EXPLORING THE TRAFFIC CONGESTION AND IMPROVING TRAVEL TIME RELIABILITY MEASURES IN HETEROGENEOUS TRAFFIC ENVIRONMENTS: A FOCUS ON DEVELOPING COUNTRIES

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Resume

Traffic congestion is a pervasive issue that affects urban areas worldwide. This study investigates congestion on urban roads in an Indian smart city. Video graphic technique was employed to collect data across various traffic volumes. Travel time for different vehicle categories was estimated, and the travel time reliability congestion index was assessed. Multiple linear regression modelling was utilized to assess the attributes influencing congestion. Traffic signal synchronization and enforcement of traffic regulations, decentralization of important offices, and regulating roadside activities received strong recommendations from the majority of inhabitants. For improving the functionality and accessibility, related to the urban road network, these attributes should be enforced. The research intended to assess the functional effectiveness of urban roads using travel time reliability measures.

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1 Introduction

Traffic congestion is a genuine concern for road users all over the world. The traffic congestion usually occurs when the existing roadway is not able to satisfy the vehicle flow demand [1-5]. Congestion has emerged as one of the biggest problems of contemporary society in any metropolis for decades without a perfect and efficient solution [2]. Unlike other global problems, like hunger, poverty, illiteracy, etc., traffic congestion is directly experienced by millions of people travelling on roads around the world everyday [3-6]. Due to the congestion, serious patients, medicines and medical equipment are not transported during emergencies, which leads to loss of human lives [7-9]. Congestion increases the undesirable waiting time beyond a certain threshold, leading road users to feel unnecessary stress and pursue unsafe driving behaviour [10-14]. Various factors have been attributed to the inception of road congestion on urban roads. While the foremost reason is regarded as the unavailability of infrastructure to satisfy the demand placed on it, many other external factors also lead to traffic congestion. Those consist of various traffic phenomena and occurrences, like the sudden vehicle breakdown and crashes, presence of construction zones, inclement weather, and other traffic incidents [15-18]. According to [19], the traffic congestion leads to highly worrisome stress in drivers and leads them to perform aggressive and unsafe driving behaviour, which could result in undesirable occurrences such as road accidents which may turn catastrophic too.

Many studies have been conducted to study and analyze the traffic congestion on roads. Further, attempts have been made to alleviate the congestion on urban roads [20]. Most of the studies on congestion pertained to the developed countries of North America and Europe [5, 9-11], whereas, the congestion studies in developing countries have been quite limited. Congestion pricing has been suggested by many researchers in the past [3, 21-24]. Similarly, many macroscopic models have

been considered by researchers to analyze the traffic congestion. Similarly, even though studies by [25-26] have suggested that fuzzy logic and multiple regression analysis are better in modelling the driver's behaviour to understand congestion and road accidents, the studies were conducted in European countries and could not be validated for developing countries. Moreover, due to an exponential increase in population resulting in overloading of streets, the problem of congestion keeps on increasing. Traffic composition and driving behaviour are the major concern in developing countries [27-31]. In developing countries, mixed traffic conditions further augment to this problem.

The existing transportation framework is facing challenges due to the increasing human resources and vehicles, making it insufficient to handle the current situation. In India, there is limited investigation conducted regarding congestion, and the presence of heterogeneous environments adds to the complexity. This research centers on travel time reliability congestion index to assess the operational efficiency of the road network and proposes feasible congestion reduction strategies.

2 Literature methodology

Reputable journals and conferences, related to traffic engineering, indexed in Scopus, Web of Science, Google Scholar, and Science Citation Index, were carefully chosen for the study focusing on traffic congestion impacts and its mitigation measures. Using the specific keywords such as "congestion index", "traffic congestion impacts" and "congestion mitigation measures," relevant articles were thoroughly explored from the collected research papers. Articles pertaining to congestion index, congestion impacts and mitigation measures were extracted after a prolonged period of observation, and the remaining articles were excluded.

3 Summary of literature

Traffic congestion can be examined in terms of its causes, impacts, prediction techniques, and mitigation measures. The discussion of various congestion causes highlights that the travel time reliability measures are frequently employed by researchers in the field of traffic congestion. The majority of researchers have utilized the travel time reliability measures to analyze the traffic congestion behaviour. The main focus of the study was on traffic congestion problems and their mitigation measures.

4 Research methodology

A well-designed research methodology is crucial for generating reliable and valid results, ensuring that the research findings would meaningfully contribute to the body of knowledge in a particular field. The current study utilized the study approach presented in Figure 1.

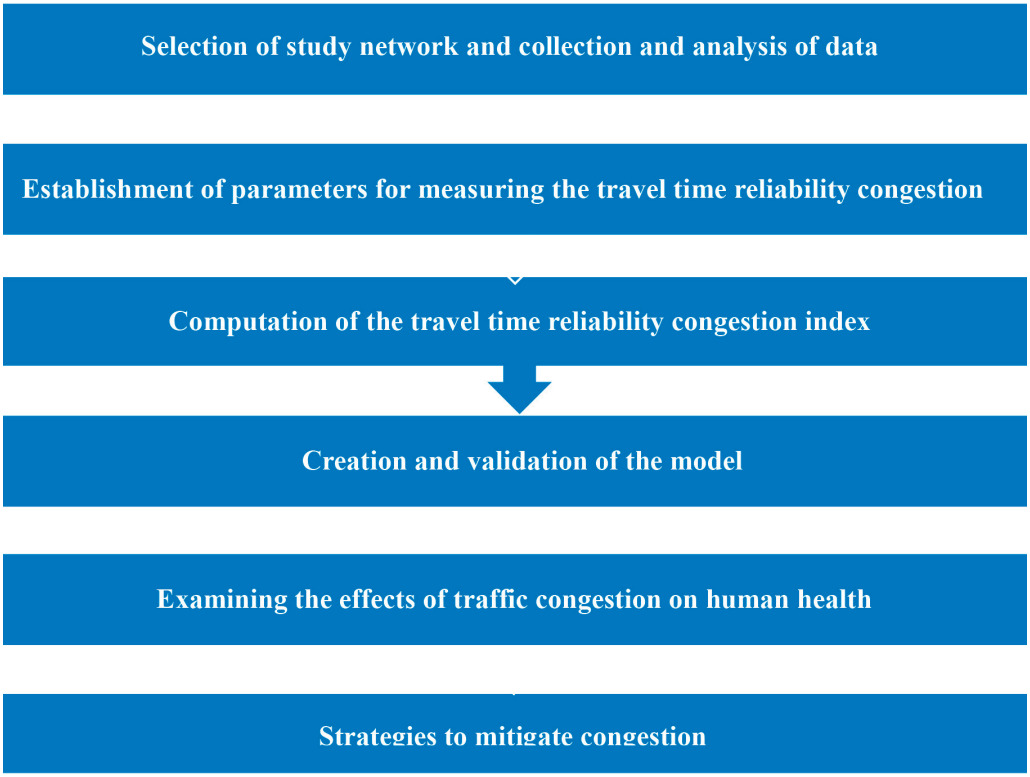

Figure 1 *Flowchart depicting the methodology*

5 Study area characteristics

The present study focuses on the arterial road network. Tiruchirappalli, situated in the state of Tamilnadu in the southern region, is the fourth largest municipal corporation and urban conglomeration within the state, located along the Kaveri River. The research is centered around the Tiruchirappalli city, renowned for its historical and traditional significance in India. Moreover, the city holds significance as a prominent educational center with prestigious institutions like Anna University, Bharathidasan University, Indian Institute of Management (IIM), National Institute of Technology (NIT), Indians Institute of Information Technology (IIIT), and Tamil Nadu National Law School (NLS).

Selecting the appropriate study area is crucial for establishing an efficient and congestion-free road network. It involves considering factors, such as existing transport infrastructure, traffic behaviour, and other research requirements. This study primarily examines the urban roads to evaluate the congestion index and

Table 1 *Information regarding the roads selected for the study*

No.	Road Name	Road Class	Lane Configuration	Length (m)
1.	Thillainagar main road	Arterial	4 lane undivided	1000
2.	Palakkarai	Arterial	2 lane undivided	650
3.	Puthur EVR	Arterial	4 lane divided	750
4.	Bishop	Arterial	2 lane undivided	1050

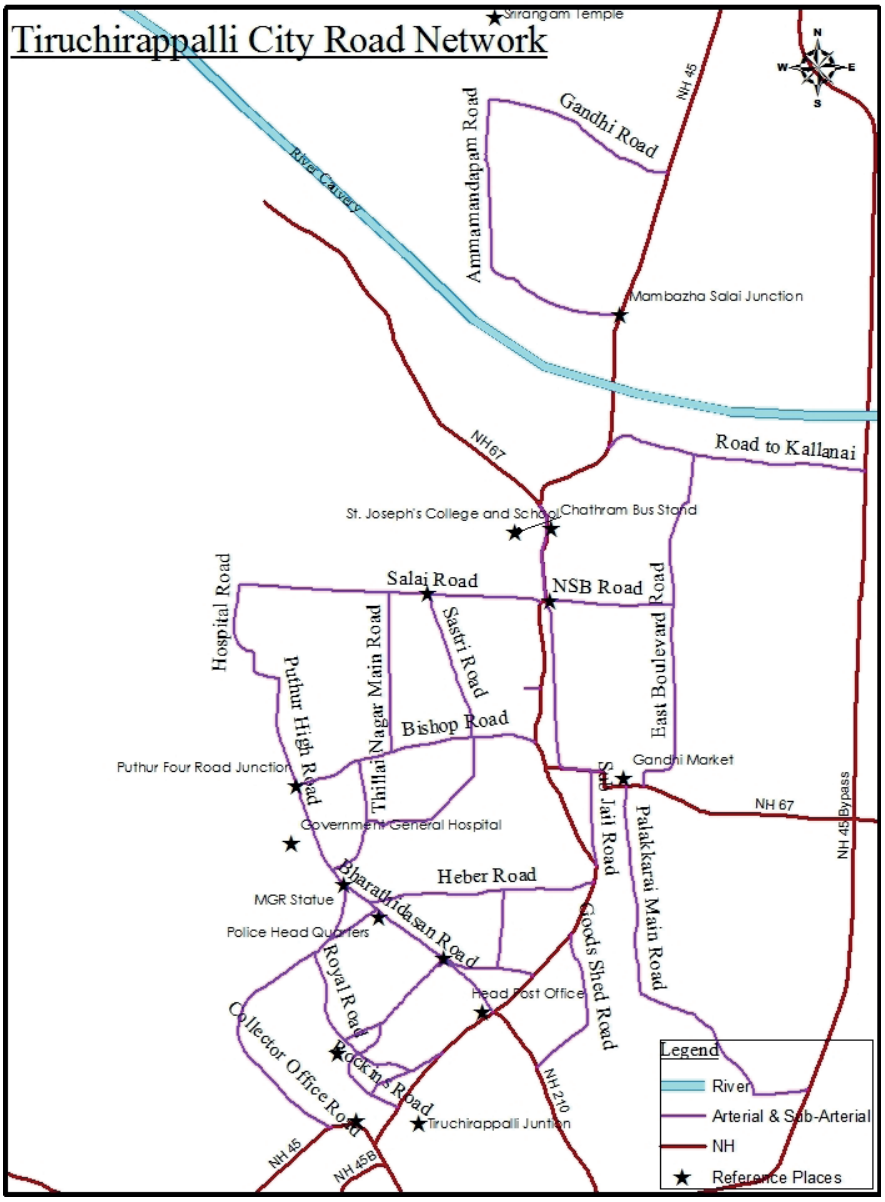

Figure 2 *Tiruchirappalli city road network*

analyze fluctuations in travel time for diverse types of vehicles in Tiruchirappalli district. The following roads have been chosen for the study:

1. Thillainagar main road,
2. Palakkarai road,
3. Puthur EVR road and
4. Bishop road.

All the roads are so chosen and studies have been conducted at midblock sections where no intersections are present within 200 m of upstream and downstream of the road stretch. Further, the stretches are selected in such a way that the side friction due to parking or any other food stalls are not affecting the vehicular movement. Thillainagar main road in Tiruchirappalli city connects Thennur Junction and Salai Junction, spanning a length of 1000 m. The road intersects with 11 other roads. It is a four-lane single carriageway with footpaths and on-street parking on both sides. The section under study, measuring 100 m, lies between the 3rd cross and 5th cross.

Palakkarai road, situated between Chatram and Railway Junction in Tiruchirappalli, is a two-lane single carriageway covering a distance of 650 m. The road features unpaved shoulders, each with a width of 1 m. Heavy vehicles like buses and trucks are not allowed on this route in the direction of Chatram.

Puthur EVR road, situated between Puthur Junction and MGR statue in Tiruchirappalli city, spans a length of 750 m. It is a four-lane dual carriageway with footpaths on both sides. On-street parking is permitted towards the Puthur Junction to MGR statue.

Bishop road, also known as Thennur High Road, is a commercial route linking Thennur Junction and Puthur Junction in Tiruchirappalli city. The road extends for 1050 m and is a two-lane single carriageway with on-street parking on both sides. It lacks footpaths but has paved shoulders on either side. The detail geometric features of the selected roads are provided in Table 1 and Figure 2 shows the aerial view of the selected road networks.

6 Data collection and extraction

Data collection and extraction are crucial steps in the research process, particularly in studies and projects that require empirical data for analysis. These steps involve gathering relevant information from various sources and organizing it for further analysis and interpretation. Data collection and extraction are fundamental steps in any research or analysis process. Thorough and careful data collection, combined with appropriate extraction and management, are crucial for obtaining the meaningful and accurate results in research studies. In the research, data were collected using video recording methods and manually extracted using the assistance of Avidemux software. Avidemux is a video editing software where videos can run in required frames per second (fps) or the frames in which it is recorded. It helps in minimizing the error during the data extraction since the videos can be run with interval of as low as 0.04 seconds (25 fps).

6.1 Travel time

Travel time is a fundamental aspect of transportation planning, management, and decision-making that directly impacts the efficiency, safety, and convenience of travel for individuals. Travel time refers to the duration taken to travel from one point to another, usually measured in minutes, hours, or any time unit. It is a critical factor in transportation and logistics as it directly affects the efficiency of movement and the overall travel experience.

6.2 Travel time reliability measures

Travel time reliability pertains to the regularity and predictability of travel times on a given route or transportation network. It is an essential aspect of transportation planning and management, as it directly impacts the efficiency and convenience of travel for commuters and goods. The travel time reliability measures are valuable for transportation planners and policymakers to identify congested areas, evaluate the impact of traffic management strategies, and prioritize infrastructure improvements to enhance overall travel experience and efficiency. Travel time reliability is a different approach from the V/O (Volume-to-Capacity) ratio, which mainly focuses on expanding roadways to accommodate existing traffic demand. However, the travel time reliability measures are centered around various performance indicators, such as mobility, serviceability, accessibility, and well-planned management of the existing transportation system.

6.3 Travel time reliability congestion index (TTRCI)

Travel time reliability congestion index is an indicator that assesses the level of congestion and the consistency of travel times on a given road or transportation network. It is used to assess the influence of congestion on travel time variability and reliability for commuters and goods. The index takes into account factors such as the variance in travel times, the probability of encountering delays, and the predictability of travel times.

$$\begin{aligned} &\textit{Travel time reliability congestion} \\ &\textit{index}\,(\,\textit{TTRCI}\,) = 95\textit{th percentile travel time} - \\ &\textit{Average Travel time}/\textit{Average travel time} \end{aligned} \tag{1}$$

Table 2 *Travel time reliability congestion index (%) of the selected roads*

Roadway	Direction	Travel time reliability congestion index (%)
Thillainagar main road	Upward	26
	Downward	28
Palakkarai road	Upward	36
	Downward	33
Puthur EVR road	Upward	26
	Downward	28
Bishop road	Upward	36
	Downward	33

The Travel time reliability congestion index is a measure of the additional travel time that commuters need to add to their expected travel time to ensure on time arrival at their destination with a certain level of confidence. It is calculated by dividing the difference between the 95th percentile travel time and the mean travel time by the mean travel time.

Four sites were chosen as the study areas, and a traffic volume measurement was conducted at the time of both morning peak hours (from 7:30 A.M. to 10:30 A.M.) and morning off-peak hours (from 12:30 P.M. to 3:30 P.M.) using the video graphic survey techniques along the designated road segments.

The congestion index for the selected roads have been calculated in both directions of movement, as shown in Table 2. A higher percentage of congestion Index suggests that more time is required for vehicles to traverse a specific road section, indicating a higher degree of congestion on that road. This variation in congestion index is influenced by factors such as the type of vehicles and lane characteristics. A smaller congestion Index indicates better serviceability and less congestion on the road.

A higher travel time reliability congestion index indicates greater variability and unpredictability in travel times, leading to less reliable and consistent travel experiences. Conversely, a lower index suggests a more reliable transportation system with consistent and predictable travel times, resulting in smoother and more efficient journeys for travellers. Transportation planners and policymakers use this index to identify congestion hotspots, prioritize infrastructure improvements, and implement traffic management strategies to enhance overall travel time reliability and alleviate congestion-related issues.

7 Travel time reliability congestion index model

The travel time reliability congestion index model is a quantitative method used to assess the level of congestion and the reliability of travel times on a road or transportation network. This model incorporates various factors, including traffic volume, speed, and variability in travel times, to calculate the congestion index. The aim of this model is to provide a numerical value that represents the level of congestion and travel time predictability experienced by commuters and goods.

The present study aimed to develop a travel time reliability congestion index model by analyzing the different factors contributing to traffic congestion. The primary elements affecting the travel time reliability were identified as vehicle speed, traffic volume and travel time. The focus of the travel time reliability congestion index model was on predicting the congestion levels. To assess the model validity, observed travel times during the peak hour from 9:00 AM to 10:00 AM were compared to the estimated values, aiming for minimal percentage of error.

7.1 Model estimation

Model estimation is the process of determining the parameters or coefficients of a mathematical or statistical model based on observed data. The goal of the model estimation is to find the best-fitting values for the model's parameters so that the model can accurately represent the relationship between the variables in the data. Proper model estimation requires careful consideration of the model's assumptions, data quality, and appropriate estimation techniques to ensure reliable and meaningful results.

Regression analysis is a common method used in model estimation, particularly for predicting numerical outcomes, where the correlation between the dependent and independent variables is explored to create a regression model. The research aimed to create a multiple linear regression models, with travel time reliability congestion index as the dependent variable, and speed, traffic volume, travel time as the independent variables. However, before initiating regression, the independent variables are subjected to Pearson correlation to determine whether the variables are mutually exclusive or dependent. The obtained R-values are provided in Table 3.

As can be seen from Table 3, R-values between the independent variables suggest that Travel time is dependent on speed with a value of 0.733. However,

Table 3 *Pearson correlation table*

Pearson Correlation Value	Actual Travel Time	Speed	Traffic Volume
Actual Travel Time	1	-.733	-.508
Speed	-.733	1	.604
Traffic Volume	-.508	.604	1

Table 4 *Regression model for determining TTRCI*

Equation	R-Square
$TTRCI = 12.414 + (0.024 * TV) - (0.028 * TT)$	0.948
$TTRCI = 28.537 + (0.348 * S) - (0.093 * TT)$	0.404

where: $TTRCI$ = Travel time reliability congestion index,
S = Speed of vehicle in km/h,
TT = Travel time in s,
TV = Volume in PCU/h.

Table 5 *The percentage of error during the validation method*

Time of day (AM)	Observed travel time reliability congestion index	Estimated travel time reliability congestion index	Error percentage, %
9:00 – 9:10	28.49	28.00	1.72
9:10 – 9:20	30.13	29.90	0.76
9:20 – 9:30	36.10	37.16	-2.93
9:30 – 9:40	35.62	34.76	2.41
9:40 – 9:50	33.98	34.18	-0.59
9:50 – 10:00	28.13	27.71	1.49

other variables are not dependent on each other strongly. Therefore, the mutually independent variables are traffic volume and speed or, traffic volume with travel time. Therefore, the two equations have been modelled to determine the TTRCI and best between them can be utilized to assess the congestion. Table 4 shows the two models with R-square values.

Equations in Table 4 shows that TTRCI can be more accurately determined from Traffic Volume and Travel time, since the equation has much better R-square value of 0.948. Further, it is also convenient to calculate both the independent variables easily on field. The formulated equation is applicable when the travel time is greater than 10 seconds and the traffic volume exceeds 650 PCU/h.

7.2 Model calibration and validation

Model calibration involves making adjustments of the parameters or coefficients of a model to improve its accuracy and fit with the observed data. It is a crucial step in the model development process, especially for predictive models and simulations, where the goal is to ensure that the model‘s predictions align well with the real-world data.

During the model calibration, the model‘s parameters are fine-tuned using optimization techniques, such as minimizing the difference between the model‘s predictions and the actual observed values. The objective is to ensure that the model is as accurate as possible and captures the underlying patterns and relationships present in the data. It ensures that the model’s predictions are reliable, and that the model can be confidently used for decision-making and forecasting purposes. The proper model calibration is essential to avoid biases and inaccuracies in model predictions and improve the model’s overall usefulness and effectiveness. Table 5 showcases the error percentage during model validation.

Model validation is a critical step in the model development process to assess the performance, accuracy, and generalization ability of the model. It involves evaluating how well the model‘s predictions align with real-world data and checking whether the model can effectively make accurate predictions for the new, unseen data. Model validation helps to ensure that the model is robust and reliable and can be confidently used for decision-making and future predictions. It helps to build confidence in the model’s performance and assists in selecting the best model among different alternatives. The proper model validation is crucial for using models effectively in decision-making processes and applications across various domains.

To validate the proposed travel time reliability congestion index model, the congestion index evaluated by the model was compared to the congestion index acquired through the field data. Separate field data

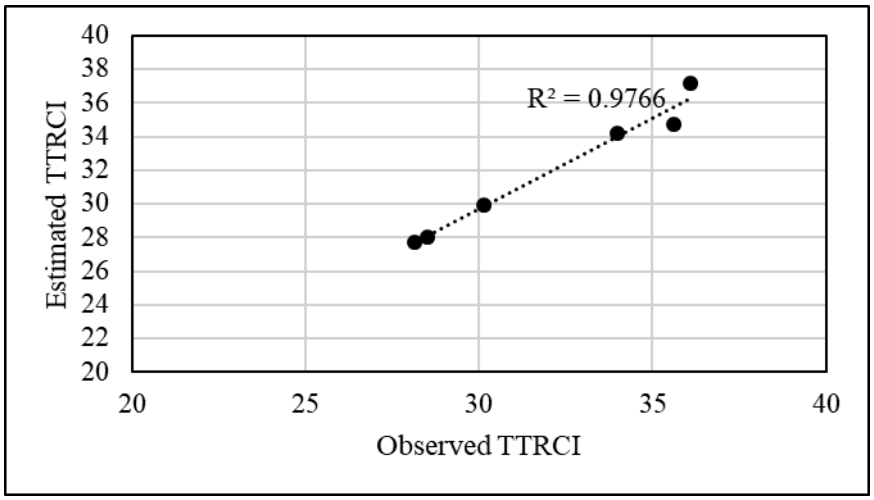

Figure 3 *The variability between observed travel time and estimated travel time*

were gathered from multiple locations of arterial road, different from the location where the model was developed. This ensured that the model's equation is not limited to a specific location and can be applied to estimate congestion index at different locations.

Table 5 presents the comparison between the travel time reliability congestion index of all the vehicle categories estimated using the proposed model and the observed congestion index collected from the field data. The results indicate that the values derived

Table 6 *Parameters influencing human health*

Parameters	Explanation	Order
Air pollution	Congested traffic is a major source of air pollution in urban areas. Traffic congestion results in the emission of pollutants like nitrogen oxides (NOx), particulate matter (PM), volatile organic compounds (VOCs), and carbon monoxide (CO) from vehicles. Prolonged exposure to these pollutants can cause respiratory issues, worsen asthma and other respiratory conditions, and elevate the chances of cardiovascular diseases.	Order I
Exposure to harmful substances	People who spend significant time in congested traffic are exposed to higher levels of harmful substances, such as diesel exhaust, which contains toxic compounds and carcinogens.	Order I
Noise pollution	Traffic congestion generates high levels of noise pollution, which can lead to stress, sleep disturbances, and hearing impairment. Chronic exposure to noise pollution has also been linked to cardiovascular issues and mental health problems.	Order I
Physical inactivity	In congested areas, people often spend more time sitting in vehicles or waiting in traffic, leading to a sedentary lifestyle. Lack of physical activity is associated with a higher risk of obesity, diabetes, and other chronical conditions.	Order III
Mental health impact	The stress and frustration caused by traffic congestion can negatively impact the mental health, leading to anxiety, irritability, and decreased overall well-being.	Order II
Road traffic accidents	Congestion can increase the likelihood of the road traffic accidents, leading to injuries and fatalities. Drivers may experience increased stress and impatience, which can contribute to risky driving behaviour.	Order II
Delayed emergency services	Congestion can impede the timely arrival of emergency services, affecting the ability to respond to accidents and medical emergencies promptly.	Order I
Environmental impact	Traffic congestion can lead to more idling vehicles, increasing fuel consumption and leads to increased greenhouse gas emissions, contributing to climate change and environmental degradation.	Order II
Unequal exposure	Low-income neighbourhoods and marginalized communities often experience higher levels of traffic congestion and pollution, leading to health disparities and environmental injustice.	Order III

from the proposed model closely match the observed field values, with percentage error varying from 0.53 to 2.93%. This indicates that the proposed model is effective in predicting the travel time reliability congestion index. Figure 3 helps in understanding the same in form of a pictorial representation. The validation process demonstrates that the proposed travel time reliability congestion index model is reliable and capable of accurately predicting travel times at different locations of arterial road. The travel time reliability congestion index model is a valuable tool for assessing the performance of transportation systems and understanding the impact of congestion on travel times. It aids in the optimization of traffic flow, enhances the overall travel experience, and contributes to more efficient and reliable transportation networks.

8 The impact of traffic congestion on human health

Traffic congestion can have significant impacts on human health, both directly and indirectly. The health effects of traffic congestion are diverse and can affect individuals in various ways. The study aims to investigate the influence of congestion on human health by gathering data from both field locations and workplaces. Some of the key parameters influencing human health are categorized as provided in Table 6.

Addressing the traffic congestion and its impact on human health requires a comprehensive approach, including promoting sustainable transportation options like public transit, cycling, and walking, implementing traffic management strategies, and reducing reliance on

Table 7 *Strategies to alleviate the traffic congestion*

Parameters	Description	Priority level
Improved public transportation	Enhancing public transportation systems, such as buses, trains, and subways, to provide reliable and efficient alternatives to the private car travel. This approach can incentivize individuals to opt for public transit, thereby decreasing the volume of vehicles on the road	Level 3
Congestion pricing	Implementing tolls or fees that vary, based on the level of congestion, time of day, or location to manage demand and encourage travel during the off-peak hours.	Level 3
Carpooling and ride sharing	Encouraging commuters to share rides by carpooling or using the ride share services, which can decrease the volume of vehicles on the road and decrease the overall congestion.	Level 2
Active transportation	Encouraging walking and cycling as feasible transportation alternatives for short trips, which can help reduce the vehicle traffic and improve public health.	Level 1
Traffic signal synchronization and enforcement of stringent traffic regulations	Optimizing the traffic signal timing to facilitate smoother traffic flow and reduce the stop-and-go congestion.	Level 1
Smart traffic management	Implementing intelligent transportation systems and traffic management technologies to monitor traffic conditions and adjust signal timings in real-time based on traffic flow.	Level 4
Expanded road infrastructure	Adding lanes, building new roads, or improving existing roadways to increase the capacity and accommodate growing traffic demands.	Level 4
Flexible work hours	Encouraging telecommuting and flexible work schedules to reduce the number of commuters during the peak hours.	Level 2
Park and ride facilities	Establishing park-and-ride facilities near the transit hubs to encourage commuters to park their cars and use public transportation for the rest of their journey.	Level 3
Transportation education and awareness campaigns	Raising public awareness about the impacts of congestion and promoting sustainable transportation options through educational campaigns.	Level 2
Decentralization of important offices	By moving important offices to multiple locations, the burden on transportation networks and public services in the central area can be alleviated, reducing the traffic congestion and overcrowding.	Level 1
Regulating roadside activities	By effectively managing the roadside activities, authorities can create a more efficient and streamlined transportation system, reducing congestion and improving overall mobility for commuters.	Level 1

private vehicles. Additionally, urban planning that gives priority to green spaces and creating pedestrian friendly environments, can assist to mitigate the adverse health effects of traffic congestion. The present study attempted to identify the parameters, which are affecting majority of inhabitants and categorized them as order I. Similarly, other factors are categorized as order II and order III.

9 Suggested approaches to mitigate congestion

Congestion mitigation refers to the actions and strategies implemented to alleviate or reduce the traffic congestion in transportation systems. These measures aim to improve the flow of traffic, enhance transportation efficiency, and minimize the negative impacts of congestion on commuters, businesses, and the environment. The central objective of this study was to enhance the existing traffic infrastructure with minimal costs and effort. Various congestion reduction strategies were considered as a part of this effort. Valuable input was obtained from the diverse perspectives, including the general public, specialists, experts, educators, engineers, and street vendors. The grouping of approaches to alleviate the traffic congestion has been presented in Table 7.

The present study prioritized the upgrading of the existing traffic framework with minimal costs consideration, rather than focusing on building new infrastructures. The study utilized a priority level approach, based on feedback gathered from various sources. Elements ranked lower (Level 1) require immediate implementation for more significant impact. Among the elements, active transportation (promoting walking and cycling as viable transportation options for short trips, which can help reduce the vehicle traffic and improve public health), traffic signal synchronization and Enforcement of stringent traffic regulations**,** decentralization of important offices, and regulating roadside activities, received the strong recommendations from the majority of inhabitants. For improving efficiency and accessibility, pertaining to urban road network, those aforementioned approaches should be promptly executed. The increasing number of motorcycles has rendered non-motorized vehicles obsolete. Proper execution of these elements needs to be taken seriously and accomplished at the earliest opportunity. A combination of these congestion mitigation strategies, tailored to specific urban environments and transportation systems, can help alleviate the traffic congestion, improve mobility, and create more sustainable and efficient transportation networks.

10 Conclusions and recommendations

Traffic congestion has become increasingly problematic on urban road networks for so many decades all over the world. In developing countries, like India, where the mixed traffic conditions prevail, the traffic congestion scenarios get further complicated. Congestion not only affects the overall economy, but negatively affects health, environment and traffic safety, as well. Due to the increase in vehicular traffic in recent times, congestion mitigation strategies have become a point of hot discussions for traffic engineers, researchers, and practitioners alike.

The main focus of the present research was on analyzing the traffic congestion and its adverse effects. Data was collected from the specific roadways in the Indian traffic scenario to propose strategies for mitigating congestion. The extent of congestion varied based on vehicle categories and lane distribution. The study evaluated the extent of congestion and analyzed its negative impact on various factors. It was found that congestion prediction in the Indian environment is challenging, and complete elimination is not feasible, particularly due to the increasing number of the two-wheeler and four-wheeler, particularly passenger cars.

The travel time reliability congestion index was utilized to assess the congestion extent on the chosen road network. The heavy traffic congestion forces residents to spend more time on the road, resulting in adverse effects on the country's overall economy. Moreover, the traffic congestion negatively impacts the environment and human health. A travel time reliability congestion index model was developed, taking into account various factors that influence travel time reliability. The observed percentage error was around 5 %, indicating that the general model is suitable and statistically significant in estimating travel time reliability congestion index. During the congested periods, motorists are required to frequently operate the brake and clutch, leading to increased fuel consumption and reduced performance and longevity of a vehicle. As a result, vehicle operating costs are closely linked to congestion. Addressing the traffic congestion and its impact on human health requires a comprehensive approach, including promoting sustainable transportation options like public transit, cycling, and walking, implementing the traffic management strategies, and reducing reliance on private vehicles. Additionally, prioritizing green spaces and creating pedestrian friendly environments in urban planning can help to mitigate the adverse health effects of traffic c ongestion.

Among the elements, promoting walking and cycling as viable transportation options for the short trips, which can help reduce vehicle traffic and improve public health, Traffic signal synchronization and enforcement of stringent traffic regulations, decentralization of important offices, and regulating roadside activities received strong recommendations from the majority of inhabitants. For improving the functionality and accessibility of the urban road network, these

aforementioned approaches should be promptly executed.

The study highlighted the importance of adopting a holistic approach, combining the technological innovations with appropriate policy interventions, to effectively manage and alleviate the traffic congestion. In developing countries such as India, the presence of a diverse and heterogeneous traffic environment further complicates the situation. Enormous traffic congestion can sometimes lead to life and death situations, with consequences that cannot be underestimated. It is crucial to establish effective coordination among different organizations, from research and planning to execution and practical implementation, to effectively address the traffic congestion. With ongoing research, collaboration, and implementation of sustainable strategies, it is possible to create more efficient, accessible, and liveable urban environments for future generations.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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