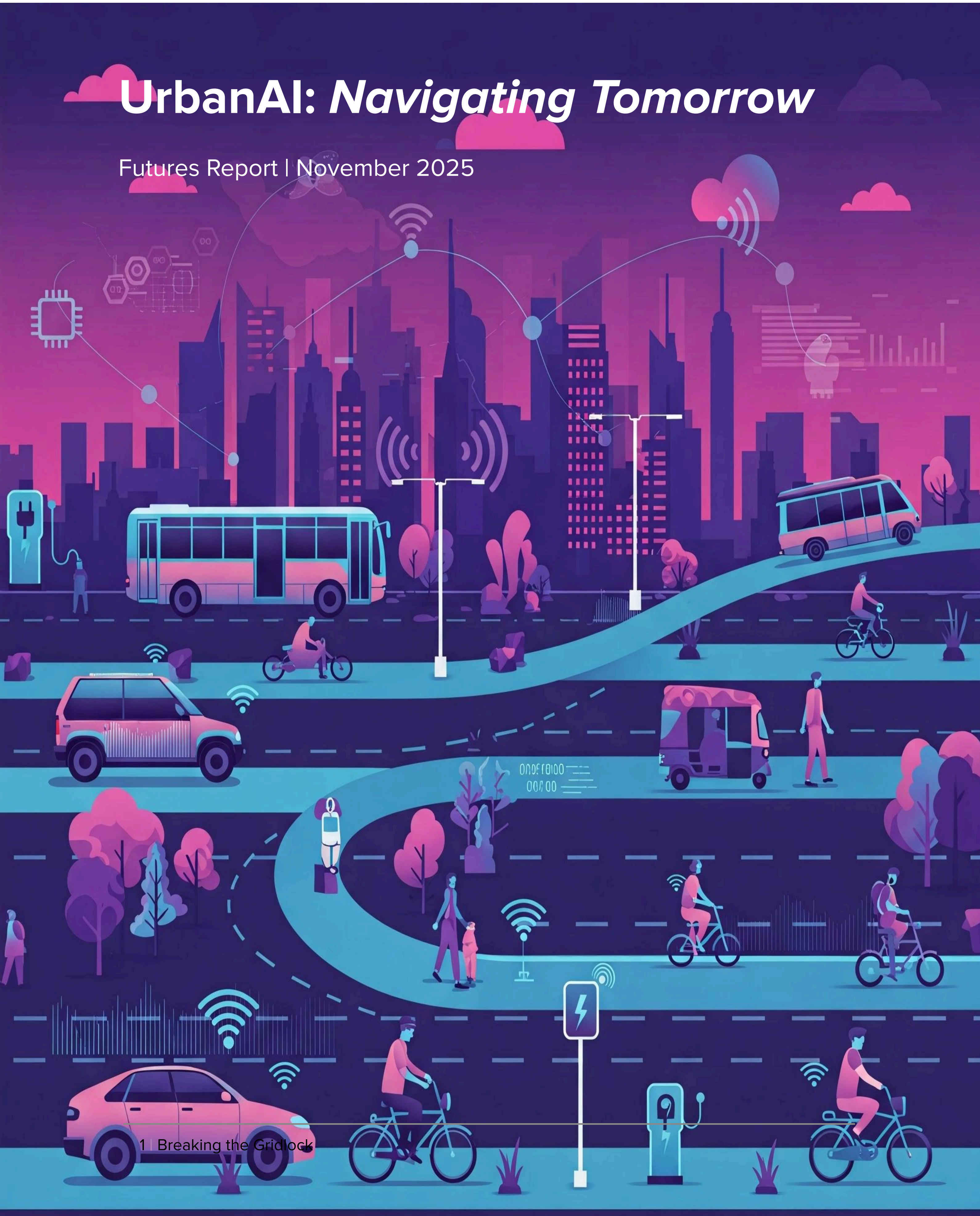
UrbanAI: *Navigating Tomorrow*

Futures Report | November 2025



UrbanAI: Navigating Tomorrow

November 2025

A Futures Report By

ITS India Forum & OMI Foundation Trust

President’s Message

Akhilesh Srivastava
President,
ITS India Forum

As India rapidly urbanizes and aspires to achieve the vision of *Viksit Bharat@2047*, the need for smarter, more adaptive, and sustainable mobility systems has never been more urgent. The convergence of artificial intelligence (AI), digital infrastructure, and urban mobility offers an extraordinary opportunity to reimagine the future of transportation - not as a reactive system, but as an intelligent, proactive, and human-centric network.

Artificial Intelligence has the potential to fundamentally transform how our cities move. From managing complex traffic patterns and optimizing public transport to dynamically guiding electric vehicle charging and congestion pricing, AI presents solutions that are not only efficient but equitable, sustainable, and scalable. However, unlocking this potential requires a clear, data-driven roadmap grounded in both theoretical insight and practical application.

In this context, the Futures Report, ***“UrbanAI: Navigating Tomorrow”***, by **ITS India Forum** and **OMI Foundation**, provides a comprehensive framework to understand how AI can address India's most pressing urban mobility challenges from traffic congestion and EV charging bottlenecks to infrastructure misallocation and behavioral inefficiencies. The report combines global case studies, deep theoretical perspectives, and a strong focus on India’s unique context to deliver actionable insights for policymakers, city leaders, and the mobility ecosystem.

At ITS India Forum, we are deeply committed to fostering intelligent, inclusive, and sustainable transportation systems. We believe in the power of collaboration among government, industry, academia, and civil society to shape the next generation of urban mobility. This report echoes our core philosophy of leveraging innovation to solve real-world problems at scale. It urges all stakeholders to adopt AI not as an experimental add-on but as a strategic pillar in shaping India’s mobility future. Let this report guide cities in piloting new ideas, shaping ethical AI frameworks, and institutionalizing smarter planning practices. Together, let us build a future where Indian cities move smarter, cleaner, and faster - powered by intelligence, governed by equity, and inspired by innovation.

Foreword

Dr R.S.Sharma IAS (Retd.)
Former Chairman, TRAI
Govt. of India

The 21st century belongs to nations that can harness the power of data, digital public infrastructure, and intelligent systems to drive inclusive growth. India has already demonstrated global leadership in digital transformation, through Aadhaar, UPI, CoWIN, and the broader Digital India architecture, establishing that technology, when designed as a public good, can dramatically improve service delivery at population scale.

Urban mobility stands at a similar inflection point. Rapid urbanization has strained transport systems, resulting in congestion, pollution, inequitable access, and economic inefficiencies. Incremental reforms will no longer suffice. What we now require is a system that is predictive rather than reactive, intelligent rather than manual, and citizen-centric rather than infrastructure-centric. Artificial Intelligence offers precisely that opportunity.

This Futures Report, ***UrbanAI: Navigating Tomorrow***, by ITS India Forum and OMI Foundation, presents a meticulous and forward-looking roadmap on how AI can transform India's urban transport, from managing complex traffic flows and optimizing public bus operations to dynamic EV charging and congestion pricing.

From TRAI's experience, one of the greatest enablers of technological innovation is interoperability and open, transparent systems. The mobility ecosystem must evolve in the same direction - open data standards, transparency in algorithms, citizen privacy protection, and accountability in automated decision-making. AI in mobility should not only improve efficiency but also reinforce trust.

I commend the ITS India Forum and OMI Foundation for spearheading this effort. I hope this report serves as an important reference for policymakers and administrators as India builds the next generation of urban mobility - data-driven, AI-enabled, and citizen-first

Foreword

Shri Giridhar Aramane, IAS (Retd.)
Former Secretary, Defence and Ministry of Road Transport and Highways.
Govt. of India

Cities today are at the centre of India's economic and social dynamism. But as they expand, the pressure on transport systems has grown faster than conventional planning or manual management can respond. Congestion, pollution, and safety concerns are symptoms of a deeper issue: our mobility systems must evolve from fragmented and reactive operations to coordinated, data-led, and citizen-oriented services. Artificial Intelligence offers a pathway to that evolution.

This Futures Report, ***UrbanAI: Navigating Tomorrow***, recognises that the future of mobility cannot rely solely on building more roads or deploying more vehicles. It requires intelligent systems that help authorities anticipate demand, prevent incidents, manage traffic in real time, and optimise the use of existing infrastructure. By illustrating applications such as adaptive signal control, multimodal integration, smart EV charging, and risk-based enforcement, the report shows how AI can support better decisions at every level - from a traffic junction to a state-wide transit network.

India has already made significant strides in creating digital public infrastructure for transport. Platforms for vehicle registration, licensing, enforcement, payments, and data collection have laid the groundwork for the next phase - predictive analytics and AI-driven planning. Capacity building in government agencies, data standards, cybersecurity safeguards, institutional coordination, and responsible governance will be equally important to ensure that these systems are trustworthy and inclusive.

I congratulate the ITS India Forum and the OMI Foundation for producing a report that brings clarity, realism, and forward-thinking into a complex subject. Its insights can help administrators, planners, and technologists moving beyond pilots toward solutions that achieve scale, reliability, and measurable public impact.

Foreword

Shri Rohit Kumar Singh IAS (Retd.)
Former Secretary, Ministry of Consumer Affairs; and Member, National Consumer Dispute Redressal Commission Govt. of India

A well-functioning mobility system is one of the most visible demonstrations of good governance. When roads are safe, transport is reliable, and information is accessible, people experience the state as responsive and accountable. Conversely, when congestion, accidents, pollution, and unpredictability dominate daily travel, citizens bear the cost in time, money, safety, and opportunity. The growing scale of Indian cities demands solutions that are faster, smarter, and rooted in evidence rather than intuition. Artificial Intelligence offers that capability.

The Futures Report, ***UrbanAI: Navigating Tomorrow***, demonstrates how AI-enabled forecasting, real-time traffic intelligence, and data-driven decision-making can bring transparency and predictability to urban transport. It outlines practical pathways to improve buses, metros, last-mile connectivity, and EV charging networks - solutions that can immediately enhance daily mobility for millions.

A key strength of this report is its focus on responsible adoption — from secure data use to transparent system design. As AI becomes embedded in mobility, citizen trust will depend on privacy, equity, and accountability being built into every layer of implementation.

India has demonstrated that technological transformation is possible at national scale when backed by strong digital infrastructure and well-defined public policy. Urban mobility is ready for such a transition. The insights in this report will be valuable to administrators, transport departments, researchers, and innovators working to build cities where every journey is safer, cleaner, and more dignified.

I commend the ITS India Forum and the OMI Foundation for advancing a forward-looking and actionable vision for AI in mobility. The recommendations presented here can help convert innovation into impact and ensure that technology ultimately serves the people it is intended to empower.

Foreword

Abhijeet Sinha
Technocrat - Ease of Doing Business;
Program Director - National Highways for Electric Vehicles (NHEV);
President - Charge Point Operators Society of India (CPOS India)

As India accelerates towards its vision of **Viksit Bharat@2047**, the vision of Common, Connected, Convenient, Congestion-free, Charged, Clean, and Cutting-edge mobility given by our Hon'ble Prime Minister is no longer a distant dream - it is becoming an urgent necessity. Future Mobility is set to become the intersection of digitisation, electrification, and clean energy infrastructure to realise the Viksit Bharat National Masterplan Ambition to achieve a single-digit GDP spent on logistics and reduced oil imports through decarbonisation of surface transport.

At **Ease of Doing Business** and through emerging tech-pilot projects like **National Highway for EV (NHEV)**, **AI Driving Score for All**, we are building a facilitation desk for extending the ease of Artificial Intelligence in 20 microeconomies and sectors for faster adoption of AI in urban landscape.

This future-ready, data-driven, and evidence-based 'Facilitator' is democratising the future regulator in this space. AI is poised to play a transformative role - from real-time inputs for urban infrastructure and mobility planning, opening an unprecedented opportunity to redesign our transport networks, not just as systems of convenience but as engines of economic growth, social equity, and environmental stewardship.

At this juncture, I extend my heartfelt appreciation to **ITS India Forum**, and **OMI Foundation** for their initiative in developing the report, ***"UrbanAI: Navigating Tomorrow"***. This comprehensive study thoughtfully blends global benchmarks with India-specific challenges, offering a pragmatic roadmap for leveraging AI in addressing urban transport bottlenecks, reducing congestion, optimizing resources, and ensuring equitable access to mobility solutions.

This report strongly resonates with our ongoing emerging-tech pilots under **Ease of Doing Business** focused on the adoption of new technologies for public good, where we are building *Single Window Clearance for green infrastructure projects, integrating AI using geospatial intelligence for transparent project qualification, and catalysing faster, credible climate financing*.

"UrbanAI: Navigating Tomorrow" should serve as both a strategic guide and a moral imperative for urban planners, city administrators, policymakers, and mobility innovators. It challenges us to embrace AI not as an auxiliary tool, but as a central pillar in building a cleaner, smarter, and more adaptive urban India.

Foreword

Ambassador (Retd.) Gautam Bambawale
Managing Trustee,
OMI Foundation

Harish Abichandani
First Trustee,
OMI Foundation

Artificial Intelligence is no longer an abstract technological promise; it is fast becoming a foundational layer in how cities function, how people move, and how societies plan for the future. Nowhere is this more urgent or full of possibility than in India's urban transport systems, which must serve a population that is young, mobile, and increasingly digital.

UrbanAI: Navigating Tomorrow by **OMI Foundation** and **ITS India Forum** is our response to this opportunity. It presents a clear, evidence-based case for embedding AI into the fabric of India's urban mobility ecosystem. From predictive congestion monitoring and adaptive traffic control to demand-responsive electric bus fleets and AI-optimised EV charging, this report offers a roadmap for integrating intelligence into urban infrastructure, ethically, equitably, and at scale.

What makes this effort distinctive is its convergence of national ambition with actionable insight. The report draws from real-world use cases in India and globally, and is anchored in the enabling policy environment created by the IndiaAI Mission, the PM e-Bus Sewa, PM e-DRIVE, MAHA EV (ANRF), and Digital India. It recommends how these initiatives can go further, thereby leveraging AI not only for operational efficiency, but also to drive sustainability, fairness, and public trust.

We thank all the collaborators, contributors, and reviewers who shaped this publication. We hope it will serve as a strategic resource for policymakers, industry leaders, researchers, and innovators seeking to build the next generation of urban mobility - one that is intelligent by design, and equitable by intent.

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Executive Summary

India stands at a critical inflection point in shaping the future of urban mobility. With rapid urbanization, increasing vehicle congestion, and rising energy demands, the country must leapfrog traditional transport models to embrace artificial intelligence (AI)-driven mobility solutions. AI has the potential to fundamentally transform how cities manage traffic, optimize public transport, and integrate electric vehicle (EV) charging infrastructure. By leveraging AI, India can not only solve its own mobility inefficiencies but also position itself as a global leader in smart mobility solutions, exporting AI-driven urban transport innovations to emerging economies worldwide.

The Need for AI in India's Urban Mobility

India's urban mobility system faces significant challenges, including:

- Severe traffic congestion exacerbated by counterintuitive phenomena like Braess's Paradox, where adding road capacity often worsens traffic (Zhuang et al., 2022).
- Inefficient public transport operations, with issues such as bus bunching reducing reliability and accessibility (Yang et al., 2024).
- EV charging station bottlenecks, driven by range anxiety, peak-hour clustering, and inadequate predictive charging infrastructure (Cox Automotive., 2024).
- Suboptimal traffic management due to static congestion pricing, uncoordinated vehicle movements, and human-driven inefficiencies (Tools of Change., 2025).

Traditional approaches - such as infrastructure expansion and manual traffic control - are insufficient in addressing these dynamic, real-time challenges. AI-driven solutions offer an alternative approach by enabling predictive modeling, real-time decision-making, and network-wide optimization, improving efficiency while ensuring sustainability (Gheorghe & Soica, 2025).

Methodology: A Multi-Pronged Approach to AI in Urban Mobility

This study employs a multi-pronged methodology that integrates theoretical analysis, case studies, and policy evaluation to assess AI's transformative role in urban mobility. The research begins by identifying key mobility challenges - traffic congestion, bus bunching, EV charging station bottlenecks, and road-use inefficiencies - through the lens of complex systems theory, network optimization, and behavioral economics. The study applies theoretical frameworks such as Braess's Paradox to examine counterintuitive traffic dynamics, while prospect theory informs how AI can be leveraged to nudge user behavior toward more efficient transport choices.

To ground the analysis in real-world applications, the report conducts a comparative case study approach, evaluating AI-driven urban mobility interventions in Singapore, Stockholm, Los Angeles, and Shanghai, alongside early AI adoption efforts in Bengaluru, Pune, and Delhi-NCR. Case studies were selected based on three primary criteria: pioneering AI implementation, relevance to Indian mobility challenges, and scalability across multiple urban contexts. The report synthesizes insights from public datasets, government policy reports, industry whitepapers, and AI-driven mobility trials, incorporating real-time traffic data and public transit analytics where available. AI-based interventions are evaluated based on effectiveness (reducing congestion and improving efficiency), scalability (adaptability across cities), cost-effectiveness (investment vs. long-term savings), and social impact (ensuring accessibility and equity in transport solutions). This methodology ensures that findings are both analytically rigorous and practically actionable, offering policymakers and industry leaders a data-driven roadmap for scaling AI-powered mobility solutions in India.

AI-Powered Urban Mobility Solutions

This report outlines five key areas where AI can revolutionize urban mobility:

1. AI for Smarter Infrastructure Planning

- ➢ AI-driven traffic simulations and predictive modeling can prevent infrastructure misinvestments and optimize road network designs before construction.
- ➢ Braess's Paradox-informed AI models ensure that road expansions reduce, rather than induce, congestion.
- ➢ AI-powered demand-responsive transit planning improves urban transport scalability and efficiency.

2. AI-Optimized Public Transport Systems

- ➢ AI-based real-time bus coordination can prevent bus bunching, improving public transit reliability.
- ➢ AI-powered passenger load balancing can distribute ridership evenly, reducing overcrowding on select routes.
- ➢ Blockchain for accountability ensures transparent fare calculation and seamless multi-operator transit integration.

3. AI-Driven Traffic Flow Optimization

- ➢ Vehicle platooning (coordinated driving through AI-powered connectivity) reduces phantom traffic jams and stabilizes urban road speeds.
- ➢ AI-enabled dynamic traffic signal control can adapt in real-time, prioritizing public transport and reducing idling times.
- ➢ AI-assisted lane discipline enforcement improves road capacity without requiring physical expansion.

4. AI for EV Charging Optimization

- ➢ AI-based predictive demand forecasting prevents peak-hour congestion at charging stations.
- ➢ Dynamic pricing models incentivize off-peak charging, balancing grid loads and reducing wait times.

- ➢ AI-powered smart routing guides EV users to the nearest available charging point, reducing unnecessary clustering.

5. AI-Enabled Dynamic Tolling & Congestion Pricing

- ➢ Real-time AI-driven congestion pricing adjusts tolls based on traffic density, discouraging peak-hour congestion.
- ➢ AI-optimized alternative route incentives nudge drivers towards underutilized roads, reducing bottlenecks.
- ➢ AI-assisted equitable tolling mechanisms ensure congestion pricing does not disproportionately impact low-income commuters.

The India Opportunity: AI as a Growth Driver

AI-driven mobility solutions align with India's strategic ambitions in smart cities, digital transformation, and clean mobility. Flagship initiatives such as the India AI Mission, Smart Cities Mission, and Digital India have already emphasized AI's role in urban governance, providing a strong policy foundation for AI-integrated mobility systems. Further, India's leadership in digital payments and mobility platforms (e.g., UPI, NCMC, and Mobility-as-a-Service models) makes AI adoption more feasible than in many other developing nations (NITI Aayog, 2018).

If India prioritizes AI-enabled mobility, it can:

- ➢ Reduce congestion and improve urban livability.
- ➢ Enhance transport efficiency and sustainability.
- ➢ Export AI-based urban mobility models to other developing nations.
- ➢ Foster domestic innovation and attract investment in AI-driven transport solutions.

Challenges & Considerations

Despite its potential, AI deployment in urban mobility faces significant challenges such as high infrastructure and data costs, regulatory and ethical concerns, and public adoption barriers. AI implementation requires advanced data collection networks, high computing power, and skilled personnel. AI-driven pricing and vehicle coordination must prioritize equity, ensuring that low-income populations are not disproportionately affected. Many AI-driven interventions, such as dynamic congestion pricing or AI-guided lane management, require behavioral adaptation and trust in automated systems (Makanadar & Shahane, 2024; Bamney & Ramadurai, 2025; ITS India Forum, 2025).

Overall, AI in India's Urban Mobility requires a concerted effort, and cohesive and ambitious policy and regulatory push for India to fully harness its potential. This includes strengthening data governance frameworks, ensuring interoperability across AI-driven transport systems, building public trust through transparent AI decision-making, and fostering cross-sector collaboration between government, industry, and research institutions. Without a strategic, well-coordinated approach, AI in urban mobility risks being fragmented, underutilized, or even counterproductive, failing to deliver the efficiency, equity, and sustainability benefits it promises (Makanadar & Shahane, 2024; IndiaAI, 2025).

Strengthening India's AI-Powered Mobility Future: A Roadmap for Action

This report outlines a structured roadmap to scale AI-based urban mobility solutions in India. To fully leverage AI's potential, the following steps are crucial:

1. Investing in AI-Integrated Transport Infrastructure

AI-driven infrastructure can dramatically improve mobility efficiency by optimizing real-time traffic flows, enhancing public transit reliability, and reducing bottlenecks (Agrahari et al., 2024; Wu et al., 2022) .

- **Adaptive Traffic Control Systems:** AI-powered traffic signals can dynamically adjust based on real-time congestion, prioritizing public transport and emergency vehicles.
- **Predictive Congestion Monitoring:** AI models can detect traffic buildup before it worsens, enabling proactive rerouting and congestion pricing strategies.
- **AI-Augmented Traffic Enforcement:** Smart AI cameras can enhance road safety by detecting violations such as lane indiscipline, over-speeding, and signal jumping.
- **Urban Mobility Digital Twins:** AI-based digital replicas of city transport networks can simulate different policy interventions before real-world implementation, reducing costly mistakes in urban planning.

2. Developing Policy Frameworks for AI-Based Congestion Pricing, EV Charging, and Platooning Regulations

AI-driven mobility solutions require clear legal and regulatory frameworks to guide their responsible deployment (Rauf et al., 2024).

- **AI-Based Congestion Pricing:** India must establish legal mechanisms for dynamic tolling, ensuring pricing structures remain fair while discouraging excessive road congestion.
- **EV Charging Optimization Regulations:** AI can dynamically allocate charging slots, predict demand, and optimize charging loads, but regulations are needed to manage data privacy, price fluctuations, and interoperability across charging networks.
- **Platooning Regulations:** AI-enabled vehicle platooning (where multiple vehicles drive in synchronized formations to reduce congestion and fuel consumption) needs a regulatory framework for V2V (vehicle-to-vehicle) communication and liability definitions in case of system failures.

3. Encouraging Public-Private Collaboration for AI-Driven Urban Mobility Pilots

- **Real-World Testing:** AI-powered mobility innovations require real-world testing in Indian cities before full-scale adoption. Governments should incentivize AI pilot programs through collaborations with startups, technology firms, and academic institutions (Invest India, 2024).

- **Testing Zones:** Live testing zones (such as AI-driven congestion pricing or AI-powered transit optimization in select cities across the country) can provide valuable insights into AI's effectiveness in Indian conditions (Krishnamurthy & Srikanteswaran, 2024).
- **Green Incentives:** Private players (including ride-hailing platforms, public transit agencies, and EV fleet operators) should be incentivized to adopt AI-driven fleet management, smart routing, and predictive maintenance technologies.

4. Establishing Ethical AI Principles to Prevent Bias & Ensure Fairness in AI-Based Transit Decisions

AI systems must be designed with fairness, inclusivity, and accountability to prevent bias and unintended social inequalities in transportation access (Numalis, 2025b, U.S. Department of Transportation, 2024).

- **Algorithmic Transparency:** AI models used for pricing, traffic control, and public transit decisions must be explainable, ensuring they do not disadvantage lower-income communities or marginalized regions.
- **Equity in Mobility Access:** AI-based congestion pricing should ensure that public transport remains affordable, preventing lower-income commuters from being disproportionately affected.
- **Privacy Protection:** AI-powered transport monitoring systems must have robust data privacy safeguards to prevent misuse of real-time movement data.
- **Regulatory Oversight:** Governments should establish AI ethics committees in transport ministries to review AI deployment and ensure fairness in urban mobility applications.

The Road Ahead

Through a blend of theoretical insights and real-world applications, this report offers a roadmap for leveraging emerging technologies to transform urban mobility. In particular, India's push toward smart mobility aligns with major government initiatives such as the IndiaAI Mission, Digital India, and Ease of Living and Mobility mission among others. These policies already emphasize the need for AI-enabled transport solutions, and this report directly contributes to that vision by identifying practical AI applications for urban transformation.

Indeed, AI offers an unprecedented opportunity to make urban mobility smarter, more efficient, and equitable. While challenges exist, thoughtfully designed AI implementations - informed by behavioral insights, predictive analytics, real-time data integration, and cross-sector collaborations - can reshape urban transportation for the better. By leading in AI-based transportation innovation, India has the potential to set global benchmarks, attract investment, and create a new paradigm for intelligent, sustainable urban mobility. The time to act is now - embracing AI in mobility will not only address existing challenges but will also propel India to the forefront of the future mobility revolution.


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1. Introduction

Urban mobility systems worldwide are undergoing a technological transformation, with artificial intelligence (AI) emerging as a game-changer in addressing persistent challenges such as congestion, inefficiencies in public transport, and infrastructure bottlenecks. Cities have long struggled with counterintuitive traffic patterns, operational breakdowns in transit systems, and the increasing complexity of electric vehicle (EV) adoption. Traditional solutions often fail to provide the adaptability and predictive capability needed to manage these evolving demands. AI offers a paradigm shift - one that goes beyond incremental fixes and instead enables dynamic, data-driven decision-making for smoother, more resilient, and sustainable mobility networks (Mirindi, 2024).

1.1. The Transformative Potential of AI in Urban Mobility

The evolution of urban mobility has been shaped by successive technological revolutions, from the advent of mechanized transport to the rise of electrification and automation. As we enter the era of artificial intelligence (AI)-driven mobility, urban transportation systems stand at the precipice of a paradigm shift. Traditional models of urban mobility planning, grounded in static optimization and infrastructure expansion, have proven inadequate in addressing the dynamic, complex, and non-linear challenges of contemporary cities. AI, with its predictive capabilities, real-time decision-making, and capacity for holistic system optimization, presents an unprecedented opportunity to redefine mobility governance and operational efficiency.

1.2. Theoretical Foundations: A Shift from Static to Adaptive Mobility Systems

The theoretical underpinnings of AI-driven mobility transformation are drawn from complex systems theory, behavioral economics, and network optimization principles. Classical urban transport models have often relied on equilibrium-based frameworks, such as Wardrop's Principles of Traffic Equilibrium (Wardrop, 1952), which assume rational agent behavior in route selection. However, real-world urban mobility is fraught with counterintuitive phenomena, such as Braess's Paradox, where adding infrastructure can exacerbate congestion (Zhuang et al., 2022). AI-driven modeling, informed by reinforcement learning and agent-based simulations, offers an adaptive alternative to traditional optimization methods by accounting for non-linear feedback loops, stochastic demand fluctuations, and emergent behavioral patterns (Divasson-J. et al., 2025).

Moreover, concepts from behavioral economics, such as prospect theory, illuminate how AI-driven interventions can nudge mobility users toward more efficient, sustainable, and equitable choices (Kahneman & Tversky, 1979). AI-enabled traffic management, for example, does not merely redistribute vehicular flow but optimizes signal timing and congestion pricing dynamically, reducing systemic inefficiencies. These AI-driven systems are particularly relevant in dense urban environments, where small shifts in behavior can lead to substantial improvements in mobility outcomes.

1.3. The India Opportunity: A Leapfrog Moment in AI-Driven Mobility

For India, the integration of artificial intelligence (AI) into urban mobility presents a strategic inflection point. As the world's most populous nation and a rapidly urbanizing economy, India faces acute mobility challenges - ranging from severe congestion and air pollution to inequitable access to transport infrastructure. However, these challenges also offer a unique opportunity to leapfrog traditional mobility models and pioneer AI-driven urban transport solutions tailored to India's socio-economic and infrastructural realities.

Several government initiatives have already acknowledged AI's role in shaping future mobility ecosystems. The India AI Mission aims to harness AI's transformative potential across key sectors, including smart cities and mobility. Simultaneously, the Digital India program is focused on expanding nationwide digital infrastructure, which serves as a critical enabler for AI-powered mobility solutions by improving data access, real-time analytics, and intelligent decision-making. Additionally, the Smart Cities Mission has laid the groundwork for AI-driven urban transportation, with pilot projects in select cities deploying AI-based traffic monitoring, predictive public transit scheduling, and real-time congestion management. These policies collectively create an enabling environment for India to become a global leader in AI-powered urban transportation, fostering both technological development and regulatory innovations (NITI Aayog, 2018).

India is also making significant strides toward AI-integrated electric mobility solutions. The PM e-DRIVE initiative and PM eBus Sewa Scheme (Ministry of Heavy Industries), along with the Mission for Advancement in High-impact Areas (MAHA EV) under the Anusandhan National Research Foundation (ANRF), are driving India's EV adoption and charging infrastructure expansion. These programs present a significant opportunity to integrate AI-driven solutions, such as predictive charging demand management, grid optimization, and autonomous fleet coordination, to improve efficiency and scalability. AI-powered energy management systems can optimize charging station distribution, prevent grid overloads, and enable real-time dynamic pricing for better load balancing. As India continues to invest in its EV ecosystem, embedding AI within these policies can enhance operational efficiencies, improve accessibility, and ensure seamless electric vehicle integration into urban mobility networks (IndiaAI, 2025).

Further advancing digital and AI-driven mobility, India is pioneering the National Digital Twin Initiative, which seeks to develop high-fidelity digital replicas of physical infrastructure for advanced urban planning and real-time mobility simulations. By integrating AI with digital twins, urban planners can predict congestion patterns, optimize multimodal transport networks, and improve emergency response coordination. Additionally, the Gati Shakti National Master Plan provides a multi-modal infrastructure framework, where AI-powered predictive analytics and digital twins can revolutionize strategic mobility planning.

Moreover, the National Common Mobility Card (NCMC) initiative is expanding India's seamless digital payment ecosystem across mobility services, presenting an opportunity for AI-driven fare optimization, congestion-based dynamic pricing, and multimodal transit planning. These advancements, combined with AI-powered mobility-as-a-service (MaaS) platforms, could enhance last-mile connectivity, reduce travel costs, and improve transport accessibility for millions.

While these initiatives demonstrate India's growing commitment to AI in urban mobility, a cohesive policy framework is needed to bridge regulatory gaps, ensure interoperability across AI-powered mobility systems, and establish clear governance mechanisms for AI-driven decision-making. Developing AI governance frameworks, promoting open mobility data ecosystems, and incentivizing AI-driven transport innovations will be crucial in positioning India as a global leader in AI-enabled mobility transformation.

1.4. Challenges and Considerations in AI-Driven Mobility Adoption

Despite its potential, AI-driven mobility faces several challenges. Data availability, interoperability, and governance remain key concerns, as the effectiveness of AI solutions hinges on access to high-quality, real-time transport data. Ensuring robust cybersecurity measures and privacy safeguards is essential in building public trust and preventing misuse of mobility data. Furthermore, AI-based transportation systems must be designed to ensure equity and inclusivity - an area of particular concern in the Indian context, where socio-economic disparities often dictate access to transport services (Servou et al., 2023).

Algorithmic bias is another challenge, as AI models trained on incomplete or skewed datasets can reinforce existing inequalities in transportation access. Addressing these risks requires strong policy frameworks, ethical AI guidelines, and regulatory oversight, ensuring that AI-driven mobility solutions enhance accessibility rather than exacerbate disparities (Sood, 2022).

1.5. Structure of This Report

This report examines the intersection of AI and urban mobility, providing a structured analysis of key challenges, technological advancements, and policy considerations. The report is organized as follows.

- **Section 1: Introduction:** Provides an overview of AI's transformative potential in mobility, the current policy landscape, and the strategic importance of AI adoption in India's urban transport sector.
- **Section 2: Methodology:** Outlines the research approach, theoretical foundations, case study selection, data sources, and evaluation criteria used to assess AI-driven mobility solutions.
- **Section 3: AI for Infrastructure Planning:** Examines how AI can optimize urban mobility infrastructure, with a focus on adaptive traffic control, congestion mitigation, and the role of AI-powered digital twins in transport planning.
- **Section 4: AI for Public Transport Optimization:** Discusses AI applications in bus scheduling, demand-responsive transit, and predictive maintenance to enhance service reliability and passenger experience.
- **Section 5: AI for Traffic Flow Optimization:** Analyzes AI-driven solutions to manage congestion, reduce stop-and-go traffic, and implement vehicle platooning strategies.

- ➢ **Section 6: AI for EV Charging Optimization:** Explores AI's role in improving EV charging efficiency through predictive demand management, dynamic pricing, and vehicle-to-grid (V2G) integration.
- ➢ **Section 7: AI for Dynamic Road Demand Management:** Investigates AI-powered congestion pricing, smart tolling, and demand-responsive road usage policies to optimize urban mobility.
- ➢ **Section 8: Limitations of AI in Urban Mobility:** Highlights key challenges such as data privacy, algorithmic bias, infrastructure constraints, and governance gaps that must be addressed for responsible AI deployment.
- ➢ **Section 9: Policy Recommendations and Way Forward:** Presents a roadmap for scaling AI-driven mobility solutions in India, emphasizing investment in AI-integrated infrastructure, regulatory frameworks, public-private partnerships, and ethical AI deployment.

By integrating theoretical insights with practical applications, this report aims to provide a comprehensive blueprint for AI-driven urban mobility in India. The findings underscore the imperative of proactive AI adoption - not merely as an enhancement to existing mobility systems but as a fundamental reimagining of how cities move, interact, and evolve in the digital age. AI has the potential to create smarter, more inclusive, and sustainable urban mobility networks, positioning India as a leader in global mobility innovation.

2. Methodology

2.1. Research Approach and Theoretical Foundations

This study adopts a multi-pronged research approach to examine the intersection of artificial intelligence (AI) and urban mobility, integrating theoretical perspectives, case study analysis, and data-driven policy recommendations. Given the complex and evolving nature of AI applications in mobility, this report employs an interdisciplinary framework, drawing on principles from complex systems theory, behavioral economics, and network optimization. These theoretical underpinnings inform the analytical methods used to evaluate AI's role in addressing urban transportation challenges.

2.2. Identification of Core Urban Mobility Challenges

The report begins by identifying core urban mobility challenges, including traffic congestion, bus bunching, and inefficiencies in electric vehicle (EV) charging infrastructure. The selection of these challenges is based on their widespread prevalence in global and Indian cities, their economic and environmental impacts, and their suitability for AI-driven interventions. The study employs transport network modeling and real-world data analysis to assess how AI can mitigate these issues. Theoretical constructs, such as Wardrop's Principles of Traffic Equilibrium and Braess's Paradox, provide critical insights into the counterintuitive effects of infrastructure expansion and traffic flow adjustments. AI's ability to leverage real-time data analytics and predictive modeling offers a dynamic alternative to traditional static transport models.

2.3. Case Study Selection Criteria

A rigorous case study selection process was undertaken to ensure relevance, scalability, and applicability to India's urban mobility ecosystem. Cities such as Singapore, Stockholm, and Los Angeles were chosen for their pioneering implementation of AI-driven congestion pricing, traffic signal optimization, and public transit scheduling. These examples provide empirical evidence of AI's potential to enhance mobility systems. Additionally, case studies from Karnataka, Tamil Nadu, and Telangana were included to reflect the early adoption of AI in Indian smart city initiatives. These regions among others provide key lessons on how AI-driven mobility interventions can be adapted to the socio-economic and infrastructural conditions of Indian urban centers. Scalability and replicability were central criteria in selecting these case studies, ensuring that the insights derived can inform broader national policy frameworks.

2.4. Data Sources and Analytical Framework

The report synthesizes a diverse range of data sources, including public datasets, academic research papers, government policy documents, and AI-driven mobility experiments. To the extent possible, real-time traffic data and public transit system reports were incorporated to validate AI intervention models. This approach allows for a more grounded assessment of AI's effectiveness in real-world conditions. Additionally, transport simulation models were employed to test the viability of AI-powered solutions under various urban congestion scenarios. The evaluation framework aligns with existing AI governance principles, ensuring that findings contribute to ongoing discussions on responsible AI deployment in mobility.

2.5. Evaluation Criteria for AI-Driven Mobility Solutions

AI-driven mobility interventions were assessed using a set of evaluative criteria, including effectiveness, scalability, cost implications, and social and environmental impact. Effectiveness was measured in terms of congestion reduction, improvements in transit efficiency, and enhanced service reliability. Scalability was considered from the perspective of replicability across urban centers with diverse mobility landscapes. Cost implications were examined by comparing upfront AI deployment investments with long-term operational savings. Social and environmental impacts were evaluated by considering factors such as accessibility, equity, and sustainability. These criteria ensure a holistic evaluation of AI's role in urban mobility transformation.

2.6. Limitations and Considerations

Recognizing the evolving nature of AI technologies, the study also acknowledges the limitations and considerations associated with AI-driven mobility interventions. Challenges such as algorithmic bias, public resistance, regulatory constraints, and privacy concerns require careful navigation. AI models, particularly those dependent on machine learning, can exhibit biases based on the quality and diversity of training datasets, necessitating continuous monitoring and corrective measures. Public acceptance of AI-driven transport solutions remains a significant factor, influenced by trust in automation, data privacy protections, and the transparency of AI decision-making processes. Additionally, regulatory and institutional readiness will play a crucial role in determining the pace and scope of AI adoption in India's mobility sector.

2.7. Path Forward: Research and Policy Alignment

While this report provides actionable insights into AI's transformative potential in urban mobility, it emphasizes the need for further on-ground piloting and policy alignment. AI deployment in mobility requires iterative testing and stakeholder collaboration to refine strategies and mitigate potential risks. Future research should explore AI-human interaction in mobility ecosystems, ethical considerations in AI-driven transport governance, and adaptive regulatory frameworks that balance innovation with public interest safeguards. By integrating these considerations, India can leverage AI as a catalyst for a more intelligent, efficient, and inclusive urban transport landscape.

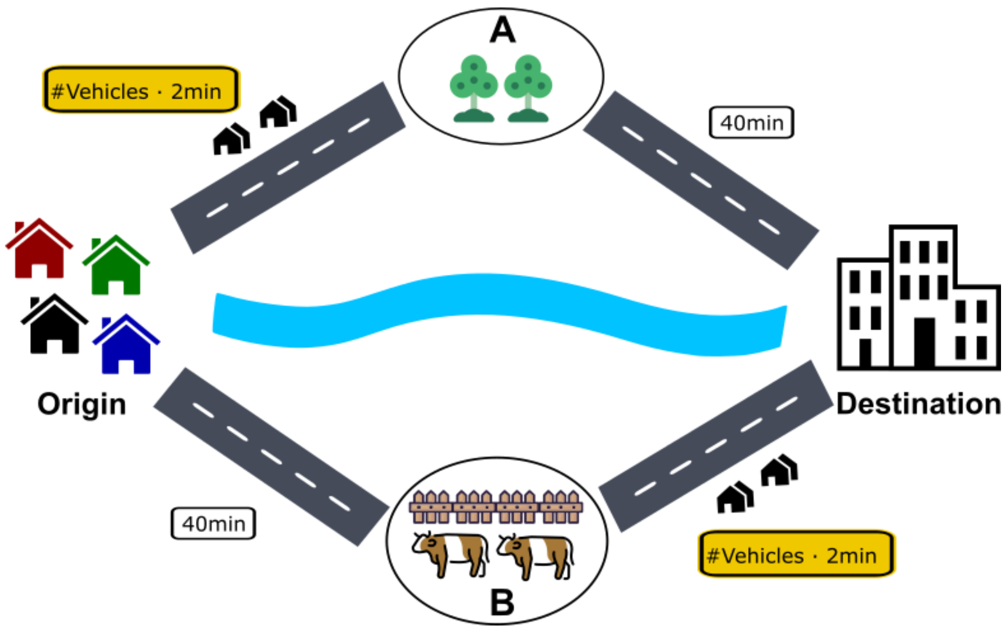
3. AI for Infrastructure Planning

3.1. Understanding Braess's Paradox in Urban Traffic

Braess' Paradox highlights a counterintuitive phenomenon in network theory, where adding a new route to a traffic network can lead to increased overall congestion. This occurs because individuals acting in their own best interest may inadvertently worsen conditions for everyone, demonstrating the complexities of optimizing shared systems. Initially observed in traffic flow, the paradox applies broadly to other networks, including communication and logistics, emphasizing the importance of holistic planning over isolated improvements (Pigou, 2017; Tumer & Wolpert, 2002).

3.1.1. Braess' Paradox: A Traffic Dilemma

Figure 1 | Model City Network Depicting Two Routes from Origin to Destination.



Braess' Paradox demonstrates a counterintuitive phenomenon in traffic networks, where adding a new, seemingly faster route can actually increase overall travel times for everyone. Consider a simplified road network where 20 drivers need to travel from an origin to a destination. Initially, the network consists of four roads forming two possible routes:

- Route A: Through the forest (Origin → A → Destination)
- Route B: Through the cattle farm (Origin → B → Destination)

In this system, two types of roads are present:

- Yellow roads: The travel time depends on traffic volume. The time to traverse these roads is 2× the number of drivers (in minutes).
- White roads: Multi-lane expressways with a fixed travel time of 40 minutes, unaffected by congestion.

3.1.2. Initial Equilibrium

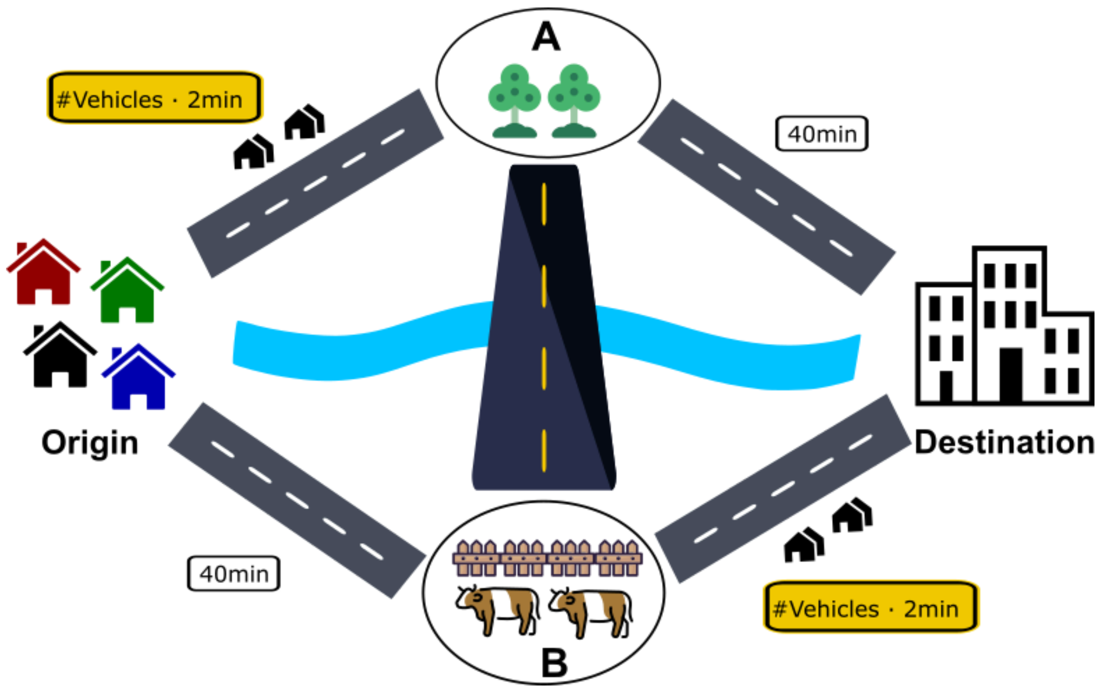
In the original setup, the equilibrium condition is when drivers evenly split between the two routes:

- ➢ For Route A (Origin → A → Destination), 10 drivers take 10 × 2 = 20 minutes on the yellow road (Origin → A) and 40 minutes on the white road (A → Destination). The total travel time is 20+40=60 minutes.
- ➢ For Route B (Origin → B → Destination), 10 drivers take 10 × 2 = 20 minutes on the yellow road (B → Destination) and 40 minutes on the white road (Origin → B). The total travel time is also 20+40=60 minutes.

Since both routes take the same time, no driver has an incentive to switch, resulting in a Nash equilibrium.

3.1.3. Introducing a New Road

Figure 2 | Integration of New Express Highway into City Road Network.



Now, imagine adding a new road directly connecting A (forest) and B (cattle farm). This road has an extremely short travel time, effectively 0 minutes relative to the other roads. This creates a new possible route: Origin → A → B → Destination.

Initially, a driver taking this new route might experience a significant time savings. For instance, consider one driver switching from Origin → A → Destination to Origin → A → B → Destination if 10 drivers still use Origin → A and 11 now use B → Destination, the travel time for the new route becomes:

- ➢ 10×2=20 minutes for Origin → A.
- ➢ 11×2=22 minutes for B → Destination.

The total travel time is 20+22=42 minutes, which is much faster than the original 60 minutes.

3.1.4. Rising Congestion

As more drivers switch to the new route, congestion worsens. When 15 drivers use the new route (Origin → A → B → Destination), the travel time becomes:

- 15×2=30 minutes for Origin → A.
- 15×2=30 minutes for B → Destination.

The total travel time is 30+30=60minutes.

Meanwhile, the drivers remaining on Route B (Origin → B → Destination) experience increased delays:

- 40+15×2=70 minutes.

To avoid this delay, all drivers eventually converge on the new route. When all 20 drivers take Origin → A → B → Destination, the travel time becomes:

- 20×2=40 minutes for Origin → A.
- 20×2=40 minutes for B → Destination.

The total travel time is 40+40=80 minutes.

Ironically, the new road, introduced as a shortcut, results in a worse outcome for everyone. Travel time for all drivers increases to 80 minutes, compared to the original 60 minutes. Neither Route A (Origin → A → Destination) nor Route B (Origin → B → Destination) remains viable, as they now take 40+20×2=80 minutes as well. If the A → B road were closed, or if drivers collectively agreed not to use it, they could return to the original equilibrium, where travel times were 60 minutes for both routes. This example highlights how individual decisions, even when rational, can lead to suboptimal outcomes for the group. It underscores the importance of systemic traffic management over reliance on individual decision-making.

3.2. Empirical Evidence of Braess's Paradox in Urban Mobility

Braess's Paradox is not merely a theoretical construct but has been empirically observed in multiple cities worldwide (Youn et al., 2008; Easley & Kleinberg, 2008; Kolata, 1990). For instance, in Seoul, South Korea, traffic flow improved after the removal of the Cheonggye Expressway during the Cheonggyecheon restoration project. Similarly, in Stuttgart, Germany, a traffic improvement only occurred after a newly constructed road segment was closed shortly after its completion in 1969. In Manhattan, New York City, the temporary closure of 42nd Street for Earth Day in 1990 unexpectedly reduced congestion in the area. A study conducted in 2008 by Youn, Gastner, and Jeong identified specific routes in cities like Boston, New York, and London where closing certain roads could reduce travel times. Following this concept, in 2009, New York City permanently closed sections of Broadway at Times Square and Herald Square after experimental closures resulted in smoother traffic and new pedestrian plazas.

3.3. Indian Case Studies: When More Roads Led to More Traffic

India's over-reliance on flyovers and expressways to address mobility challenges often leads to unintended consequences like worsened traffic congestion due to Braess's paradox. A possible example is the Gurugram-Delhi Expressway, which has become synonymous with gridlock, as it has induced demand and concentrated traffic overwhelms the route instead of improving overall mobility. This pattern is likely mirrored in cities such as Bengaluru, Hyderabad, and Chennai, where localized optimizations of road networks fail to account for global traffic dynamics. The limitations of traditional tools - restricted data availability and insufficient analytical power - prevent a holistic, system-level approach to urban planning.

3.4. AI's Transformative Potential to Strengthen Infrastructure

AI, however, offers transformative potential to address these challenges, enabling cities to identify, analyze, and mitigate the effects of Braess's paradox (Servou et al., 2023). Below are key ways AI can revolutionize urban mobility planning:

3.4.1. Comprehensive Traffic Data Collection and Integration

AI systems can process and integrate massive datasets from diverse sources, offering unprecedented insights into traffic dynamics:

- ➢ Data Sources: AI can leverage real-time data from GPS-enabled vehicles, traffic cameras, mobile apps, toll systems, and IoT devices embedded in road infrastructure.
- ➢ Dynamic Traffic Models: AI algorithms use this data to build accurate, dynamic models of traffic flow, capturing the interplay between road usage patterns and individual driver decisions.
- ➢ Pattern Recognition: Machine learning algorithms can detect patterns and anomalies, identifying areas where new roads or changes in infrastructure might unintentionally worsen congestion.
- ➢ System-Wide Approach: AI algorithms, such as genetic algorithms and swarm intelligence, can optimize traffic flows across the entire network by considering all potential routes simultaneously.

3.4.2. Predictive Modeling and Simulation

AI enables urban planners to simulate the impact of road network changes before implementation:

- ➢ Network Simulations: Using AI-powered simulation tools, planners can test scenarios, such as adding or removing roads, introducing tolls, or altering traffic rules. These simulations highlight potential instances of Braess's paradox, where a change may increase overall congestion.
- ➢ What-If Scenarios: Reinforcement learning, a subset of AI, can model how drivers might respond to new infrastructure and adapt their routes. This helps planners predict how traffic might redistribute globally in the system, and not just locally.

- ➢ Long-Term Forecasting: AI can account for future variables, like population growth, economic trends, or increased vehicle ownership, ensuring that solutions are sustainable.
- ➢ Multi-Criteria Optimization: AI can balance competing objectives, such as minimizing travel time, reducing fuel consumption, and avoiding environmental impact, to find globally optimal solutions.
- ➢ Behavioral Insights: AI analyzes how drivers adapt when roads are removed or repurposed, identifying trips that disappear entirely due to mode shifts (e.g., from cars to public transport).

3.5. Rethinking Feasibility Studies: From Static Reports to Dynamic Intelligence

AI-driven urban mobility solutions have the potential to fundamentally alter the way infrastructure planning is conducted, particularly in addressing counterintuitive traffic phenomena such as Braess's Paradox. Traditional infrastructure development relies heavily on detailed project reports (DPRs) and consultancy-driven feasibility studies, which are often time-consuming, expensive, and highly localized. However, AI-based dynamic traffic simulations, predictive modeling, and system-wide optimization offer a more scalable, adaptive alternative that can reduce dependence on costly case-specific studies.

Unlike conventional static feasibility reports, AI-powered infrastructure planning tools can continuously analyze real-time traffic patterns, simulate multiple scenarios, and provide ongoing optimization recommendations. This enables policymakers to make more informed decisions without requiring individualized consultancy at every level of planning, potentially saving significant financial and administrative resources. Moreover, AI solutions can help identify when expanding road infrastructure may lead to unintended congestion effects, ensuring that investments align with long-term urban mobility goals rather than reinforcing outdated planning assumptions.

3.6. Challenges in Implementing AI-Based Optimising

While AI-driven traffic optimization holds great potential, key challenges include:

- **Data Limitations:** Inconsistent, incomplete, or outdated traffic data can hinder AI model accuracy.
- **Computational Complexity:** Real-time traffic optimization requires significant processing power and sophisticated algorithms.
- **Infrastructure Constraints:** Legacy traffic control systems may lack the sensors and connectivity required for real-time AI insights.
- **Unpredictable Driver Behavior:** Diverse driving patterns, road conditions, and unexpected events can reduce AI model reliability.

Right Turn: Smarter Infrastructure Investment in Mobility and Beyond

Given the lessons from metropolitans around the world, Indian cities should prioritize AI-driven simulations before large-scale infrastructure projects. Instead of reactive road-building, AI-based mobility planning can predict congestion patterns and guide investment towards more efficient, adaptive solutions.

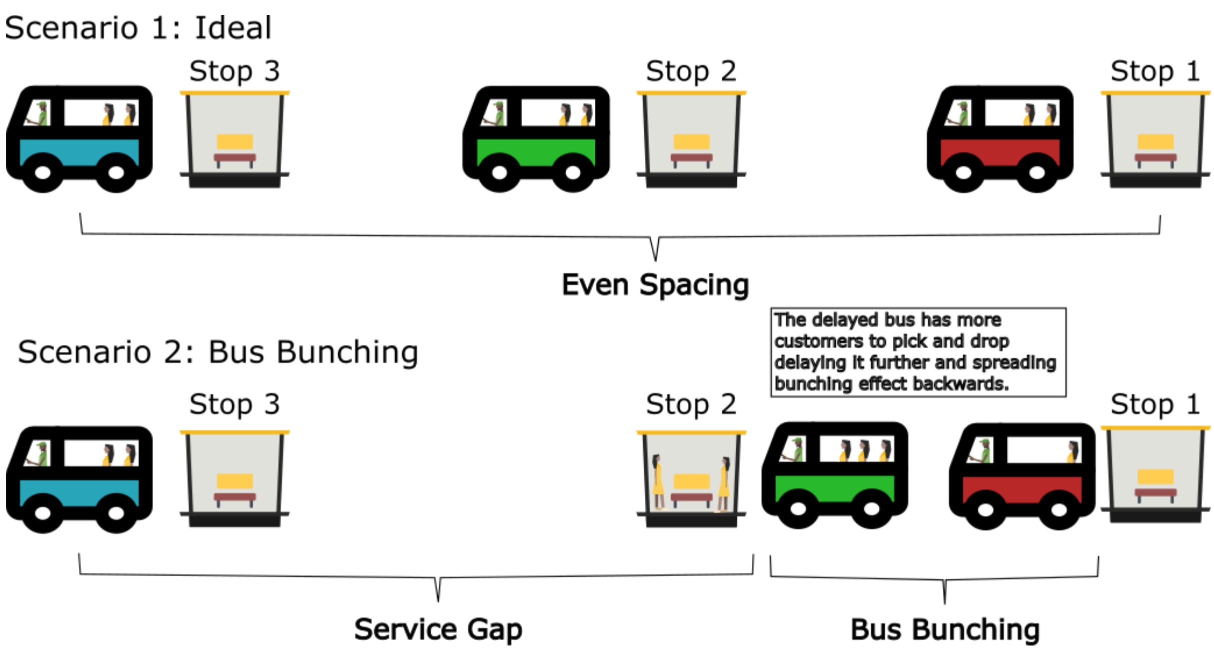
Furthermore, Braess's paradox, initially observed in traffic networks, extends far beyond mobility to areas like power grids, nanoscopic electron systems, mechanical systems, biology, team sports, and blockchain networks. In each case, adding resources or connections can paradoxically reduce efficiency or performance, such as decreased conductance in electron systems, unexpected weight changes in spring systems, or higher fees in blockchain networks. These counterintuitive outcomes highlight the redundancy and inefficiencies that can emerge in complex systems. AI can play a crucial role in identifying, analyzing, and mitigating such redundancies, ensuring optimized performance across diverse domains.

4. AI for Public Transport Optimization

4.1. Understanding the Bus Bunching Problem

Bus bunching is a well-documented issue in public transit systems where buses scheduled to maintain consistent intervals along a route ultimately cluster together. This phenomenon is widespread and is an everyday affair during peak travel hours in major cities around the world. Bus bunching results in uneven service delivery, with some buses becoming overcrowded while others remain underutilized. Such inefficiencies contribute to delays, passenger inconvenience, and reduced system reliability. The root cause lies in minor delays that compound over time, forming a feedback loop that exacerbates the problem (Rezazada et al., 2024) .

Figure 3 | Uneven Service Gaps Trigger Delay Buildup, Leading to Bus Bunching.



4.1.1. Mechanism and Outcomes of Bus Bunching

Consider a scenario where multiple buses operate on the same route, ideally separated by a fixed time interval creating equal spacing between them. We assume that passengers on an average uniformly arrive at all the bus stops in regular intervals, and the number of passengers waiting depends on the time elapsed since the last bus departed.

When a bus experiences a delay, it encounters a larger group of passengers at subsequent stops, resulting in longer boarding and eventually longer deboarding times. This delay accumulates as the bus proceeds along the route, further increasing its stopping times. Meanwhile, the bus behind the delayed bus, now closer to the first, encounters fewer waiting passengers due to the earlier arrival of the delayed bus. Consequently, the second bus spends less time at stops, effectively accelerating its journey and further reducing the gap between the two buses.

Over time, this dynamic causes the second bus to catch up to the delayed bus, and they end up traveling in close proximity, disrupting the intended schedule and reducing service efficiency. The phenomenon is driven by a feedback loop inherent to transit operations. When a bus is delayed, its workload increases, as more passengers accumulate at stops. Simultaneously, the trailing bus benefits from reduced workloads, as fewer passengers are left waiting. This imbalance amplifies the delay of the leading bus and accelerates the trailing bus, perpetuating the cycle and resulting in the two buses clustering together.

Bus bunching significantly affects the efficiency and appeal of public transport systems, leading to several negative consequences. It causes irregular service intervals, where passengers endure long waits followed by multiple buses arriving simultaneously, disrupting schedule reliability. This issue results in overcrowding on the leading bus, creating discomfort for passengers, while trailing buses remain underutilized, reducing overall efficiency. Additionally, bunched buses face longer boarding times and slower travel speeds, further compounding delays. Such unreliable and uncomfortable service frustrates passengers, often pushing them to seek alternative modes of transport like private vehicles. For transit agencies, bus bunching leads to operational inefficiencies, including uneven resource allocation and increased costs, ultimately decreasing the system’s overall throughput. Together, these factors undermine the competitiveness of public transit, making it a less attractive choice compared to other transportation options.

4.2. Indian Case Studies: Bus Bunching in Action

In almost every major Indian city, bus bunching is an everyday occurrence, leading to longer wait times, passenger dissatisfaction, and reduced service reliability.

4.2.1. Delhi's DTC Bus System

A 2022 study found that Delhi’s buses arrive in bunches due to signal delays and uncoordinated scheduling. At peak hours, buses on routes like Outer Ring Road often operate as a single unit rather than at scheduled intervals, affecting system-wide efficiency (Ramachandra Rao et al., 2022).

AI intervention opportunity: Real-time GPS-based bus coordination to dynamically adjust departure intervals.

4.2.2. Bengaluru’s BMTC Challenges

Bengaluru’s Bus Priority Lane (BPL) initiative along Outer Ring Road aimed to improve punctuality, but data showed that buses still bunched together due to inconsistent traffic light prioritization (Jha et al., 2011; Deepa et al., 2023).

AI intervention opportunity: Implementing adaptive signal prioritization, where traffic lights extend green signals for delayed buses.

4.2.3. Kolkata's Traffic-Induced Bunching

Kolkata's extensive private bus system experiences severe bunching, particularly on Esplanade, Howrah, and Park Street routes (Ganguly & Maitra, 2024).

States like Tamil Nadu and Telangana have already utilized AI to enhance public transport safety (OpenGov Asia, 2022; Telangana Today, 2024). AI further presents an opportunity for intervention through innovative AI-driven "bus platooning" models, where an intelligent system manages multiple buses as a fleet, ensuring optimal spacing and improved efficiency. *Also see* Chapter 5.

4.3. How AI and Emerging Technologies Can Solve Bus Bunching

Advancements in AI and other technologies offer powerful solutions to mitigate bus bunching, improving public transport reliability and efficiency (Yang et al., 2024; Ola Mobility Institute, 2021).

4.3.1. AI-Based Real-Time Bus Coordination

AI systems using GPS and IoT-enabled devices can track buses' locations and speeds in real time. Machine learning models can analyze this data to detect early signs of bunching and predict potential disruptions before they occur.

For instance, Singapore's AI-powered public transit scheduling system dynamically holds back or accelerates buses based on real-time congestion analysis. A similar approach can be tested on Delhi's DTC and Mumbai's BEST bus networks.

4.3.2. Dynamic Scheduling and Interventions

AI algorithms can adjust bus schedules dynamically by:

- Holding Strategies: Temporarily stopping buses at designated points to restore even spacing.
- Speed Adjustments: Advising drivers to slow down or speed up to maintain intervals.

These interventions can be implemented in real time through automated systems or driver-assistance tools.

London's iBus System uses real-time tracking to prevent buses from clustering at high-traffic stops (Transport for London, 2024). Likewise, Bengaluru's Majestic Bus Terminal can implement AI-based "bus pause" mechanisms at critical transfer points.

4.3.3. Passenger Load Balancing

AI-powered mobile apps and digital signage can inform passengers about real-time bus capacities and wait times, encouraging them to board less crowded buses. This helps redistribute passenger loads and reduces the operational strain on individual buses.

The Moovit app in Israel and Europe guides passengers to less crowded buses based on real-time data (Moovit, 2021). Likewise, Delhi's One Delhi App, Mumbai's Chalo App, and similar apps in Chennai, Hyderabad, and Kolkata, too for instance, can integrate similar AI-driven bus occupancy tracking.

4.3.4. Optimized Route Planning, Predictive Scheduling & Demand Forecasting

AI can optimize route design and scheduling by simulating different scenarios, identifying bottlenecks, and adjusting frequencies based on demand patterns. Historical data analysis helps in designing schedules that minimize the likelihood of bunching.

Beijing's AI-driven "demand-responsive transit system" adjusts schedules based on historical patterns and live data (Zhou et al., 2024). Mumbai's BEST buses can use AI to forecast commuter surges, ensuring fewer empty or overcrowded buses.

4.3.5. Integration with Smart Infrastructure

Connected Traffic Lights: Synchronizing signals with bus movements to prioritize delayed buses can help maintain consistent intervals.

For instance, Los Angeles' ATSAC system prioritizes buses to reduce delays (Mobility Innovators, 2022). Likewise, Chennai's AI-based smart signals can be adapted to dynamically adjust bus stop timing.

4.3.6. Blockchain for Accountability

Blockchain-based systems can ensure transparency in data collection and sharing between transit operators, enabling coordinated actions across multiple routes and systems.

Blockchain technology offers a transformative approach to ensuring transparency and accountability in urban mobility systems. Globally, cities have begun integrating blockchain into transit operations to prevent data manipulation, improve fare reconciliation, and streamline multi-operator coordination. For example, Dubai's Roads and Transport Authority (RTA) employs blockchain for vehicle lifecycle management, ensuring that registration, insurance, and service records remain tamper-proof (Cointelegraph, 2018). In Shanghai, blockchain secures smart parking transactions, preventing overcharging and fraudulent ticketing (Kalbhor et al., 2024). These implementations highlight how blockchain can enhance trust and efficiency in transit data management.

For India, blockchain can strengthen transparency in transport governance, particularly in multi-operator transit payments, subsidy distribution, and fare reconciliation. Integrating blockchain into the National Common Mobility Card (NCMC) can enable secure, auditable transactions across metro, bus, and EV charging networks, ensuring revenue integrity and reducing disputes. Additionally, blockchain can be leveraged for ride-hailing platforms and auto-rickshaw fare validation, preventing fare manipulation and dynamic pricing irregularities. In the EV ecosystem, blockchain can record real-time energy transactions, ensuring fair pricing and optimal load distribution at charging stations. By adopting blockchain solutions, India can enhance data security, eliminate revenue leakages, and build a more accountable mobility ecosystem in alignment with its smart cities and digital governance vision.

4.4. Challenges in Implementing AI Solutions for Bus Bunching

Despite the potential of AI to mitigate bus bunching, several challenges hinder its effective deployment, particularly in the Indian context:

- **Data Quality and Availability:** Inconsistent GPS data, outdated bus route information, and incomplete passenger flow records limit AI model accuracy. Many Indian cities still rely on manual data collection, making real-time insights challenging.
- **Infrastructure Gaps:** Indian bus networks often lack integrated systems for dynamic signal control, automated fleet management, and real-time passenger information, reducing the effectiveness of AI interventions.
- **Unpredictable Traffic Conditions:** The chaotic nature of Indian roads, characterized by mixed traffic, jaywalking, and informal stops, complicates AI-driven coordination strategies.
- **Affordability and Investment:** Many state-run bus corporations face budget constraints, limiting investments in AI infrastructure and software solutions.

Addressing these challenges requires a phased rollout strategy, with pilot programs in high-density corridors, improved data collection practices, and capacity-building initiatives for transit staff.

Right Turn: Moving Towards AI-Optimized Public Transit

Indian cities should urgently integrate AI-driven transit optimization into their bus networks to improve reliability, reduce wait times, and enhance passenger experience.

To start, pilot programmes in major urban agglomerations can assess the impact of:

- AI-driven real-time bus coordination.
- Passenger load balancing through smart apps.
- Adaptive traffic signal prioritization for public transit.

With the right AI interventions, public bus services can become not just a fallback option - but the preferred choice for urban commuters.

By using AI and emerging technologies, public transit systems can:

- Improve schedule reliability and service quality.
- Enhance passenger satisfaction through reduced wait times and overcrowding.
- Optimize operational efficiency, lowering costs for transit agencies.
- Increase public transport adoption by providing a dependable alternative to private vehicles.

These innovations pave the way for a smarter, more sustainable urban transit ecosystem.

5. AI for Traffic Flow Optimization

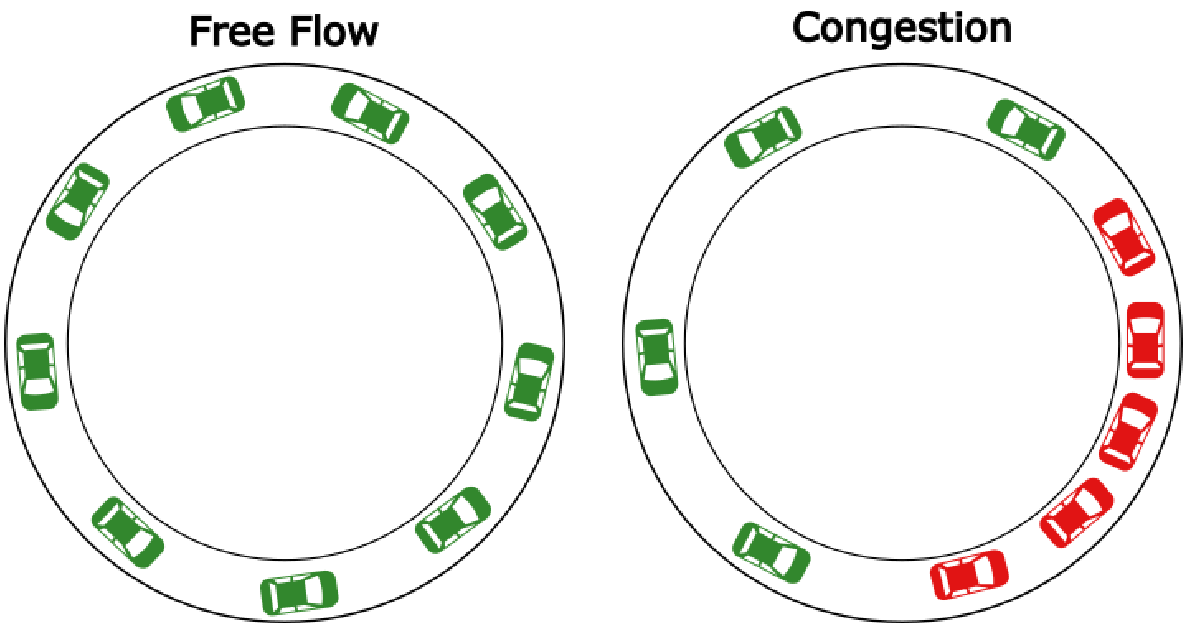
Traffic congestion is not always a result of excessive vehicle volume; it can also arise due to speed fluctuations, inconsistent driving behavior, and sudden braking patterns, leading to self-reinforcing traffic waves or "phantom jams." AI-driven vehicle platooning offers a solution by ensuring that vehicles move harmoniously in coordinated clusters, reducing unnecessary stops and fluctuations in speed (Krall et al., 2020; Stepanenko et al., 2012).

5.1. Understanding the Problem: How Traffic Waves Form

Traffic congestion can emerge even when the number of vehicles is below the road's capacity, caused by fluctuations in vehicle speeds, sudden braking, uneven road conditions like potholes or pedestrian crossings. This self-reinforcing phenomenon is akin to a "phantom traffic jam," where localized disturbances cascade through the system, disrupting the overall flow (Bergenheim et al., 2012).

Speed fluctuations lead to congestion when a small disturbance, such as a vehicle slowing for a pothole or navigating a sharp turn, causes following vehicles to reduce speed. Due to drivers' reaction times, each subsequent vehicle decelerates slightly more than the one before, amplifying the disruption into a "stop-and-go" wave that propagates backward through the traffic flow, even if the initial vehicle resumes normal speed. This results in vehicles bunching up, increasing the local traffic density and further slowing down movement, despite the road being below its nominal capacity.

Figure 4 | Heterogeneous Driving Behavior Can Cause Stop-and-Go Traffic Congestion



Consider the following model illustration to understand the effect.

Assume a road operating at the following conditions:

- Road Capacity: 2,000 vehicles/hour.
- Traffic Flow: Operating at 1,800 vehicles/hour (below capacity).
- Operating Speeds: Vehicles are moving uniformly at 40 km/h (~11.1 m/s).

Initial Disruption:

- A car slows down to 30 km/h (~8.3 m/s) for 5 seconds to avoid a cattle.

Distance Calculations:

- Distance Covered During Normal Operation (40 km/h):
    - At 40 km/h, a car travels: 11.1 m/s × 5 s = 55.5 meters.
- Distance Covered During Slowdown (30 km/h):
    - At 30 km/h, the car travels: 8.3 m/s × 5 s = 41.5 meters.
- Reduction in Distance Covered:
    - The slowing car travels 14 meters less than it would have at its original speed: 55.5 m - 41.5 m = 14 m.

Impact on Following Vehicles:

- When the car slows down, the following vehicle must also reduce its speed to maintain the gap it had earlier with the vehicle ahead of it. Ideally, the following vehicle would adjust its speed to cover only 27.5 meters during the same 5 seconds, calculated as: 41.5 m - 14 m = 27.5 m. Accounting for the 14 meter less distance travelled by the vehicle ahead of it from slowing down.
- To achieve this, the following vehicle would need to slow down to an average speed of: 27.5 m / 5 s = 5.5 m/s (~19.8 km/h).

However, vehicles often cannot reduce their speed drastically in such a short time. As a result, the distance between the two vehicles decreases. This reduction in gap propagates through the traffic, forcing subsequent vehicles to slow down more and more. Eventually, this leads to a stop-and-go traffic pattern or even a traffic jam, despite the traffic volume being below the road's capacity. This example illustrates how small disruptions, such as slowing down for a pothole, can ripple through traffic and amplify congestion. Over time, such disruptions can cause "phantom traffic jams," even when the road is operating below its maximum capacity.

Traffic wave formation occurs when disruptions, such as potholes or slow drivers, cause vehicles behind them to form dense clusters, reducing the average speed of traffic in that segment. These clusters persist long after the initial disturbance is resolved. As drivers instinctively brake or swerve to avoid obstacles, further disturbances are created, amplifying congestion downstream. Once a "stop-and-go" wave forms, delays become self-reinforcing, with vehicles in the dense region accelerating and decelerating unpredictably, leading to inefficiencies. Even after the traffic clears, residual speed fluctuations prevent a smooth return to flow. This phenomenon of induced congestion is common in places like India, where external factors such as frequent pedestrian crossings, roaming animals, and inconsistent vehicle conditions, coupled with erratic driving speeds, contribute to congestion even when the road's vehicle count is below its capacity.

5.2. Indian Case Studies: Self-Induced Congestion

5.2.1. Mumbai's Western Express Highway

Despite well-structured lane divisions, congestion occurs due to random lane switching and erratic acceleration/braking patterns (Pawar, 2011; Gupta, et al., 2018).

AI solution opportunity: AI-driven platooning strategies for commercial and public transport vehicles could smoothen traffic flow, minimizing start-stop effects (Mushtaq, et al., 2021; Oriol, et al., 2024).

5.2.2. Delhi's Urban Arterials

A study by IIT Delhi found that minor speed fluctuations among vehicles caused sudden congestion waves on various urban arterials in the city (Rao & Rao, 2015).

AI solution opportunity: Implementing AI-assisted Adaptive Cruise Control (ACC) systems in public transport vehicles could reduce unnecessary braking (Younas, 2022, Temple University News, 2023).

5.2.3. Bengaluru's Traffic Chaos

Severe congestion at Silk Board Junction and Whitefield Road is driven by uncoordinated lane switching, inconsistent vehicle speeds, and inefficient intersection management. These factors contribute to traffic bottlenecks, increasing travel times and fuel consumption, particularly during peak hours. Studies have shown that daily gridlocks in Bengaluru have quadrupled in recent years, emphasizing the urgent need for intelligent traffic management systems (Deccan Herald, 2024; The Indian Express, 2024).

AI solution opportunity: Implementing AI-driven smart lane coordination and vehicle clustering systems could optimize traffic flow, reducing erratic acceleration-deceleration cycles and improving throughput at key intersections. AI-powered adaptive traffic signals and vehicle-to-infrastructure (V2I) communication can further enhance mobility by dynamically adjusting signal timing and managing lane usage in real time (Numalis, 2025a).

5.3. Leveraging Platooning of Vehicles to Solve Congestion Issues

Platooning refers to a system where multiple vehicles travel together in a coordinated manner, maintaining a tight, constant gap between them. By leveraging AI, autonomous vehicles, and advanced communication technologies, platooning has the potential to address congestion caused by fluctuations in speed, road irregularities, and other disturbances.

5.3.1. AI-Based Speed Coordination, and Gap Reduction Between Vehicles

Platooning enables vehicles to communicate with each other in real-time. Autonomous vehicles equipped with vehicle-to-vehicle (V2V) communication systems can share data such as speed, position, and braking behavior. This allows them to synchronize their movements, reducing fluctuations in speed caused by human driver reactions or external disruptions.

Platooning also allows vehicles to travel in close proximity, reducing the gap between them without compromising safety. These smaller gaps can increase road efficiency by allowing more vehicles to use the same lane, without causing the "phantom" traffic jams that occur due to inconsistent braking and acceleration.

AI systems can predict and manage the behavior of each vehicle in the platoon, adjusting their speeds smoothly in response to changes in road conditions. For example, if one vehicle slows due to a pothole or obstacle, the AI can dynamically adjust the entire platoon's speed in real-time to avoid abrupt decelerations or accelerations. This helps mitigate the ripple effect that usually causes congestion.

Global Examples and India Applications

- ➢ The Netherlands' "Truck Platooning" project uses AI-based Vehicle-to-Vehicle (V2V) communication to coordinate freight trucks and improve highway efficiency (TNO, 2025).
- ➢ India Application: Delhi-Mumbai Expressway can deploy AI-guided truck platooning to improve long-distance freight movement.

5.3.2. Predictive AI for Congestion Reduction

AI predicts traffic disturbances before they happen and instructs vehicles to adjust speeds proactively.

Global Examples and India Applications

- ➢ California's Caltrans project deploys AI-assisted adaptive driving algorithms that detect early congestion signs and suggest platooning solutions (California Government Operations Agency, 2024).
- ➢ India Application: Bengaluru's traffic control center can integrate AI-powered predictive congestion alerts for bus and logistics fleets as well as vehicles affiliated with passenger mobility fleet operators or ride-hailing/ rideshare platforms.

5.3.3. AI-Enabled Adaptive Traffic Lights to Assist Platooning

AI-powered traffic signals can adjust green light durations based on platoon movement, ensuring smoother traffic flows.

Global Examples and India Applications

- ➢ Singapore's Green Link Determining (GLIDE) AI system improves urban traffic flow using real-time platoon coordination (Land Transport Authority, 2024).
- ➢ India Application: Hyderabad's AI-based traffic signal adaptation project can be expanded to include platoon-based signaling adjustments.

5.4. Challenges in Implementing AI-Based Platooning

While AI-driven platooning offers immense benefits, key barriers include (Hou et al., 2023):

1. Infrastructure Gaps: India's road networks lack embedded sensors for real-time AI tracking.
2. Mixed Traffic Conditions: Unlike Western countries, Indian roads accommodate trucks, two-wheelers, auto-rickshaws, and pedestrians, making AI-guided platooning more complex.
3. Regulatory Uncertainty: Legal frameworks for V2V communication and AI-guided vehicle automation remain underdeveloped.

Right Turn: Pilot AI-Based Platooning on High-Density Corridors

To test AI-driven platooning in India, the Ministry of Road Transport & Highways (MoRTH) and state transport authorities should:

- Pilot AI-coordinated truck platooning on Mumbai-Pune Expressway for freight vehicles.
- Deploy AI-assisted adaptive lane coordination in Bengaluru's high-density roads.
- Integrate AI-powered congestion prediction tools in Delhi's Outer Ring Road traffic control system.

With structured AI adoption, platooning can dramatically reduce stop-and-go congestion, fuel wastage, and emissions, improving India's urban and highway mobility efficiency.

6. AI for EV Charging Optimization

As electric vehicle (EV) adoption accelerates in India, charging infrastructure is emerging as a critical bottleneck. The congestion at EV charging stations is not just a result of infrastructure limitations - it is also driven by human behavior, range anxiety, and inefficient use of charging resources. AI can play a transformative role in optimizing charging station utilization, reducing peak-time congestion, and guiding users toward efficient charging behavior (Franke & Krems, 2013).

6.1. Understanding the Problem: Why EV Charging Congestion Happens

The rapid adoption of electric vehicles (EVs) has brought increased demand for charging infrastructure. While technological and infrastructural challenges play a role in congestion at EV charging stations, human behavior is a critical factor exacerbating the issue. This review explores the psychological, social, and logistical behaviors contributing to charging station congestion and offers insights into mitigation strategies (Andrenacci & Valentini, 2023).

Figure 5 | AI Generated Image Depicting EV Charging Gridlock in Urban Centers.

6.1.1. Key Behavioral Factors Contributing to EV Charging Congestion

Range Anxiety

Range anxiety is the fear of depleting an EV's battery before reaching a charging point or destination. Drivers often overestimate the required charge for a trip, leading to premature charging even when sufficient battery remains. Range anxiety prompts "just-in-case" charging, causing unnecessary demand at charging stations, especially during peak hours. Research from Cox Automotive indicates that over 80% of EV drivers experience range anxiety, significantly influencing charging behavior (Cox Automotive, 2024).

Inefficient Use of Charging Stations

Drivers frequently occupy charging stations longer than necessary to achieve a full charge, even when a partial charge would suffice for immediate travel needs.

Clustered Charging Behavior

The tendency of EV users to converge at certain charging stations due to perceived reliability, visibility, or convenience. Drivers often avoid less familiar or slightly less convenient charging stations, leading to underutilization of some chargers and overutilization of others. Real-world examples include urban areas where central stations face heavy congestion while peripheral stations remain underused.

Charging During Peak Hours

Many drivers opt to charge during specific times, such as morning commutes or evenings after work. This creates temporal bottlenecks, as most drivers follow similar schedules, overwhelming the available infrastructure.

Lack of Charging Etiquette

Drivers often engage in behaviors such as blocking charging points or failing to vacate stations promptly after charging. Social Impact: Such behaviors lead to frustration and longer wait times for other users, compounding congestion issues.

6.1.2. Consequences of Behavioral Patterns

Increased Waiting Times

Congestion results in longer queues at charging stations, reducing the overall efficiency of the charging network and frustrating users.

Underutilization of Infrastructure

Behavioral clustering means some charging stations remain idle, while others are overwhelmed, creating inefficiencies.

Negative Perception of EVs

Persistent congestion and the resulting inconvenience may deter potential EV adopters, slowing the transition to electric mobility.

Reinforcement of Anxiety

Congestion at stations perpetuates range anxiety, leading to a vicious cycle where drivers charge more frequently and unnecessarily, further exacerbating the problem.

6.2. Leveraging New Technologies to Solve EV Charging Congestion

The congestion at EV charging stations, often exacerbated by human behavior, can be mitigated through the strategic application of emerging technologies such as wireless charging, artificial intelligence (AI), and big data analytics. These technologies enhance the efficiency, accessibility, and user experience of EV charging infrastructure (EV Charging Summit, 2023; Appvin Technologies, 2024).

6.2.1. Artificial Intelligence (AI)

AI-Based Predictive Charging Demand Management

- ➢ AI algorithms analyze historical and real-time data to predict charging station demand, enabling operators to dynamically allocate resources and optimize usage.
- ➢ Tesla's Supercharger Network uses AI-driven demand forecasting to preemptively reroute users to less congested stations (ForoCuatro, 2024).
- ➢ India Application: AI-based charging demand predictions for Delhi NCR could reduce congestion at Cyber Hub, Connaught Place, and Saket stations.

Smart Charging Recommendations Using AI-Driven Navigation

- ➢ AI-powered systems in vehicles or mobile apps can guide users to less crowded charging stations, and suggest optimal charging times, and alternative routes, etc., thereby reducing clustering behavior.
- ➢ Europe's PlugSurfing App provides AI-based smart routing, directing drivers to underutilized chargers (PlugSurfing, 2024).
- ➢ India Application: AI can be integrated into platforms like Tata Power EZ Charge and BESCOM's EV app to nudge users toward alternate stations.

Dynamic Pricing & Incentives for Off-Peak Charging

- ➢ AI can dynamically adjust charging rates across stations, ensuring even distribution of power and preventing overloading at high-demand locations. In other words, by adjusting charging costs dynamically, AI can encourage users to charge during off-peak hours.
- ➢ Singapore's Smart Charging Pilot uses AI-driven congestion pricing to reduce peak-hour station loads (Land Transport Authority, 2024).

- India Application: BESCOM in Bengaluru could offer dynamic pricing discounts for EV charging during non-peak hours (e.g., late-night or early morning).

6.2.2. Big Data Analytics

- Behavioral Insights: By analyzing user patterns, big data helps identify common inefficiencies, such as prolonged stays or peak usage trends, allowing targeted interventions like dynamic pricing.
- Infrastructure Planning: Data-driven insights inform the placement and number of charging stations to meet projected demand, reducing spatial congestion.
- Demand Forecasting: Big data models anticipate future growth in EV adoption and adjust charging infrastructure expansion accordingly.

6.2.3. Integration with Smart Grids

- AI can balance power supply and demand by allowing EVs to return excess power to the grid during peak demand periods.
  - Energy Management: Smart grids coordinate energy supply and demand between charging stations and the broader power network, ensuring sufficient energy availability during peak hours.
  - Vehicle-to-Grid (V2G): This technology allows EVs to return unused energy to the grid during high demand, effectively turning them into distributed energy resources and easing pressure on charging infrastructure.
- Japan's AI-driven V2G system manages EV-to-grid energy transfers, reducing charging congestion by distributing electricity intelligently (Zhang et al., 2024).
- India Application: Maharashtra's DISCOMs could implement AI-based smart grids to allow EVs to inject surplus power back into the grid.

6.2.4. Autonomous Vehicle Integration

- Self-Driving EVs: Autonomous EVs can schedule charging during off-peak hours and drive themselves to less crowded stations, reducing human-induced clustering.
- Fleet Optimization: AI-powered systems can manage autonomous ride-sharing EV fleets, ensuring efficient charging rotations without disrupting service.

6.2.5. Wireless Charging, and Automated Charging to Reduce Idle Time

- Dynamic Charging: Wireless charging systems embedded in roads allow EVs to charge while in motion, reducing reliance on stationary charging stations and minimizing peak demand (OMI Foundation, 2025).
- Inductive Charging Pads: At parking lots or frequently visited locations, inductive charging pads eliminate the need for physical plugging and can automatically disconnect once the vehicle reaches a set charge level, preventing prolonged occupation of charging points.
- Further, robotic charging solutions, optimized by AI, can automatically disconnect once charging is complete.

- India Application: AI-enabled automated charging hubs in Mumbai and Delhi metro stations can minimize unnecessary station occupation.

The combination of wireless charging, AI, big data, and other emerging technologies offers transformative solutions to EV charging station congestion. These innovations optimize resource allocation, predict and manage demand, and improve user behavior, leading to a seamless and efficient charging experience that supports the broader adoption of electric mobility. India currently has over 25,202 EV charging stations, with EV sales rising steadily (PIB Delhi, 2024). Given this rapid growth, optimizing the efficiency and usability of charging stations is crucial to enhancing the viability of electric vehicles and advancing toward a more sustainable future.

6.3. Challenges & Implementation Barriers

While AI-based charging optimization has immense potential, key challenges must be addressed:

1. Limited AI Integration in Existing Charging Networks: Most Indian charging operators do not yet use AI-powered demand management tools.
2. User Adoption & Behavioral Resistance: Many EV users may be reluctant to rely on AI-driven smart recommendations.
3. Regulatory & Policy Gaps: India lacks clear policies for AI-driven congestion pricing, wireless charging, and V2G integration.

Right Turn: Scaling AI-Based Charging Optimization in India

To decongest EV charging stations, policymakers and industry stakeholders should:

- Deploy AI-based demand forecasting models for major urban centers like Delhi, Bengaluru, and Mumbai.
- Integrate AI-powered smart routing in India's major EV charging platforms (Tata Power, BESCOM, ChargeZone).
- Introduce AI-driven congestion pricing & off-peak charging incentives in metropolitan charging hubs.
- Pilot AI-powered wireless charging & automated disconnection technologies at select metro stations.
- Develop regulatory guidelines for AI-enabled V2G energy optimization in India's smart grid framework.

By harnessing AI, India can maximize its existing charging infrastructure, reducing congestion and making EV adoption seamless and efficient.

7. AI for Dynamic Road Demand Management

As Indian cities grapple with increasing vehicular congestion, traditional road expansion projects fail to keep pace with rising demand. Instead of continuously building new roads, AI-driven dynamic tolling and congestion pricing offers a smarter, more efficient solution - one that adjusts pricing based on real-time traffic conditions to encourage better road usage patterns (Pandey, S. C., & P, V. K. 2025; Lombardi et al., 2021).

7.1. Understanding the Problem: Why Congestion Persists Despite Road Expansion

7.1.1. Peak-Hour Overloading

In cities like Delhi, Bengaluru, and Mumbai, traffic congestion follows predictable patterns, with excessive road usage during morning and evening rush hours. Mumbai's Western Express Highway, for instance, sees severe speed reduction during peak times, despite continuous road-widening efforts.

7.1.2. Lack of Price-Based Incentives to Reduce Demand

Indian roads are mostly free-to-use, except for toll highways, leading to no cost deterrent for peak-hour driving. This can be seen in the expressway across the country, which faces extreme congestion daily, despite existing tolls, because pricing remains static regardless of traffic conditions.

7.1.3. Induced Demand: More Roads, More Traffic

When new roads are built, traffic increases to fill available capacity, often worsening congestion rather than solving it (Braess's Paradox). The Eastern Peripheral Expressway around Delhi, initially designed to divert trucks away from city roads, is now congested.

7.1.4. Inefficient Use of Road Space

Some roads remain overcrowded, while parallel routes are underutilized because drivers lack real-time congestion pricing signals. In Bengaluru, Outer Ring Road faces severe congestion, while parallel arterial roads remain relatively empty due to lack of dynamic route pricing.

7.2. How AI Can Optimize Road Usage Through Smart Pricing

As urban centers grow and traffic congestion intensifies, traditional measures to manage road networks often fall short. Dynamic tolling and congestion pricing, driven by AI and real-time data, offer a transformative approach to these challenges. By adapting toll rates based on live traffic conditions, these systems not only optimize road usage but also promote sustainability, equity, and efficiency. This innovative strategy aims to balance mobility demands with environmental and social considerations, paving the way for smarter and more responsive urban transport systems (Dorcas, 2022).

Dynamic toll and congestion pricing are effective tools to manage traffic flow, reduce congestion, and optimize road usage (Arora, 2019). By leveraging artificial intelligence (AI), these systems can become more efficient, adaptive, and equitable. AI can analyze real-time traffic patterns, predict congestion, and adjust toll rates dynamically to influence driver behavior and improve overall mobility.

Figure 6 | AI-generated Image Showing Dynamic Toll Pricing: Enhancing Road Efficiency and Optimizing Infrastructure Usage.

7.2.1. Key Components of AI-Driven Dynamic Pricing Systems

Real-Time Data Collection and Processing

AI leverages traffic sensors and IoT devices to monitor vehicle counts, speeds, and traffic density in real-time. GPS data from navigation systems enhances this by providing detailed insights into routes, delays, and congestion hotspots. Additionally, external factors such as weather conditions and events are integrated into the analysis, ensuring a comprehensive understanding of traffic patterns to inform dynamic pricing and congestion management strategies.

Predictive Traffic Modeling

AI employs machine learning models to analyze historical and real-time data, enabling accurate predictions of traffic congestion. These models can forecast traffic flow patterns and pinpoint critical bottlenecks, allowing for proactive measures to optimize road usage and minimize delays.

7.2.2. How AI Can Optimize Road Usage Through Smart Pricing

AI-Driven Congestion Pricing Based on Live Traffic Data

AI can monitor real-time vehicle density and adjust toll rates accordingly, discouraging road use during peak congestion periods.

Singapore's Electronic Road Pricing (ERP), which adjusts tolls based on real-time congestion levels, reducing peak-hour traffic, is a case in point (Ministry of Transport Singapore, 2024). Similarly, AI-based congestion pricing for Delhi's Ring Road or Mumbai's Western Express Highway could incentivize off-peak commuting.

AI-Powered Alternative Route Incentives

AI can analyze road congestion patterns and offer toll discounts for drivers choosing less congested routes.

For instance, Stockholm's congestion pricing system offers discounts for alternative routes, reducing peak-hour traffic by 20% (Tools of Change, 2025). Likewise, Bengaluru's Outer Ring Road vs. NICE Road dynamic pricing could help redistribute traffic more efficiently.

Smart Carpool & Public Transport Incentives

AI can offer toll reductions for carpooling and public transit users, encouraging sustainable travel choices.

Los Angeles' Express Lanes system reduces tolls for HOV (high-occupancy vehicle) users, incentivizing carpooling (Metro ExpressLanes, 2024). In a similar fashion, AI-based reduced tolls for shared taxis (Ola, Uber), public transport, and EVs (personal and commercial) on Mumbai-Pune Expressway could promote shared mobility.

AI-Optimized Time-Based Tolling to Flatten Peak Demand

AI can gradually increase tolls before congestion peaks, nudging some drivers to travel earlier or later to even out road demand.

Real-time congestion data allows for immediate adjustment of toll rates. Higher tolls during peak hours incentivize travelers to choose alternative routes, off-peak travel times, or other modes of transport, effectively redistributing traffic and alleviating congestion.

For instance, London's Congestion Charge adjusts fees based on the time of day, reducing peak traffic (Transport for London, 2024). Likewise, AI-driven morning vs. afternoon toll adjustments on Delhi-Noida Expressway could help balance peak congestion.

AI-Enabled Road User Pricing for Fair Toll Distribution

AI can customize toll rates based on a vehicle's frequency of road use, ensuring equitable distribution of road fees.

Dynamic tolling systems incorporate discounts or exemptions for low-income travelers, ensuring equitable access to transportation. Additionally, incentives such as reduced tolls for carpooling or using eco-friendly vehicles encourage sustainable travel behaviors, supporting environmental and social goals.

Milan's Area C pricing system varies tolls based on vehicle type & frequency of entry (Moulin & Urbano, 2025). Similarly, AI could implement fair tolling on Bengaluru-Mysuru Expressway, or tolls in Delhi-NCR, where EV users or shared mobility users (public transport and intermediate public transport users) and emergency vehicles pay lower rates.

7.2.3. AI-Driven Congestion Pricing Workflow

AI-powered systems revolutionize toll management by continuously monitoring traffic conditions using data from cameras, sensors, and GPS-enabled devices. Congestion is detected when traffic density in a particular area exceeds predefined thresholds, triggering dynamic price adjustments. For instance, during peak hours, toll rates on a congested highway could rise from ₹20 to ₹50, encouraging drivers to choose alternative routes or adjust their travel times. These adjustments are complemented by behavioral impact analysis, where AI tracks changes in driver behavior, such as increased reliance on public transit or off-peak travel, to refine pricing strategies. A feedback loop further enhances the system, as AI learns from the effectiveness of toll adjustments and optimizes future decisions. This integrated approach helps reduce congestion, promote sustainable travel, and improve overall traffic efficiency.

7.2.4. Benefits of AI-Driven Toll and Congestion Pricing

AI-driven tolling systems optimize traffic flow by redistributing vehicles across less crowded routes and time periods, reducing congestion and smoothing stop-and-go patterns, which in turn lowers emissions and fuel consumption. These systems enhance road network efficiency by ensuring high-demand routes are used optimally, preventing overuse of specific corridors. By promoting sustainable practices, such as the use of public transportation, carpooling, or non-peak travel, they contribute to environmental and societal goals. Additionally, dynamic tolling generates revenue for infrastructure maintenance and investment in public transit systems. To ensure fairness, AI can balance pricing strategies to avoid disproportionately impacting vulnerable groups, maintaining equity and accessibility within the transportation network.

AI-driven dynamic toll and congestion pricing present a transformative approach to urban mobility challenges. By leveraging advanced prediction models, real-time vehicle-to-infrastructure communication, and integration with Mobility-as-a-Service platforms, cities can optimize traffic flow, reduce environmental impacts, and promote sustainable travel behaviors. As these technologies evolve, they hold the potential to create efficient, equitable, and environmentally friendly urban transport systems, paving the way for smarter, more livable cities.

7.3. Challenges in Implementing AI-Driven Congestion Pricing

While dynamic tolling and congestion pricing can significantly improve road efficiency, barriers remain:

1. Public Resistance to Road Pricing: Many drivers oppose paying tolls for roads that were previously free.
2. Lack of Policy Frameworks for AI-Based Pricing: India has no formal legal framework for AI-driven congestion pricing.
3. Implementation Costs & Enforcement Challenges: Dynamic tolling requires AI-driven monitoring infrastructure, which is still lacking in most cities.

Right Turn: Piloting AI-Based Congestion Pricing in India

Given global success stories, India should test AI-driven tolling solutions on high-traffic corridors:

- ➢ Pilot AI-driven congestion pricing in Delhi, Mumbai, and Bengaluru, where peak-hour traffic is unsustainable.
- ➢ Introduce AI-based route pricing & alternative route incentives, nudging users to take less congested paths.
- ➢ Offer AI-powered toll discounts for EVs, carpoolers, and off-peak travelers, encouraging sustainable transport choices.
- ➢ Develop an AI-based congestion pricing framework under NITI Aayog's Smart Mobility initiatives.

By leveraging AI for dynamic tolling, India can manage road congestion intelligently, reducing traffic overload while ensuring equitable road access.

8. Limitations of AI in Urban Mobility

While AI presents transformative opportunities in urban mobility, its implementation faces critical challenges that could impact scalability, equity, and long-term effectiveness. Policymakers and urban planners must acknowledge and address these limitations to ensure AI-driven mobility solutions remain inclusive, efficient, and sustainable (Fagnant & Kockelman, 2015; Lim & Taeihagh, 2019, Fafoutellis & Mantouka, 2019, U.S. Department of Transportation, 2024).

1. Infrastructure and Resource Constraints

High Initial Investments: Implementing AI-driven systems requires significant financial outlays for infrastructure, including sensors, communication networks, and computational resources, which may be unaffordable for many cities.

Maintenance and Upgradation: Sustaining and upgrading the technology infrastructure over time requires additional resources, trained personnel, and technical expertise. These skilled individuals and resources are currently severely limited in India.

2. Data-Related Challenges

Data Availability and Quality: The effectiveness of AI solutions relies heavily on the availability of accurate, high-quality, and comprehensive data. Many urban areas lack sufficient mechanisms to collect and integrate such data.

Privacy and Security Risks: The collection and use of real-time traffic, vehicle, and user data raise significant privacy concerns, necessitating stringent data governance frameworks. Cybersecurity threats also pose risks to system integrity and public trust.

3. Human Behavior and Social Acceptance

Unpredictable Human Behavior: Despite advanced predictive models, human decision-making - such as route choices, mode preferences, or compliance with new policies - can introduce variability that AI systems cannot always anticipate or mitigate.

Public Resistance to Change: The adoption of innovative measures like dynamic toll pricing, vehicle platooning, or real-time congestion management often meets resistance due to perceived inequities, skepticism about AI's fairness, or concerns about automation replacing human jobs.

4. Governance and Policy Barriers

Lack of Institutional Capacity: Many cities may lack the institutional frameworks or technical expertise required to implement and oversee AI-driven solutions effectively.

Regulatory Hurdles: Legal and regulatory frameworks are often slow to adapt to emerging technologies, creating delays in the adoption of AI-powered systems.

Equity and Inclusion Concerns: Ensuring that AI-driven solutions are accessible and beneficial to all sections of society, particularly marginalized and low-income groups, remains a significant challenge.

5. Technological and Model Limitations

Algorithm Bias and Unintended Outcomes: AI systems can perpetuate or even amplify existing biases in urban mobility systems, leading to unintended social or economic disparities.

Dependency on Assumptions and Historical Data: Predictive models are often built on historical data and assumptions that may not hold true in rapidly evolving urban environments, limiting their reliability over time.

Interoperability Issues: Integrating AI solutions with existing infrastructure and systems, which may be outdated or fragmented, can present significant technical and logistical challenges.

6. Environmental and Socioeconomic Impacts

Energy Consumption: The deployment and operation of large-scale AI systems can significantly increase energy usage, which may conflict with sustainability goals.

Economic Disruption: Automation and AI-driven management may disrupt local economies, particularly those reliant on manual jobs in transportation and urban planning.

These limitations highlight the need for a balanced and phased approach to implementing AI and emerging technologies in urban mobility. Mitigating these challenges will require collaborative efforts between governments, private stakeholders, and civil society, supported by robust policy frameworks, continuous public engagement, and iterative refinement of technological solutions.

9. Policy Recommendations for Scaling AI-Driven Mobility in India, and Way Forward

To fully leverage AI in urban mobility, India needs a structured policy roadmap covering AI-integrated transport infrastructure, regulatory frameworks, public-private partnerships, and ethical AI deployment.

9.1. Investing in AI-Integrated Transport Infrastructure

AI can significantly improve traffic efficiency, enhance public transport reliability, and reduce urban congestion. Key policy actions include:

- ➢ Adaptive Traffic Control Systems: AI-powered traffic signals should be standardized across major cities, integrating real-time congestion data to dynamically adjust signal timing and prioritize public transit and emergency vehicles.
- ➢ Predictive Congestion Monitoring: AI-based models should be deployed for early congestion detection in urban centers, enabling proactive traffic rerouting and congestion pricing adjustments.
- ➢ AI-Augmented Traffic Enforcement: Smart AI-driven enforcement systems should be expanded nationwide, using automated violation detection (e.g., lane indiscipline, over-speeding) to improve road safety.
- ➢ Urban Mobility Digital Twins: AI-powered digital replicas of city transport networks should be piloted in select metropolitan regions to simulate the impact of various policy interventions before real-world implementation.

9.2. Developing AI-Specific Regulatory Frameworks for Mobility

To ensure safe, responsible, and effective AI integration, India must establish clear legal frameworks for:

- ➢ AI-Based Congestion Pricing: Dynamic pricing policies should be formally recognized within transport law, ensuring that pricing adjustments are transparent, equitable, and data-driven.
- ➢ EV Charging Optimization Regulations: AI-powered EV charging demand prediction and automated load balancing should be included in PM e-DRIVE, other national and state EV policies, ensuring efficient grid integration and consumer protection.
- ➢ Platooning Regulations for AI-Guided Vehicle Coordination: The Ministry of Road Transport & Highways (MoRTH) should define regulatory protocols for AI-driven vehicle platooning, including V2V (vehicle-to-vehicle) communication standards, liability guidelines, and safety protocols.

9.3. Encouraging Public-Private Collaboration for AI Pilots

India must accelerate real-world testing of AI mobility solutions through structured pilot programs involving government, startups, and academia.

- ➢ City-Level AI Test Zones: AI-powered transit management systems, congestion pricing models, and AI-driven public transport optimizations should be piloted in high-density corridors of cities like Mumbai, Delhi, and Bengaluru.
- ➢ Incentives for AI-Enabled Mobility Startups: The government should expand funding and tax incentives under initiatives like Startup India to encourage AI-based fleet management, smart routing, and predictive transit maintenance solutions.
- ➢ AI Integration in Ride-Hailing and EV Fleet Operations: The transport ministry should create guidelines for AI-powered fleet optimization, ensuring data-sharing protocols between private operators and urban transport authorities to improve traffic efficiency and fleet utilization.

9.4. Establishing Ethical AI Principles for Fair and Inclusive Mobility

To prevent bias, exclusion, and unintended disparities in AI-driven transport decisions, India must:

- ➢ Ensure Algorithmic Transparency: AI models for congestion pricing, traffic control, and public transit optimization must be explainable, auditable, and publicly accountable to prevent unfair outcomes.
- ➢ Promote Equity in AI-Based Mobility Access: Congestion pricing models must ensure affordable public transport options, preventing lower-income commuters from being disproportionately affected by AI-driven pricing mechanisms.
- ➢ Enhance Data Privacy Protections: AI-powered transport monitoring systems must include strong data privacy safeguards, ensuring that real-time movement data is not misused.
- ➢ Establish Regulatory Oversight for AI in Transport: The government should create AI ethics committees within transport ministries to review and regulate AI adoption in urban mobility applications.

9.5. Conclusion: Aligning AI in Mobility with India's Digital Future

India’s AI-powered mobility future depends on strong policy interventions that align with broader national goals such as Digital India, Smart Cities Mission, and the India AI Initiative, etc. While AI-driven mobility innovations are gaining traction globally, India has a unique opportunity to leapfrog traditional transport models and pioneer AI-enabled urban mobility at scale.

By investing in AI-integrated transport infrastructure, developing clear regulatory frameworks, fostering public-private partnerships, and ensuring ethical AI deployment, India can position itself as a global leader in AI-driven mobility solutions. These policy interventions will not only improve urban transport efficiency but also enhance sustainability, equity, and economic growth in India’s fast-urbanizing landscape.

The time to act is now - by adopting AI in urban mobility, India can build smarter, more livable, and globally competitive cities for the future.

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