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Simulating and Evaluating Traffic Flow for Accident Mitigation in Urban Environments through BIM and VISSIM Integration

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ABSTRACT:

Urban traffic congestion and road safety are critical challenges, leading to increased accident rates, delays, and fuel consumption. This paper develops an integrated traffic simulation model using BIM and PTV VISSIM to evaluate public transit and private vehicle interaction in mixed traffic conditions. The study aims to optimize traffic management strategies, address gaps in existing research, and improve urban mobility and reduce congestion. The methodology involves using tools like Google Earth Pro, GPS Visualizer, and Autodesk Civil 3D to create a detailed road network model, which is then imported into VISSIM for simulation and analysis. The paper focuses on optimizing traffic flow, signal control, and other interventions to mitigate accidents and enhance overall traffic efficiency.

Keywords: BIM, VISSIM, traffic simulation, urban mobility, accident mitigation, mixed traffic, signal optimization

Introduction:

Urban traffic congestion and road safety are significant concerns in modern cities. The increasing number of vehicles, coupled with rapid urbanization, has led to higher accident rates, longer commute times, and increased fuel consumption. Mixed traffic conditions, where public transit and private vehicles share the same road infrastructure, further complicate traffic flow and create accident hotspots. Many cities lack real-time traffic management and predictive analysis capabilities, hindering effective accident mitigation. This paper aims to address these challenges by developing an integrated traffic simulation model that combines the capabilities of Building Information Modeling (BIM) and PTV VISSIM. BIM provides a detailed 3D digital representation of urban infrastructure, aiding in precise road design and accident risk analysis. VISSIM, a microscopic traffic simulation tool, enables the analysis of vehicle interactions, optimization of signal control, and testing of safety measures. The integration of BIM and VISSIM offers a data-driven approach to traffic planning, facilitating the identification of high-risk accident zones and the simulation of various traffic management strategies.

Literature Review:

A comprehensive review of existing literature reveals several key areas of research in traffic simulation and urban traffic management. Kothuri & Kumar (2018) focused on traffic flow analysis and proposed solutions for congestion and safety improvement. Alkhaddar et al. (2020) explored the integration of BIM in traffic simulation to enhance traffic management and optimize road network efficiency. Zeng et al. (2019) studied the application of VISSIM for accident simulation and safety analysis. Anastasopoulos et al. (2012) analyzed the impact of traffic accidents on urban transportation networks. Bai et al. (2021) investigated the optimization of mixed traffic flow in urban areas using BIM and VISSIM. Ibrahim et al. (2019) reviewed various simulation models and their effectiveness in accident mitigation. Zhang et al. (2022) discussed BIM-based techniques for traffic safety analysis and accident prevention. Huang & Li (2020) focused on optimizing traffic signal control using VISSIM for accident reduction. Li et al. (2023) examined methods for reducing accidents, including intelligent transportation systems and traffic modeling. Reza et al. (2021) focused on the integration of BIM and traffic simulation for smart city traffic management, emphasizing safety improvements.

Gaps in the Literature:

While previous research has contributed significantly to the field, several gaps remain. Existing studies often lack a detailed representation of mixed traffic conditions, failing to explicitly model the interaction between public transit and private vehicles in realistic urban settings. There is also limited exploration of public transit prioritization strategies, such as the impact of bus lanes, signal priority, and multimodal integration to improve transit performance. Furthermore, many studies lack a robust optimization framework for enhancing traffic efficiency through advanced techniques like AI, machine learning, or simulation-based optimization. Finally, the environmental and sustainability aspects of traffic flow optimization, such as reduced emissions and energy efficiency, are often not adequately addressed.

Problem Statement:

This paper aims to address the identified gaps by focusing on "Simulation and Optimization of Mixed Traffic Conditions: A BIM-VISSIM Integration for Public Transit and Private Vehicles." The study will explicitly focus on mixed traffic conditions with multimodal transport integration, incorporate optimization techniques for improved traffic control, utilize real-world data calibration to enhance accuracy, scale BIM-VISSIM to urban-level traffic planning beyond project-specific improvements, and include sustainability considerations for better urban mobility planning.

Objectives:

The primary objectives of this research are:

- To develop an integrated traffic simulation model using BIM and PTV VISSIM in urban environments.
- To evaluate the interaction between public transit (buses) and private vehicles, focusing on improving traffic flow and reducing congestion.
- To optimize traffic management strategies through interventions like signal optimization, and improved urban mobility.

Methodology:

The methodology adopted in this study integrates BIM-based road design using Autodesk Civil 3D with microscopic traffic simulation in PTV VISSIM. Initially, Google Earth Pro and GPS Visualizer were used to extract accurate spatial and elevation data of the study area—Nehru Outer Ring Road, Hyderabad. This data was converted into UTM coordinates and imported into Civil 3D to create 3D road geometry, intersections, and corridor models. These BIM models were exported in IFC format and integrated into VISSIM to simulate real-world traffic conditions, including mixed traffic flow involving cars, buses, motorcycles, and auto-rickshaws.Within VISSIM, vehicle compositions, signal controllers, conflict areas, and reduced-speed zones were defined to reflect typical urban conditions. The simulation was run under multiple scenarios to test different configurations such as signal timing optimization, dedicated bus lanes, and adaptive speed control. Data was then collected through data collection points, queue counters, and vehicle travel time segments to evaluate network performance. This integrated approach allowed a high-fidelity analysis of traffic behavior and identification of congestion hotspots for accident mitigation as shown in figure 1

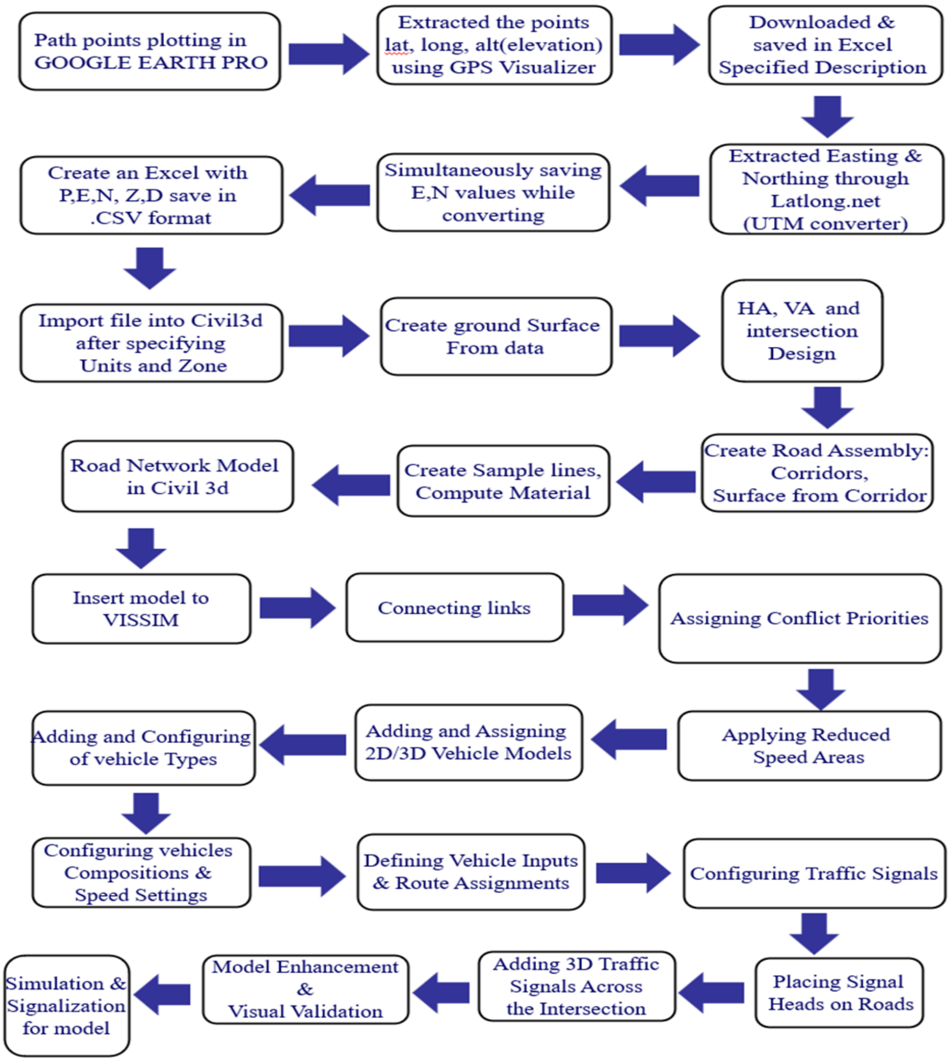

Figure 1: methodology

Software and Data Acquisition: The initial phase involves the selection and installation of appropriate software tools, specifically Autodesk Civil 3D for BIM-based road network modeling, PTV VISSIM for microscopic traffic simulation, and Google Earth Pro for initial spatial data capture. Emphasis is placed on ensuring software compatibility and adherence to system requirements. The necessary input data, including road network geometry and attributes, are then acquired. This data must conform to the PENZD format (Point Number, Easting, Northing, Elevation, Description) to ensure compatibility with Civil 3D as shown fig.2

Figure 2: Software Tools Used in Simulation

Road Network Model Development: The development of the road network model is carried out in a series of steps. Road network paths are digitized from Google Earth Pro, and the corresponding geographic coordinates (latitude, longitude) and altitude data are extracted using GPS Visualizer. These coordinates are then transformed into the Universal Transverse Mercator (UTM) coordinate system using latlong.net to ensure accurate representation in the Civil 3D environment. The transformed data is imported into Civil 3D, where a digital terrain model (DTM) is generated. Subsequently, the horizontal and vertical alignments of the road network are designed, adhering to relevant geometric design standards. Intersections are designed to facilitate smooth traffic flow and ensure safety. Finally, road assemblies, comprising lanes, shoulders, and medians, are created, and a corridor model is generated to represent the three-dimensional road structure. The horizontal and vertical alignments of the road network are designed, adhering to relevant geometric design standards. Intersections are designed to facilitate smooth traffic flow and ensure safety. Finally, road assemblies, comprising lanes, shoulders, and medians, are created, and a corridor model is generated to represent the three-dimensional road structure as shown in figure 3

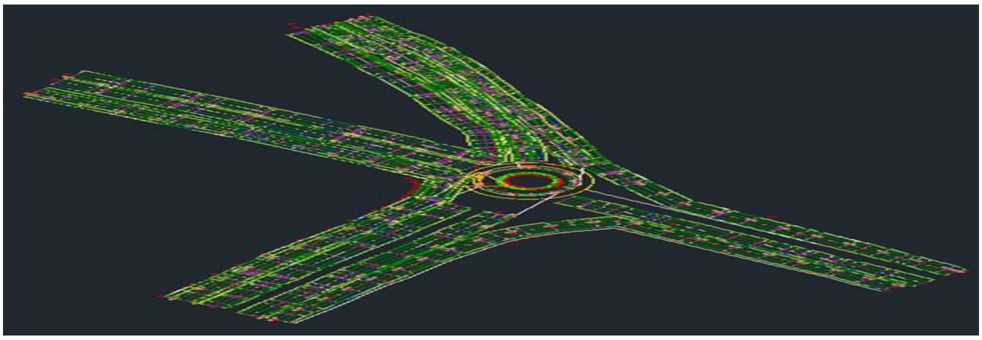

Figure 3: Road Network Modelling in Autodesk Civil 3D

Traffic Simulation Model Setup: The BIM-generated road network model is exported from Civil 3D in Industry Foundation Classes (IFC) format to ensure interoperability with the VISSIM simulation environment. The IFC file is then imported into VISSIM, where road links are established, and connectivity is ensured using connectors. To accurately model real-world driving behavior, reduced speed areas are defined at appropriate locations, such as free left-turn lanes. A variety of 2D and 3D vehicle models, representing different vehicle types (e.g., cars, buses, motorcycles), are incorporated into the simulation. The distribution of these vehicle models within the traffic stream is carefully assigned to reflect the actual traffic composition.

Simulation Configuration and Execution: The simulation is configured to accurately represent traffic conditions. This involves defining various vehicle types with their specific attributes (e.g., dimensions, performance characteristics) and specifying the composition of the traffic flow, including the proportion of different vehicle types. Design speeds for each vehicle type are adjusted to match observed field conditions. Vehicle inputs, representing traffic volumes at entry points, are defined based on available traffic count data. Vehicle routes are established using static route definitions to guide vehicle movements through the network. Traffic signals are configured, including signal phasing, timing, and coordination, based on field data and traffic management objectives. Signal heads are placed at appropriate locations within the network. The simulation is then executed in both 2D and 3D modes as shown in figure 4 performance. The model is further enhanced with additional elements, such as landscaping and bus stops, to improve its realism and facilitate the analysis of specific scenarios.

Figure 4: Model Enhancement and Visual Validation

RESULTS

Data Collection Results: The simulation gathered key traffic parameters such as acceleration (0.90–1.81 m/s²), deceleration (2.24–4.81 m/s²), and vehicle speeds (6.34–9.83 m/s), indicating a range from moderate to constrained traffic flow. Occupancy values at certain points exceeded 43%, signifying congestion buildup. Queue delays ranged from 0.06 to 0.41 seconds, identifying varying levels of lane saturation as shown in figure 5

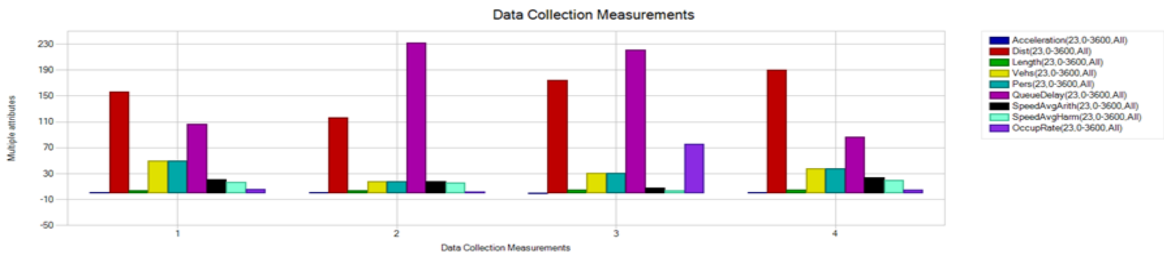

Figure 5: Bar chart of speed vs. occupancy

Delay Results: The simulation revealed a gradual increase in overall network delay. Total vehicle delay rose from 9,737 s to 12,027 s; stop delay increased from 6,791 s to 8,161 s. Vehicle stops went up from 4,231 to 5,122, and percentage delay peaked at 28%. These results reflect the effects of increased traffic density and signal inefficiency as shown in figure 6

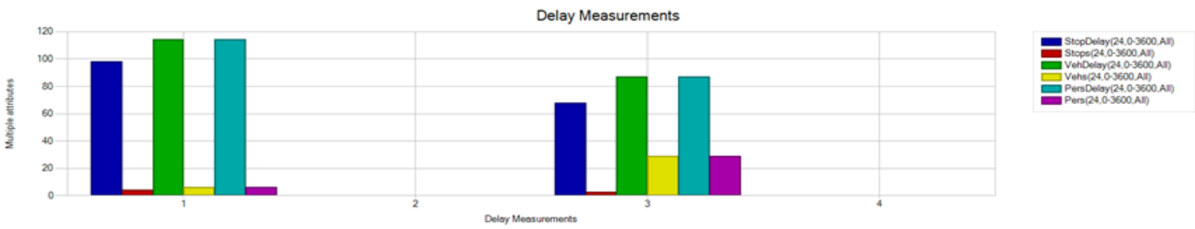

Figure 6: Delay vs. simulation interval chart

Vehicle Travel Time Results: With each simulation run, vehicle travel time increased—from 113,107 s to 130,000 s. The number of vehicles completing trips also rose (from 2,244 to 2,500), indicating heavier usage. The average travel time per vehicle increased from 50.39 s to 55.78 s, suggesting reduced system efficiency under higher traffic loads.

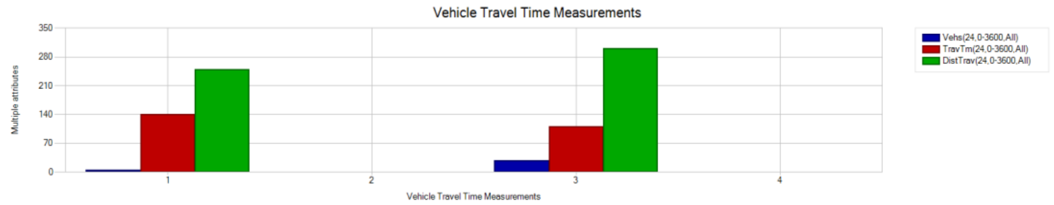

Figure 7: Bar chart of Vehicle Travel Time Results

Queue Counter Results:

Average queue lengths ranged between 10.25 m and 128.65 m, while maximum queues reached up to 198.42 m, highlighting heavy congestion at specific points. Queue stops ranged from 163 to 761, with the highest values near intersections, suggesting potential geometric or control issues.

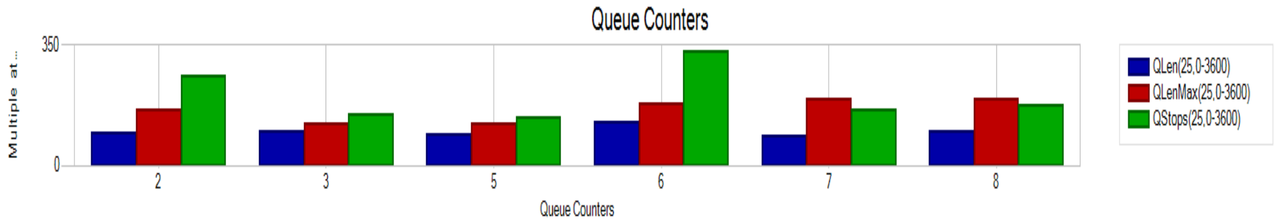

Figure 8: Bar chart of Queue Counter data visualizing QLen, QLenMax, and QStops.

Discussions:

Interpretation of Traffic Patterns:Data from collection points highlighted inconsistent flow patterns across the network. Speeds as low as 6.34 m/s combined with occupancy rates above 43% confirm congestion. Queue delays validate the presence of upstream flow restrictions. Incorporating real-time data into the simulation supports adaptive geometry and signal control modifications.

Implications of Delay Patterns:The steady rise in vehicle and stop delays underscores the importance of real-time traffic control. Delay increases signal the inefficiency of fixed-time signals under variable demand. Implementing adaptive signal control could significantly reduce these figures and improve throughput.

Travel Time Analysis:While the network supported increasing volumes, the efficiency suffered. The rising average travel time per vehicle indicates a nearing threshold of saturation. This stresses the importance of preemptive design interventions, especially in high-growth urban corridors.

Queue Length Insights:Excessive queue lengths and stop counts at certain junctions pinpoint areas needing optimization. These data points are ideal candidates for implementing signal prioritization or geometric changes such as dedicated turning lanes.

Benefits of BIM-VISSIM Integration:

The study validated that combining BIM's accurate 3D modeling with VISSIM's behavior-based simulation provides a reliable environment for diagnosing traffic problems and testing solutions before implementation. This digital twin approach fosters proactive, data-informed decision-making in traffic management and infrastructure planning.

Conclusion:

The integration of BIM and VISSIM offers a powerful tool for simulating and optimizing traffic flow in complex urban environments. By addressing the limitations of current research and focusing on the specific challenges of mixed traffic conditions, this study contributes to the development of more effective strategies for accident mitigation and improved urban mobility. The proposed methodology provides a framework for creating detailed and accurate traffic simulation models that can be used to evaluate different traffic management scenarios and inform decision-making. Future research could explore the application of advanced optimization techniques, such as machine learning and artificial intelligence, to further enhance the efficiency and effectiveness of traffic management strategies.

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