Traffic Simulation Analysis: Evaluating SUMO and SiMTraM for Heterogeneous Traffic Scenarios

Background and Motivation

Urban transportation systems worldwide face significant challenges due to rapid urbanization and increasing vehicle populations. Traffic congestion has emerged as a critical obstacle to urban development, hindering economic progress and reducing quality of life. While infrastructure expansion projects can address some capacity issues, they often cannot keep pace with the exponential growth in vehicle numbers and travel demand. This gap necessitates sophisticated transportation planning approaches that can maximize the efficiency of existing road networks (Patel et al., 2016)

Traffic simulation tools play a vital role in modern transportation planning by enabling planners to model, analyze, and predict traffic patterns without implementing costly physical changes. These simulation platforms allow researchers and engineers to test various scenarios, evaluate different interventions, and make data-driven decisions about transportation infrastructure investments. However, the effectiveness of these tools depends heavily on their ability to accurately represent real-world traffic conditions (Malik et al., 2019)

The Challenge of Heterogeneous Traffic Representation

Most available traffic simulation platforms were developed with Western traffic patterns in mind, where vehicles maintain strict lane discipline and the vehicle mix is relatively homogeneous. These simulators typically enforce rigid lane-based movement rules that work well for organized traffic flow but fail to capture the complexity of traffic in developing nations.

Traffic patterns in countries like India present unique characteristics that challenge conventional simulation approaches. Indian roads accommodate a diverse mix of vehicles including two-wheelers, three-wheelers, cars, buses, and heavy goods vehicles, all sharing the same road space. More significantly, smaller vehicles such as motorcycles and scooters do not maintain strict lane discipline and often utilize available lateral space within lanes to position themselves alongside other vehicles. This lateral freedom allows for higher vehicle density but creates complex interactions that traditional lane-based simulators cannot accurately model.

Overview of Traffic Simulation Platforms

HETEROSIM

HETEROSIM represents vehicles as rectangular blocks moving on road segments, supporting mixed traffic with relaxed lane discipline. The simulator employs a position-based car following and overtaking model that better reflects traffic behavior where strict lane adherence is not maintained. However, the platform has significant limitations that restrict its practical application. It was developed using C++ programming and remains unavailable as open-source software. The simulation framework has limited configurability, with built-in car following and overtaking models that cannot be customized. These constraints make HETEROSIM suitable only for small-scale studies and prevent its use in citywide transportation planning applications.

SUMO (Simulation of Urban Mobility)

SUMO stands out as a sophisticated, open-source microscopic traffic simulator designed to handle large-scale scenarios. The platform offers extensive configurability across multiple dimensions including road network parameters, vehicle characteristics, routing patterns, traffic control devices, and right-of-way rules. Users can customize lane counts, road lengths, permitted vehicle types, acceleration profiles, maximum speeds, and numerous other parameters. The simulator includes multiple car following and overtaking models, providing flexibility in representing different driving behaviors.

SUMO incorporates several features that make it attractive for traffic research. It provides a fast OpenGL-based graphical interface for visualization, executes simulations efficiently, supports runtime integration with external applications through the TraCI interface, and generates detailed output at edge, vehicle, and detector levels. These capabilities have made SUMO widely adopted in transportation research globally.

Despite its strengths, SUMO has a fundamental limitation when applied to heterogeneous traffic scenarios. The simulator enforces strict lane discipline on all vehicle movements, including smaller vehicles like motorcycles. This requirement means that even a motorcycle occupies an entire lane width, preventing other vehicles from utilizing the lateral space that would naturally be available. In contexts where two-wheelers constitute a substantial portion of the vehicle fleet, this limitation leads to unrealistic representations of traffic flow, underestimating road capacity and misrepresenting vehicle interactions.

SiMTraM (Strip-based Traffic Model)

Recognizing the limitations of SUMO for heterogeneous traffic, researchers at IIT Bombay developed SiMTraM by modifying SUMO to support less restrictive lateral movement. The key innovation involves subdividing lane width into multiple configurable strips, with each vehicle type assigned a fixed number of strips based on its width. This strip-based approach allows multiple narrow vehicles to share the same lane width simultaneously, better reflecting real-world lateral positioning behavior.

SiMTraM retains all the core features available in SUMO while adding this enhanced spatial representation. The simulator can import road networks from open-source mapping platforms, supports custom vehicle categories with varying attributes, and allows individualized routing for each vehicle or flow. However, the original SiMTraM implementation was based on SUMO version 0.12, which became obsolete as SUMO continued to evolve. Additionally, the original version exhibited stability issues, particularly when simulating large vehicle volumes or extensive road networks, resulting in runtime crashes that limited its practical utility.

Development of Enhanced Simulation Platform

To address the limitations of the existing SiMTraM implementation, a comprehensive redevelopment effort was undertaken using SUMO version 0.17, which was the most current stable release at the time. The development team analyzed the source code modifications made in the original SiMTraM to understand how strip-based modeling was implemented in SUMO 0.12. Similar modifications were then carefully implemented in the SUMO 0.17 codebase, taking advantage of improvements and bug fixes incorporated in the newer version.

The upgraded platform was developed on the Fedora 17 operating system and made available to the research community through open-source distribution. Complete source code, documentation listing all modified and added files, and implementation guides were published online to enable other research groups to further upgrade the platform as newer SUMO versions become available. This collaborative approach aims to maintain a continuously improving simulation tool appropriate for heterogeneous traffic analysis.

The enhanced version demonstrated significant improvements in stability, successfully handling simulations with more than five thousand vehicles per hour without encountering the runtime errors that plagued the original implementation. This increased robustness enables the platform to support realistic large-scale urban traffic studies.

Experimental Design and Configuration

To evaluate the comparative performance of SUMO and the upgraded SiMTraM, comprehensive simulations were conducted using real road networks from Ahmedabad, India. Two distinct road segments were selected to provide diverse testing scenarios. The first segment spans 34 kilometers along the Sarkhej-Gandhinagar highway, while the second covers 8 kilometers of the 132-foot ring road from IIM Ahmedabad to the RTO office.

Each road segment was simulated under two traffic control conditions: with traffic signal control and without traffic signals, providing four distinct scenario combinations. Vehicle insertion rates were systematically varied from 500 vehicles per hour to 5,000 vehicles per hour in increments of 500, allowing examination of system behavior across free-flow, transitional, and congested conditions. All simulations ran for three hours of simulated time to capture steady-state behavior, with a thirty-minute warm-up period excluded from data collection to eliminate initialization effects.

Vehicle Composition and Characteristics

The simulation scenarios employed a vehicle mix representative of typical Indian urban traffic, with distribution and dimensions obtained from local transportation studies and manufacturer specifications:

Vehicle Type	Proportion	Dimensions (m)
Motorcycle	36%	2.0 × 1.0
Bicycle	3%	2.0 × 1.0
Auto-rickshaw	17%	3.0 × 2.0
Car	38%	4.0 × 2.0
Heavy Goods Vehicle	5%	10.0 × 3.0
Bus	1%	10.0 × 3.0

Notably, two-wheelers and bicycles together comprise 39% of the vehicle mix, while cars represent 38%, closely reflecting the vehicle composition observed on Indian urban roads. Traffic metrics including vehicle counts and speeds were aggregated every ten minutes using Python scripts, enabling detailed temporal analysis of traffic flow characteristics.

Passenger Car Unit (PCU) equivalents for different vehicle types were calculated based on the ratio of vehicle speeds and projected rectangular areas. This approach normalizes different vehicle types into equivalent passenger car units, facilitating meaningful comparisons of traffic flow across different vehicle compositions.

Comparative Performance Analysis

Traffic Flow Capacity

Analysis of vehicle flow rates revealed significant differences between the two simulation platforms. Under free-flow conditions with vehicle insertion rates between 500 and 2,000 vehicles per hour, both simulators produced similar flow measurements. At these lower demand levels, the road network has sufficient capacity regardless of lateral space utilization efficiency.

However, as demand increased to 3,000-5,000 vehicles per hour, substantial divergence emerged. The lane-based SUMO simulator exhibited congestion-related flow reductions as vehicles competed for limited lane space. In contrast, the upgraded SiMTraM maintained higher throughput by allowing smaller vehicles to share lateral space efficiently. Flow improvements of 10-40% were observed with SiMTraM compared to SUMO under these higher demand conditions.

This pattern held consistent across both signalized and unsignalized scenarios and across both tested road segments. The difference stems fundamentally from spatial representation: when a motorcycle must occupy an entire lane in SUMO, it prevents other vehicles from using available width. In SiMTraM, that same motorcycle consumes only the strips corresponding to its actual width, leaving adjacent strips available for other narrow vehicles.

Vehicle Movement Speeds

Speed analysis paralleled the flow findings. Under free-flow conditions (500-2,000 vehicles per hour), average speeds remained similar between platforms, with vehicles traveling at or near their desired speeds without significant interaction delays. As demand increased beyond this threshold, SUMO showed marked speed reductions as the network approached capacity and vehicles began experiencing delays from insufficient lane space.

The upgraded SiMTraM platform maintained substantially higher speeds under the same demand levels, with improvements of 10-50% compared to SUMO. This speed advantage reflects the reduced congestion enabled by efficient lateral space utilization. When multiple motorcycles can travel side-by-side within a lane, they experience fewer delays from lane-changing maneuvers and reduced interference from lane-blocking vehicles.

Flow-Speed Relationships

The relationship between traffic flow and average speed provides insight into network performance characteristics. In SUMO simulations, speed deterioration began at relatively low flow levels—approximately 400 PCU per 10-minute interval for signalized segments and 500 PCU per 10-minute interval for unsignalized segments. This early onset of speed reduction indicates premature capacity constraints.

SiMTraM demonstrated substantially different flow-speed characteristics. The platform maintained higher speeds across all flow levels examined, with more gradual speed reductions as flow increased. Even when speeds did decline at higher flows (400-800 PCU per 10-minute interval), the reduction was less severe than in SUMO. This behavior aligns more closely with observed traffic patterns on heterogeneous roads where lateral flexibility helps maintain flow efficiency.

Conclusions and Implications

This comparative evaluation demonstrates that strip-based traffic modeling significantly improves the representation of heterogeneous traffic scenarios compared to traditional lane-based approaches. The upgraded SiMTraM platform, built on the more recent and stable SUMO version 0.17, provides both enhanced simulation accuracy and improved operational reliability.

The key findings indicate that SiMTraM enables more realistic traffic density, higher vehicle speeds, and more accurate capacity estimation when simulating traffic scenarios with substantial two-wheeler presence. The platform allows for 10-40% higher flow rates and 10-50% higher average speeds compared to SUMO under congested conditions, better reflecting the actual performance of roads accommodating mixed vehicle types with flexible lateral positioning.

These improvements have practical significance for transportation planning in contexts with heterogeneous vehicle fleets. Capacity estimates derived from lane-based simulators may substantially underestimate actual road performance, leading to potentially unnecessary infrastructure investments or incorrect prioritization of improvement projects. Strip-based modeling provides planners with more accurate tools for evaluating existing networks and proposed interventions.

The open-source availability of the upgraded SiMTraM platform, including complete source code and documentation of modifications, facilitates continued development by the research community. As SUMO continues to evolve with new features and improvements, the documented modification approach enables researchers to upgrade SiMTraM to newer SUMO versions, ensuring the platform benefits from ongoing developments while maintaining its enhanced spatial representation capabilities.

Future Development Directions

Several avenues for future enhancement can build upon this foundation. Updating SiMTraM to incorporate the latest SUMO releases would leverage recent advances in simulation methodology, computational efficiency, and visualization capabilities. The current work used SUMO 0.17, but the platform has progressed through multiple subsequent releases with significant improvements.

Development of more sophisticated car-following and lane-changing models specifically tailored to heterogeneous traffic could further improve realism. Current models, while functional, were originally designed for lane-disciplined traffic and may not fully capture the lateral interactions and positioning behaviors characteristic of mixed traffic streams. Custom models incorporating lateral freedom and multi-vehicle lateral positioning could enhance the accuracy of simulated trajectories and interactions.

Validation against comprehensive field data from multiple locations would strengthen confidence in the platform's accuracy and generalizability. While the current study demonstrates improved realism through comparative analysis, detailed empirical validation with ground-truth measurements would provide quantitative assessment of prediction accuracy and identify any systematic biases requiring correction.

Extension to more complex network features including intersection modeling, priority rules at conflicting movements, and multi-modal interactions would broaden the platform's applicability. The current validation focused on link-level performance, but realistic network simulation requires accurate representation of junction behavior, turning movements, and conflicts between different traffic streams.

Summary

The development and evaluation of the upgraded SiMTraM platform represents an important advancement in traffic simulation capabilities for heterogeneous conditions. By combining the robust features and scalability of SUMO with strip-based spatial modeling that accommodates flexible lateral positioning, the platform provides researchers and practitioners with a tool better suited to analyzing traffic in contexts where strict lane discipline does not apply.

The demonstrated improvements in flow capacity, speed maintenance, and overall network performance representation validate the strip-based modeling approach. Making this tool available as open-source software with comprehensive documentation ensures its accessibility to the broader research community and facilitates ongoing improvement and adaptation to evolving simulation needs. This work contributes to the development of transportation planning tools that better reflect the diversity of global traffic patterns and support evidence-based decision-making in contexts beyond those for which most existing tools were originally designed.

Reference

Malik, F., Khattak, H. A., & Ali Shah, M. (2019). Evaluation of the impact of traffic congestion based on SUMO. *ICAC 2019 - 2019 25th IEEE International Conference on Automation and Computing*. https://doi.org/10.23919/ICONAC.2019.8895120

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