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Data Science Lab for Smart Cities

Final Essay

Feasibility Study of ERP in Bangalore: Lessons from Singapore

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Abstract

This study explores the feasibility of introducing an Electronic Road Pricing (ERP) system in Bangalore, starting from the 2015 report commissioned by the Bangalore Metropolitan Transport Corporation, which had already proposed ERP as a potential solution to rising urban congestion. Ten years later, with traffic conditions having worsened and public concern increasing, this work reassesses whether the current institutional, infrastructural, and social landscape is suitable for the effective and sustainable implementation of such a system. The analysis follows a comparative approach between Bangalore and Singapore, focusing on differences in urban planning, demographic structure, and governance capacity, particularly examining the roles of DULT and LTA. Two areas, MG Road and Koramangala, emerge from the initial assessment as relevant entry points for a more detailed technical and social feasibility study. The study ultimately aims to provide grounded insights into how congestion pricing could be adapted to Bangalore's context, and whether the conditions now exist to transition from pilot proposals to actionable implementation.

Contents

1 What is Traffic Congestion: Definitions and Thresholds

Traffic congestion is a multifaceted phenomenon that lacks a universally agreed-upon definition, but is generally understood as a condition where the number of vehicles attempting to use a roadway exceeds its capacity, resulting in slower speeds, longer trip times, and increased vehicle queuing (1). Scholars and institutions have proposed various definitions, which can be broadly grouped into three categories (2): (i) demand-capacity related, where congestion is seen as an imbalance between traffic demand and road capacity (3; 4); (ii) delay and travel-time related, where it is defined by increased travel times compared to free-flow conditions (5; 6); and (iii) cost-related, which focuses on the economic and social costs caused by reduced mobility and increased travel time (7). According to Bovy and Salomon (8), congestion is also characterized by high traffic density and low speeds relative to a reference state.
The paper Measuring Traffic Congestion – A Critical Review by Aftabuzzaman (2) synthesizes previous research on congestion metrics and underscores the lack of a universally accepted measure capable of fully capturing the complexity of traffic congestion. Drawing on foundational work by Turner (9), Levinson and Lomax (10), Lomax et al. (11), and Boarnet et al. (12), the study identifies six essential criteria for evaluating congestion measures: clarity and simplicity, ability to describe congestion magnitude, comparability between cities, continuity of values, incorporation of travel time, and relevance to public transport congestion relief. In an effort to operationalize the concept of congestion, the literature has proposed a wide range of quantitative indicators. According to Aftabuzzaman (2), these measures can be broadly classified into four main categories: (i) basic measures, (ii) ratio-based measures and (iii) level of service (LOS). Each category reflects a distinct methodological approach aimed at capturing different dimensions of congestion, including temporal delay, spatial extent, user experience, and overall network performance.

The following sections examine each of these categories in detail, assessing their definitions, methodological basis, strengths and limitations, and alignment with the six evaluation criteria outlined above.

1.1 Traffic Measures

1.1.1 Basic and Ratio-Based Indicators

Traffic congestion is commonly estimated as travel delay, defined as the additional time spent compared to free-flow or acceptable travel time. Different studies use varying thresholds to define congestion: for example, Lindley (13) considers it beginning at a volume-to-capacity ratio of 0.77, while Schrank and Lomax (14) apply fixed speed thresholds such as 60 mph for freeways. The Texas Transportation Institute (15) bases its benchmark on the 85th percentile speed recorded during off-peak hours.

Delay can be calculated either in vehicle-minutes or in person-minutes, depending on whether vehicle occupancy is included (11). These indicators are widely used in transport economics, such as in the estimation of annual delay per traveler, due to their simplicity and intuitive interpretation. However, they often lack spatial detail and can be difficult to compare across urban areas with different traffic patterns or infrastructure layouts (11).

An alternative approach involves ratio-based indicators that compare actual travel performance to acceptable benchmarks. A fundamental metric is the travel rate, defined as the time required to traverse a standard unit of distance. From this, several congestion measures are derived: the delay rate (difference between actual and acceptable travel rates), the relative delay rate (delay as a proportion of acceptable travel time), and the delay ratio (share of total time considered as delay) (5; 16). These metrics are useful for evaluating specific corridors, although their applicability to large-scale urban networks remains limited.

1.1.2 Level of Service (LOS) Measures

Level of Service (LOS) is a widely adopted traditional measure of traffic congestion, originating from the 1985 Highway Capacity Manual (17). It categorizes traffic conditions into six levels (A to F) based on vehicle flow characteristics such as speed, volume-to-capacity (V/C) ratio, and density. These categories describe operating conditions ranging from free flow to breakdown flow, and are widely used due to their simplicity and intuitive appeal, especially for non-technical audiences. However, the LOS approach has several limitations: it offers only a stepwise scale rather than continuous values, is sensitive to threshold effects (potentially misrepresenting conditions near a category boundary), and reflects only localized congestion without capturing regional impacts (18).

LOS Class	Traffic State and Condition	V/C Ratio
A	Free flow	0.00–0.60
B	Stable flow with unaffected speed	0.61–0.70
C	Stable flow but speed is affected	0.71–0.80
D	High-density but the stable flow	0.81–0.90
E	Traffic volume near or at capacity level with low speed	0.91–1.00
F	Breakdown flow	¿ 1.00

Table 1: Level of Service (LOS) classification based on V/C ratio, Adapted from Roess et al. (1985)

1.2 Historical Reference: The 2015 ERP Pilot Proposal

A milestone in the formal recognition of traffic congestion as a systemic issue in Bangalore was reached with the publication of a study by the Japan International Cooperation Agency (JICA) in 2015 (19). Commissioned in collaboration with local authorities, the report aimed to provide a structured overview of urban mobility challenges in the city, offering preliminary guidance on possible interventions. Its contribution lay in bringing institutional attention to the need for demand-side solutions in road management. For this reason, the report introduced for the first time the proposal of an Electronic Road Pricing (ERP) system for Bangalore taking inspiration from Singapore, envisioning it as a pilot project in high-density corridors to curb peak-hour congestion.

1.2.1 How Congestion Was Defined and Measured Then

In the JICA report, traffic congestion is defined as a condition in which traffic demand exceeds the available road capacity, leading to reduced travel speeds, increased delays, and overall deterioration in traffic service quality. The measurement of congestion relies primarily on the analysis of speed–flow curves, which illustrate the relationship between vehicle speed and traffic volume, expressed in passenger car units per hour (PCU/h). As shown in the Figure 1, vehicle speeds gradually decline as flow increases, until a critical threshold is reached, identified for Indian urban roads at 24 km/h. This point marks the transition to Level of Service F (LoS F), which indicates severe congestion with unstable traffic flow and frequent stop-and-go conditions. In the graph, this is represented by the sharp downturn in the fitted red curve, where further increases in traffic volume result in a disproportionate drop in speed. All operating conditions below this threshold are considered symptomatic of structural congestion. To support this analysis, the JICA study also incorporates empirical data from travel time surveys, classified vehicle counts, and origin–destination studies (20).

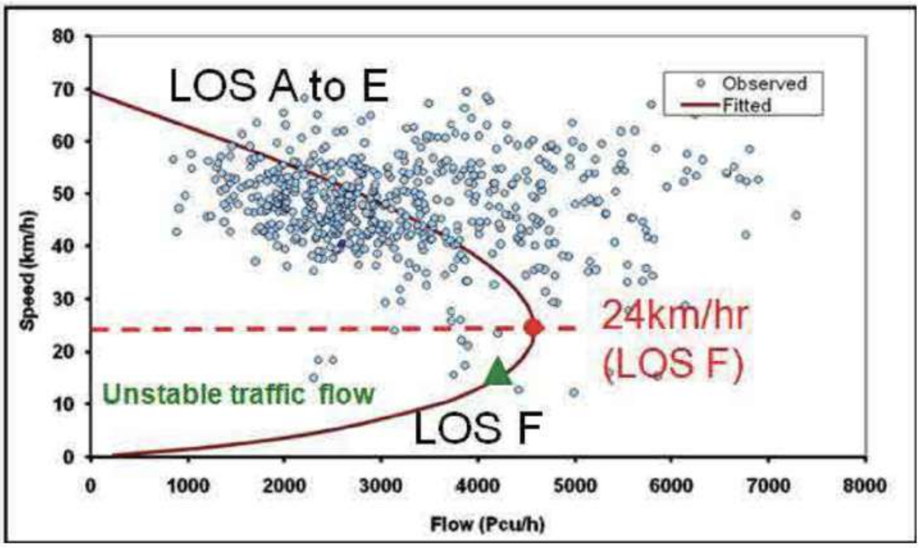

Figure 1: Speed-Flow Curve in Chennai by Indian Institute Technology

1.3 Why Congestion Pricing in Bangalore Is Urgent Today

Although congestion pricing has been widely discussed in Bangalore since the mid-2010s, the initiative remained on paper due to multiple interconnected factors. At that time, JICA itself acknowledged that the ERP could only function effectively if paired with significantly improved transportation alternatives, yet both the metro and bus networks were still expanding and lacked the capacity to absorb the volume of motorists who would seek alternatives to avoid the charge (19; 21). Furthermore, no dedicated metropolitan transport authority was formed and the necessary state-level regulations were never enacted, leaving the proposal mired in feasibility studies rather than moving forward through policy channels (19). Finally, public acceptance proved elusive: many drivers viewed the charge as an unfair financial burden, particularly in the absence of targeted exemptions or subsidies for lower-income groups, and there was no concerted campaign to communicate the potential benefits in reduced travel times or improved air quality (21).

1.3.1 Severity in Numbers: From 2015 to 2025

In 2015, the JICA Master Plan ITS for Bengaluru painted a stark picture of the city's traffic woes. The report highlighted that the strategic road network, approximately 6,000 km in length, was operating "at or above capacity," with average peak-period speeds plummeting below 15 km/h due to roadside friction, ad hoc parking and inadequate junction management (22). Rapid motorisation compounded the problem: between 1995 and 2010 the number of vehicles in the metropolitan area grew by an average of 10% per year, far outstripping both population growth and road-infrastructure expansion, resulting in a 45% decrease in journey speeds between 2008 and 2011 (22). The modal split further underscored the challenge: private two-wheelers and cars accounted for 72% and 18% of traffic respectively, while buses, despite carrying 42% of all commuters, represented only 2% of the total vehicle fleet, revealing a profound mismatch between transport demand and supply (22).

Actually, Bangalore ranks among the most congested cities in the world. According to the TomTom Traffic Index 2024 (23), drivers in Bengaluru spend on average 34 minutes and 10 seconds to travel just 10 km in peak traffic. This represents an increase of 50 seconds compared to 2023, showing that congestion is worsening. Drivers lose around 117 hours per year during rush hours, more than 14 full working days annually. The city registers a 38% congestion level, and it ranks 3rd globally for average travel time per 10 km. These figures place Bengaluru alongside cities like Barranquilla (Colombia) and Kolkata (India) at the top of global congestion rankings. According to the TomTom Index, average speeds in Bangalore's roads are just around 17,7 km/h, placing them below acceptable standards at Level of Service F, indicative of oversaturation.

1.3.2 Public Perception of Congestion Nowdays

The perception of traffic congestion in Bangalore among its residents is overwhelmingly negative, as confirmed by extensive survey findings which reveal the depth and breadth of frustration experienced across demographics. These findings come from the study "Bangalore Traffic's Impact on General Public" (24), which used Google Forms to collect self-reported data from residents about how traffic affects their mental health, productivity, daily routines, and trust in infrastructure. However, the study presents some limitations: it was conducted over a short timeframe, with a limited and possibly non-representative sample, and focused primarily on certain urban areas. A striking 94.2% of respondents acknowledged being directly affected by the city's traffic, suggesting that the issue has become a near-universal burden in daily life. Far beyond being a mere nuisance, the congestion exerts a tangible toll on mental well-being, with over three-quarters (76.7%) of those surveyed reporting stress, anxiety, or even anger as recurring emotional responses to their commutes. This psychological strain is compounded by the routine nature of delays, 62.1% of individuals experience them either frequently or always, highlighting the chronic and systemic nature of the issue. Commute times further underscore the severity: while nearly half of the respondents spend between 30 minutes and an hour commuting, a significant proportion (over 30%) endure daily travel times of up to or beyond two hours.

Notably, traffic congestion is not only an inconvenience but also a critical disruptor of professional and personal life. Respondents frequently cited missed work, educational commitments, and delayed appointments, with 77.7% stating that traffic has negatively impacted their schedules. The issue has also shaped perceptions of work satisfaction, where only a marginal 3% of individuals claimed to be highly satisfied with their current situation, while many reported moderate to high dissatisfaction, primarily due to commute-related pressures. Moreover, a staggering 77.7% admitted to experiencing mental health issues, including stress and emotional fatigue, as a direct result of traffic jams.

Public confidence in institutional responses is also low: only 18.4% of those surveyed believe that local authorities are effectively managing the problem, while nearly 40% expressed outright skepticism. Even awareness about infrastructure projects is fragmented, with the population split nearly evenly between those who know about ongoing developments and those who do not. The sense of helplessness is further reinforced by the finding that many residents rely heavily on personal navigation tools like Google Maps (used by 78.6%) to navigate the chaos, often in the absence of effective systemic solutions.

2 Comparative Analysis Between Bangalore and Singapore: Lessons for Smart Mobility

2.1 Comparing Two Urban Models

The 2015 report on urban mobility in Bangalore (19) gave significant attention to the idea of introducing an Electronic Road Pricing system, inspired by the model implemented in Singapore. It emphasized the system's effectiveness in reducing traffic congestion compared to conditions prior to its introduction. However, the report's analysis was limited to a descriptive comparison of traffic impacts and did not explore the broader context in which such a system operates. Key contextual dimensions, such as demographic and socioeconomic factors, urban planning and infrastructure design, and the institutional and governance frameworks, were largely overlooked, despite being crucial to understanding why a solution like ERP succeeded in Singapore and whether it could be replicated in Bangalore.

This chapter aims to fill that gap by offering a structured comparative analysis of Bangalore and Singapore across these critical dimensions. By examining how demographic trends, urban infrastructure, institutional setups, and policy ecosystems influence the deployment of systems like ERP, as well as Singapore's complementary tools (EMAS, GLIDE, and ITS), the aim to isolate which lessons are transferable, and under what conditions.

2.1.1 Demographic and Socioeconomic Differences

Demographics

The demographic trajectories of Bangalore and Singapore reveal a striking contrast with significant implications for urban mobility planning. According to data from the *United Nations* (25), Bangalore's population is projected to reach approximately 14.4 million in 2025, with an annual growth rate of 2.76% (Figure 2), continuing a trend of rapid expansion that has intensified since the 1980s. In contrast, Singapore's population is expected to stabilize at around 6.15 million, with a much lower annual growth rate of just 0.62% (Figure 3).

This divergence in growth patterns underscores how Bangalore is under increasing demographic pressure, which places a considerable strain on its transport infrastructure and urban services. Singapore, by contrast, has benefited from a more stable population, allowing for proactive and coordinated long-term urban planning.

Further highlighting this contrast is the difference in population density. Bangalore, with its 14 million residents spread over approximately 8,005 square kilometers (26), has a density of about 1,749 people per km^2. Singapore, by comparison, accommodates over 6 million people within just 735 square kilometers (27), resulting in a much higher density of more than 8,370 people per km^2.

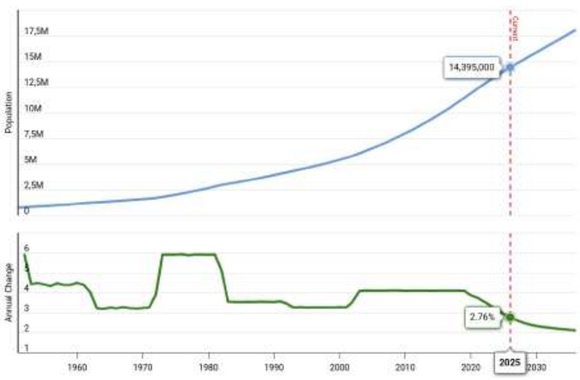

Figure 2: *
Bangalore Metro Area Population
(1950–2025)

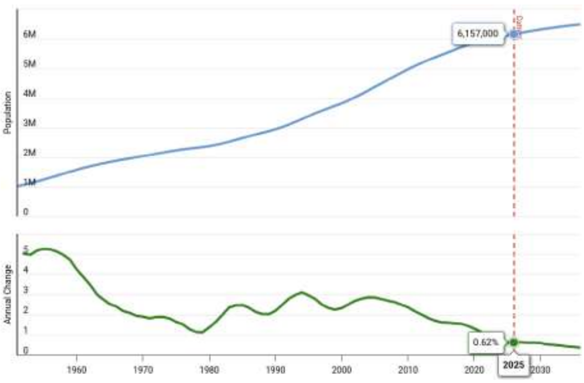

Figure 3: *
Singapore Metro Area Population
(1950–2025)

Figure 4: Population growth and annual change comparison between Bangalore and Singapore; source: United Nations, World Population Prospects via Macrotrends (28), (29)

Socioeconomic

The socioeconomic landscapes of Bangalore and Singapore reflect stark contrasts in terms of income levels, inequality, and spatial distribution of economic opportunity. In 2024, the average monthly salary in Bangalore was estimated at approximately 21,826 rupies (around 200 euro)(30), but this figure masks extreme disparities within the city's population. A large share of workers remains employed in the informal sector, with limited access to stable wages, healthcare, or education. India's national Gini coefficient, measuring income inequality, stood around 0.410(31) in recent years, indicating persistent economic disparity. These inequalities are also spatially visible in Bangalore, where affluent tech corridors such as Whitefield or Electronic City coexist with informal settlements and peripheral neighborhoods lacking basic infrastructure and economic opportunities.

In contrast, Singapore reported a median monthly income of $6.282 in 2024 (approx. 4279 USD)(32), reflecting sustained economic growth and a strong middle class. However, despite its wealth, Singapore also faces inequality: its Gini coefficient before taxes and transfers was 0.435 in 2024(31). Yet, through proactive redistributive measures, such as social transfers, housing subsidies, and progressive taxation, this figure was reduced to 0.364(31), the lowest level recorded since 2000. Crucially, while income gaps exist in Singapore, they are not spatially segregated to the same extent as in Bangalore. The city-state's dense urban fabric and public housing policies have created economically mixed neighborhoods, limiting the spatial concentration of poverty.

These differences point to a fundamental divergence in how inequality manifests and is managed in the two cities. Bangalore's combination of high income disparity and pronounced spatial segregation reinforces cycles of exclusion and limits access to urban resources for low-income populations. Singapore, while not immune to inequality, benefits from a more cohesive urban and policy framework that buffers its social impacts. Any attempt to draw lessons from Singapore for Bangalore must therefore consider not only differences in income levels, but also the institutional capacity to manage inequality through spatial and fiscal integration.

2.1.2 Contrasting Urban Planning

Urban planning in Bangalore and Singapore reflects two fundamentally different models that shape how each city approaches development and traffic management. As cities like Bangalore look to adopt successful policies from Singapore it's important to recognize that these strategies are not just technical fixes. They are the product of, and deeply embedded in, specific planning cultures and institutional arrangements. Without understanding the planning foundations behind these policies, attempts at replication risk being superficial.

Urban planning in Bangalore is formally governed by the Karnataka Town and Country Planning Act (1961), along with the Karnataka Municipal Corporation Act (1964) and the Bangalore Development Authority Act (1976) (33; 34; 35). Central to this framework is the Master Plan, which defines zoning, land use, and infrastructure priorities, especially roads. To implement it, the local authority (BBMP) typically acquires land either through compensation or, more commonly due to budget constraints, via the Transfer of Development Rights (TDR). This mechanism grants landowners additional construction rights elsewhere in the city in exchange for land surrendered for public use. While TDR aims to facilitate development without direct financial costs, it suffers from issues like market saturation, vague valuation, and limited transparency. Digitizing records and better integrating TDR into spatial planning are among the reforms proposed to address these shortcomings (36).

However, despite this formal structure, Bangalore's urban planning faces deeper challenges. As Sundaresan argues (37), the city operates under a system of *vernacular governance*, where planning outcomes are shaped not by formal rules alone, but through ongoing negotiations between public and private actors. Violations of the Master Plan are not exceptions, they are routine and expected results of how planning is practiced. Through "planning for violations," legal norms are bypassed or reinterpreted to meet the interests of powerful networks. Even well-intentioned tools like TDR risk becoming part of this fragmented and opaque system unless embedded within accountable planning practices. Given this context, addressing Bangalore's traffic problems cannot rely solely on infrastructure upgrades or policy adjustments. Any meaningful solution must also confront the underlying dysfunctions in urban planning.

In contrast, Singapore's urban planning is guided by a clear, forward-looking framework led by the Urban Redevelopment Authority (URA) (38), designed to optimize the use of limited land while ensuring long-term sustainability. At its core lies the Long-Term Plan, updated every 10 years, which sets strategic directions for land use over a 50-year horizon. This is operationalized through the statutory Master Plan, reviewed every five years, which provides legally binding and detailed guidelines for development over the next 10–15 years. Planning in Singapore is deeply data-driven, with URA leveraging geospatial technologies and analytics to enable smart, adaptive decisions. Urban design plays a crucial role, ensuring that new developments integrate harmoniously with existing environments, paying attention to livability, public space, and walkability. Public participation is also central to the process, as residents are regularly engaged in consultations on draft plans, helping ensure alignment between planning goals and community needs. More broadly, Singapore represents a strong case of centralized and efficient state capitalism, where urban policies are formulated and implemented by a technocratic administration endowed with significant legitimacy, financial means, and operational capacity. (39) Thus, while Singapore offers valuable lessons for cities like Bangalore, especially in managing urban mobility, the effectiveness of these approaches cannot be divorced from their planning context.

2.1.3 Institutional and Governance Architectures (DULT vs. LTA)

The Directorate of Urban Land Transport (DULT) in Bangalore was established in 2007 as a state-level agency under the Urban Development Department of the Government of Karnataka. Its primary role is to coordinate urban mobility plans and promote sustainable transportation modes across various cities in Karnataka. However, DULT's mandate is largely strategic and consultative, lacking direct control over transport operations or infrastructure execution. This limitation often results in fragmented implementation of transport policies and projects (40).

In contrast, the Land Transport Authority (LTA) of Singapore, formed in 1995 as a statutory board under the Ministry of Transport, possesses comprehensive authority over the nation's land transport ecosystem. LTA is responsible for the planning, development, and regulation of all land transport infrastructure and systems, including roads, rail, and public transport services. It also integrates land use and transport planning, enhancing policy coherence and operational efficiency (41).

DULT operates with limited autonomy and relies heavily on approvals and funding from higher administrative bodies. Its financial resources are constrained, and it lacks the authority to execute large-scale infrastructure projects independently. This dependence hampers its effectiveness in implementing comprehensive urban transport solutions (42).

On the other hand, LTA benefits from financial independence and streamlined governance structures. As a statutory board, it has the authority to plan, fund, and execute large-scale, technology-driven infrastructure projects, such as the Electronic Road Pricing system (43).

2.2 Singapore's Electronic Road Pricing

Singapore's implementation of road pricing is a leading example of urban congestion management. In 1975, the city-state introduced the Area Licensing Scheme (ALS)(44), a manual system requiring vehicles to display daily paper permits when entering the central business district during peak hours. While initially effective, reducing traffic by 44 percent, the scheme was limited by inflexibility, high enforcement costs, and insufficient control over repeated trips, as a single permit allowed unlimited entries.

In 1998, the ALS was replaced by the ERP system(45). Using Dedicated Short-Range Communication (DSRC) technology, the system introduced in-vehicle units and smart cards to enable per-entry toll collection. Charges are deducted automatically, and enforcement is managed through gantry-mounted sensors and cameras. This change improved system responsiveness and allowed tolls to vary throughout the day according to traffic conditions.

ERP pricing aims to maintain target speeds between 20 and 30 kilometers per hour on urban roads and 45 and 65 kilometers per hour on expressways. When speeds fall below these thresholds, charges increase, while higher speeds may lead to lower tolls. This dynamic model supports real-time congestion control and demand balancing.

Despite lower per-pass charges, ranging from 0.50 to 2.50 Singapore dollars compared to the ALS flat rate of 3.00 dollars, ERP reduced central business district traffic by 10 to 15 percent during operation hours. The effect was most significant among users making multiple daily entries, who represented about 23 percent of trips under the ALS. The shift to per-entry pricing discouraged repeated trips and encouraged greater use of public transport during the day (46).

ERP 2.0 (rollout began in late 2023) represents a technological upgrade, shifting from gantry-based infrastructure to a satellite-based system using the Global Navigation Satellite System (GNSS). This change enables virtual tolling without physical gantries and allows broader integration with digital services. The core device is the On-Board Unit (OBU), which replaces the previous in-vehicle unit and includes a Processing Unit, Antenna, and optional Touchscreen Display. The system supports smartphone pairing and provides access to real-time data such as ERP charges, incidents, school zones, speed cameras, and parking availability. Additional features will include alerts for virtual toll zones, licensing payments, and cross-border tolling. During the transition, pricing remains location and time-based, but GNSS enables future adoption of more refined models, including distance-based charging. Payments are handled through CEPAS cards or backend wallets, and all transactions are recorded digitally. The system ensures privacy by storing only vehicle-specific data for enforcement and using anonymized, aggregated data for planning (47). However, technical challenges persist. GNSS accuracy is insufficient in dense urban areas without Road-Side Units using DSRC or signal boosters. Because the OBU independently applies charges, the reliability and consistency of performance across devices become critical, especially when compared to smartphone alternatives. System costs also remain uncertain, as RSUs in built-up areas may not offer significant savings compared to gantries. The legacy ERP system relied on proprietary technology, and it is unclear whether ERP 2.0 has achieved greater openness or interoperability. The OBU has faced criticism for limited features and unclear cost-benefit advantages (47).

Although Singapore currently applies uniform ERP rates regardless of vehicle emissions, the GNSS platform could support differentiated pricing by distance, emissions, or location. While electric vehicle uptake is encouraged through fiscal incentives, ERP continues to reflect a usage-based approach that is neutral to fuel type.

Several lessons emerge. Long-term planning must account for lifecycle and upgrade costs. Compatibility and government-funded device installation facilitate adoption. GNSS-based systems require supporting infrastructure and must be evaluated in dense settings to ensure performance. Framing road pricing in terms of congestion control, environmental goals, and infrastructure funding helps build public acceptance. Singapore's case demonstrates how dynamic pricing can be integrated into broader transport policy to support sustainable urban mobility (48).

3 Methodology

3.1 Main Reseach question: Is it feasible to implement an ERP system in the context of Bangalore in 2025?

The central research question that guides this study is: Is it feasible to implement an ERP system in the context of Bangalore? This question is intentionally broad and is not intended to have a binary answer. Rather, it serves as a starting point for a critical examination of the multifaceted dynamics surrounding such a policy intervention. The objective is not to determine definitively whether Bangalore should or should not adopt ERP, but to explore a range of contextual, infrastructural, economic, and social factors that could influence, and be influenced by, the potential introduction of such a system.

To operationalize this inquiry, the study is structured around a series of subordinate research questions that address specific aspects of feasibility:

- In Which Areas of Bangalore should ERP be applied?
- Can ERP be implemented from the Infrastructural and Technological point of view?
- Can ERP be implemented without disproportionately affecting vulnerable populations?

By examining these dimensions, the research seeks to shed light on how an ERP model, similar to that implemented in Singapore, might interact with the specific urban conditions of Bangalore. This involves not only assessing potential barriers and enabling factors, but also uncovering broader implications for urban mobility, equity, public acceptance, and governance.

3.2 Research Question 1: In Which Areas of Bangalore should ERP be applied?

In order to identify areas within Bangalore that may be particularly suited to the implementation of an ERP system, a composite indicator referred to as the *Traffic Stress Index* (TSI) is constructed.

The TSI is formally defined as:

$$\text{TSI}_i = CL_i \cdot \left(1 + \frac{IR_i}{100}\right) \cdot \left(1 + \frac{100 - AS_i}{100}\right)$$

where:

- CL_i denotes the congestion level observed in area i,

- IR_i represents the number of incident reports in area i,
- AS_i indicates the average speed (in km/h) recorded in area i.

This formulation is designed to reflect how traffic stress intensifies in the presence of high congestion levels and frequent disruptions, while being mitigated by efficient traffic flow. The inclusion of normalized modifiers for incident reports and inverse average speed ensures that the index captures compounding effects where multiple adverse conditions co-occur.

The data employed in the construction of the TSI originates from a publicly accessible dataset hosted on Kaggle [1], derived from real-time traffic data provided by the Government of Karnataka. The dataset encompasses daily observations between January 1st, 2022 and August 9th, 2024, collected at key roads and intersections across Bangalore. Variables included in the dataset comprise, among others: congestion level, average speed, traffic volume, travel time index, incident reports, road capacity utilization, environmental impact, public transport usage, parking demand, pedestrian and cyclist counts, weather conditions, and roadwork activity.

3.3 Research Question 2: What Infrastructural and Technological Factors Influence the Feasibility of ERP?

Before evaluating the potential effectiveness of an ERP system, it is necessary to assess its technical feasibility. This dimension refers to the infrastructural and technological conditions required for implementing such a system in the selected high-stress zones of Bangalore. The analysis will consider three main aspects: the physical layout of the road network, the presence of surveillance infrastructure, and the compatibility with existing digital tolling technologies.

First, the analysis will focus on the identification of the main entry and exit points of the selected road segments. Since ERP systems rely on controlling access at specific gates, it is essential to verify whether the structure of the road network allows for a limited number of access points that can be effectively monitored. To do so, the study will use OpenStreetMap data and process it with the `osmnx` Python library, which enables the construction of a directed graph of the road network. The graph will then be filtered to isolate critical ingress and egress nodes, which will inform the system design and placement of control infrastructure.

Second, the presence of CCTV cameras will be examined to understand whether existing surveillance infrastructure can be leveraged to support ERP enforcement. In particular, attention will be paid to the spatial distribution of publicly available CCTV devices. The dataset, published by the Government of Karnataka[2], will serve as a preliminary reference to identify locations where infrastructure such as poles and power supply is already in place, facilitating the future deployment of Automatic Number Plate Recognition (ANPR) systems.

Finally, the study will consider the presence of FASTag technology, which is already in use across India for highway toll collection. Given its widespread adoption, the potential for adapting FASTag to urban ERP applications will be explored. Particular attention

[1] `https://www.kaggle.com/datasets/preethamgouda/banglore-city-traffic-dataset`

[2] `https://data.opencity.in/dataset/bengaluru-cctv-cameras/resource/bengaluru---cctv-cameras-map`

will be paid to whether existing readers and payment mechanisms could be repurposed in an urban environment to reduce implementation costs and improve user acceptance.

3.4 Research Question 3: Can ERP be implemented without disproportionately affecting vulnerable populations?

In the evaluation of ERP feasibility, it is essential not only to consider the technical and infrastructural readiness of the city, but also to assess the potential social implications of such a system. One critical aspect of this assessment involves identifying areas inhabited by socioeconomically disadvantaged populations. This analysis is necessary because, in contexts where ERP is implemented, there is a risk that pricing mechanisms may disproportionately affect individuals who rely on private vehicles due to inadequate access to public transportation or reside in poorly connected zones. Mapping these vulnerable zones allows for an understanding of whether the roads targeted for ERP coincide with areas of concentrated economic hardship. If a significant overlap exists, it may indicate that the system could impose additional burdens on already marginalized populations.

Another important component of the social feasibility analysis concerns the availability of public services, specifically, access to affordable and efficient public transportation. Even in cases where ERP might affect low-income residents, the existence of nearby alternatives such as metro stations or bus routes could mitigate the system's impact by offering viable substitutes to private vehicle use.

For this purpose, geospatial datasets on the distribution of metro stations[3] and bus stops and routes by ward[4] were analyzed and overlaid with data on slum locations[5].

4 Data Analytics

4.1 Identifying High-Stress Zones

Index	Area Name	TSI
4	Koramangala	157.445286
5	M.G. Road	150.521530
2	Indiranagar	144.825017
1	Hebbal	131.185480
3	Jayanagar	126.236185
6	Whitefield	111.423952
7	Yeshwanthpur	99.425705
0	Electronic City	86.336230

Table 2: TSI values for different areas in Bangalore

Table 2 presents the TSI (Traffic Stress Index) values recorded across selected areas in Bangalore. Among these, **Koramangala**, **M.G. Road**exhibit the highest TSI values (157.45, 150.52 respectively) indicating that they are the most congested and traffic-intensive zones in the dataset. These areas likely experience higher vehicle density, fre-

[3] https://data.opencity.in/dataset/bengaluru-metro-stations

[4] https://data.opencity.in/dataset/bus-stops-and-routes-map-by-ward

[5] https://data.opencity.in/dataset/bengaluru-slums-map

quent bottlenecks, and elevated commuter stress, making them critical candidates for traffic mitigation strategies like ERP.

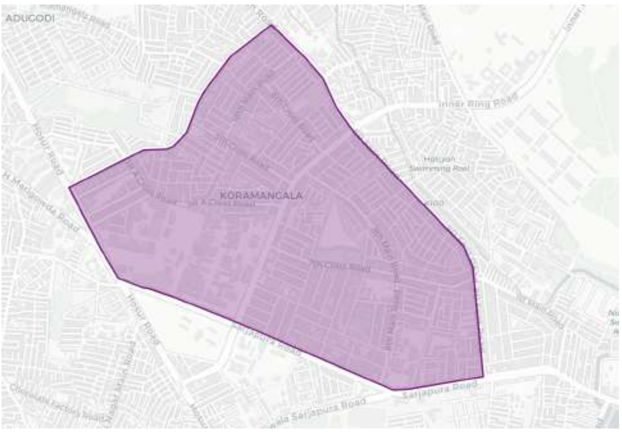

Figure 5: Koramangala Area

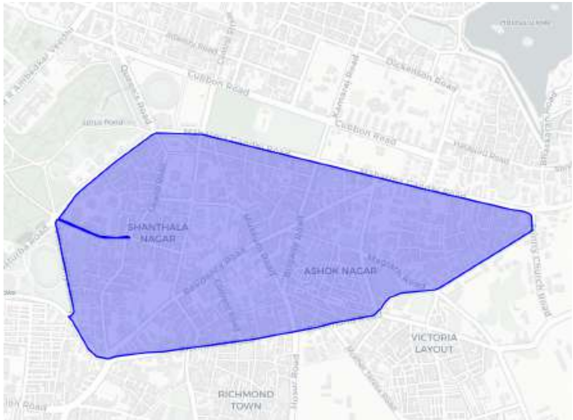

Figure 6: M.G. Road Area

In Figures 5, 6 the locations of the most traffic-stressed zones, identified according to the Traffic Stress Index (TSI) are highlighted. Within each of these zones, the main arterial roads have been delineated to represent their structural role in the urban mobility network. Understanding the functional significance of these road segments and areas is a necessary step toward assessing their suitability for targeted ERP implementation and further policy analysis.

4.2 Description of selected roads

Koramangala is a well-established neighborhood in the southeastern part of Bengaluru. Initially developed in the 1970s by the Bangalore Development Authority (BDA) as a planned residential area, it was designed to accommodate the city's expanding population while ensuring accessibility and infrastructure provision (49; 50).

Over the decades, Koramangala has evolved into a prominent mixed-use locality that balances residential zones with significant commercial activity. It is known for its tree-lined streets, wide roads, and a diverse range of housing types, including individual houses, builder-floor apartments, and gated communities (50; 51). Its proximity to major IT corridors such as Electronic City and Outer Ring Road has attracted numerous tech companies, co-working spaces, and startups, making it a recognized innovation hub in the city (51; 36).

The area also hosts a thriving social and recreational ecosystem, with shopping malls, independent boutiques, restaurants, cafes, and cultural venues drawing residents and visitors alike (51). This convergence of land uses, residential, commercial, and recreational, has led to sustained and often high levels of vehicular traffic, particularly during peak hours, thus making Koramangala a critical candidate for congestion-management strategies like Electronic Road Pricing (52).

Mahatma Gandhi Road (MG Road) is one of Bengaluru's most iconic thoroughfares, reflecting the city's historical evolution and contemporary urban dynamics. Originally established during the British colonial period as South Parade, it was renamed in 1948 to honor Mahatma Gandhi following India's independence (53).

Strategically located in the heart of the city, MG Road has transformed into a vibrant commercial and cultural hub. The area is characterized by a mix of colonial-era architecture and modern developments, housing a plethora of retail outlets, restaurants, theaters, and office spaces (54). Its proximity to significant landmarks such as Brigade Road and Church Street further accentuates its importance in Bengaluru's urban landscape.

MG Road is also a critical node in the city's transportation network. The presence of the MG Road Metro Station, part of the Namma Metro's Purple Line, enhances its connectivity, facilitating commuter movement across various parts of Bengaluru (53). Despite these infrastructural advancements, the area experiences substantial traffic congestion, a reflection of the broader challenges faced by the rapidly urbanizing city (55).

4.3 Technical feasibility

4.3.1 Koramangala Technical feasibility

Area-Based Analysis

The map in Figure 9 illustrates a potential implementation of an ERP system over the area of Koramangala, covering approximately 2.33 km^2 and enclosed by the main arterial roads Sarjapur Road, Hosur Road, 80 Feet Road, and Srinivagilu Main Road. The area is rapresented by a polygon, it features numerous access points (red dots) along its boundary and a partial network of existing surveillance cameras (green dots), which represent critical infrastructure components for any pricing or enforcement strategy.

The internal layout of the road network, as shown in Figure 7, is marked by a high density of internal nodes (blue dots), corresponding to intersections, junctions, and branching points within the local street grid. This distribution reveals a highly ramified and fine-grained network, typical of mixed-use urban neighborhoods.

Further structural insights are offered by Figure 8, which categorizes streets by function, residential (light green) and service roads (dark green) dominate the interior, while primary (orange) and secondary roads (yellow) are almost exclusively located along the perimeter.

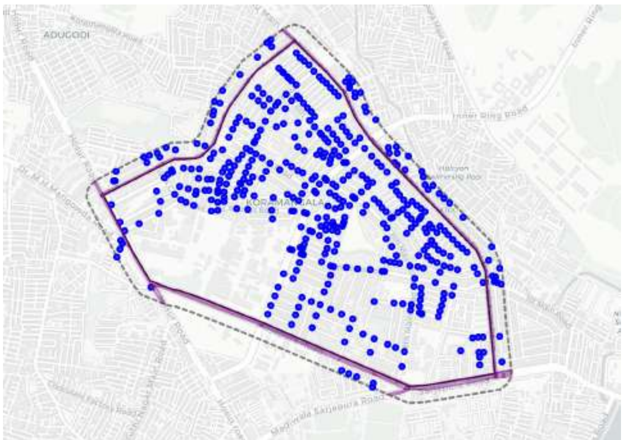

Figure 7: Koramangala Internal Nodes

Figure 8: Koramangala: Street Types and Layout

Implementing an area-wide ERP scheme in Koramangala, whether through fixed-point enforcement (ERP 1.0) or GNSS-based tracking (ERP 2.0), is neither technically justified nor contextually appropriate. Koramangala is a primarily residential neighborhood, characterized by a dense urban fabric, numerous small access roads, and fragmented internal

Figure 9: Koramangala ERP Boundary: Access Points and Camera Coverage

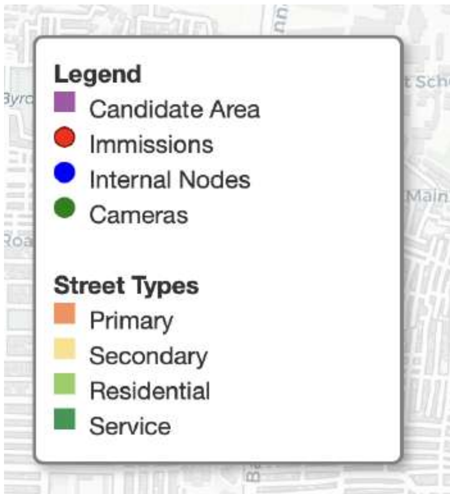

Figure 10: Legend

circulation. Attempting to enforce congestion pricing across the entire area would require controlling a large number of entry and exit points, resulting in high implementation costs and significant disruption to everyday local movement, including that of residents, service vehicles, and emergency services.

Moreover, most of the traffic pressure in Koramangala does not stem from internal circulation but from external vehicles using its main arterial roads. Given this configuration, a more effective and proportionate strategy would be to abandon the idea of pricing the entire area and instead focus ERP enforcement, and study the technical feasibility on major arterials sush as Hosur Road and Sarjapur Road

Streets-Based Analysis

As a complement to the area-based analysis, the maps in Figures 11– 13 explore the feasibility of a street-based ERP implementation, focusing on a linear corridor along Hosur Road and Sarjapur Road, which connects the Madiwala area to eastern Koramangala.

Figure 11: Koramangala Main Streets

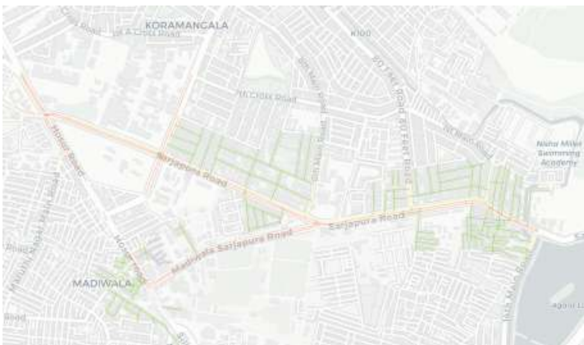

Figure 12: Global View of Selected Areas

The corridor is composed primarily of primary roads, flanked by a dense and hierarchical network of residential and service streets as shown in Figure 12. As shown in Figure 13, red points mark the access nodes, green dots represent existing surveillance

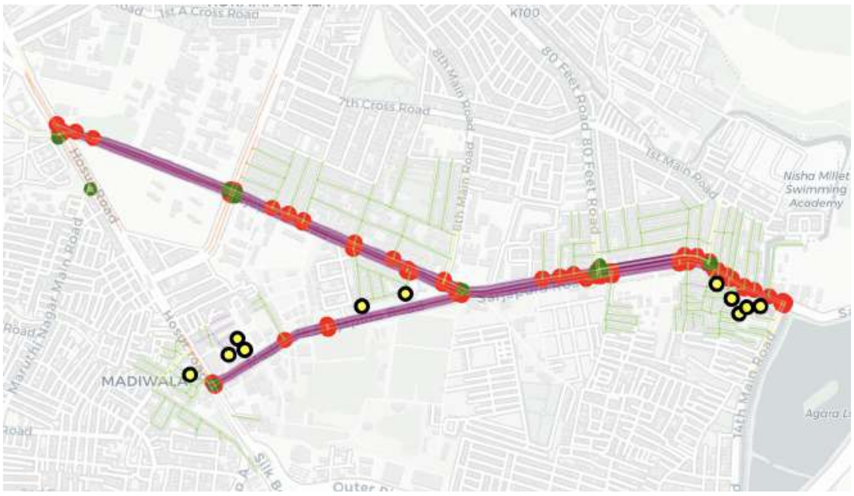

Figure 13: Koramangala ERP Boundary: Access Points and Camera Coverage

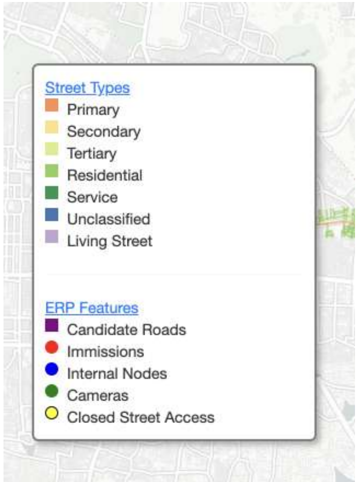

Figure 14: Legend

cameras, while yellow markers indicate entries to dead-end streets, that is, local branches that do not allow through traffic and are not relevant for pricing enforcement.

In the context of ERP 1.0, the high number of intersections would require substantial physical enforcement infrastructure. However, the identification of non-through access points allows for a more efficient delineation of control nodes, potentially reducing the number of gantries required.

By contrast, the corridor structure strongly supports an ERP 2.0 model, based on GNSS tracking and dynamic tolling. The linear geometry simplifies monitoring, and the separation between arterial and local streets allows for route-based pricing while minimizing the burden on local users. The spatial layout of dead-end entries reinforces the feasibility of a targeted and scalable ERP 2.0 deployment, whereas the ERP 1.0 variant would entail significant operational complexity and infrastructure costs.

4.3.2 Mahatma Gandhi Road Technical feasibility

Area-Based Analysis

Figures from 15 to 17 explore the applicability of an area-based ERP system in the MG Road district, enclosed by the roads Mahatma Gandhi, Kasturba, Trinity Church, Mallya, Victoria, Rajaram Mohan Roy, and Richmond. The resulting perimeter encloses approximately 2.54 km^2, covering a dense urban core known for its commercial, retail, hospitality, and administrative functions. As shown in Figure 17, red dots identify entry points to the area, while green dots indicate the presence of existing surveillance cameras. Although some portions of the perimeter are already partially monitored, several segments, especially on the western and northeastern sides, would require significant infrastructure reinforcement under an ERP 1.0 regime. The high number of access points and the need to preserve pedestrian and commercial accessibility complicate the implementation of traditional boundary control.

Figure 15 reveals a clear distinction between high-capacity arterial roads forming the perimeter and a finer internal mesh of secondary, service, and residential streets. This structure would technically support boundary pricing, but operational challenges arise from the area's functional density and exposure to diverse traffic flows (commuters, de-

Figure 15: M.G.Road Main Streets

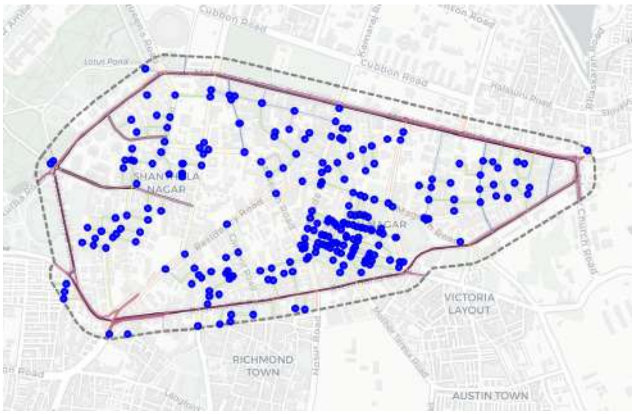

Figure 16: M.G.Road Internal Nodes

Figure 17: M.G.Road ERP Boundary: Access Points and Camera Coverage

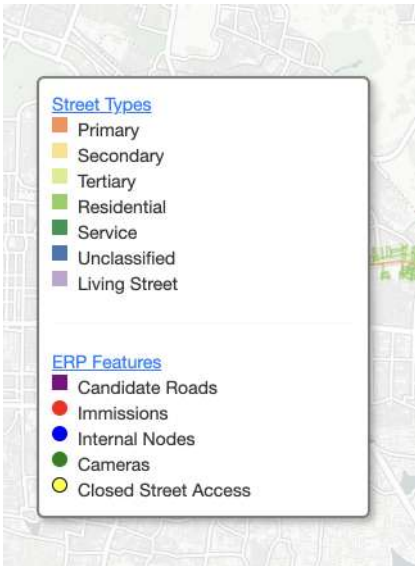

Figure 18: Legend

livery vehicles, shoppers, tourists).

As shown in Figure 16, the distribution of internal nodes is highly saturated, reflecting the mixed-use intensity of the area. While this density suggests high local trip volumes, the dominance of non-residential land use makes it difficult to distinguish between internal and through traffic. Moreover, the large surface and centrality of MG Road raise concerns of disproportionate administrative and logistical complexity to implement ERP setup.

For this reason, a smaller subset of the district, was also analyzed to assess the viability of a more targeted ERP zone.

The smaller area selected, covering approximately 0.8 km^2, is enclosed by the roads Mahatma Gandhi Road, Mark's Road, Anil Kumble Circle, Trinity Church Road, Richmond Road, Hayes Road, and Brigade Road. This boundary defines a compact urban block within the broader MG Road district, as depicted in Figures 19- 21. The configuration of access points highlighted in red in Figure 21 reveals a limited number of strategic entry routes, which facilitates control under an ERP 1.0 framework.

Moreover, a considerable presence of existing surveillance infrastructure (green dots) is distributed along these entry points, supporting the feasibility of implementing automated

Figure 19: M.G.Road Smaller Area Main Streets

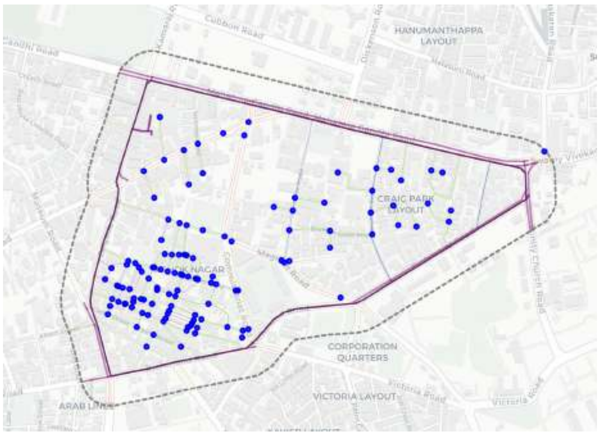

Figure 20: M.G.Road Smaller Area Internal Nodes

Figure 21: M.G.Road Small Area ERP Boundary: Access Points and Camera Coverage

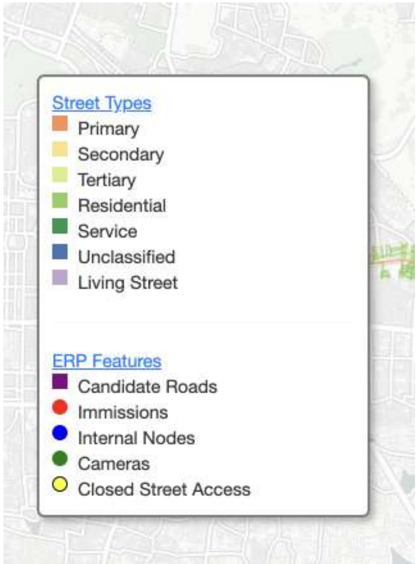

Figure 22: Legend

monitoring without requiring a full overhaul of the area. Internally, the network density remains significant (Figure 20 , but more contained than in the broader MG Road sector). These features suggest that this smaller zone may represent an optimal candidate for piloting congestion pricing in Bangalore's central commercial areas.

Streets-Based Analysis

The technical feasibility of implementing an ERP scheme along a linear corridor, rather than an enclosed area, is illustrated in Figures 23- 25.

The selected corridor comprises Mahatma Gandhi Road and its vertical connectors, including Trinity, Anil Kumble, and Mark's Road, forming a continuous axis. This configuration enables a simpler tolling infrastructure, as vehicle flows can be monitored and priced at discrete, linear control points rather than requiring a full ring of enforcement.

Figure 25 shows a dense presence of existing cameras (green) and access points (red), especially concentrated near major junctions and intersections, suggesting that a line-

Figure 23: M.G.Road Main Streets

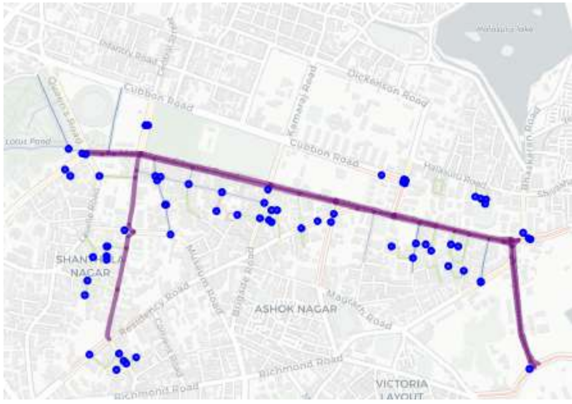

Figure 24: M.G.Road Internal Nodes

Figure 25: M.G.Road ERP Boundary: Access Points and Camera Coverage

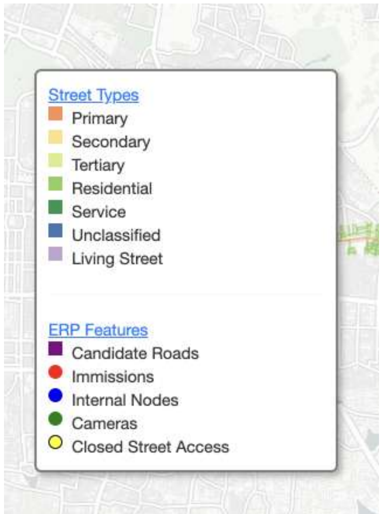

Figure 26: Legend

based ERP can rely on infrastructure already in place with minimal additional deployment. The road types (Figure 23) are predominantly primary and secondary, supporting the argument that this corridor handles strategic flows suited for congestion pricing. Figure 24 confirms the presence of a high number of internal connections from residential and service roads, which could still feed into the corridor, but are manageable through strategic gate placement or one-way restrictions.

4.3.3 Technological Infrastructure

India's FASTag system, based on RFID, has reached near-universal adoption, with over 80 million tags active by late 2023 and 98% coverage of national toll lanes (56; 57). While granular data for Bangalore is limited, national figures suggest that most local vehicles are already FASTag-equipped, minimizing infrastructure barriers for ERP models akin to Singapore's DSRC system.

Bangalore also shows strong readiness on the payment front. In March 2025 alone, the city registered over 8 million UPI transactions, reflecting high engagement with real-time, digital payments (58). UPI's nationwide infrastructure and 300M+ monthly users support the feasibility of automated ERP toll debits.

Finally, smartphone penetration in urban India, including Bangalore, exceeds 80%, supported by over 1.12 billion active cellular connections nationwide (59; 60). This provides the technological baseline for GNSS-based ERP 2.0, which requires mobile apps for tolling, user notifications, and balance management.

These three indicators, FASTag saturation, UPI ubiquity, and smartphone access, confirm that Bangalore is technically ready for both DSRC and GNSS-based ERP systems.

4.4 Social Feasibility

4.4.1 Public Transport

An essential prerequisite for the successful implementation of ERP is the availability of efficient, accessible, and multimodal public transport options that can serve as viable alternatives to private vehicle usage. In the context of Bengaluru, public transport infrastructure, particularly bus routes and metro corridors, plays a critical role in mitigating the potential displacement effects of ERP systems.

Koramangala

Since Koramangala is primarily a residential neighborhood, implementing an area-based ERP scheme would disproportionately affect residents and contradict the goal of congestion pricing, which is to discourage through, traffic without penalizing local access. For this reason, the analysis focuses on applying ERP only along the external ring of main roads, specifically Sarjapur Road and Hosur Road, which serve as strategic corridors linking Koramangala to key employment and commercial hubs such as Electronic City and central Bangalore.

Figure 27 shows the public transport infrastructure along these two roads, highlighting bus stops and route groupings by color. While several bus lines operate across this corridor, including multiple east–west and north–south connections, the absence of a metro station within or near the area significantly limits mass transit capacity. Furthermore, given Bangalore's well-documented congestion patterns, bus services, especially during peak hours, often fail to provide consistent travel times and high reliability.

M.G. Road

In contrast, MG Road presents a favorable context. The larger 2.5 km^2 perimeter, initially considered as a candidate, was ruled out due to the complexity of monitoring a dense, mixed-use zone. As a result, the other two candidates are more realistic options: (i) a smaller 0.8 km^2 area bounded by Mahatma Gandhi, Mark's, Anil Kumble, Trinity, Richmond, Hayes, and Brigade Roads (Figure 28); or (ii) a line-based ERP along MG Road, between the intersections at Queen's Circle and Trinity Church (Figure 29). From a transport standpoint, this corridor benefits from excellent multimodal connectivity. The Purple Line of the Namma Metro runs directly beneath MG Road, forming part of Bangalore's most strategic east-west transit axis. It connects key nodes such as Whitefield, Indiranagar, MG Road itself, Vidhana Soudha, and Majestic, the city's central interchange. Metro stations are located at both ends of the proposed ERP segment, ensuring convenient access. In addition, numerous bus stops (shown as colored circles) provide complementary surface-level service. This combination of high-capacity rail and dense bus coverage offers credible alternatives to car travel, strengthening the social acceptability and functional viability of ERP implementation along MG Road.

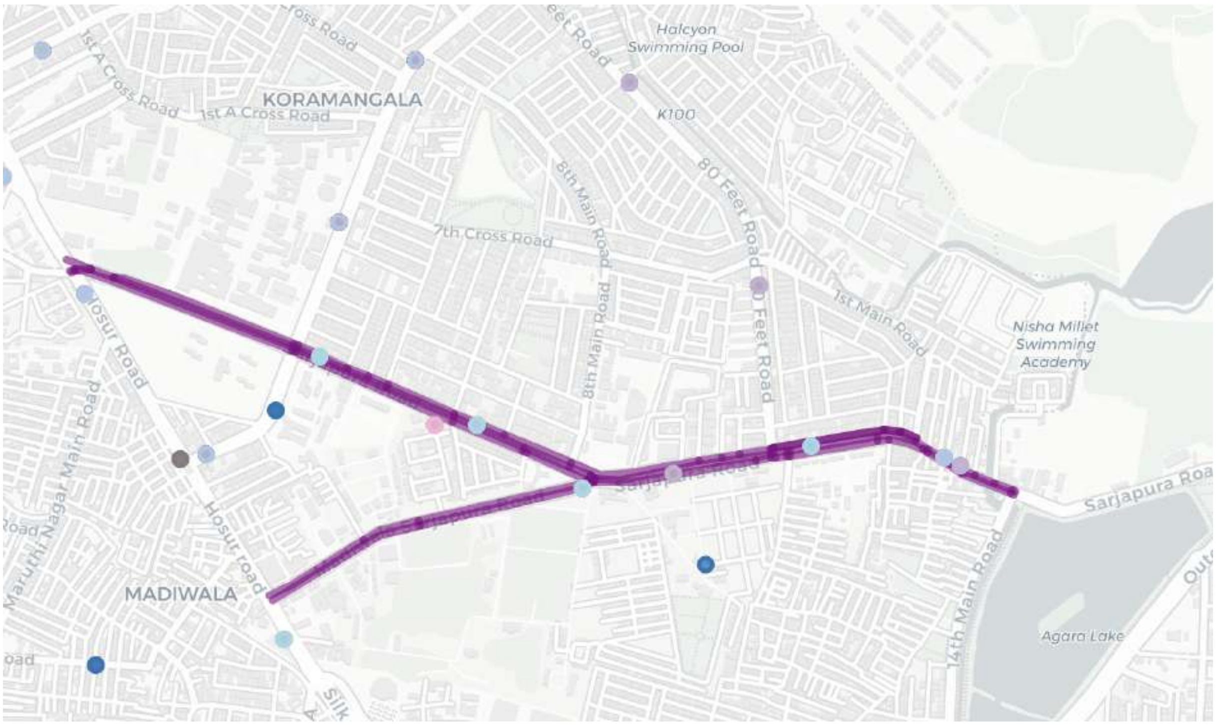

Figure 27: ERP Candidate Roads with Bus and Metro Access in Koramangala.

Figure 28: ERP Candidate Area with Bus and Metro Access in M.G.Road

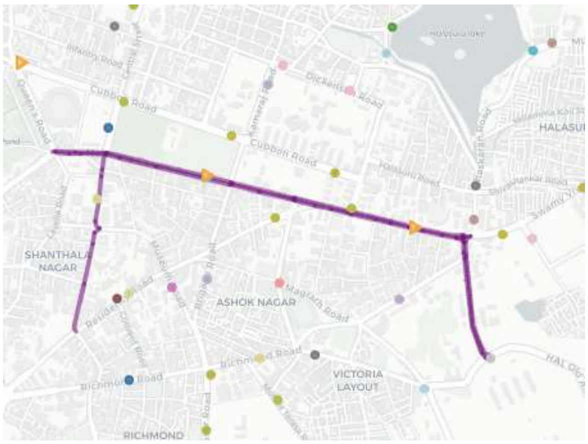

Figure 29: ERP Candidate Roads with Bus and Metro Access in M.G.Road

4.4.2 Vulnerable Populations Near ERP Zones

The spatial distribution of registered slum areas in Bangalore suggests that neither of the two proposed ERP corridors, Koramangala (Figure 30) and MG Road (Figure 31), would directly impact vulnerable populations. As shown, slum clusters tend to be concentrated in peripheral zones or near industrial belts, significantly distanced from the highlighted ERP boundaries.

This absence of spatial overlap supports one of the core premises of this study: that it is possible to design a geographically targeted ERP pilot in Bangalore without imposing a disproportionate burden on vulnerable populations

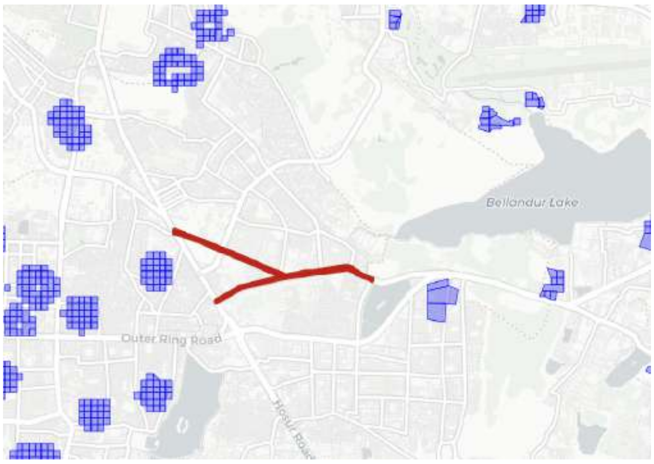

Figure 30: Koramangala Slums

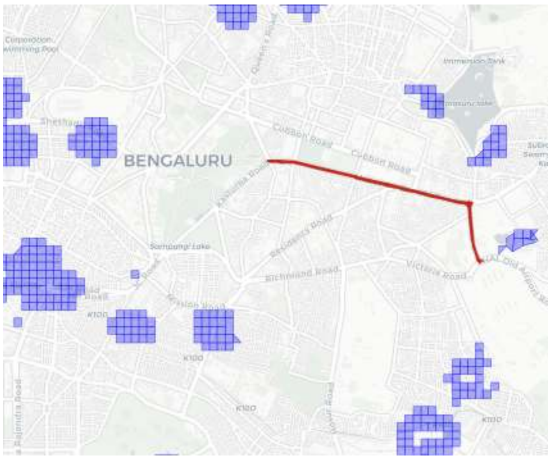

Figure 31: MG road Slums

5 Lessons, Constraints, and Implementation Pathways

The implementation of an ERP system in Bengaluru demands a careful consideration of the urban, functional, and social characteristics of the proposed zones. While the idea of extending ERP to areas like Koramangala stems from the legitimate need to reduce traffic congestion, the current conditions make such a proposal problematic on multiple levels.

Koramangala is a predominantly residential neighborhood with extremely high population density and an underdeveloped public transport infrastructure. The near absence of metro stations and the lack of a well-connected bus network severely limit alternatives to private vehicle use. Furthermore, major roads such as 100 Feet Road and Sarjapur Road are heavily used by daily commuters traveling to the city center or IT hubs like Outer Ring Road and Electronic City. Implementing ERP under these conditions would generate a double negative effect: it would weaken the effectiveness of the system, as a significant share of the traffic originates from local residents, and it would compromise equity by penalizing non-resident users who have no viable modal alternatives.

This stands in sharp contrast with Singapore's introduction of ERP, which was preceded by decades of investment in a robust, multimodal public transport system and focused on commercial corridors with high modal substitution potential. One of the key lessons from Singapore is that pricing mechanisms can only function equitably and effectively when commuters are offered reliable, accessible alternatives to car use. In Koramangala, this condition is not yet met.

Given these constraints, the priority should be the expansion and strengthening of public transport services in Koramangala. This includes the introduction of new bus routes, the development of dedicated bus lanes, and a long-term plan to extend the metro network. Only after substantial improvements in public transit accessibility can a restrictive measure like ERP be justified.

In contrast, MG Road presents a far more favorable context for the technical implementation of ERP. As a commercially, oriented area with a limited number of vehicle entry points and a well-developed public transport network, including the strategically located Purple Line of the Namma Metro and numerous surface bus connections, this corridor is technically suitable for the installation of electronic gantries and entry control cameras, whether applied to the entire zone or selected road segments.

Singapore's success also underscores the importance of choosing zones where pricing can be easily enforced due to clear physical boundaries and predictable traffic flows. MG Road shares some of these characteristics, making it an appropriate testing ground for pilot implementation.

However, the core challenge is not technical but institutional, and remains one of the key barriers that prevented the implementation of ERP in 2015. Unlike Singapore's LTA, which functions as an autonomous entity with executive power, financial capacity, and streamlined governance, Bengaluru's institutional landscape is fragmented. The DULT, while officially responsible for urban transport planning, operates with limited autonomy and depends heavily on approvals and funding from higher administrative levels. Its constrained resources and lack of authority to independently implement large-scale infrastructure projects greatly hinder its capacity to lead integrated urban mobility solutions.

Once again, Singapore's experience demonstrates that institutional consolidation and policy continuity are central to long-term success. The ability of the LTA to plan, finance, and enforce policy without fragmented oversight has been instrumental. Replicating this in Bengaluru would require not just new mandates but a fundamental strengthening of DULT's institutional capacity.

In this context, institutional strengthening of DULT is essential. The agency should be transformed into a body with greater financial, operational, and decision-making autonomy. It must play a leading role in coordinating the ERP project, overseeing all phases from planning to implementation, and facilitating the establishment of an inter-institutional steering committee involving key stakeholders such as the Traffic Police, the Bengaluru Development Authority, and representatives of civil society.

Only through a more robust and integrated governance structure will it be possible to ensure that ERP in Bengaluru is technically sound, socially fair, and fiscally transparent. ERP revenues should be reinvested directly into public transport improvements, particularly in underserved areas like Koramangala. Strengthening transit options in such zones, where deficiencies are acute and commute-related frustration is high, would not only address structural mobility gaps but also enhance the social acceptability of ERP, ensuring it functions as a tool for inclusive and sustainable urban mobility.

References

[1] Anthony Downs. *Still Stuck in Traffic: Coping With Peak-Hour Traffic Congestion*. Brookings Institution Press, 2004.

[2] Md Aftabuzzaman. Measuring traffic congestion: A critical review. In *30th Australasian Transport Research Forum*, 2007.

[3] Sandra Rosenbloom. Peak-period traffic congestion: a state-of-art analysis and evaluation of effective solution. *Transportation*, 7(2):167–191, 1978.

[4] V.R. Vuchic and S. Kikuchi. The bus transit system: its underutilized potential. Technical Report DOT-T-94-29, Federal Transit Administration, Washington, D.C., 1994.

[5] T. Lomax, S. Turner, G. Shunk, H.S. Levinson, R.H. Pratt, P.N. Bay, and G.B. Douglas. Quantifying congestion, volume 1 & 2. Technical Report NCHRP Report 398, Transportation Research Board, Washington, D.C., 1997.

[6] G. Weisbrod, D. Vary, and G. Treyz. Economic implications of congestion. Technical Report NCHRP Report 463, Transportation Research Board, Washington, D.C., 2001.

[7] Victoria Transport Policy Institute. Congestion reduction strategies: identifying and evaluating strategies to reduce congestion. `https://www.vtpi.org/tdm/tdmcongestion.pdf`, 2005. In: Online TDM Encyclopaedia, Victoria, British Columbia, Canada.

[8] P.H.L. Bovy and I. Salomon. Congestion in europe: measurements, patterns and policies. In E. Stern, I. Salomon, and P.H.L. Bovy, editors, *Travel Behaviour: spatial patterns, congestion and modelling*. Edward Elgar, Cheltenham, 2002.

[9] S. M. Turner. Urban traffic congestion. *Transportation Research Board Special Report*, 201, 1992.

[10] David Levinson and Tim Lomax. Developing a congestion performance measure. *Transportation Research Record*, 1564:18–25, 1996.

[11] Tim Lomax, David Schrank, and Shawn Turner. Quantifying congestion. Technical report, Texas Transportation Institute, 1997.

[12] Marlon G Boarnet et al. Measuring traffic congestion. *Access Magazine*, (13):7–9, 1998.

[13] Jeffrey A. Lindley. Urban freeway congestion: Quantification and control. *ITE Journal*, 57(1):27–32, 1987.

[14] David Schrank and Tim Lomax. The 2005 urban mobility report. *Texas Transportation Institute*, 2005.

[15] Texas Transportation Institute. Urban mobility study methodology, 2005.

[16] K. Hamad and S. Kikuchi. Developing a measure of traffic congestion: fuzzy logic approach. *Transportation Research Record*, 1802:77–85, 2002.

[17] Roger P. Roess, Elena S. Prassas, and William R. McShane. *Highway Capacity Manual*. Transportation Research Board, National Research Council, 1985.

[18] G. Byrne and J. Mulhall. Evaluating congestion measures. *Transportation Quarterly*, 1995.

[19] Japan International Cooperation Agency (JICA). The comprehensive traffic and transportation study for bangalore metropolitan region (ctts) – final report. Technical report, Japan International Cooperation Agency (JICA), New Delhi, India, 2015. Prepared in collaboration with the Directorate of Urban Land Transport (DULT), Government of Karnataka.

[20] Japan International Cooperation Agency (JICA). Final report on bengaluru congestion charging. Technical report, JICA and Directorate of Urban Land Transport (DULT), 2015. Relevant sections: 3.2.2 (definition of congestion), 3.2.3 (critical speed and Level of Service), 3.5.6 (measurement methods including surveys and traffic counts).

[21] Moneycontrol. Mc explains: Why congestion tax is unlikely to be implemented in bengaluru anytime soon, 2015. Online article.

[22] Japan International Cooperation Agency. Master plan its for bengaluru. Technical report, JICA, 2015. Paragraph 1.2.1.1.

[23] TomTom International BV. Tomtom traffic index: Ranking of cities worldwide, 2023.

[24] Bangalore traffic's impact on general public. *International Journal for Research in Applied Science and Engineering Technology (IJRASET)*, 12(III):2124–2136, 2024. SJ Impact Factor 7.538, ISRA Journal Impact Factor 7.894.

[25] United Nations Department of Economic and Social Affairs, Population Division. World population prospects. `https://population.un.org/wpp/`, 2022.

[26] Government of Karnataka, Office of the Registrar General, and India Census Commissioner. Bengaluru urban district profile and census handbook (2011), 2011.

[27] World Bank. Singapore - world development indicators, 2024.

[28] Singapore, singapore metro area population 1950–2025. `https://www.macrotrends.net/cities/22447/singapore/population`. www.macrotrends.net. Retrieved 2025-04-04.

[29] Bangalore, india metro area population 1950–2025. `https://www.macrotrends.net/cities/21176/bangalore/population`. www.macrotrends.net. Retrieved 2025-04-04.

[30] Ministry of Statistics and Programme Implementation. Average wage/salary earnings during the preceding calendar month. `https://mospi.gov.in/average-wage-salary-earnings-during-preceding-calendar-month-regular-wage-salarie`
2022.

[31] World Bank. Gini index (world bank estimate), 2024.

[32] Ministry of Manpower, Singapore. Summary table: Income. https://stats.mom.gov.sg/pages/income-summary-table.aspx, 2025.

[33] Government of Karnataka. *The Karnataka Town and Country Planning Act, 1961*. Government Press, 1961.

[34] Government of Karnataka. *The Karnataka Municipal Corporations Act, 1964*. Government Press, 1964.

[35] Government of Karnataka. *The Bangalore Development Authority Act, 1976*. Government Press, 1976.

[36] H. S. Kumara and S. Gopiprasad. Transfer of development rights (tdr) as an instrument for spatial planning implementation: Case of bengaluru metropolitan area (bma). 2020.

[37] Jayaraj Sundaresan. Urban planning in vernacular governance: Land use planning and violations in bangalore, india. *Progress in Planning*, 118:1–23, 2017.

[38] Urban Redevelopment Authority. Planning, 2024.

[39] Manjira Dasgupta. Singapore's state capitalism vs. the indian economy: Comparing the economic systems of two potential allies. MPRA Working Paper MPRA Paper No. 54631, M.S. University of Baroda, June 2013. Posted 09 Apr 2014 19:42 UTC.

[40] Council on Energy, Environment and Water. Strengthening india's urban transport governance through a state-level institutional framework, 2021.

[41] Land Transport Authority. The lta story, 2022.

[42] Friedrich-Ebert-Stiftung. Revert or readjust? designing mobility for liveable and social cities, 2021.

[43] Land Transport Authority. Lta financial statements for the financial year ended 31 march 2022, 2022.

[44] National Library Board, Singapore. Area licensing scheme (als). https://www.nlb.gov.sg/main/article-detail?cmsuuid=072b1248-63b0-4b30-8a04-ba1742961351, 2021. National Library Board Infopedia.

[45] Bonny Tan. Electronic road pricing system. https://www.nlb.gov.sg/main/article-detail?cmsuuid=7b3bfea7-2173-4dd9-bd9d-626e8c621ede, 2016. Singapore Infopedia, National Library Board.

[46] Kian-Keong Chin. Road pricing–singapore's 30 years of experience. *CESifo DICE Report*, 3(2):11–18, 2005.

[47] Land Transport Authority. Erp 2.0 – next generation erp system. https://onemotoring.lta.gov.sg/content/onemotoring/home/driving/ERP/erp-2-0.html, 2024.

[48] Walter Theseira. Singapore's experience with road user charges. Session 4 Presentation, ITF-OECD Expert Workshop on "International Best Practices to Promote Eco-Friendly Cars", January 2021. 25–26 January 2021, Singapore University of Social Sciences.

[49] Bangalore Development Authority. About bda: History and functions. `https://www.bdabangalore.org/`.

[50] H.S. Sudhira, T.V. Ramachandra, and M.H.B. Subrahmanya. City profile: Bangalore. *Cities*, 24(5):379–390, 2007.

[51] Deepak Baindur and Pallavi Rao. Equity in public transport—a case of bangalore's city bus transport. *Journal of Sustainable Urbanization, Planning and Progress*, 1(1):32–40, 2016.

[52] Nivedita Kumari and Prakash S Hanjagi. An analysis of traffic congestion zones along mysore road, bangalore. *International Journal of Scientific & Engineering Research*, 9(2):223–227, 2018.

[53] Poorna Chinnappa and V. P. Priya. The unfolding of a historic urban metaphor – mg road, bangalore. `https://www.academia.edu/37894161/THE_UNFOLDING_OF_A_HISTORIC_URBAN_METAPHOR_MG_ROAD_BANGALORE`, 2018. Department of Architecture, BMS College of Engineering.

[54] Sivanandan N. The evolution of mg road bangalore: From british influence to modern hub, 2024.

[55] The Economic Times. Bengaluru's traffic nightmare isn't just a meme: Nikhil kamath asks if vips are above the law, police explain why it's getting worse, 2025.

[56] The Economic Times – ET Infra. Fastag's success and penetration. December 2022.

[57] The Financial Express. Budget 2024: Fastag penetration of 98% as of nov 2023. November 2023.

[58] National Payments Corporation of India. District-wise upi statistics, March 2025.

[59] GSMA Intelligence. The mobile economy 2025. Technical report, 2024.

[60] DataReportal. Digital 2024: India, 2024.