Conventional And Modern Approaches To Measure Urban Traffic Congestion: A Review

K.C.Varmora*

* Government Polytechnic, Kheda (India).

Abstract:

Urban traffic congestion is becoming more severe in many developing countries, especially in areas where mixed traffic conditions are common. For planning the traffic control system and sustainable urban mobility, it is essential to take accurate measurements of traffic congestion and congestion levels to overcome such issues. Several methods are employed to measure traffic congestion using different approaches. This study details the various techniques used to measure traffic congestion on urban roads under mixed traffic. The paper summarizes conventional and modern methods, emphasizes key metrics such as speed, volume-to-capacity ratio, travel time, and discusses modern techniques when applied to traffic characterized by diverse conditions.

Keywords: *mixed traffic, traffic congestion, urban roads.*

1. Introduction

Urban areas that are affected by traffic congestion suffer major issues in terms of economic losses, environmental degradation, and a reduction in quality of life. India is one of the developing countries where the combination of many types of vehicles, like two-wheelers, cars, buses, auto rickshaws, and non-motorized vehicles, affects the traffic stream. Such a combination of vehicles results in mixed traffic situations and consequently contributes to the traffic congestion. Mixed traffic, in contrast to homogeneous traffic systems, does not adhere to strict lane discipline and does not have vehicles that are uniform in size, which makes it more challenging to evaluate congestion. Also, the vehicles occupy the same lane at varying speeds.

This study aims to review several approaches employed to measure traffic congestion systematically. It highlights the methodologies, indicators, and parameters commonly used in conventional and modern techniques. The study discusses the effectiveness and uses of different methods in capturing congestion levels. By studying these approaches, the paper provides valuable insights for researchers and practitioners and helps improve congestion assessment.

2. Understanding Mixed Traffic and Its Challenges

Mixed traffic streams have various vehicle types, each displaying unique static and dynamic properties. Both motorized and non-motorized vehicles fall under these categories. Typically, these streams operate without lane discipline, leading to complex interactions and considerable unpredictable movement among the different vehicles.

Challenges of Mixed Traffic:

- Irregular vehicle spacing.
- Variable vehicle speeds.
- Lack of lane discipline.
- Lack of exclusive lanes or priority rules.

These qualities necessitate the utilization of congestion measuring approaches that consider vehicle variability, heterogeneity, and behavior that does not rely on lanes.

3. Conventional Techniques for Measuring Congestion

Conventional methods to measure traffic congestion include:

3.1 Volume to Capacity Ratio (v/c ratio)

The volume-to-capacity ratio (v/c ratio) is a key parameter used in traffic engineering to assess the performance and level of congestion on a roadway segment or intersection. It is expressed as:

$$\text{v/c ratio} = \frac{Traffic\ volume\ (v)}{Roadway\ Capacity\ (c)}$$

Where:

Traffic volume (v) is the number of vehicles passing a particular point on a roadway for a specified period. Roadway capacity (c) is the maximum sustainable hourly flow traversing a point or segment under prevailing roadway conditions.

Importance in Traffic Congestion Analysis

- A low v/c ratio indicates that the roadway operates well below capacity, implying smooth traffic flow.
- A v/c ratio approaching 1.0 suggests the road is becoming congested and is operating at or near capacity.
- A v/c ratio greater than 1.0 indicates overloaded conditions, likely resulting in queues, delays, and reduced speeds.

3.2 Travel Time and Delay Studies

Travel time and delay studies are fundamental methods for evaluating a roadway's operational efficiency. They help identify traffic congestion, quantify its severity, and suggest appropriate remedial measures.

3.2.1 Travel Time:

Travel time refers to the total time taken by a vehicle to travel between given points along a particular road segment. It includes running time and delay time. Reduced travel time signifies smoother traffic flow, whereas extended travel time suggests congestion.

3.2.2 Delay:

Delay is the extra time a vehicle takes to travel due to interruptions compared to the expected time under ideal conditions, like free-flow conditions. Types of delays include:

Fixed delay: It is caused by traffic control devices.

Operational delay: Due to fluctuations in traffic demand.

Congestion delay: Caused by excessive demand beyond capacity, leading to traffic jams.

Delays are a direct measure of congestion, with higher delays signifying reduced efficiency and higher user costs. Travel time and delay data suggest measurable evidence of congestion. For example, if a 5 km corridor usually requires 10 minutes to traverse in free-flow but takes 30 minutes under some unavoidable conditions, the delay is 20 minutes. Methods of Conducting Travel Time and Delay Studies include Floating car, License plate matching, GPS and Bluetooth tracking, and Video surveillance.

3.3 Speed-Based Metrics

Average speed and percent-free-flow speed (%FFS) are common congestion indicators. Considering the average speeds, the lower average speeds indicate higher congestion levels. Another is a speed reduction metric that indicates how much the current speed has reduced compared to the free-flow speed. However, these metrics are often ineffective in mixed traffic due to variable driver behavior and vehicle sizes.

Several researchers widely use the conventional method to arrive at the congestion level. [1], [2], [3], [4], [5], [6].

4. Modern Techniques for Measuring Congestion

With advancements in data analytics and machine learning, researchers are using hybrid methods to evaluate congestion under mixed traffic:

4.1 Machine Learning and Clustering Techniques in Traffic Congestion:

Traffic congestion is a serious traffic engineering problem affecting travel time, fuel consumption, and environmental pollution. Today, traffic congestion is measured using Machine Learning (ML) techniques that analyze extensive traffic data. The learning patterns obtained through ML can detect congestion, predict future congestion levels, and classify traffic conditions (e.g., Level of Service). ML is categorized into two types: supervised machine learning and unsupervised machine learning. In supervised machine learning, the output is known in advance. Algorithms used in this approach include linear regression, Support Vector Regression (SVR), neural networks, and random forest regression. Conversely, the output is unknown in unsupervised machine learning. Some examples of unsupervised machine learning are K-means, K-means++, Gaussian Mixture Models (GMM), Fuzzy C Means, and Density-Based Spatial Clustering (DBSCAN).

As real-world traffic data is generally unlabeled, unsupervised machine learning methods, particularly clustering algorithms, serve as practical approaches to categorize traffic conditions into meaningful congestion levels (i.e., free flow to congested). Many researchers have conducted studies to assess the Level of Service (LOS) using speed, which is alternatively valuable for understanding traffic congestion.

4.2 Simulation-Based Models:

Traffic simulation models simulate individual vehicle movements and driver behavior over time. They consider each vehicle's speed and acceleration, lane-changing behavior, headways, reaction times, etc. This level of detail enables traffic engineers to assess congestion patterns on urban road networks under various traffic control strategies, infrastructure designs, or traffic volumes. Microscopic simulation tools such as AIMSUN, VISSIM, and SUMO simulate driver behavior and vehicular movement, offering detailed congestion assessment under various conditions.

Several Indian and international studies have attempted to measure congestion under heterogeneous conditions using ML, clustering, simulation, and other data-driven techniques. [7], [8], [9], [10], [11], [12], [13] [14].

5. Limitations of Existing Approaches

Despite the progress in measuring traffic congestion, significant limitations remain as mentioned below:

- Many methods assume a uniform traffic flow.
- Delay-based metrics fail to capture real-time variability.
- Simulation tools need calibration, which is often time-consuming and data-intensive.
- Conventional LOS categories may not accurately reflect user perception under Indian conditions.

6. Recommendations and Future Scope

Video recordings, GPS, CCTV, and IoT sensors can capture real-time data for dynamic congestion monitoring. City-specific TCI models can be created to consider vehicle mix and driving behavior. Machine learning models can be applied for pattern recognition, prediction, and classification of congestion levels, using proper validation parameters to support the results.

7. Conclusion

This study thoroughly examines conventional and modern techniques for assessing traffic congestion, particularly in mixed traffic. Conventional approaches, including the Volume-to-Capacity ratio, speed, and travel time, provide a basic understanding but often fail to reflect real-time and varied traffic dynamics accurately. Modern methodologies, such as machine learning and simulation, offer improved precision in measuring traffic congestion. Future research should concentrate on integrating these methodologies to develop more accurate congestion measurements.

References:

[1] J. Jun, "Understanding the variability of speed distributions under mixed traffic conditions caused by holiday traffic," *Transp Res Part C Emerg Technol*, vol. 18, no. 4, pp. 599–610, Aug. 2010. https://doi.org/10.1016/j.trc.2009.12.005.

[2] A. Mohan Rao and K. Ramachandra Rao, "MEASURING URBAN TRAFFIC CONGESTION – A REVIEW," *International Journal for Traffic and Transport Engineering*, vol. 2, no. 4, pp. 286–305, Dec. 2012.

[3] C. Bian, C. Yuan, W. Kuang, and D. Wu, "Evaluation, Classification, and Influential Factors Analysis of Traffic Congestion in Chinese Cities Using the Online Map Data," *Math Probl Eng*, vol. 2016, pp. 1–10, 2016. https://doi.org/10.1155/2016/1693729.

[4] Verhoef, E. T., Rouwendal, J., & Rietveld, P. (1999). Congestion Caused by Speed Differences. *Journal of Urban Economics*, *45*(3), 533-556. https://doi.org/10.1006/juec.1998.2105.

[5] M. Ramezani and E. Ye, "Lane density optimisation of automated vehicles for highway congestion control," *Transportmetrica B: Transport Dynamics*, vol. 7, no. 1, pp. 1096–1116, Dec. 2019. https://doi.org/10.1080/21680566.2019.1568925.

[6] M. Taylor, "Exploring the Nature of Urban Traffic Congestion: Concepts, Parameters, Theories and Models," in *16th ARRB Conference*, Perth, Australia, 1992, pp. 9–13.

[7] A. Elfar, A. Talebpour, and H. S. Mahmassani, "Machine Learning Approach to Short-Term Traffic Congestion Prediction in a Connected Environment," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2672, no. 45, pp. 185–195, Dec. 2018. https://doi.org/10.1177/0361198118795010.

[8] V. Kanagaraj and M. Treiber, "Self-driven particle model for mixed traffic and other disordered flows," *Physica A: Statistical Mechanics and its Applications*, vol. 509, pp. 1–11, Nov. 2018.

[9] J. WU, Z. GAO, and H. SUN, "SIMULATION OF TRAFFIC CONGESTION WITH SIR MODEL," *Modern Physics Letters B*, vol. 18, no. 30, pp. 1537–1542, Dec. 2004. https://doi.org/10.1142/S0217984904008031.

[10] Y. Y. Qin, H. Wang, W. Wang, and Q. Wan, "Mixed traffic flow string stability analysis for different CACC penetration ranges," *Jiaotong Yunshu Xitong Gongcheng Yu Xinxi/Journal of Transportation Systems Engineering and Information echnology*, vol. 17, no. 4, 2017.

[11] Z. Zheng, D. Wang, J. Pei, Y. Yuan, C. Fan, and F. Xiao, "Urban Traffic Prediction through the Second Use of Inexpensive Big Data from Buildings," in *Proceedings of the 25th ACM International on Conference on Information and Knowledge Management*, New York, NY, USA: ACM, Oct. 2016, pp. 1363–1372. https://doi.org/10.1145/2983323.2983357.

[12] N. Patel and A. B. Mukherjee, "Assessment of network traffic congestion through Traffic Congestability Value (TCV): a new index," *Bulletin of Geography. Socio-economic Series*, vol. 30, no. 30, pp. 123–134, Dec. 2015. http://dx.doi.org/10.1515/bog-2015-0039.

[13] D. H. Widyantoro and M. D. Enjat Munajat, “Fuzzy traffic congestion model based on speed and density of vehicle,” in *2014 International Conference of Advanced Informatics: Concept, Theory and Application (ICAICTA)*, IEEE, Aug. 2014, pp. 321–325. https://doi.org/10.1109/ICAICTA.2014.7005962. .

[14] P. K. Bhuyan and K. V. K. Rao, “DEFINING LOS CRITERIA OF URBAN STREETS USING GPS DATA: K-MEANS AND K-MEDOID CLUSTERING IN INDIAN CONTEXT,” *TRANSPORT*, vol. 27, no. 2, pp. 149–157, Jun. 2012. https://doi.org/10.3846/16484142.2012.692354.