A Survey on Traffic Modeling and Mitigation Techniques

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Abstract—The growing road traffic congestion in India is becoming more prevalent nowadays, the worst hit being the metropolitan and developed cities. Its ever-increasing nature poses a threat to development and requires quick action to help ease the troubles faced by people on a day-to-day basis. Modern technology offers a great aid to these efforts by providing mechanisms to model the travel patterns of a region and provide quick congestion relief by introducing adaptive traffic signals that operate based on the current traffic density of the road. In this paper, we present a survey of the most popular techniques involving travel demand modeling and adaptive signal control and compare the various methods employed by researchers to tackle both of these issues separately. The survey focuses on analyzing these methods from the perspective of implementation in an Indian scenario and offering a theoretical solution that involves the use of both these techniques to ease the problem of traffic congestion.

Index Terms—road traffic congestion mitigation, adaptive traffic signal, travel demand modeling,

I. INTRODUCTION

The main characteristics of heavy traffic on the roads include slower speeds, longer travel times, and an increase in vehicle queuing. Several Indian towns are plagued by this serious issue. Mumbai, Delhi, and Bangalore have routinely ranked among the top 10 most crowded cities in the world according to several traffic indices during the past few years. From [1], Mumbai has remained in the top five and was ranked first in 2018. This is turning into a major problem that has to be resolved immediately. Travel expenses and accessibility are both affected by traffic congestion. Long-term exposure has serious negative consequences, including an increase in noise pollution, stress among drivers, lowered mental satisfaction, and increased passenger delays.

One of the current solutions deployed in India is manual surveillance where traffic policemen are stationed at highly congested junctions. They coordinate with other policemen to manually control the traffic flow. This indeed gives results but it requires a lot of manpower and is infeasible to do for entire cities at once. It is also prone to error due to human judgment which may not always be accurate and provide a holistic picture of the traffic situation of large regions. The most obvious solution is creating more road space, but even with more roads, infrastructure has been unable to keep pace with the growing number of vehicles. With the advent of technology and more sophisticated gadgets being deployed for

traffic solutions, there are possibilities for automating traffic control.

One such solution is dynamic control of traffic lights using adaptive signal timings based on traffic density. Real-time data gathered from sensors [2] or CCTV cameras [3] is used to calculate vehicle counts to estimate the optimal signal times for the amount of traffic at the current moment. This aids in quick traffic decongestion by altering signal times such that the vehicles in the lanes with maximum density are allowed to pass for longer times than those with relatively lesser vehicles. This leads to a better traffic flow and efficient utilization of time and space, thus allowing more vehicles to pass through a junction on average.

In this paper, we present a survey of the common techniques used for understanding the travel demand of a region along with the algorithms and techniques employed for easing traffic congestion by using adaptive signal controls. Both these techniques are explored since it is necessary to not only provide quick solutions to road traffic congestion but also gain an estimate of the demand of a region and the forecasted growth for efficient infrastructure planning and development. In a developing nation like India, this consideration is of heightened importance as infrastructure must keep pace with rapid growth and urbanization.

The rest of the paper is organized as follows: Section II talks about the categorization of the types of papers surveyed. Section III explores in detail the various travel demand models that are used and provides a comprehensive review of the papers that either explain or implement these concepts. Section IV discusses the various techniques researchers employ to create systems for traffic decongestion using adaptive signal times, including enhanced infrastructure or advanced algorithms. Section V presents concluding remarks based on the papers surveyed.

II. CATEGORIES UNDER CONSIDERATION

To effectively understand the travel demand of a city to gain insight into the way the population moves, it is necessary to create models that not only explain the current demand but also provide an estimate of the growth likely in the future. Based on available traffic data, it is necessary to develop techniques and algorithms that can aid in the quick detection and mitigation of traffic congestion. The survey is divided into two categories

and the various techniques involved in each are explained in detail in figure 1.
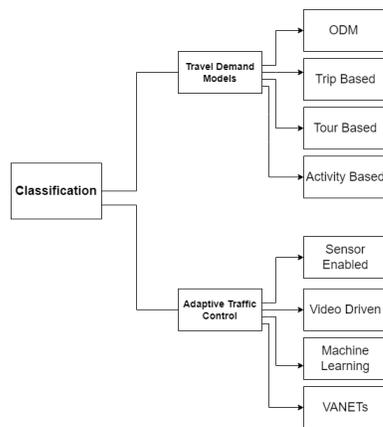

Fig. 1. Classification of survey topics

Travel demand modeling is the process of creating a computer model that can be used to estimate travel behavior and travel demand for a specific region in a certain future time frame, based on several assumptions. It is necessary to understand the growth of a city or region in terms of the population and the resulting traffic situations to be able to effectively curb congestion issues.

By dynamically altering the green split timings, the adaptive traffic control system adjusts to real-time traffic patterns to maximize traffic flow. Based on the amount of traffic at the junctions and projected arrivals from nearby intersections, the ATCS algorithm continuously modifies traffic signal timings. By gradually advancing cars through green signals, the algorithm significantly reduces travel time and increases flow efficiency, which eases traffic congestion.

III. TRAVEL DEMAND MODELING

The most common techniques employed for Travel Demand Modeling are elaborated in the next subsections. A comparative analysis of the surveyed papers is presented in table 1.

A. Origin Destination Matrix Estimation

A description of mobility in a certain area is called an ODM or Origin Destination Matrix, which is used to gauge the demand for transportation. Each cell in an OD matrix represents the intersection of a trip from an origin to a destination, and the more trips there are along a certain route, the more popular that route is.

To analyze and simulate transportation networks, Kuusela, Pirkko, et al. suggest a new approach for calculating origin-destination (OD) matrices. The approach is based on a conditionally binomial model that treats the number of observed travels between origins and destinations as having a probability parameter and a binomial distribution. As a function of different explanatory factors, including distance, transit duration, and population, the probability parameter is modeled. A case study based on data from the Helsinki metropolitan region

is used to compare the proposed technique to other widely used methods. The findings demonstrate that the suggested method outperforms the other methods in terms of accuracy and computing efficiency [4].

The Growth Factor Model and the Gravity Model are two methods to distribute trips among destinations. The two methods for developing the O-D Matrix are presented and criticized by Dragu, Vasile, and Eugenia Alina Roman. Growth factor methods assume that in the future the trip-making pattern will remain the same as today but that volume of trips will increase according to the growth of the generating and attracting zones. In this method, the current travel allocation matrix is assumed to be known. The gravity models, also called synthetic models, are used to form a trip distribution according to the socio-economic parameters of the analyzed zones [5]. A case study is done, and the advantages, disadvantages, and similarities of both methods are listed.

As an example, the OD matrix for a city named Bogor in Indonesia is estimated using the Gravity model by Ekowicaksono, I., F. Bukhari, and A. Aman. The following assumptions were used to estimate the O-D matrix: (i) forces between two different zones are related to some existing parameters such as population, social-economic condition, etc. (ii) the people's movements are influenced by accessibility from origin to destination, and the accessibility affected by distance, time, cost [6]. It uses a concept of the deterrence function, namely, it assumes that the interaction between two sites declines with increasing distances, cost, and time of travel but is positively correlated with the amount of activity at each site. The Hyman method is used to calibrate the deterrence function as it was found to be more robust and effective than other methods.

B. Trip Based Travel Demand Modeling

The fundamental unit of analysis in trip-based models sometimes referred to as four-step models, is the trip interchange between two geographic sites, or an origin-destination pair. Trip-based models' main task is to estimate all trips in a region, categorize them by location and mode, and forecast how they will use transportation networks.

Reference [7] explains the four-step process for trip-based traffic modeling with reference to the Sitapura industrial region in Jaipur, India. They make use of the LOGIT model and present results for vehicular traffic including buses, cars, and two-wheelers.

Average trip generation rates are traditionally applied to static household-type definitions. However, trip generation is more heterogeneous with some households making no trips and other households making more than two dozen trips. Two improvements for trip generation are presented by Moeckel, Rolf, Leta Huntsinger, and Rick Donnelly. First, the household type definition, which traditionally is based on experience or habits rather than science, is revised to optimally reflect trip generation differences between household types. Secondly, a microscopic trip generation module has been developed that specifies trip generation individually for every household. Micro-simulating trips offer several benefits. The actual trip

TABLE 1
TRAVEL DEMAND MODELING

Paper	Category	Purpose	Techniques	Model	Region of Focus	Dataset
[4]	ODM	To investigate a conditionally binomial model's capacity to make use of correlations caused by shared traffic	Optimization via statistical analysis FAST-MCD	Doubly Stochastic Conditionally Binomial Model	Tampere, Finland	15 minute traffic count data of Tampere from 2011-2014
[6]	ODM	To estimate a worker's morning trip using ODM	Hyman Method	Gravity Model	Bogor, Indonesia	Bogor City data
[5]	ODM	To present and critique two ODM development approaches and present their similarities and differences	Fratar Method Furness method	Growth Factor Gravity Model	Romania	A region in Romania
[7]	Trip Based	To demonstrate the use of the 4-step model in the case of the industrial region of Sitapura	Dijkstra's Method	LOGIT	Sitapura, India	91 wards of Jaipur Municipal Corporation
[8]	Trip Based	To create a module that captures more household attributes than aggregate approaches	Big Data Research	Maryland Statewide Transportation Model	Maryland	2007-2008 TPB/BMC Household Travel Survey
[10]	Tour Based	To prove that tour-based modeling is a reasonable near-term alternative to the 4 step process	-	Boise model New Hampshire Portland	Regions in the US	-
[11]	Tour Based	To create a model that depicts the relationship between daily travel choices as a travel pattern and prove the advantages of new generation models	HOV policy	MTC model system Discreet choice model	Kofu, Japan	Survey in 2005 of 17,391 households with 42,118 members in Kofu
[13]	Activity Based	To create a large-scale agent-based traffic simulation system for the city of Amsterdam	Simulation in MATSim with mapping in OSM	Data driven travel demand model	Amsterdam	Map data for 2014 that includes number of cars
[14]	Activity Based	To create a random utility-based travel demand model that considers time decisions	MNL	SCAPER	Stockholm, Sweden	1240 locations (zones) in Stockholm

frequencies observed in travel demand surveys are preserved, and it adds flexibility if additional household attributes are added in the future [8]. A limitation of this approach is that travel behavior is still represented in trips and not in activities that result in tour generation. Activity-based models care for the actual purpose of making a trip.

C. Tour Based Travel Demand Modeling

Tour-based models arrange travel into units called tours. Tours are events that start in one location and return to that same place.

Hasnine, Md Sami, and Khandker Nurul Habib discussed the strengths and weaknesses of existing tour-based mode choice models. Previous studies on tour-based mode choice models are grouped into seven categories, ranging from simplified main tour mode to complex dynamic discrete choice models Challenges with data-hungry models, simulation-based models, and static models are discussed elaborately. The paper proposes a few methodological suggestions for researchers and practitioners for finding an appropriate mode choice modeling framework for activity-based models. It also provides guidelines on how to incorporate automated vehicles and Mobility-as-a-Service within the framework of tour-based mode choice models [9].

The development and use of tour-based travel demand models in the US are covered by Rossi, Thomas F., and Yoram Shiftan. The authors contend that by taking into account the interdependence of trips and the influence of tour-level factors like trip purpose, duration, and mode choice, tour-based models provide a more accurate representation of travel behavior. The paper provides an overview of the evolution of travel demand modeling in the U.S., from early trip-based models to the more recent tour-based models. The authors describe the key features and advantages of tour-based models, including their ability to capture tour patterns, travel time budgets, and complex interactions between tours and mode choices. The paper also discusses the challenges

and limitations of tour-based modelings, such as the need for detailed data and computational resources. The authors provide examples of tour-based models that have been developed and applied in various U.S. regions, including California, Oregon, and Virginia [10].

In contrast to the conventional method of modeling individual trips, the research suggests a new approach for forecasting travel demand based on individual tour patterns. According to Omer, Mohamed, et al., this method enables a more accurate description of the intricate relationships between travel objectives and modes of transportation. To create and calibrate their model, the authors use information from a personal trip survey conducted in Seoul, South Korea. They then apply the model to a variety of scenarios, such as the launch of a new transit service and the adoption of a congestion fee. The findings demonstrate that, compared to conventional trip-based models, the tour-based model offers a better understanding of the effects of policy changes on travel behavior [11].

D. Activity Based Travel Demand Modeling

Activity-based models are predicated on the idea that people's daily activity patterns can be used to predict travel demand. Activity-based models forecast which tasks will be carried out when, where, for how long, for whom, and with whom, as well as the travel arrangements that will be made to execute them. Researchers, practitioners, and policymakers can evaluate the impact of alternative policies on people's travel behavior at a high level of temporal and spatial resolution and choose the best policy alternative taking into account a potentially wide range of performance indicators thanks to the availability of such a detailed model.

Chu, Zhaoming, Lin Cheng, and Hui Chen have identified recent advances in activity-based travel demand modeling. Trip Based Travel Demand Models are discussed followed by Activity-Based Travel Demand Modeling. They have discussed various methods used in activity-based travel analysis, including discrete choice models, hazard duration models,

structural equation models, and computational process models. They have elucidated the various phenomena that can be modeled using activity-based travel models - In-Home and Out-of-Home Activity Substitution, Interpersonal Dependencies, Daily Activity-Travel Patterns, and Integration of Activity-Based Modeling and Dynamic Traffic Assignment. They have concluded that the following topics require further research - Time-Space Interaction in Activity Behavior and Analysis Unit [12].

Melnikov, V. R., et al have attempted to model real-life traffic scenarios in Amsterdam. They have made use of MATSim to simulate the city road network using an Agent-based model. A part of the city (22 km * 22km) was chosen as the target and modeled using OpenStreetMap. Models for the road network, travel demand, population synthesis, agent activity, and agent inflow and outflow were defined. A simulation was carried out using 41,000 agents yielded data that is fairly close to the observed traffic [13].

Saleem, Mohammad, et al have presented a new random utility-based travel demand model called SCAPER that can be used for large-scale simulations in integration with MATSim to generate travel patterns. The paper outlines the salient characteristics of the activity-based approach, such as the use of synthetic populations to represent various demographic groups, the modeling of activity schedules and durations, and the incorporation of mode choice models to record the various modes of transportation used for each activity. The complexity and diversity of travel patterns in contemporary urban contexts, according to the authors, cannot be fully captured by traditional models that rely on trip-based techniques [14].

Manoj et al. have examined the potential of activity-based travel demand models (ABMs) to evaluate the impact of sustainable transportation policies. The authors argue that ABMs provide a more accurate and detailed understanding of travel behavior than traditional travel demand models, which focus on trip-based analysis. This approach allowed for the assessment of policy interventions that affect the timing, location, and duration of activities, as well as the mode of transportation chosen [15]. The paper presented case studies from various regions of the world, including North America, Europe, and Asia, to illustrate the use of ABMs in evaluating sustainable transportation policies. The results of the case studies show that ABMs can help policymakers identify effective strategies for reducing greenhouse gas emissions, congestion, and air pollution while improving access to transportation options for all citizens.

IV. Adaptive Traffic Control

The classifications of the approaches to solving the problem of dynamic traffic signal time adjustments are explained in the following subsections. The classification is done based on the method applied for vehicle counting. A comparative analysis of the surveyed papers is presented in table 2.

A. Sensor Enabled

Multiple types of sensors can be used to estimate the number of vehicles on the road. These include piezoelectric sensors, magnetic sensors, acoustic detectors, IR sensors, etc.

The study conducted by Wen, W suggests a dynamic and autonomous traffic signal control system as a remedy for the problem of traffic congestion. To improve traffic flow, they suggest a system that automatically modifies the timing of traffic signals using real-time data from sensors and cameras. Data gathering, data analysis, and traffic light control make up the system's three key parts. The data-collecting component uses sensors, RFID tags, and cameras to collect data on the amount, speed, and density of traffic. To find patterns and forecast future traffic conditions, the data analysis component processes this data. Using this data, the traffic light control component then dynamically modifies the timing of the traffic lights to improve traffic flow. The authors use simulated tests to show how well their system works [16].

The design and construction of a dynamic traffic signal control system employing an adaptive algorithm are discussed in the study conducted by Sayyed, Shabnam, et al.. By altering signal timings based on current traffic circumstances, the system seeks to enhance traffic flow and decrease congestion. The algorithm utilized in the system makes use of the length of the traffic line measured using IR sensors and the amount of time that cars are stopped at intersections to determine the ideal signal timings. When compared to conventional fixed-time signal control systems, the system performed better in a simulation scenario. The dynamic traffic signal control system has the potential to improve traffic management and lessen congestion on highways [17].

B. Video Driven

One of the most popular methods to count vehicles is to use CCTV footage and use computer vision for processing. Various algorithms are used to detect and identify vehicles.

H. Zhou, D. Creighton, L. Wei, D. Y. Gao, and S. Nahavandi propose a technique for video-driven traffic modeling. They use four procedure components: (1) video processing to collect traffic data; (2) traffic modeling and simulation using Paramics; (3) evaluations of traffic interventions in road networks or control systems; (4) visualization for decision making. Paramics is used for simulating road and traffic conditions. Compared to the traditional fixed timing method, the proposed method can reduce vehicle delay time and queue length and thus reduce traffic congestion problems [18].

A lot of work has been done to develop efficient methods to reduce congestion by regulating traffic flow at junctions. Kanungo, Anurag, Ayush Sharma, and Chetan Singla present a dynamic traffic signal time-varying procedure to reduce traffic congestion on roads and provide safe transit to people while reducing fuel consumption and waiting time. The algorithm is applicable for one 4-way junction. Smart cameras are installed with signals that capture video data. The program calculates the density on all sides and the traffic light time is adjusted according to this value. The experiment provides promising

TABLE 2
ADAPTIVE SIGNAL CONTROL

Paper	Category	Proposed Solution	Techniques	Simulator	Hardware	Performance
[16]	Sensor Enabled	DATLCS with 7 components making use of RFID tags for detection	Queue based algorithm for traffic control	Arena	RFID tags, RFID reader, PDA	94% training,82.4% testing patterns - accuracy
[17]	Sensor Enabled	DTLC with Infrared sensors for vehicle detection	IR sensors for vehicle detection with emergency vehicle priority	-	IR-LED ,Microcontroller 89c51AT	-
[18]	Video Driven	VDTM that includes data collection using video processing, modeling, and adaptive signal control	Background modeling Hough technique	Paramics	-	87% accuracy
[19]	Video Driven	Design of a simple and cost-effective video-based dynamic signal adjustment system for one 4 way junction	Background modeling Density based signal time adjustment	MATLAB	-	35% improvement on an average with respect to static times
[20]	Machine Learning	Using an ANN and a fuzzy logic controller to dynamically adjust signal times	Sliding window technique RGB to grayscale with normalizaton	-	Fuzzy logic controller	Average error of 2%
[21]	Machine Learning	Creation of a real-time dynamic traffic light control system using 3 modes allowing for emergency vehicle priority.	Priority-based mode switching based on vehicle count using RFID mechanism	-	RC522RFID Reader, ARDUINO, HC-SR04 Ultrasound module	92.8% (daytime) 85.77% (nighttime) reliability
[22]	Machine Learning	Modeling the control problem as a reinforcement learning problem and using CNN for feature extraction	Reinforcement learning Deep neural network training	SUMO	-	86% vehicle delay reduction
[23]	Machine Learning	Development of an adaptive traffic signal system using the concepts of approximate dynamic programming	Approximate dynamic programming, TD RL learning, perturbation learning	MATLAB	-	67% vehicle delay reduction
[24]	VANETs	Comparison of the VANET-based algorithm as compared to Webster's method and pre-timed algorithms.	OAF(oldest arrival first) algorithm	SUMO INET/ OMNET++	GPS receiver Speedometer sensor	-
[25]	VANETS	VATSC to enable car-to-car communication to create an adaptive traffic signal system	DBCV - data dissemination protocol	NCTUns	GPS and digital maps	20% reduction in number of vehicles stopped at intersections

results in terms of the total number of vehicles that pass through in a given time window (with an improvement of approximately 35 percent) and the wait times incurred in the process with low installation and maintenance costs [19].

C. Machine Learning

With the use of machine learning (ML), which is a form of artificial intelligence (AI), software programs can predict outcomes more accurately without having to be explicitly instructed to do so. To forecast new output values, machine learning algorithms use historical data as input.

An approach for the same is explored by A. A. Zaid, Y. Suhweil, and M. A. Yaman. They present a method to dynamically alter signal durations using a neural network and a fuzzy logic controller. The captured image is converted to grayscale and the sliding window technique is used to identify cars. A neural network is trained to count the number of vehicles which is converted to a linguistic value that is sent to the fuzzy logic controller which adjusts the timing accordingly [20].

The research conducted by Ariffin, Wan Nur Suryani Firuz Wan, et al. suggests a traffic light control system that can prioritize emergency vehicles while also adapting in real-time to changing traffic conditions. The technology predicts traffic flow using machine learning algorithms and then modifies the timing of the traffic lights accordingly. In addition, it makes use of a wireless communication system to recognize incoming emergency vehicles and give them priority over other traffic by modifying traffic lights to permit safe and swift passage. As compared to conventional traffic signal control systems, the system was examined through simulation and revealed improved traffic flow and shorter emergency vehicle response times [21].

Gao, Juntao, et al. suggest a novel approach for deep reinforcement learning-based adaptive traffic light control (DRL). The authors contend that DRL offers a promising alternative to conventional traffic signal control techniques, which are frequently ineffective and unable to adapt to shifting traffic conditions. A neural network is used in the proposed method to train a traffic signal control policy from historical and real-time traffic data. The authors present several methods, such as experience replay and a target network, to enhance the DRL algorithm's stability and effectiveness. With the use of simulations of traffic movement in a metropolitan network, the authors assess the suggested approach. The findings demonstrate that, especially in situations with highly fluctuating traffic circumstances, this method surpasses more established ones in terms of average trip time and delay [22].

Based on past and present traffic data, the solution suggested by Cai, Chen, Chi Kwong Wong, and Benjamin G. Heydecker. uses a neural network to approximate the ideal traffic signal control policy. The authors present a novel method for neural network training based on an iterative algorithm that strikes a balance between exploring and exploiting the solution space. With the use of simulations of traffic movement in a metropolitan network, the authors assess the suggested approach. The results demonstrate that, especially under highly fluctuating traffic situations, the ADP-based strategy outperforms conventional methods in terms of average travel time, delay, and queue length. The constraints and difficulties of applying the suggested strategy in practical contexts are also covered in this work, including the requirement for trustworthy data collecting and adequate processing capacity [23].

D. VANETS

A collection of moving or stationary automobiles connected by a wireless network makes up a vehicular ad hoc network. VANETs are essential for giving drivers in moving settings safety and comfort. They offer real-time information, intelligent traffic control, and event allocation.

Pandit, Kartik, et al suggest an innovative approach to adaptive traffic signal regulation that makes use of vehicular ad hoc networks (VANETs). The suggested approach makes use of a centralized controller to gather traffic data from linked vehicles, process it, and then adjust the timing of traffic signals. The authors suggest many methods, such as a priority system for emergency vehicles and a method for dealing with communication delays, to increase the effectiveness and efficiency of the VANET-based control system. With the use of simulations of traffic movement in a metropolitan network, the authors assess the suggested approach. The findings demonstrate that, especially in situations with highly changeable traffic circumstances, the VANET-based strategy performs better than conventional methods in terms of average travel time, delay, and queue length [24].

Maslekar, Nitin, et al. outline a technique that makes use of vehicle-to-vehicle communication to gauge traffic density in vehicular ad hoc networks (VANETs). In this study, a novel traffic signal control method based on vehicular ad hoc networks and vehicle-to-vehicle (V2V) communication is proposed. The suggested system enables cars to transmit their locations, speeds, and planned directions to close-by traffic lights, which may then make use of this data to dynamically change signal timings in response to traffic circumstances. As compared to conventional fixed-time and actuated traffic signal management, the suggested system can minimize traffic delays and enhance traffic flow, [25].

V. CONCLUSION

With rapid growth and urbanization in India, it is of the utmost importance to have a comprehensive view of current traffic conditions as well as the estimated value in the coming years. Based on the survey of the most popular techniques in travel demand modeling and adaptive signal control, India would benefit from the use of Tour Based models for forecasting and a Video Driven adaptive signal control system. This is because a tour-based model offers a close approximation of an activity-based model without requiring a massive dataset. Since most junctions in cities are already equipped with CCTV cameras, the video-driven system would be the most straightforward approach to combat road traffic congestion issues. Both methods together hold the potential for taking efficient steps toward building smarter cities in India.

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