

Assessment of Public Acceptance and Compliance with Traffic Congestion Pricing: A Case Study of Ranchi City, India

Rajeev Kumar, Ajai Singh



Abstract: This work evaluates the necessity and efficacy of congestion pricing on the main road in Ranchi city, aiming to provide a detailed roadmap for its implementation and address potential challenges. Extensive data analysis reveals severe traffic congestion, particularly during peak hours, with Passenger Car Units (PCU) peaking at 2,747 and Peak Hour Factors (PHF) reaching 0.97. Economic assessments highlight significant losses resulting from prolonged travel times, increased fuel consumption, and elevated environmental costs associated with emissions. The findings indicate that time loss costs for commuters and businesses are substantial, with heavy motor vehicles incurring up to ₹2.53 per km in time costs and ₹12 per km in fuel costs. Environmental costs are also considerable due to increased CO₂ emissions. The proposed congestion pricing strategy includes a charge of ₹50 for heavy vehicles, ₹30 for four-wheelers, ₹20 for three-wheelers, and ₹10 for two-wheelers during peak hours. This strategy aims to optimize traffic flow, reduce delays, and improve air quality. This study highlights the pressing need for effective traffic management solutions to improve urban mobility and economic efficiency in urban areas.

Keywords: Congestion Pricing, Traffic Management, Peak Hour Factor, Passenger Car Units, Urban Mobility, Fuel Consumption, CO₂ Emissions.

Abbreviations:

SDGs: Sustainable Development Goals
RMC: Ranchi Municipal Corporation
LOS: Level of Service
LCC: London Congestion Charge
JSRTC: Jharkhand State Road Transport Corporation
ANPR: Automatic Number Plate Recognition
PCU: Passenger Car Units
DSV: Design Service Volume
PHF: Peak Hour Factor
IRC: Indian Roads Congress

I. INTRODUCTION

Traffic demand management strategies aim to reduce unnecessary private vehicle usage and promote more

efficient, eco-friendly, and energy-conserving alternatives, such as public transit, walking, and cycling. Traffic congestion has become a significant issue in contemporary urban life, resulting in substantial time wastage and frustration for both commuters and freight transport operators. Efforts are being made to develop sustainable transport and mobility. This shall also achieve the 17 Sustainable Development Goals (SDGs). The transportation industry is evolving rapidly, and as more people and goods move between cities, mobility is expected to increase. By 2030, annual passenger traffic is expected to surpass 80 trillion passenger-kilometres, representing a 50% increase from 2015. There will be twice as many cars on the road as there are now, with an additional 1.2 billion cars [1]. With over half of the world's population living in cities and that number expected to rise to two-thirds by 2030, urbanization is crucial. [2]. The individual impact is profound, with Indian drivers spending an average of 135 hours annually stuck in traffic, resulting in significant fuel wastage and productivity loss, which amounts to \$22 billion [3]. In 1982, it is estimated that 0.8 billion gallons of fuel were wasted in the United States due to traffic congestion, and that rose to a peak of 3.6 billion gallons of wasted fuel in 2019. In 2020, the COVID-19 pandemic led to a precipitous drop in congestion and wasted fuel, reaching a low of 1.8 billion gallons, a level not seen since 1995. However, since 2020, congestion has again been on the rise, resulting in 3.3 billion gallons of wasted fuel in 2022 [4].

Congestion pricing stands out as a viable solution, involving the imposition of fees on motor vehicles for road usage. Setting the cost at an optimal level, dissuades a percentage of cars from utilizing congested routes, thereby enhancing road service quality for those who opt to pay and continue their journey. It incentivises vehicle users to switch to more efficient and environmentally friendly transportation modes, such as public transit, alter their travel routes or timings, or even forgo the trip altogether. Over the last decade, traffic congestion and its mitigation have become a priority for many Indian cities. Despite the advantages, only a handful of cities have successfully implemented congestion charges [5]. The physics of congestion suggests that congestion delay is significantly affected by trip timing. If morning departures from home could be spread more evenly throughout the day, congestion delay could be considerably reduced without necessarily affecting arrival times. Thus, there is significant potential for efficiency improvement through trip rescheduling, even if total traffic volume remains constant.

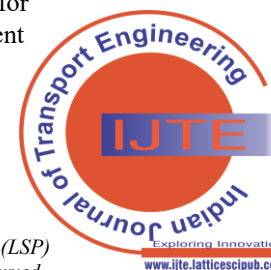
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Congestion tolling aims to achieve such temporal dispersion by implementing a toll that varies based on congestion levels.

Developed cities such as London and Stockholm achieved a 20% reduction in traffic jams by implementing congestion charges [6]. The London Congestion Charge (LCC) provides credible estimates on the willingness to pay to avoid traffic using the housing market. This policy curtails road traffic by imposing a fee on anyone driving into the charge zone. The findings suggest that the consequential improvement in traffic conditions due to the LCC has generated a substantial windfall of more than £3.8 billion for homeowners in the zone [7]. In 2006, Stockholm faced significant road congestion. To address this issue, authorities implemented a trial congestion charge of EUR 2 for vehicles entering the city centre [8]. Travel demand modelling techniques were used to assess the impact of congestion charges on travel behaviour in Shanghai. The study indicated a shift towards public transportation and non-motorised modes following the implementation of congestion charges, contributing to reduced traffic congestion and improved air quality [9]. There is a need for integrated transportation planning and investment in alternative modes to complement congestion pricing strategies and achieve sustainable urban mobility. The importance of context-specific policy interventions and integrated transportation planning in addressing the unique challenges of congestion management in Indian cities is required [10]. The implementation of congestion charges effectively reduced traffic congestion levels in the London city centre during peak hours [11]. The study identified Technological barriers related to electronic toll collection systems, enforcement mechanisms, and data management infrastructure in a survey for Jaipur city in India [12].

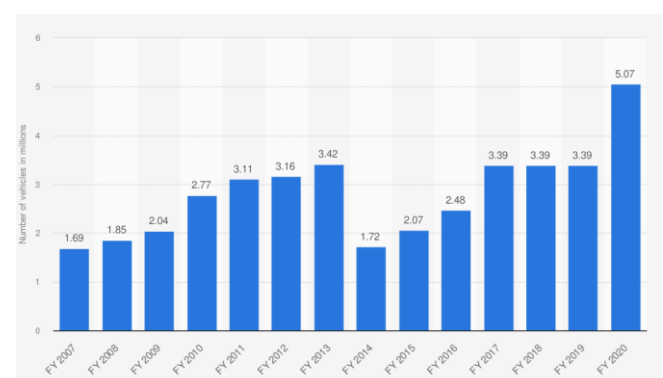
A mixed-methods approach, combining surveys, interviews, and traffic simulation models, was employed to analyse the challenges of implementing congestion charges in Delhi. The study revealed significant opposition from various stakeholders, logistical difficulties in fee collection, and concerns regarding equity and social justice [13].

A study found mixed economic effects, with some sectors experiencing declines in revenue while others benefited from improved accessibility and reduced travel time in Barcelona [14]. The benefits of congestion pricing, in terms of reducing traffic congestion, improving air quality, and generating revenue for sustainable transportation investments, were also explored for Indore [15]. Mixed public opinion and varying levels of political support for congestion pricing, influenced by factors such as perceived fairness, trust in government institutions, and electoral dynamics, were observed in a study conducted in Lucknow. Proactive stakeholder engagement, coalition building, and strategic communication were recommended to establish public and political consensus for congestion charging policies in Indian cities [16]. Potential reductions in vehicular emissions and improvements in air quality concentrations were observed in Ahmedabad following the implementation of congestion pricing measures [17]. The importance of behavioural insights in designing effective congestion charging schemes tailored to the local context and user preferences in Indian megacities has also been highlighted [18].

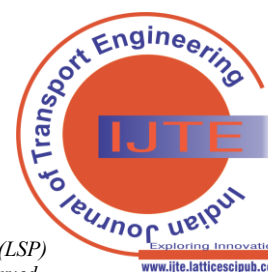
Long-term effects of congestion pricing and the role of complementary policies in promoting sustainable urban

mobility in Indian cities are to be studied [19]. A study found high levels of public acceptance and compliance with congestion pricing policies in Singapore, attributed to effective communication strategies and tangible benefits, such as improved traffic flow and reduced travel time [20].

The social impact assessment was conducted to evaluate the equity implications of congestion charges in Seattle. The study identified spatial disparities in the distribution of congestion charges and potential inequities in access to transportation services for marginalized communities [21]. There are disparities in the distribution of congestion charges and potential inequities in accessibility and mobility options for different socioeconomic groups in the Delhi National Capital Region [22]. An analysis of traffic crash data to evaluate the impact of congestion charges on road safety in Lisbon revealed the potential increase in traffic in peripheral areas due to traffic diversion [23]. In India, the number of four-wheeler vehicles increased from 2,838,820 in 2019 to 3,616,450 in 2023 [24]. There were over five million registered vehicles across the Indian state of Jharkhand at the end of fiscal year 2020. The total number of different types of registered vehicles over the last five years is illustrated in Fig. 1 [25]. Although there is a limited amount of road space in cities, demand for it continues to grow. Since private motor vehicles occupy the most space per person per kilometre travelled, they are the primary cause of traffic congestion. Increasing road infrastructure will temporarily alleviate traffic congestion. It is not sustainable over the long term, both financially and environmentally. The most effective way to ease traffic congestion is to reduce motor vehicle traffic through various travel demand management strategies and provide people with sustainable alternatives, such as smooth and efficient public transportation. As more drivers are drawn to the additional road capacity, traffic congestion returns. In this study, an effort has been made to address traffic management through the implementation of congestion pricing. We have also attempted to quantify the degree of congestion to determine the Level of Service (LOS). An optimal congestion fee encompassing delay costs, fuel wastage, and environmental impacts has been explored for Ranchi city as a case study.



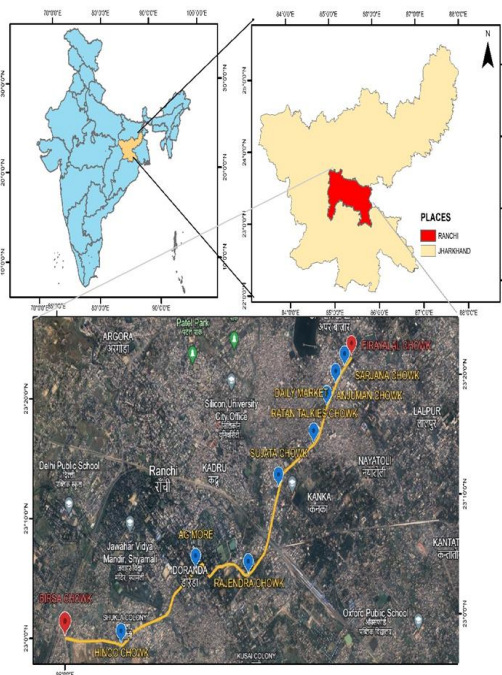
[Fig.1: Total Number (in Millions) of Registered Motor Vehicles Across Jharkhand from 2007 to 2020 [25]]



II. MATERIALS AND METHODS

A. Description of Study Area

Ranchi, the capital city of Jharkhand, is a bustling urban centre experiencing rapid growth and development. Situated amidst the verdant landscapes of eastern India, Ranchi presents a unique position of urban infrastructure and natural beauty, making it an intriguing candidate for the implementation of traffic congestion pricing measures. Fig. 2 shows the route from Birsa Chowk to Firaylal Chowk. This stretch of road, regulated by the Ranchi Municipal Corporation (RMC), comprises a two-lane, bi-directional thoroughfare with an average width of 25 meters. Within this corridor, a myriad of significant establishments thrive, ranging from governmental edifices and educational institutions to bustling commercial complexes and vibrant residential areas. Public transportation emerges as a lifeline within Ranchi's bustling thoroughfares. A diverse array of transport modes, including buses, auto-rickshaws, and cycle rickshaws, crisscross the city's arteries, providing vital connectivity to commuters. Within the study area, the Jharkhand State Road Transport Corporation (JSRTC) operates an extensive network of bus services, catering to the diverse commuting needs of Ranchi's populace. Statistical data, gleaned from various government reports such as those by the Ministry of Transport (2022), unveils the burgeoning vehicular traffic that plies Ranchi's streets. With a notable annual increase of approximately 10%, this surge in vehicles poses significant challenges in addressing congestion within the city. Furthermore, Ranchi's climatic tapestry reveals an average annual temperature of 25°C, with precipitation levels ranging from 1,300 mm to 1,700 mm annually, underscored by an average of 120 rainy days per year.



[Fig.2: Location of the Study Area]

B. Traffic Survey

The most widely implemented forms of congestion pricing methods are Flat-rate toll roads, Cordon pricing, Area-wise

charges, High-occupancy toll (HOT) lanes, Variable tolls on entire roadways, time-distance- and/or place-based pricing, and Methods of Toll Collection. A questionnaire survey was conducted to assess the current traffic conditions and gather opinions on congestion charging. The traffic survey data from the peak hour has been converted into Passenger Car Units (PCU) to ensure uniformity in the units. The V/C method has been employed to identify the Level of Service (LOS) of the road. The Design Service Volume (DSV) for urban roads has already been provided in the IRC guidelines. To fix the traffic congestion charge with the help of time loss, fuel loss, and environmental loss, and implement it in specific road stretches. A traffic survey was conducted in the morning from 9:00 am to 11:00 am and in the evening from 5:00 pm to 7:00 pm to collect peak-hour traffic data and traffic volume between Birsa Chowk and Firaylal Chowk, and to gauge public opinion on congestion pricing. To convert different vehicle classes to a single class, such as the passenger car conversion factor, is known as the passenger car unit. PCU values have been suggested by the IRC 106 (1990) [26].

Peak hour factor (PHF): It refers to the amount of traffic utilizing a specific approach, lane, or lane group during the hour of the day when the highest traffic volumes are observed.

PHF = Hourly volume/peak rate of flow within the hour (1)
For 15-minute periods

PHF = $V/4 \times V_{15}$ (2)

where v is the peak hour volume and V_{15} is the volume during the peak 15 minutes of flow

The V/C (Volume to Capacity) method was utilized to determine the Level of Service (LOS) of the road. The Design Service Volume (DSV) provided in the IRC (Indian Roads Congress) guidelines for urban roads was used for this purpose. Six LOS are described in the Highway Capacity Manual according to various operating situations. A road with LOS A indicates the best operating circumstances (free flow) among all levels of services, while a highway with LOS F is the worst (most crowded) of all defined LOS. There are six levels of service, ranging from LOS A to LOS F. The design service volume for urban roads was taken from IRC 106 (1990). On the Ranchi major route, manual count statistics are collected to calculate the time, fuel, and environmental damage resulting from congestion. For every kind of vehicle, manual count statistics are collected. The trail was about seven kilometres long. The difference between the time required to run one kilometre in free-flow versus peak-hour flow is the time loss. Fuel loss is calculated as the difference between fuel consumption per kilometre during peak-hour flow and free-flow conditions. CO₂ emissions from the additional fuel used during peak flow are considered the environmental cost. The quantity of CO₂ released multiplied by its cost, or environmental damage, is the cost of CO₂ loss.

C. Data Collection

Traffic count data were collected from the Ranchi smart city office's Command, Control, Communication Centre (C4) using Automatic Number Plate Recognition (ANPR) cameras, strategically



positioned at various junctions, capture and accurately record vehicle movements. However, at particular junctions where the cameras are currently out of operation, traffic data is collected manually. A survey was conducted among 300 people on the main road in Ranchi. A study of traffic conditions and opinions towards congestion pricing is provided as supplementary material in Annexure I. According to the preliminary research, the average mileage during free flow is 45 km/l for two-wheelers, 28 km/l for three-wheelers, 18 km/l for four-wheelers, and 5 km/l for heavy motor vehicles, while during peak flow, the average mileage decreases to 35 km/l for two-wheelers, 22 km/l for three-wheelers, 12 km/l for four-wheelers, and 3 km/l for heavy motor vehicles.

D. Economic Cost Analysis

Travel time cost is estimated by using the following equation.

Time loss during traffic congestion (min/km) = time taken in peak flow - time taken in free flow.

Cost of time loss = (average annual income per person)/(365×8.5×60) × time loss during traffic congestion, working hours assumed to be 8.5 hours daily, and the average yearly income per person is considered to be equal to ₹120655 Total fuel loss during traffic congestion (ml/km) = fuel consumed during congested condition – fuel consumed during free flow condition. The cost of CO₂ loss is calculated as the amount of CO₂ emitted multiplied by its price, representing the environmental damage.

The fossil fuel emissions per litre of CO₂ are 2.7 kg CO₂ equivalent. Total environmental cost(₹/km) = fuel loss(ml/km) × CO₂ emission rate(gm/ml) × price of CO₂ (₹/gm) CO₂ emission rate for petrol engine 2.3kg/l = 2.3gm/ml and for diesel engine 2.7kg/l = 2.7gm/ml Price of CO₂= 3.3 ₹/kg = 0.003 ₹/gm

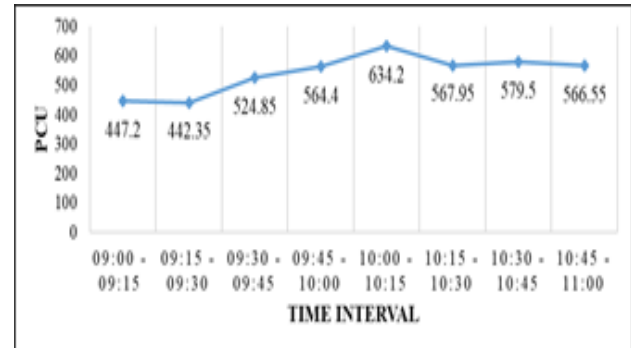
III. RESULTS AND DISCUSSIONS

Various parameters, such as maximum Passenger Car Units (PCUs) at different hours, peak hour factors, traffic volume, level of service, and economic losses due to traffic congestion, are critical in understanding and managing urban traffic flow. Specifically, the maximum PCU varies significantly across different hours, indicating periods of intense congestion. The peak hour factors further highlight these critical times, which often correspond with increased traffic volume and a decreased level of service. Economic losses due to traffic congestion are substantial, encompassing time, fuel, and environmental costs. Time-cost analysis reveals the productivity losses resulting from prolonged travel times, while fuel-cost analysis accounts for the additional fuel consumed during periods of congestion. Environmental cost analysis examines the increased emissions and their impact on air quality and public health.

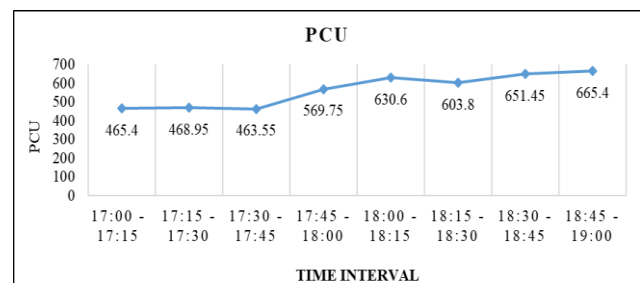
A. Determination of Traffic Volume on Different Roads in Ranchi

The traffic conditions between 9:00 AM to 11:00 AM show significant congestion, with the maximum hourly traffic volume reaching 2,348 PCU and the peak traffic flow between 10:00 AM to 11:00 AM with a Peak Hour Factor (PHF) of 0.92, indicates high traffic density (Fig. 3). From

5:00 PM to 7:00 PM, traffic congestion intensifies and the peak traffic flow particularly between 6:00 PM to 7:00 PM was recorded with a maximum hourly traffic volume of 2,551 PCU and a PHF of 0.95 which reflects even greater congestion than morning time (Fig. 4). The heavy traffic flow is observed along a 1.4 km stretch of road between Birsa Chowk and Hinoo Chowk, Ranchi.

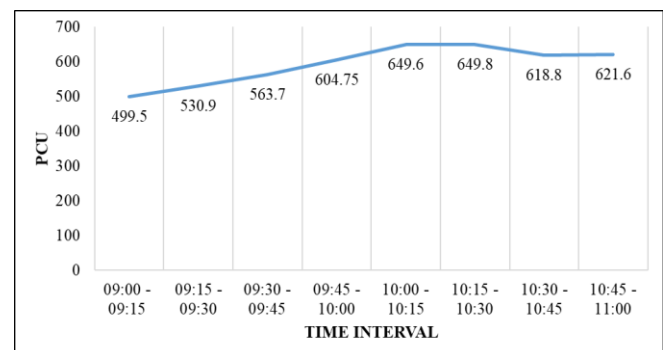


[Fig.3: Morning Peak Hour Between Birsa Chowk and Hinoo Chowk in Ranchi]



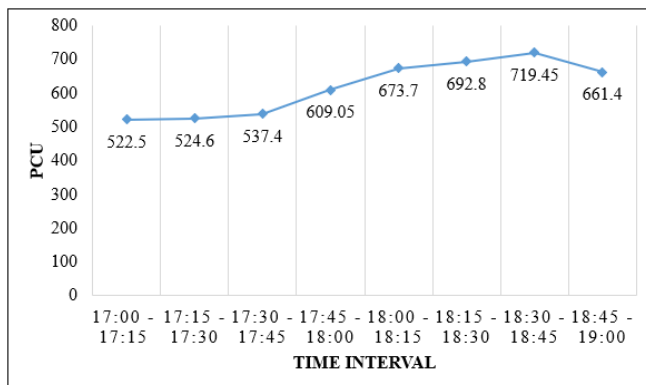
[Fig.4: Evening Peak Hour Between Birsa Chowk and Hinoo Chowk]

Figure 5 displays the traffic flow between 9:00 AM and 11:00 AM, revealing a maximum hourly traffic volume of 2,539 PCU between 10:00 AM and 11:00 AM, and a Peak Hour Factor (PHF) of 0.97. In the evening, the maximum hourly traffic volume between 6:00 PM and 7:00 PM reaches 2,747 PCU with a PHF of 0.95 (Fig. 5). These observations indicate significant congestion during peak hours. The road segment between Hinoo Chowk and Rajendra Chowk, spanning 2.6 km, experiences substantial traffic (Fig. 6).



[Fig.5: Morning Peak Hour Between Hinoo Chowk and Rajendra Chowk]





[Fig.6: Evening Peak Hour Between Hinoo Chowk and Rajendra Chowk]

A similar study was conducted for the route from Rajendra Chowk to Sujata Chowk in the city of Ranchi. The maximum hourly traffic volume between 10:00 AM and 11:00 AM was observed to be 2,348 PCU with a PHF of 0.94. In the evening, the maximum hourly traffic volume between 6:00 PM and 7:00 PM reaches 2,715 PCU with a PHF of 0.93. The 1.1 km long road segment between Rajendra Chowk and Sujata Chowk is particularly congested due to heavy traffic. For Sujata Chowk to Anjuman Chowk (1.7), the maximum hourly traffic volume between 10:00 AM and 11:00 AM was found to be 2,256 PCU with a PHF of 0.97. The maximum hourly traffic volume was recorded as 2,400 PCU, with a

PHF of 0.97, during the 6:00 to 7:00 PM period. These data points underscore substantial congestion during these peak periods. The maximum hourly traffic volume between 10:00 AM and 11:00 AM was 2,423 PCU with a PHF of 0.96 for Anjuman Chowk to Firayalal Chowk (1.3 km). In contrast, the maximum hourly traffic volume of 2,487 PCU, with a PHF of 0.93, was recorded from 6:00 to 7:00 PM.

Traffic congestion significantly impacts the level of service (LOS) on urban roads, which is a critical measure of traffic flow and efficiency. The LOS is categorized from A to F, with A representing free-flow conditions and F indicating severe congestion with stop-and-go traffic. Table 1 shows that the stretch between Birsa Chowk and Hinoo Chowk experiences a Level of Service C, indicating stable flow but with noticeable restrictions on manoeuvrability and potential delays during peak hours. This level suggests moderate congestion where traffic moves steadily but is approaching capacity. In contrast, the segment from Hinoo Chowk to Firayalal Chowk is classified as Level of Service F, reflecting deplorable traffic conditions characterised by heavy congestion, frequent stoppages, and extensive delays. The LOS F indicates that traffic demand exceeds roadway capacity, leading to a breakdown of flow and severe unreliability in travel times.

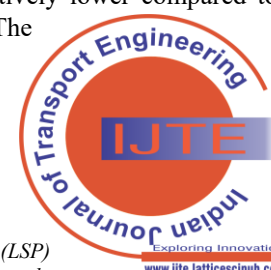
Table 1: Level of Service Between Birsa Chowk and Firayalal Chowk

Route	Link Type	Link Length	Peak Hourly Volume (PCU/hr)	Service Volume (PCU/hr)	Volume Capacity Ratio (V/C)	Level of Service
Birsa Chowk to Hinoo Chowk	Arterial	1.4	2251	2400	0.9379167	E
Hinoo Chowk to Rajendra Chowk	Arterial	2.6	2747	2400	1.1445833	F
Rajendra Chowk to Sujata Chowk	Arterial	1.1	2715	2400	1.13125	F
Sujata Chowk to Anjuman Chowk	Arterial	1.7	2400	2400	1.00	F
Anjuman Chowk to Firayalal Chowk	Arterial	1.3	2487	2400	1.03625	F

B. Economic Cost Analysis

Traffic congestion incurs substantial costs in terms of time, fuel, and environmental impact. Table 2 shows that the economic and time loss costs are significant, as commuters and goods experience delays, leading to decreased productivity and extended travel times. This not only affects individual schedules but also hampers economic activities and business operations. Fuel loss cost arises from vehicles idling and operating inefficiently during congestion, resulting in higher fuel consumption. This not only increases the direct expenses for drivers but also strains national fuel reserves and contributes to higher overall fuel prices. Environmental cost loss is another critical aspect, as traffic congestion leads to increased emissions of greenhouse gases and pollutants. Figure 7 shows the ratio of different losses in terms of time, fuel, and environmental loss. The prolonged idling and stop-and-go driving patterns exacerbate air quality issues, contributing to health problems and environmental degradation. Collectively, these costs underscore the urgent need for effective traffic management solutions to enhance mobility, reduce economic burdens, and protect the environment. According to the preliminary survey, the

average time loss for two-wheelers, three-wheelers, four-wheelers, and heavy motor vehicles is 2.15 minutes per kilometre, 2.86 minutes per kilometre, and 3.11 minutes per kilometre, respectively. and 3.9 minutes per kilometre, respectively. The preliminary survey indicates the average mileage for two-wheelers, three-wheelers, four-wheelers, and heavy motor vehicles during free flow as 45 km/l, 28 km/l, 18 km/l, and 5 km/l, respectively. In peak flow, the corresponding figures are 35 km/h, 22 km/h, 12 km/h, and 3 km/h, respectively. Traffic congestion poses a significant economic burden, affecting various cost dimensions, including time, fuel, and environmental costs, across different vehicle types, including two-wheelers, three-wheelers, four-wheelers, and heavy motor vehicles. Each vehicle type contributes uniquely to the overall congestion costs, which can be quantified to understand the broader economic implications. For two-wheelers, the cost of traffic congestion is relatively lower compared to other vehicles, but still notable. The financial cost per kilometre due to congestion for two-wheelers is ₹2.08. This



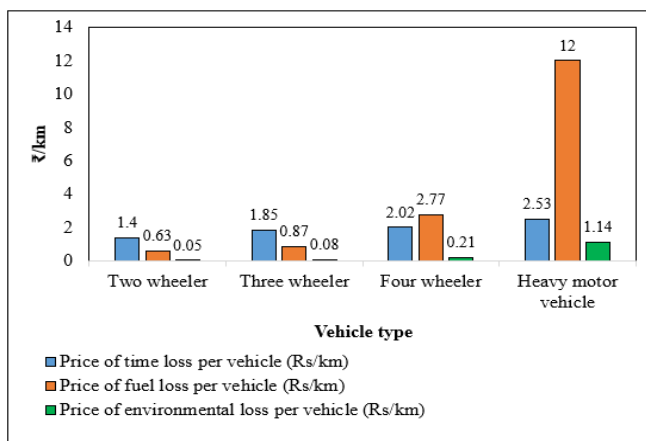
cost includes the time lost in traffic, additional fuel consumption due to frequent stops and idling, as well as the environmental impact of increased emissions. Despite their smaller size and higher manoeuvrability, two-wheelers contribute to congestion costs through cumulative delays and pollution.

Three-wheelers, commonly used for public transport or as goods carriers in many regions, incur a higher congestion cost of ₹2.80 per kilometre. The slightly higher price reflects the additional fuel usage and emissions from these vehicles, as well as the economic impact of delayed transportation of goods and passengers. Four-wheelers, which include personal cars and small delivery vehicles, have a significantly higher congestion cost of ₹5 per km. The higher price is attributed to greater fuel consumption, increased emissions, and the substantial time lost by individuals and businesses due to traffic delays. The environmental impact is also more pronounced due to the higher emissions per vehicle. Heavy motor vehicles, such as trucks and buses, bear the highest

congestion cost at ₹14.64 per km. These vehicles consume large amounts of fuel, produce higher emissions, and cause significant traffic delays. The economic impact extends beyond direct costs to affect the supply chain and public transportation efficiency, leading to broader economic inefficiencies. The total financial losses due to traffic congestion between Birsa Chowk and Firayalal Chowk, with a road length of 7 km, for two-wheelers, three-wheelers, four-wheelers, and heavy motor vehicles are ₹14.56, ₹19.60, ₹35, and ₹102.48, respectively. These costs reflect the combined impact of time delays, increased fuel consumption, and environmental degradation caused by congestion. Moreover, the public's willingness to pay for congestion charges further underscores the severity of the issue. The suggested contributions range from 5 to 10 rupees for two-wheelers and three-wheelers, and ₹10 to 15 for four-wheelers, indicating a recognition of the need for measures to alleviate congestion.

Table-II: Economic Loss Data Due to Congestion

Vehicle Type	Time Loss (min/km)	Fuel Loss (ml/km)	CO ₂ Emitted (gm/ml)	Price of Time Loss per Vehicle (₹/km)	Price of Fuel Loss per Vehicle (₹/km)	Price of Environmental Loss per Vehicle (₹/km)	Total Price Loss per Vehicle (₹/km)	Total Price Loss in 7 km Distance Travelling per Vehicle (₹)
Two wheeler	0:02:09	6.351	2.3	1.4	0.63	0.05	2.08	14.56
Three wheeler	0:02:52	9.74	2.6	1.85	0.87	0.08	2.8	19.60
Four wheeler	0:03:07	27.77	2.3	2.02	2.77	0.21	5	35.00
Heavy motor vehicle	0:03:54	133.33	2.6	2.53	12	1.14	14.64	102.48



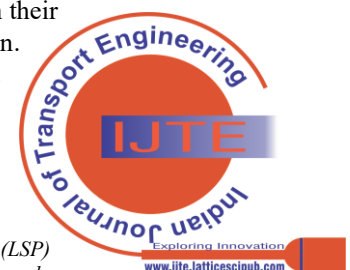
[Fig.7: Ratio of Time, Fuel and Environment in Total Cost Loss]

C. Challenges for Implementation of Traffic Congestion Pricing

Implementing traffic congestion pricing presents several multifaceted challenges that must be addressed for successful deployment. One of the primary challenges is political concern. Policymakers often face resistance from constituents who are wary of new charges, fearing that congestion pricing is just another tax burden. This resistance can be extreme in areas where public transportation alternatives are limited, making driving a necessity rather than a choice. Additionally, politicians may be reluctant to support measures that could be perceived as unpopular,

especially in regions where car usage is deeply entrenched in the local culture. Privacy issues also play a significant role in the implementation of congestion pricing. The systems used to monitor and charge vehicles often rely on technologies such as GPS tracking and automatic number plate recognition (ANPR), which can raise concerns about surveillance and data security. Ensuring that personal data is protected and used responsibly is crucial to gaining public trust. Without stringent privacy safeguards, the fear of government overreach or misuse of data can lead to significant opposition from civil liberties groups and the general public.

Public opposition and awareness are additional hurdles. Many people may not fully understand the benefits of congestion pricing or may view it solely as a financial penalty rather than a tool for improving traffic flow and reducing pollution. Effective public communication campaigns are crucial for informing citizens about how congestion pricing can result in shorter travel times, lower emissions, and improved overall urban mobility. However, changing public perception is often a slow and challenging process, requiring consistent and transparent engagement from authorities. Equity concerns are another critical issue. Congestion pricing can disproportionately affect lower-income individuals who may not have flexible work hours or viable alternatives to driving, as they often rely on their vehicles for transportation. Addressing this requires careful consideration of how pricing is structured



and the availability of subsidies or exemptions for those who might be unfairly burdened. Additionally, investments in improving public transportation options and infrastructure in underserved areas can help mitigate these equity concerns by providing more viable alternatives to driving.

Utilization of revenue generated from congestion pricing is a key factor in gaining public support and ensuring the long-term success of the scheme. Revenues must be managed transparently and reinvested in transportation improvements, such as expanding public transit, enhancing road infrastructure, or implementing green initiatives. Clear communication about how the funds are being used can help build trust and demonstrate the tangible benefits of congestion pricing to the community. The costs and benefits of implementing congestion pricing must also be carefully evaluated. The initial setup costs, including technology deployment, administration, and enforcement, can be significant. However, these costs can be offset by long-term benefits, including reduced traffic congestion, lower pollution levels, and an improved quality of life for city residents. A comprehensive cost-benefit analysis can help make a compelling case for congestion pricing by highlighting the potential economic, environmental, and social benefits.

The traffic effect of congestion pricing is a critical measure of its success. Effective congestion pricing should lead to a noticeable reduction in traffic volumes, improved travel times, and enhanced air quality. However, this requires meticulous planning and adjustment based on real-time data and feedback. There can be unintended consequences, such as traffic spillover into adjacent areas or changes in driving behavior that might negate some of the intended benefits. Continuous monitoring and willingness to adapt the pricing structure are essential to address these issues and ensure that the goals of congestion pricing are met. Congestion pricing has the potential to significantly improve urban traffic conditions and environmental outcomes, but its implementation is fraught with challenges. Political hurdles, privacy concerns, public opposition, equity issues, revenue utilisation, cost-benefit analysis, and actual traffic effects all need to be thoughtfully addressed to ensure that congestion pricing achieves its intended objectives.

IV. CONCLUSIONS

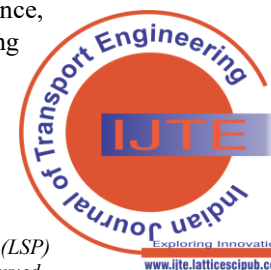
This work examines the implementation of traffic congestion pricing on Ranchi's main road, focusing on quantifying congestion levels and assessing public opinion towards congestion charging. The study area spans approximately 7 km from Birsa Chowk to Firayalal Chowk, a two-lane thoroughfare regulated by the Ranchi Municipal Corporation. Through a comprehensive traffic survey, peak-hour traffic data were collected and converted into Passenger Car Units (PCU) using recommended values by the Indian Roads Congress (IRC). The V/C method was employed to determine the Level of Service (LOS), utilizing Design Service Volume (DSV) guidelines for urban roads. Survey results indicated a preference for two-wheelers, four-wheelers, and public transportation, with congestion impacting daily routines and businesses. Analyzing the economic costs of congestion reveals significant losses in terms of time, fuel, and environmental impact. For instance,

two-wheelers incur a fee of ₹2.08 per km, three-wheelers ₹2.80 per km, four-wheelers ₹5 per km, and heavy motor vehicles ₹14.64 per km due to traffic congestion, considering factors like time loss, fuel consumption, and CO₂ emissions.

The traffic conditions between Birsa Chowk and Hinoo Chowk from 9:00 AM to 11:00 AM show significant congestion, with the maximum hourly traffic volume reaching 2,348 PCU and a Peak Hour Factor (PHF) of 0.92, indicating high traffic density during this period. In the evening, from 5:00 PM to 7:00 PM, traffic congestion intensifies, with the maximum hourly traffic volume of 2,551 PCU and a PHF of 0.95, reflecting even greater congestion than in the morning. The heavy traffic flow is observed along a 1.4 km stretch of road between Birsa Chowk and Hinoo Chowk. In the morning, peak hour volumes reach as high as 2,348 PCU/hr with a PHF of 0.926, and in the evening, the volume reaches 2,551 PCU/hr with a PHF of 0.95. Similar studies were performed for other segments of the roads. Traffic congestion significantly impacts the level of service (LOS) on urban roads, a critical measure of traffic flow and efficiency. The LOS is categorized from A to F, with A representing free-flow conditions and F indicating severe congestion with stop-and-go traffic. The stretch between Birsa Chowk and Hinoo Chowk experiences a Level of Service E, indicating stable flow but with noticeable restrictions on manoeuvrability and potential delays during peak hours. This level suggests moderate congestion where traffic moves steadily but is approaching capacity. In contrast, the segment from Hinoo Chowk to Firayalal Chowk is classified as Level of Service F, reflecting deplorable traffic conditions characterised by heavy congestion, frequent stoppages, and extensive delays. The LOS F indicates that traffic demand exceeds roadway capacity, leading to a breakdown of flow and severe unreliability in travel times.

For two-wheelers, the total fuel loss is 6.35 ml/km with a total fuel cost of 0.63 ₹/km; for three-wheelers, it is 9.74 ml/km with a total fuel cost of 0.87 ₹/km; for four-wheelers, it is 27.77 ml/km with a total fuel cost of 2.77 ₹/km; and for heavy motor vehicles, it is 133.33 ml/km with a total fuel cost of 12 ₹/km. The cost of CO₂ loss was calculated as the amount of CO₂ emitted multiplied by its price, which is the environmental loss.

During traffic congestion, average speeds range from 12 km/h to 18 km/h, resulting in an average time loss of approximately 2 to 3.5 minutes per km travelled. The preliminary survey indicates that the average time loss per kilometre for two-wheelers, three-wheelers, four-wheelers, and heavy motor vehicles is 2.15 minutes, 2.86 minutes, 3.11 minutes, and 3.9 minutes, respectively. The analysis highlights the severe impact of traffic congestion in Ranchi city, particularly on the main roads during peak hours. The significant economic, environmental, and productivity losses underscore the need to implement congestion pricing and other effective traffic management strategies to mitigate these adverse effects. However, implementing congestion pricing faces political resistance, privacy concerns regarding surveillance technologies, and public opposition stemming from a lack of



awareness and equity issues. Overcoming these challenges requires transparent communication, equitable pricing structures, and responsible revenue utilization. Successful implementation hinges on careful evaluation of costs and benefits, continuous monitoring, and adjustment based on real-time data to ensure tangible improvements in traffic flow and environmental quality. Despite these challenges, congestion pricing holds the potential to transform urban mobility and ecological outcomes in Ranchi city.

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After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
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