A Review of Techniques, Indicators and Devices for Traffic Congestion Monitoring

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Abstract

Road transport undeniably constitutes the predominant mechanism for facilitating the transportation of both goods and individuals on a global scale, serving as an essential backbone for economic and social interactions across diverse regions and cultures. The noticeable decrease in the flow of vehicles, which can be attributed to a plethora of internal and external factors, with a particular emphasis on the phenomenon of congestion, has profound implications that significantly influence fuel consumption rates, contribute to pollution associated with emissions, adversely affect the health and well-being of bystanders, and culminate in a considerable loss of time for individuals navigating these congested environments. In light of their elevated population densities coupled with their classification as emerging economies, South Asian countries find themselves necessitated to implement automated systems for the critical processes of predicting, identifying, and effectively addressing the challenges posed by road traffic congestion in order to enhance urban mobility and overall transport efficiency. This thorough research carefully explores the various techniques that have been utilized to recognize traffic congestion, presenting an extensive assessment of their individual strengths and weaknesses, thus offering insightful observations about the existing situation in this field of study. The examination of the diverse approaches and advanced technologies that have been utilized for the operation of lane-less roadways have been conducted, revealing substantial potential for further innovations that could greatly assist future researchers in their endeavors to enhance traffic management and improve roadway safety and efficiency.

Keywords: Road Traffic, Congestion Detection, Lane Less Driving, Prediction.

مراجعة تقنيات ومؤشرات وأجهزة مراقبة الازدحام المروري

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الخلاصة:

لا شك أن النقل البري يشكل الآلية السائدة لتسهيل نقل البضائع والأفراد على نطاق عالمي، ويعمل بمثابة العمود الفقري الأساسي للتفاعلات الاقتصادية والاجتماعية عبر المناطق والثقافات المتنوعة. إن الانخفاض الملحوظ في تدفق المركبات، والذي يمكن أن يعزى إلى عدد كبير من العوامل الداخلية والخارجية، مع التركيز بشكل خاص على ظاهرة الازدحام، له آثار عميقة تؤثر بشكل كبير على معدلات استهلاك الوقود، وتساهم في التلوث المرتبط بالانبعاثات، وتؤثر سلبًا على صحة ورفاهية المارة، وتبلغ ذروتها في خسارة كبيرة للوقت للأفراد الذين يتنقلون في هذه البيئات المزدحمة. في ضوء الكثافات السكانية المرتفعة إلى جانب تصنيفها كاقتصادات ناشئة، تجد دول جنوب آسيا نفسها مضطرة إلى تنفيذ أنظمة آلية للعمليات الحاسمة للتنبؤ بالتحديات التي يفرضها الازدحام المروري على الطرق وتحديدها ومعالجتها بشكل فعال من أجل تعزيز التنقل الحضري وكفاءة النقل الشاملة. يستكشف هذا البحث الشامل بعناية التقنيات المختلفة التي تم استخدامها للتعرف على الازدحام المروري، ويقدم تقييمًا شاملاً لنقاط القوة والضعف الفردية، وبالتالي يقدم ملاحظات ثاقبة حول الوضع الحالي في هذا المجال من الدراسة. تم إجراء فحص الأساليب المتنوعة والتقنيات المتقدمة التي تم استخدامها لتشغيل الطرق بدون حارات، مما يكشف عن إمكانات كبيرة لمزيد من

الابتكارات التي يمكن أن تساعد الباحثين المستقبليين بشكل كبير في مساعيهم لتعزيز إدارة حركة المرور وتحسين سلامة الطرق وكفاءتها.

1. Introduction

The robot manipulator has a high nonlinearity in Transportation encompasses the detailed procedure that allows for the transit and transfer of both persons and assorted items between different geographical sites, involving a multitude of approaches and modes. Notwithstanding the existence of a multitude of alternative transportation modes including but not limited to air travel, maritime transport, road transit, and railway systems road transportation continues to assert its dominance as the primary and most utilized method for facilitating mass travel across diverse populations [1]. In light of the substantial population density in India, along with the unique characteristics and spatial distribution of urban centers, road transportation emerges as the most economically viable mode of transit available to the populace. Moreover, vehicle travel grants individuals an outstanding amount of versatility, permitting them to modify their journey schedules fluidly, investigate various routes, and proficiently traverse both rural and metropolitan terrains with comfort and productivity. The Intelligent Transportation System (ITS) represents a sophisticated integration of advanced communication and information technologies within the transportation sector, which aims to significantly enhance management capabilities and monitoring processes, ultimately resulting in improved safety standards and operational efficiency [2]. The principle behind a Vehicular Ad hoc Network (VANET) concerns the sophisticated interaction and dialogue between automobiles, traffic control centers, and the appropriate authorities, which all work collaboratively for the key aim of traffic surveillance and governance. It is important to note that ITS encompasses a wide and diverse array of applications designed to optimize various aspects of transportation management and user experience [3] .

A specific classification of applications is fundamentally associated with the intricate domain of traffic management, which encompasses a multitude of essential components including intersection control mechanisms, systematic incident detection protocols, comprehensive vehicle classification systems, continuous monitoring methodologies, and effective revenue collection strategies [4]. An alternative spectrum of applications exists that can significantly assist commuters by generating detailed congestion maps that visually represent traffic density, estimating precise trip durations based on real-time data, providing comprehensive information regarding public transportation options, managing the operations of individual vehicles through advanced algorithms, and efficiently addressing and managing the aftermath of traffic accidents. In modern traffic control scenarios, delivering urgent aid after accidents is critically vital and should be emphasized. At the inception of what is now recognized as the Intelligent Transportation System (ITS) era, Garcia-Ortiz underscores the various advanced technologies that are currently being implemented within the framework of the Intelligent Transportation System in the United States [5]. In their 2010 collaborative effort, Papadimitriou et al. deliver a thorough and extensive review of the various technologies, intricate communication channels, and established protocols that are significant to the area of Vehicular Ad Hoc Networks (VANET) [6]. Traffic congestion is caused by local factors like road design and broader factors like urban growth, where small issues can lead to widespread congestion through a chain reaction. This survey article meticulously enumerates a variety of congestion measurement indicators, which encompass critical metrics such as vehicle speed, overall travel time, traffic volume, and the overall level of service experienced by road users. The primary challenges that confront the functionality of VANET are numerous and include the unpredictable characteristics of the radio communication channel, the inherent high mobility of vehicles, the necessity of adherence to established road maps, persistent security concerns, the lack of interoperability among the various existing systems, and the insufficient global standardization that hampers cohesive operation [7]. The applications of VANET are diverse and multifaceted, encompassing areas such as user comfort and entertainment, safety enhancements, sign extension capabilities, vehicle diagnostics and maintenance functionalities, and the collection of pertinent information from other vehicles on the road [8].

Road congestion, which presents a considerable challenge to everyday life, not only drains valuable time and energy for individuals but also plays a significant role in various environmental pollution types that adversely influence urban areas. The phenomenon of traffic congestion represents a pressing concern for commuters traversing urban landscapes across the globe [9], as the intricate dynamics of transportation systems continue to evolve. A multitude of metropolitan areas is currently grappling with traffic congestion that ranges from moderate to severe levels, which can lead to a multitude of adverse effects on the quality of life.

The deplorable conditions of road infrastructure, including uneven carriageways and inconsistent shoulder widths, the presence of pedestrians obstructing thoroughfares, the inappropriate allocation of land for pedestrian activities, the noncompliance of lanes with established traffic regulations, inadequately positioned or poorly designed bus stops, the existence of diverse vehicle types operating under varying conditions, and the rampant issue of uncontrolled parking on urban streets collectively indicate that traffic-related problems are pervasive across the globe. The operation of an exceptionally high volume of vehicles on narrow highways creates an environment in which traffic congestion becomes an inevitable and recurring reality for commuters. This congestion is predominantly attributed to the significant imbalance that exists between the supply of transportation infrastructure and the demand for vehicular movement, a disparity that manifests in both domestic and international contexts of traffic [10]. In an attempt to decrease the profound reliance on personal vehicles, the Shanghai administration has established strict car ownership policies, thereby advocating for public transport as a more sustainable method for navigating the city.

A recent evaluation conducted by the GPS technology firm TomTom has revealed that Bangkok and Mexico City are currently the two cities that experience the most severe traffic congestion during the evening rush hour, with Bangkok and Mexico City ranking first in Thailand and Mexico, respectively. In the case of Bangkok, the driving experience is characterized by a lack of adherence to lane discipline, resulting in a rather chaotic and less organized approach to vehicular navigation, whereas in Mexico City, there exists a more structured system that follows lane-based driving protocols. To highlight the disparities in traffic behaviors between these two city environments, Figure 1 delivers a meticulous illustration of the varying traffic dynamics noted in the two municipalities.

Bangkok, Thailand

Mexico City, Mexico

Figure (1): – Globally Top Ranked Cities with worst rush hour traffic (Zhang and Nie, 2022).

In the realm of urban transportation and mobility studies, two distinct categories of traffic congestion can be identified, namely recurrent traffic congestion and non-recurrent traffic congestion [11]. Recurrent traffic congestion pertains to the systematic emergence of traffic congestion patterns that materialize with notable frequency over a defined temporal interval, characterized by their predictability and regular occurrence. During weekdays, the busiest traffic times are usually seen between 8:30 AM and 10:30 AM as well as from 6:00 PM to 8:00 PM, which corresponds well with the functioning hours of schools and different job places [12].

Conversely, non-recurrent traffic congestion is characterized by its sudden onset and the absence of any discernible or consistent pattern, rendering it more unpredictable in nature. Illustrative examples of non-recurrent traffic congestion encompass scenarios induced by severe weather phenomena, large-scale public rallies, social events or gatherings, as well as incidents such as vehicular accidents and mechanical failures, [13].

It is essential that maintain an ongoing assessment of traffic dynamics and execute useful initiatives that address the challenges of traffic congestion, whether it is a recurring or one-time situation. The arrangement of this report is laid out in this fashion: In Section II, an extensive overview of the various strategies used for spotting road traffic congestion is provided, while Section III catalogs the different simulation applications accessible for the examination of Vehicular Ad hoc Network Technology (VANET). Section IV meticulously delineates both the challenges encountered and the scope of the investigation undertaken, whereas Section V culminates the discourse with a thorough presentation of the conclusions drawn from the findings.

2. Techniques

Traffic congestion results from both local factors, such as road design, and broader influences like urban growth, where minor issues can escalate into significant delays, that significantly disrupts the customary and expected flow of vehicular movement, thereby leading to potential delays and safety concerns for all users of the transportation infrastructure [14].

The author emphatically emphasized the critical importance of not only recognizing and identifying such anomalous traffic events but also effectively communicating this information to all individuals utilizing the roadways, with the essential aim of reducing traffic congestion and improving the connectivity between vehicles, ultimately working towards the ambitious goal of establishing a highly efficient and intelligent urban environment known as a smart city.

It is vital to grasp that only recognizing the existence of congestion on any certain road does not, on its own, serve as an adequate fix for resolving the complications tied to that congestion. Hence, carrying out a meticulous analysis of traffic patterns and precisely tracing the root issues of congestion in a specified zone is of utmost significance to effectively adopt strategies that can alleviate the congestion and avert its overflow into adjacent thoroughfares, potentially worsening the challenge.

Many methodologies for sensing, which include the strategic deployment of static sensors situated along roadways, the meticulous installation of sensors on various types of mobile vehicles, and the innovative application of hybrid sensing approaches, have been shown to effectively acquire and analyze data from automobiles [15].

Static sensors, which comprise a spectrum of technologies such as video observation systems, acoustic sensors that capture sound waves, and radio frequency (RF) sensors that gather electromagnetic signals, are extensively deployed to monitor and assess the current state of road traffic in detail, [16]. Mobile sensing is an approach that uses GPS in transportation, smartphone sensors, crowdsourced data, specialized vehicle hardware, and social media to enhance data collection and sharing.

The hybrid sensing mode, which is an innovative approach in the realm of data collection, systematically gathers information through a network of sophisticated sensors that are strategically installed along various road segments and integrated into vehicles, thereby creating a comprehensive framework for monitoring traffic conditions. The organization of these sensors precisely illustrates the advancements currently taking place in sensor types, which cover but are not restricted to, inductive loop sensors, RFID systems, magnetometers, infrared sensors, and vision-based strategies, [17].

In order to successfully tackle any potential ambiguities that could emerge while retrieving data, fuzzy logic systems are deliberately applied to secure real-time information that is both correct and dependable, [18]. Additionally, high-level neural networks have been adopted to facilitate an extensive study of traffic data collected from genuine circumstances, which in turn augments our grasp of traffic flow. Through their remarkable input to the discipline, Li et al. unveil an all-encompassing traffic forecasting framework that skillfully integrates wavelet decomposition strategies intended to meaningfully lessen the disturbances frequently caused by the unpredictable characteristics of random travel situations, [19].

Moreover, Li et al. adeptly harnesses a fuzzy logic methodology to flexibly modify traffic oversight measures in response to the current traffic environment, exemplifying the actual use of their theoretical insights. In light of the comprehensive analysis executed by Wang et al., a division of four varied types of traffic forecasting practices is recognized, including nonlinear models, historical value-centric models, nearest neighbor techniques, and real-time data methodologies that harness the power of traffic simulators to refine forecasting precision, [20].

A comprehensive and innovative framework designated as CoTEC, an acronym for Cooperative Traffic Congestion Detection, which ingeniously employs a sophisticated fuzzy logic system that integrates variables such as traffic density alongside vehicle speed as critical inputs, ultimately generating an output that reflects the level of congestion experienced on the roadway [21].

Furthermore, in conjunction with the conventional static sensors that are strategically installed within the Roadside Units (RSU) and the dynamic mobile sensors that are deployed in probe vehicles, the advent of smartphones has recently instigated a significant transformation in the domain of road traffic sensing methodologies. These handheld gadgets are inherently loaded with numerous cutting-edge sensors, including but not limited to accelerometers, tools for audio and video recording, and GPS tracking functions, thus ensuring the fluid exchange of information across diverse networks like Wi-Fi and GSM mobile data services.

An empirical approach to headway computation for automobiles functioning in the diverse traffic landscape of Chennai, India, finding that the distribution patterns of vehicles show remarkable variability correlated with elements such as vehicle type and journey duration [22].

The predictive modeling related to traffic parameters shows a notable improvement in expanding the dataset's dimensions for further analysis. In our discourse, the diverse sensing methods used to identify road traffic congestion are systematically classified into several distinct categories, namely vision-based approaches, loop detector-based methodologies, acoustic-based techniques, radio frequency identification (RFID)-based systems, GPS-based strategies, along with various other alternative approaches [23].

A. Vision-based:

The comprehensive study by Yusuf et al. meticulously explores and explains the different dimensions and categories applicable to the vehicle under examination [24].

This sophisticated system incorporates a multifaceted approach that employs adaptive background extraction techniques, intricate edge detection algorithms, and a specialized shadow detection algorithm, all aimed at significantly reducing the probability of erroneous alarms occurring in various operational contexts. Historically, a sophisticated surveillance system that integrates closed-circuit television (CCTV) technology with centralized control equipment, in conjunction with sophisticated loop detectors [25], has been ingeniously developed specifically for monitoring and managing the unique challenges associated with underground tunnel environments. This advanced surveillance system is adept at identifying and addressing various impediments, which can include hazardous conditions such as ice accumulation, dense fog, and other adverse weather phenomena that may impair visibility and safety.

Furthermore, in addition to the critical process of feature extraction, researchers have systematically employed a set of established rules governing the characteristics of images to independently predict and forecast the movements of vehicles under a diverse array of illumination conditions, whether in the bright light of day or the low light of night [26].

Xiying Li proposed a sophisticated motion analysis technique, as detailed in the research conducted by [27], which serves to extract critical traffic data parameters including, flow velocity and the extent of road area occupancy, thereby contributing significantly to the field of traffic management.

This innovative approach effectively utilizes the established framework of highway surveillance video systems, which are integral for monitoring and assessing real-time traffic conditions. Within this context, we meticulously engineer the system to thoroughly analyze the incoming video stream, adeptly extract pertinent parameters, and accurately forecast potential congestion levels that may arise under varying traffic scenarios.

Yen-Azimjonov et al. introduced a novel vision-based traffic surveillance system specifically designed for nighttime operations, addressing the recognized inadequacy of existing daytime vision capturing and surveillance methodologies when applied to nocturnal conditions, as articulated in their study published in 2023 [28].

This advanced system strategically deploys high-resolution cameras on elevated structures positioned over highways or freeways, thereby maximizing the field of view and enhancing monitoring capabilities. Furthermore, the system is meticulously designed to isolate luminous objects captured within the photographic frames, thereby effectively identifying and distinguishing between the headlights and taillights of various automobiles traversing the roadway.

Yu et al. proposed a thorough approach aimed at meticulously revealing and systematically outlining various anomalies that could occur in road traffic situations by utilizing a variety of detailed traffic data, encompassing crucial aspects such as the comparative velocity among various vehicles, the patterns and occurrence of lane changes, along with the temporal intervals present between vehicles, commonly known as inter-vehicle time gaps [29].

To enhance the identification of outliers in this intricate dataset, the researchers apply the lowest eigenvalue extracted from the covariance matrix formulated on the previously outlined parameters, thus fostering a more sturdy and streamlined strategy for detecting anomalies. In a related study, Chakraborty & Dey innovatively developed a sophisticated distributed load balancing mechanism specifically aimed at enhancing the storage efficiency of video data, which effectively serves to eliminate redundant data within the context of long-established methodologies employed in the processing of road scene videos, thereby optimizing resource allocation and system performance [30].

Video sensors have proficiently captured real-time traffic dynamics, thereby facilitating the extraction of essential macroscopic parameters pertinent to the analysis of vehicular movement patterns and congestion levels. Throughout our analysis, Support Vector Machine classifiers are diligently employed, being highly developed algorithms designed for the detailed task of image classification., to boost the correctness and productivity of the classification method. The proposed system meticulously suggests a robust algorithm intended to categorize traffic flow into distinct categories such as light, medium, or heavy, as elaborated in the comprehensive study conducted by [31].

Cameras strategically positioned at multiple intersections and along lane boundaries proficiently obtain high-resolution images which serve as critical data points for further analysis, (Xie, 2024) [32]. Through our methodology, we have successfully identified Maximally Stable Extreme Regions from the vast collection of photographs, which effectively characterize the shape of the board in both monochromatic and color representations. Following the identification of the board's shape, we will rigorously assess the symbolism present on the board utilizing the Support Vector Machine (SVM) approach, ensuring a precise evaluation of the visual data. Sanjeewani et al. have similarly employed the identical real-time video processing technology within the urban landscape of Bengaluru, India, by creatively incorporating vibrant colorful strips along the roadways that delineate the lanes [33].

The assessment of vehicle density is achieved through the meticulous calculation of the percentage of the colored strip that becomes obscured by the presence of vehicles, providing insights into traffic patterns and density levels. In our research efforts, we have utilized extensive video recordings to gather heterogeneous traffic situations, which have subsequently led to the development of a comprehensive lumped macroscopic traffic flow model that encapsulates various traffic dynamics.

Aberna & Agilandeeswari have also innovatively extracted grayscale images from live video feeds and employed the Large Binary Pattern technique to enhance their analysis [34].

In a related context, Chaurasia et al. make use of video cameras for monitoring purposes, from which they derive image frames taken from the unending stream of active videos, later converting these visuals into grayscale versions before implementing background subtraction and segmentation techniques. Despite their endeavors to locate Binary Large Object (BLOB) images, the application of morphological techniques enables the differentiation of moving objects and vehicles; however, the identification of cars and their respective shapes within congested conditions remains a formidable challenge due to the resulting complexities of overlapping structures that obscure clear visibility [35].

B. Loop Sensor

Narsimhulu et al. formulated a sophisticated vehicle classification methodology that employs a dual-loop system, which significantly enhances the capability to gather real-time data pertaining to trucks on the road. This advanced approach is underpinned by a network of wireless magnetic sensors that not only offers remarkable flexibility but also results in a marked reduction in both installation and maintenance expenditures when juxtaposed with conventional sensing technologies [36].

Furthermore, Kodupuganti and Pulugurtha adeptly implemented this innovative technology at various critical points, including intersections and freeway routes, thereby optimizing traffic management systems [37].

In a parallel vein, Kim et al. developed a cutting-edge detection system that integrates magnetic sensors with a similarity-based algorithm, which serves the dual purpose of meticulously analyzing traffic flow patterns and accurately forecasting vehicle arrival times [38].

Additionally, Ribeiro proposed a novel incident detection system that harnesses the capabilities of advanced detectors in conjunction with the NETSIM traffic simulation software to enhance incident response strategies [39].

In the last few years, the research team led by SP et al. has undertaken extensive investigations into the complexities of lane-less traffic systems unique to India, and alongside their efforts in real-time predictions of bus arrival times, they are also in the process of establishing multiple inductive loop detection systems that will significantly enhance traffic monitoring capabilities [40].

C. Acoustic-Based

Fu et al., 2024, [41] engaged in the innovative application of a smartphone, which was meticulously integrated with accelerometers alongside rudimentary techniques for the detection of honking signals. They systematically implemented a rigorous calculation methodology for the Doppler frequency shift, which served as a predictive tool for estimating the velocity of vehicles. The singular condition that must be fulfilled is the imperative requirement for all vehicles to possess a smartphone as an essential component. Razali & Rahman, in their scholarly pursuits, employed a solitary omnidirectional microphone strategically positioned at various road crossings [42].

The acoustic signals presented by the surrounding environment are constituted of a diverse array of sounds, including engine noise, the audible expression of honking, the sounds generated by tire friction, and the turbulence created by the movement of air. In our research endeavors, the mel-frequency spectrum coefficients derived from the captured sound waves are utilized to effectively evaluate the levels of road congestion, which is accomplished by juxtaposing these coefficients against the statistical patterns indicative of previously recorded congestion behaviors. To mitigate the potential for misinterpretation of sound patterns, we strictly prohibit honking in designated noise-sensitive zones such as educational institutions and healthcare facilities. At present, a significant number of pedestrians navigate the roadways while wearing headsets, which inadvertently leads to a pronounced reduction in their attentiveness to the surrounding traffic dynamics and the swift approach of nearby vehicles. Hasan and Hasan, 2022 [43] introduced a sophisticated system designed to transmit auditory alerts through the headsets of pedestrians, with the primary aim of warning those individuals who are at risk of being struck by swiftly advancing automobiles.

A specialized module embedded within smartphones is capable of detecting the auditory patterns associated with vehicle noise, thereby enabling the prediction of vehicle movement trajectories. However, this particular method is fraught with numerous shortcomings, which include the glaring absence of established benchmarks for uniformity, an inadequate standardization of recording duration across instances, and a lack of clarity regarding the documentation of external noise captured by audio recorders on devices such as iPhones and other smartphones, which are often stowed away in pockets or bags.

D. RF/RFID-based

Yusuf et.al, 2024 associates have diligently engineered a cutting-edge framework that employs Radio Frequency Identification (RFID) tags, which are securely attached to the windscreens of all kinds of vehicles, consequently aiding in the swift identification and tracking of cars navigating the roads [44]. In this innovative framework, RFID readers are strategically positioned at various street segments or critical road junctions to effectively detect and monitor the movement of vehicles as they traverse the roadway, thereby enhancing traffic management capabilities. In a similar vein, Choudhury et.al, 2024 have proposed an RFID-based traffic monitoring system that ingeniously utilizes traffic cones, which are integrated to collect parallel inputs derived from visual imagery, thereby enriching the data acquisition process for traffic observation [45]. Further, Merdan and Waqas, in their individual academic pursuits, harness the fundamental variability present in the qualities of the received signal, which is distinguished in both Line of Sight (LOS) and Non-Line of Sight (NLOS) locations, thereby refining the accuracy of traffic monitoring systems [46], [47].

In their experimental setup, they have meticulously installed a sophisticated wireless transmitter-receiver pair that operates within the sub-GHz frequency range, specifically positioned across the roadway to facilitate seamless communication. The transmitting unit continuously emits signals that are specifically intended for reception by the corresponding receiver module situated at the opposite end of the communication link. As soon as these signals are acquired, the receiver module meticulously evaluates different link metrics, including the Received Signal Strength Indicator (RSSI), which is fundamental in categorizing the signal environment as line of sight (LOS) or non-line of sight (NLOS), thereby providing indispensable perspectives on the communication conditions (RSSI).

Furthermore, Marazi along with his associates has performed investigations that reveal the considerable occurrence of slow-moving vehicles on the streets, which ultimately causes an escalation in traffic congestion, thus stressing the importance of effective traffic management approaches [48].

Additionally, Almatar et.al, 2023 have presented a comprehensive system specifically designed for the monitoring and measurement of road traffic congestion, showcasing the importance of accurate data collection in traffic analysis [49]. By utilizing RFID sensors situated at key junctions, this system is capable of detecting active RFID tags that are affixed to the probe vehicles, thereby allowing for precise tracking of traffic flow. To enhance the efficacy of this system, we have interconnected RFID readers with a modem and a ZigBee RF module, thereby facilitating robust data transmission. Through this integration, we are able to gather RFID data from a multitude of vehicles, which enables us to quantify the levels of traffic congestion by employing cluster centroids derived from the Generalized Equilibrium Fuzzy C Means clustering methodology, thus providing a sophisticated approach to traffic analysis [50].

E. GPS-based

The emergence and widespread adoption of the Global Positioning System technology have significantly streamlined and enhanced the efficiency of surveillance operations in various contexts. Gopalan and colleagues (2023) [51] present a thorough structure that outlines the detailed approach required for the efficient sharing of essential information across the intricate systems that enable communication among vehicles, as further detailed in the later study by Graser and team (2024) [52], which carefully examined the interaction processes taking place between the Roadside Unit (RSU) and the On-Board Unit (OBU) using a laptop, specifically assigned for this task as the OBU, on mobile vehicles equipped with an external GPS receiver to support real-time data sharing. Our investigation allows us to distinctly divide traffic statistics into two fundamental groups: Eulerian, which refers to the traffic flow information that is thoroughly amassed from designated, fixed spots along the road, and Lagrangian, which pertains to the data that comes from the routes of traveling vehicles throughout time.

Yatiraj implemented the use of notebooks equipped with Global Positioning System (GPS) technology to meticulously collect and analyze critical data pertaining to the latitude, longitude, and velocity of automobiles traversing the urban landscape of Bangkok [53]; this comprehensive data acquisition ultimately facilitated the derivation of vehicular flow metrics from the velocity information gathered. CarTel represents an advanced mobile sensor-based networking solution that is specifically designed to systematically collect, process, and modify a wide array of road traffic data, thereby enhancing the overall understanding of traffic dynamics. This innovative system establishes an opportunity network that utilizes various communication technologies, such as Wi-Fi, Bluetooth, or GSM, depending on their availability in the immediate environment. Marques et al. have undertaken a thorough exploration of how mobile sensor data integrates with loop detector data, yielding important revelations for modern traffic management strategies [54].

Achar et al. (2022) [55] have adeptly employed the sophisticated Kalman filtering technique to forecast the complex and heterogeneous patterns of road traffic in India, with a particular focus on the bustling metropolitan area of Chennai. Ferniest and Hamzic have meticulously extracted GPS traces from a specific 21-line public bus route and have subsequently employed the Haversine distance formula, derived from the provided longitudinal and latitudinal coordinates, in conjunction with running time calculations utilizing the Kalman filter methodology [56].

In their 2024 study, Cai et al. presented a novel technique for evaluating vehicle density, employing flow metrics extracted from video clips in conjunction with time readings from GPS devices placed inside vehicles. Li et.al, 2024 have designed strong frameworks that support the storage and application of vast historical data archives, vital for obtaining significant insights into traffic flow patterns. [57] .

In 2024, Nie et.al effectively leveraged GPS technology to systematically gather and scrutinize important parameters such as latitude, longitude, timestamps, and the distances separating sequential data samples, which consequently aids in the reliable calculation of trip velocities. In their research, they have systematically classified the levels of congestion into various service categories, which range from A to H, thereby providing a nuanced understanding of traffic conditions. Furthermore, we have designed a sophisticated technique intended to forecast pollution levels that are attributable to vehicle population density by methodically assessing the concentration of various oxides present in the atmosphere.

China has meticulously established a sophisticated and intricate system designed specifically for the comprehensive estimation and prediction of traffic congestion, which astutely employs a substantial fleet of approximately 12,000 taxicabs throughout a designated period of one month, as evidenced by the scholarly work of Chen and Li in 2024 [58].

The different features that have been meticulously reviewed and scrutinized in this system cover significant components like the complete length of streets, the amount of lanes existing, in addition to the general traffic density faced on these pathways. In our investigation, we have adeptly utilized fuzzy logic methodologies to effectively identify and delineate instances of traffic congestion. Additionally, we have employed the Particle Swarm Optimization (PSO) approach to adeptly estimate forthcoming traffic flow, consequently refining the forecasting proficiency of our model.

In a 2023 publication, Elijah and team introduced ABEONA, an inventive beacon-based algorithm for traffic congestion, referencing the Roman goddess of journeys. This advanced algorithm operates on the principle that all vehicles that are equipped with Global Positioning System (GPS) technology emit beacons that encompass critical information such as a unique vehicle identification number, positional road data, and relevant historical traffic data [59].

In a separate contribution, Van Sandt et al. proposed a novel traffic density measurement technique that thoughtfully considers both the length of the roadway and the presence of intersections within the transportation network, as detailed in their 2024 study [60].

The length of each roadway segment, coupled with the established transmission range, dictates the number of discrete cells that can be designated for each section of the road. Each of these cells possesses the capability to dynamically modify its dimensions in accordance with its coverage range, and it designates a leader to systematically collect and compile data from vehicles operating within its range of influence. The aforementioned model has been executed using sophisticated simulation software, specifically GloMoSim and VanetMobiSim.

In their recent publication, Sundar et.al have carefully outlined the structure for an innovative system [61], where every single vehicle is equipped with a Radio-Frequency Identification (RFID) tag that contains a distinctive identifier for monitoring purposes. The Roadside Unit (RSU) employs an RFID reader to effectively monitor the movement of passing vehicles by scanning the RFID tags, thereby facilitating the enumeration of vehicles and assisting in the identification of stolen automobiles by continuously tracking them via their unique identification numbers. In a notable study conducted by Shaygan et al., GPS technology was harnessed through the involvement of 3,600 drivers and the collection of 10,000 GPS traces, utilizing the statistical software R to meticulously analyze traffic patterns and subsequently generate XML file formats suitable for display on websites, as discussed in their 2022 publication [62].

They observed that a surprisingly small percentage, ranging from only 2 to 3 percent, of smartphones are sufficiently equipped to accurately measure traffic flow and predict traffic patterns with a reasonable degree of reliability. Liu and Yuan (2024) compiled and analyzed traffic patterns derived from public transportation vehicles, categorizing them by day of the week, and notably revealed that Sunday presents a distinct and unique traffic pattern when compared to the other days [63].

In a connected exploration, Mendoza et.al, 2024 retrieved GPS footprints from taxis in Beijing and evaluated that the traffic dynamics observed remain stable for every day of the week, apart from Sunday, which contrasts with this pattern. In 2024, Shen and team stressed the essential nature of vehicle interactions, culminating in the development of two innovative protocols aimed at refining traffic measurement: the Sampled Measurement Estimation (SAME) and the Timer-Based Ordered Measurement (TOME) [64].

Additionally, Md et al. (2023) undertook the development of a comprehensive database designed to archive GPS trajectories, which includes detailed information encompassing latitude, longitude, date, start time, finish time, vehicle identification number, and speed metrics.

Lastly, Silva (2023) proposed an advanced system that effectively identifies instances of traffic congestion and accidents through the utilization of GPS traces, in conjunction with digital mapping data sourced from OpenStreetMap (OSM) [65].

The intricate system intricately correlates the various traces obtained from numerous sources with the comprehensive digital map, subsequently designating appropriate labels, and accurately identifies significant events through an elaborate spatiotemporal analysis that examines the interplay of both space and time. In a recent study, researchers have meticulously presented and simulated a sophisticated technique that effectively identifies traffic congestion specifically caused by the presence of automobiles, utilizing advanced big data technologies within the structured environments of SUMO and OMIT++, thus contributing to the existing body of knowledge in this field [66], [67].

In addition, Beenish et al. have recently introduced a hybrid observer model that aims to estimate the critical traffic density parameter by employing a generalized likelihood ratio approach, thereby enhancing the precision of traffic assessments [68]. Furthermore, Hossain (2023) proposed a comprehensive spatiotemporal model known as ConLSTM, which stands for Conventional Long Short-Term Memory, specifically designed for the short-term prediction of congestion levels across various segments of the road network.

In a notable advancement [69]. Dabbas and Friedrich (2024) developed an innovative analytical tool aimed at congestion assessment by methodically partitioning road segments into discrete cells, utilizing the sophisticated technique of unscented Kalman filtering to enhance the accuracy of their evaluations [70].

F. Social Networking-Based

Individuals who possess accounts on the social media platform Twitter and actively engage in the practice of documenting and disseminating information regarding traffic conditions via tweets can effectively serve as a valuable form of sensor data. The application of text mining techniques to analyze and interpret traffic flow conditions reveals a significant enhancement in the speed and efficiency of information processing when utilizing real-time data derived from these social media interactions.

The analysis of temporal data collected in Italy reveals noteworthy insights, as highlighted by the research conducted by Haucke et al. (2024) [71], which employs sensor data obtained from municipal authorities in conjunction with the comprehensive event details provided by authentic social media platforms. In a similar vein, Aburas (2023) capitalizes on the rich dataset of tweets generated through Twitter, seamlessly integrating this information with GPS trajectory data to facilitate the delivery of highly precise and timely crowdsourced information aimed at the identification of traffic irregularities [72].

Furthermore, tweets originating from various Twitter accounts are strategically employed to extract and deduce geographic locations, a process that is thoroughly demonstrated by the findings presented by McKitrick et al. (2023) [73].

Tweet counts obtained from the Twitter platform have been meticulously analyzed in order to extract the Written observations pertaining to a multitude of safety-related incidents or catastrophic occurrences that have been recorded over time. In our research endeavor, we undertook a comprehensive analysis of the written observations concerning various safety-related incidents and catastrophic occurrences that have been documented by multiple individuals across diverse social media platforms.

The data aggregation tool that we employed serves the essential purpose of extracting and synthesizing traffic information in a manner that is both efficient and effective. Specifically, this aggregation tool is harnessed to extract relevant traffic data that reflects the dynamics of user interactions and information flow.

Zhang et.al, 2024 demonstrate clear empirical support that we can retrieve current traffic updates based on the user comments submitted into the platform [74]. Various social networking platforms, with Twitter being a prime example, serve as vital communication channels where a diverse array of users actively engage and share information. A multitude of users leverage these social media platforms to connect with one another, fostering relationships that encompass friendships, community ties, professional networks, shared interests, and collective experiences that reflect their passions and fascinations.

The overarching objective of the system is to create a robust network of shared annotations; this framework is designed to integrate annotations that pertain to a wide spectrum of interests, including but not limited to safety, accidents, congestion, and other relevant topics, thereby enriching the collective knowledge base. Such a comprehensive framework not only integrates these annotations effectively but also retrieves authentic data that is invaluable for further analysis and understanding of these critical issues.

G. others

The advanced and transformative system, branded VGrid by Jerry et al., stands for Vehicular-based Networking and Computing Grid, representing a sophisticated architecture that integrates an array of stationary sensors with vehicle-mounted sensors, all scrupulously managed and aligned by a central coordination entity, as explored in the detailed research authored by Anda and others in 2005 [75].

The utilization of wireless sensor networks, which are characterized by their remarkably low cost, distributed computational capabilities, and compact physical dimensions, allows for the efficient and effective collection of myriad traffic parameters from various roadways, thereby significantly enhancing the understanding of traffic dynamics, as proposed by Agrahari et al. in their 2024 publication [76].

Hassan, 2024 introduced a highly sophisticated system specifically crafted to reliably measure road traffic intensity, which in turn enhances the real-time regulation of traffic signals, illustrating a significant evolution in traffic management technology; importantly, this system is capable of functioning without necessitating an onboard device for each vehicle. The sensors employed in this system, which may be of either the ultrasonic or infrared variety, are strategically positioned at critical junctions and are responsible for periodically reporting comprehensive traffic conditions to the central controlling units utilizing the Zigbee communication protocol.

In their 2022 study, Xu et.al introduced an innovative sensing method that effectively integrates an offline node selection strategy aimed at minimizing energy usage while also maintaining outstanding coverage quality across the sensing network [77].

Matsui and Yoshihiro (2024) introduced an innovative strategy aimed at mitigating traffic congestion, which effectively capitalizes on the sensing area within the framework of Vehicle Ad Hoc Networks (VANET), employing a dynamic size that adapts to real-time traffic conditions [78].

Hao and Hsieh (2024) recommended the integration of hierarchical fuzzy rule-based systems with genetic algorithms (GA) to facilitate the selection of pertinent variables and their subsequent ranking, which serves to enhance the predictability of traffic congestion incidents occurring on roadways [79].

Kumar and Hemrajani (2024) conducted an analysis utilizing the Beibei tunnel dataset, which involved a comprehensive normalization of the data and the implementation of a support vector machine for predicting traffic jams, with its parameters being optimized through the application of the whale optimization algorithm [80].

Embury et al. (2024) amalgamated data derived from a multitude of sources concerning road traffic, including the extraction of vehicle density metrics from cellular network data, although we contend that the GPS data utilized is inherently biased, as it relies solely on information obtained from public transit systems [81]. The team led by Jasim detailed the developing tech paradigm termed the 5G millimeter wave system, which constitutes a substantial improvement in wireless communication technology

Table (1): Advantages and Challenges of different sensing techniques

Methodology	Advantages	Issues	Scope
Vision based	Can monitor the cause of incidents, lively.	1. Need continuous recording of road scenarios, which need more network bandwidth and processing capabilities. 2. Background detection is difficult as color of road is mostly matching with the roof top of public buses. 3. Bicycles and three wheelers (auto-rickshaws) can get shadowed by heavy vehicles.	Can enhance Image processing algorithms. Can be stored as Big Data
Loop Detector based	Can count the vehicles.	1. Need to place multiple detectors at regular intervals of the road segment. 2. Maintenance or modifications of the sensors need the road to be dug and damage the surface. 3. Detectors are theft prone.	Can be used at specific junctions with built-in road structures
Acoustic based	No modification in vehicle	1. Cannot guarantee that all vehicles may use honks for notification/alerts as vehicles are able to send signals to one another.	Can develop high quality signal processing algorithms

		2. Most of the road lanes are restricted to use honks, especially near hospitals and schools.	
RF/RFID based	Feasible for Vehicle Identification and maintenance of history of records – toll collection, tax payments	RFID tags can be easily stolen, damaged or can be fitted on other vehicles	Should have security Mechanism
GPS based	Widely and Cheaply available Feasible to track vehicles in transit	Can have errors in heterogeneous roads	Need to minimize error.
Social Networking based	Can get real time information. Widely available	Feasible to spread fake alarms	Should have secure mechanism to validate trust of data

3. Accessible Devices

Models play an instrumental role in aiding scholars and researchers in their endeavors to analytically depict and represent the intricate dynamics of traffic patterns, while simultaneously facilitating the generation of vehicular traffic scenarios for the purposes of simulation studies. In our extensive investigation, we have scrutinized a wide array of models that effectively illustrate the complex behaviors associated with vehicular patterns, including, but not limited to, the Car Following model, the Cellular Automata model, and the

Gas Kinetic model, amongst several other noteworthy methodologies. Furthermore, researchers have rigorously analyzed a variety of simulation platforms with respect to their topological characteristics, thereby elucidating the significant influence exerted by the configuration of the map layout and the varying levels of traffic density on the efficacy of message dissemination within the context of Vehicular Ad hoc Networks (VANET) as articulated by Anfray and Nicolas in their 2024 publication [82].

(Marcelino, 2023) emphasizes the critical importance of employing visualization technologies that play a significant role in aiding both users and scholars in their efforts to achieve a deeper understanding of complex traffic scenarios. The simulation of vehicular communication requires a fundamental reliance on three distinct categories of simulation tools, which include traffic simulators, network simulators, and interface tools, each serving a unique function within the overarching framework. Below, several notable simulators are meticulously enumerated for reference [83].

Recognizing the fact that a vehicle-oriented ad hoc network varies significantly from a traditional ad hoc network is crucial, especially since it fundamentally relies on comprehensive road maps that shape vehicle flow. Traffic simulators are specifically designed to generate vehicle traffic patterns that are derived from road topologies, which can either be specified by the user or extracted from comprehensive mapping resources [84]. In our analysis, we have chosen to utilize OpenStreetMap as a supplementary technological resource that enables us to extract and derive intricate road networks from existing and widely accessible maps. [85] Among the most notable traffic simulators that have gained recognition in the field are the Simulation of Urban Mobility (SUMO) and SiMTraM, which is an advanced and modified version of SUMO tailored to accommodate a variety of diverse, lane-less driving scenarios.

Traffic simulators are adept at delineating and modeling the intricate movement patterns of automobiles, while network simulators are tasked with the replication of the communication models that exist among these vehicles. Once the vehicular traffic patterns have been established and thoroughly analyzed, it becomes imperative to develop a corresponding communication model that facilitates effective data transfer among the various nodes, which include vehicles, intermediary Road Side Units (RSUs), and central coordinating servers, ensuring seamless connectivity and data exchange. Instances of such models and their applications can be observed in the works of (Kaleibar & St-Hilaire, 2024; Nguyen, 2023) [86], [87].

Interfacing Tools: These sophisticated and highly specialized tools serve the critical function of establishing connections between traffic simulators and network simulators, thereby facilitating the transformation of intricate road traffic data into pertinent inputs for various network models that are essential for accurate analysis and simulation. For instance, TraNS [88] exemplifies this integration by effectively combining the traffic simulation capabilities of SUMO with the network simulation functionalities of ns2, while another notable tool, Veins, adeptly merges the SUMO traffic simulator with the OMNet++ network simulation framework. Moreover, hybrid simulators represent a category that encompasses not only integrated traffic simulators and network simulators but also proprietary interfacing tools that have been specifically developed for enhanced simulation accuracy and performance [89]. In addition, the efforts of Mangharam et al. (2006) reveal a blended simulator that embodies a layered technique for simulation by merging multiple factors to elevate the total modeling potential [90].

4. Indicators of Traffic Congestion

A Matlab Simulink system is built to embrace the theoretical work. Traffic congestion metrics can be systematically categorized into four fundamental classifications, which include: (i) basic measures that provide foundational insights into traffic flow, (ii) ratio measures that offer comparative assessments of traffic conditions, (iii) level of service metrics that indicate the quality and efficiency of roadway use, and (iv) indices that aggregate various performance indicators into a single evaluative framework [91]. In the later sections, we will execute a meticulous and profound study of every different category of these measurements, investigating their specific qualities and ramifications with great detail. To reach this target, we have thoroughly formulated a series of congestion metrics and have engaged in an exhaustive review of their specific strengths and weaknesses, consequently providing a more intricate comprehension of their relevance and efficiency in dealing with traffic congestion matters.

4.1. Fundamental Indicators

Fundamental metrics are intrinsically linked to the comprehensive assessment of delays experienced by road users during their travels. Delay can be comprehensively defined as the additional temporal interval that a road user encounters when compared to either the unobstructed flow of traffic, often referred to as free-flow travel, or the designated duration that is permitted for the journey to be completed. In the realm of transportation research, scholars have systematically employed a diverse array of threshold values that serve as indicators for the initiation of delay within the process of estimating such delays accurately. In a pivotal study conducted by Botshekan in 2024, a congestion threshold was notably established at a volume to capacity (V/C) ratio of 0.77, which is directly correlated to a travel speed of 55 miles per hour, thus providing a quantitative measure for assessing road congestion [92]. Vosough and Roncoli, in their 2024 research, specifically utilized a set of defined values applicable to a variety of roadway categories, which were meticulously derived from a consensus achieved through discussions among both technical experts and non-technical stakeholders, in order to delineate acceptable travel times along with the critical threshold that signals the commencement of congestion, as illustrated in Table 2 of their publication [93]. In another significant contribution to the field, Taylora in 2023 regarded the established speed limit as the nominal free-flow speed, thereby providing a baseline for evaluating traffic conditions. Furthermore, Camacho, in 2024, employed a free-flow speed benchmark of 60 miles per hour for freeway segments and 35 miles per hour for arterial roadways, facilitating a comparative analysis with the speeds observed during congested traffic conditions [94]. Lastly, Lan and Zhao adopted the 85th percentile speed recorded during off-peak hours as the pertinent free-flow speed, thereby augmenting the understanding of traffic dynamics in non-peak travel periods [95].

Table (2): Peak period acceptable travel rate values(Vosough & Roncoli, 2024) [93]

Area type	Acceptable travel rates (minutes per mile)					
	Freeway main lane	**Freeway HOV lane**	**Major street**	**Bus on street**	**Rail in street**	**Bike**
Central Business district	1.7	1.0	5.0	7.0	6.0	6.0
Major activity centre	1.5	1.0	3.0	5.0	4.5	5.5
Suburban	1.33	1.0	2.4	4.0	5.0	5.0
Fringe	1.2	0.9	2.0	3.4	3.0	4.0

4. 2 Ratios

Engaging in the process of formulating various ratios that serve the purpose of evaluating the extent of traffic congestion by systematically dividing one specific component of travel time or delay by another distinct component of the same nature. A multitude of ratio measures have been meticulously established, which include, but are not limited to, delay rate, relative delay rate, and delay ratio, all of which are fundamentally grounded in the concept of travel rate [93]. For the purpose of this analysis, we have articulated the concept of travel rate (measured in minutes per mile) as being representative of the velocity at which a particular road segment is traversed by vehicles. The conversion factor is utilized to multiply the inverse of speed in order to ascertain the acceptable travel rate that can be maintained. Furthermore, the threshold delineated in Table 2 articulates the maximum travel rate, or alternatively, the minimum travel speed, at which an individual can successfully navigate a segment or complete an entire journey without experiencing an undesirable level of mobility disruption.

4. 3 Level of service Indicators

Historically, throughout various periods of urban development and transportation evolution, the assessment of traffic congestion has prominently hinged upon the utilization of the Level of Service (LOS) as a critical metric for evaluation. The conceptual framework surrounding the Level of Service (LOS), which was meticulously established in the 1985 edition of the Highway Capacity Manual, (Akinsulire & Fadare, 2020), represents a comprehensive spectrum of operational conditions that can be encountered on roadways [96]. Determining the Level of Service (LOS) for any transportation facility is intrinsically shaped by a variety of important factors associated with traffic flow, which feature, but are not restricted to, the vehicle density on the road, the volume-to-capacity ratio, the typical speed of vehicles, and the delays at intersections, all of which fluctuate based on the specific facility type being studied. The metric of Level of Service (LOS) is systematically divided into six distinct categories, which are systematically labeled from A to F, as illustrated in Table 3 of the referenced document.

A primary benefit tied to the Level of Service (LOS) metric is its simple accessibility, enabling most individuals without technical training in transportation engineering to readily comprehend and interpret it. However, despite its widespread utility, the Level of Service (LOS) metric is not without its limitations, as it exhibits several notable deficiencies, including the inability to provide a continuous and nuanced spectrum of congestion values. In a critical analysis, (Heyer, 2021) explicitly rejected the application of level-of-service analysis as a reliable measure of congestion, arguing that it captures only the specific phenomena related to location-based bottlenecks and fails to adequately represent the broader or more regional patterns of congestion that may be present in the transportation network [97]. Further, (Menezes-Júnior et al., 2024) maintained that applying a stepwise Level of Service (LOS) criterion could potentially mislead interpretations, particularly in instances where traffic situations approach critical thresholds that may cause immediate changes in service levels [98].

Table(3): Levels of service with operating conditions(Akinsulire & Fadare, 2020) [96]

Level of Service	Operating Conditions	V/C ratio for arterials
Level-of-service A	Represents a free flow. Individual users are virtually unaffected by others in the traffic stream. Freedom to select desired speeds and to maneuver within the traffic stream is extremely high.	0.00 to 0.60
Level-of-service B	Represents the range of stable flow but the presence of other users in the traffic stream begins to be noticeable. Freedom to select desired speeds is relatively unaffected but there is a slight decline in the freedom to maneuver within the traffic stream from LOS A.	0.61 to 0.70
Level-of-service C	Represents the range of stable flow but the selection of speed is affected by the presence of others. Maneuvering within the traffic stream requires substantial vigilance on the part of the user.	0.71 to 0.80
Level-of-service D	Represents high-density but stable flow. Speed and freedom to maneuver are severely restricted.	0.81 to 0.90
Level-of-service E	Represents operating conditions at or near capacity level. All speeds are reduced to a low but relatively uniform value. Freedom to maneuver within the traffic stream is extremely difficult.	0.91 to 1.00
Level-of-service F	Represents forced or breakdown flow.	Greater than 1.00

5. Scope and Difficulties

A multitude of sensing systems characterized by their unique operational frameworks, it is essential to recognize that each of these systems inherently embodies a set of particular advantages and disadvantages, which are complemented by specific assumptions and contextual conditions that govern their effective implementation in practical scenarios [57]. Considering this, Table 1 illustrates a detailed breakdown of the complex benefits and intrinsic challenges connected to each separate sensing method, thereby enriching our insight into their specific capabilities and restrictions.

Figure (2): Lane-less driving during peak hour at Chennai.

A diverse and comprehensive spectrum of academic fields of study aimed at significantly enhancing the efficiency and functionality of smart transportation systems. In particular, within the context of urban environments in Indian cities, there exists the potential to strategically develop specific geographical regions into fully operational smart cities by effectively leveraging the existing infrastructure that is already in place.

This strategic development includes the innovative employment of parked vehicles for the purpose of cluster head formation or their utilization as dynamic Roadside Units (RSUs); additionally, it encompasses the harnessing of vehicle-generated power or renewable solar energy, along with the meticulous design of systems that are compatible with a wide range of vehicle types, which include but are not limited to two-wheelers, bicycles, three-wheelers, light vehicles, and heavy vehicles. Figure 2 serves to illustrate that the roadways of Chennai present a quintessential scenario in which a diverse array of automobiles operate under increasingly undisciplined and lane-less driving behaviors that characterize the urban driving experience. The driving patterns observed in India uniquely permit two-wheelers to navigate laterally between lanes, thereby effectively capitalizing on the available space that exists between lighter and heavier vehicles on the road. This maneuverability allows two-wheelers to achieve a significantly higher rate of speed in comparison to their heavier counterparts, consequently resulting in observable fluctuations in congestion levels among the various types of vehicles present on the roadways.

Worldwide, in the broad area of transport research, a number of scholars and experts have earnestly utilized cutting-edge machine learning strategies in an effort to predict and analyze the intricate issue of traffic congestion on roadways, leveraging a diverse set of visual data sources that have been well-documented in the academic literature (Cheung et al., 2005; Zhang et al., 2005) [99, 100], while also exploring GPS trajectory data that has undergone thorough investigation in several research undertakings (Gramaglia et al., 2014; Kong et al., 2016) [101, 102], along with various other inquiries that have further enriched this growing compendium of knowledge [103].

In the year 2010, the prestigious IEEE International Conference on Data Mining, in a notable partnership with the renowned navigation technology company TomTom, organized and sponsored a highly competitive contest focused on the prediction of traffic patterns and dynamics. This particular contest was meticulously designed with the objective of fostering the development of innovative, machine learning-driven solutions tailored specifically for the transportation sector, [104, 105, 106]. Traffic Simulation Framework, which is designed to effectively anticipate, manage, and optimize vehicular traffic flow within complex urban environments [107].

6. Conclusion

Delving into the historical aspects of transportation, the broad usage of animal-driven vehicles, including bull carts and horse-pulled wagons, along with the functioning of public buses and the rising dominance of cars, has noticeably influenced the issue of traffic jams, thus complicating the overall efficiency of transportation frameworks. The escalating incidence of privately owned vehicles, coupled with the pronounced tendency of individuals to arrive at their destinations well in advance during the peak hours of commuting, serves as a substantial factor that exacerbates the existing congestion on roadways. Entering an epoch identified by innovative technologies and fresh ideas, it is essential to underline the importance of fostering the Internet of Vehicles (IoV), which promotes the uninterrupted connectivity among vehicles, allowing them to relay messages to one another at all times and in every conceivable environment. The process of interlinking vehicles, thereby enabling them to autonomously predict potential obstacles on their routes and subsequently recalibrating their trajectories in real-time, ultimately leads to the realization of a highly sophisticated smart transportation system. This research endeavor presents a comprehensive examination of various algorithms designed for the detection of traffic congestion and concurrently highlights numerous avenues for further scholarly inquiry, particularly with the objective of promoting the advancement of smart transportation methodologies within the context of developing nations.

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