IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 18, April 2026
Impact Factor: 8.2

Geometric Highway Design Parameters for Enhanced Road Safety and Performance: A Review

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Abstract: *The paper reviews existing modeling approaches, including the use of cellular automata models, for simulating bidirectional traffic flow under heterogeneous conditions. Such models are effective in capturing the complex interactions between different vehicle types and traffic behaviors. Additionally, the impact of rapid urbanization and rising economic standards, leading to increased vehicle ownership and pedestrian movement, is discussed as a major contributor to traffic congestion and safety concerns. The review emphasizes the need for efficient traffic management strategies and advanced modeling techniques to address the growing pressure on urban road networks. Overall, the study provides insights into traffic flow behavior and highlights the importance of integrated planning and simulation-based approaches for improving transportation system performance..*

Keywords: Traffic Flow Modeling, Cellular Automata, Bidirectional Traffic, Heterogeneous Traffic, Traffic Volume.

I. INTRODUCTION

India's road system is the world's second longest with more than 5,603,293 kilometers in length. As of March 2020, there are 111,111 kilometers of Nationalized Highways linking all of the main cities & stated-capitals. Only 2.7% of India's roads are national highways, although they transport 40% of the country's traffic. There are often two lanes. As of May 2016, almost 26,000 kilometers have been extended to four lanes, two in each way. Rarely can you find cement concrete in the construction of a National Highway. Morethan 85% of the country's passenger traffic and over 65% of its freight traffic travel on national highways [1,3].

The pace of road construction in India has increased rapidly in recent years, from 12 kilometers per day on average in 2014–15 to 27 kilometers per day in 2017–18. The national goal is to construct 40 kilometers of roadway each day. India's National Highway9 runs the greatest distance of any major north-south highway in the country. Srinagar is the starting point and Kanya kumari is the finishing point. The road goes through a numberof different states. The National Highway 9 (NH-9) was built and is maintained by the CPWD [4].

The Government of India has begun the Bharatmala road and highways project in 2017, with the goal of building about 83,000 kilometers of new roadways at an estimated cost ofUS $78 billion. By 2021-22 [8], Bharatmala (Phase -I) aims to have built 34,800 kilometersof roadways (including the remaining projects under NHDP).

ANALYSIS OF TRAFFIC FLOW CHARACTERISTICS

Traffic studies involve the analysis of traffic composition and flow variations to understand movement patterns and roadway performance. Key parameters such as maximum, minimum, and average speeds in different flow directions are evaluated based on field data collected at selected locations. Among the most important aspects of traffic analysis are traffic volume and spot speed studies. Traffic volume refers to the number of vehicles passing a specific point or section of road within a given time interval, typically measured in vehicles per hour or per day. These studies are essential for infrastructure planning, as they help in designing pavements, pedestrian facilities, signals, crosswalks, subways, and other transportation elements, while also enabling the analysis of traffic flow patterns.

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Traffic volume count surveys are usually conducted over extended periods, such as 12 hours, with data recorded at regular intervals (e.g., every 15 minutes) to determine peak-hour characteristics and variations. Two primary methods are used for traffic counting: manual and automatic approaches. In the manual method, vehicles are counted directly by observers, either through simple counting techniques or direct recording. This approach allows for the collection of detailed information such as vehicle classification and turning movements and provides immediate usability of data. However, it is labor-intensive, prone to human error, and unsuitable for high traffic volumes or long-duration studies.

Alternatively, the indirect or automatic method involves recording traffic using video cameras for later analysis. This method is more suitable for high-volume traffic and long-duration studies, as it allows data verification and detailed analysis of multiple traffic parameters. It is particularly useful for non-lane-based traffic conditions. However, it requires appropriate camera placement, good lighting conditions, and additional time for data extraction and processing. Moreover, the quality of the recorded data may be affected by environmental factors such as poor lighting or weather conditions. Despite these limitations, both methods play a crucial role in comprehensive traffic flow analysis and transportation planning.

Related Study

Chao Gao et al. (2020) investigated the impact of heavy vehicles on traffic flow characteristics using field data and SPSS-based modeling. Their study revealed that the average traffic speed decreases as the proportion of heavy vehicles increases, particularly under higher traffic volumes. The developed predictive model demonstrated strong agreement between observed and estimated speeds, highlighting the significant influence of vehicle composition on congestion behavior.

L. Zheng et al. (2019) analyzed vehicle-type-dependent car-following behavior using NGSIM trajectory data. Their findings indicated that drivers maintain larger headways and safety margins when following heavy vehicles. Both micro- and macro-level analyses confirmed that vehicle type significantly affects driving behavior and traffic dynamics, emphasizing the importance of considering heterogeneity in traffic modeling.

Mohammed Feroz Ahmed Khan et al. (2018) focused on capacity estimation of Indian highways under heterogeneous traffic conditions. Using field data and VISSIM simulation, they established speed-flow relationships and estimated highway capacity at approximately 4100 PCU/hr/lane/direction. Their study highlighted the limitations of applying international models to Indian traffic conditions and stressed the need for localized approaches.

Abrar Ul Haq Bhat et al. (2018) examined traffic patterns at a key intersection, emphasizing the role of traffic volume, speed, and density in determining safety and efficiency. Their study demonstrated the importance of traffic surveys and data analysis in improving traffic management strategies.

Devaraj Hanumappa et al. (2018) discussed urban traffic challenges such as increasing vehicle numbers, inadequate infrastructure, and environmental concerns. Their case study emphasized the need for effective planning and management to address growing congestion issues.

Akash Rajkumar Wadhwa et al. (2017) highlighted the complexities of two-lane, two-way traffic flow, particularly under mixed traffic conditions. They noted that overtaking opportunities and capacity are significantly influenced by traffic composition and directional flow.

Jain K. et al. (2016) and Y. Qiu et al. (2012) further explored traffic flow characteristics, focusing on speed-flow relationships and Passenger Car Unit (PCU) estimation. Their studies emphasized the impact of heterogeneous traffic on flow dynamics and capacity, reinforcing the need for adaptive modeling techniques.

II. CONCLUSION

The reviewed studies collectively highlight the significant impact of heterogeneous traffic conditions on traffic flow characteristics, capacity, and safety. A consistent finding across the literature is that the presence of heavy vehicles adversely affects average traffic speed, headway, and overall flow efficiency, especially under high traffic volumes. Vehicle-type diversity plays a crucial role in influencing both micro-level driving behavior, such as car-following and

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safety margins, and macro-level parameters like speed-flow relationships and roadway capacity. The studies also emphasize that conventional traffic models developed for homogeneous conditions are not directly applicable to regions like India, where mixed traffic prevails. Overall, this review establishes that understanding and modeling heterogeneous traffic conditions are fundamental to improving transportation system performance. Future research should focus on developing advanced, flexible models and integrating modern technologies to enhance traffic prediction, management, and safety in rapidly growing urban environments.

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