3D visualization of California's road network on Google Earth

Data Rizz

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ABSTRACT

The primary goal of our project was to enhance the visualization and analysis of California's expansive road network through an interactive 3D model on Google Earth. The key idea was to synthesize various datasets, including OpenStreetMap for roadways, FABDEM for elevation, and local traffic data, to create a comprehensive tool that could improve urban planning and traffic safety. The project's pinnacle achievement was the development of a scalable model that displayed a high degree of accuracy in representing traffic congestion, bottlenecks, and accident hotspots, all within a user-friendly interactive interface.

1 Introduction

1.1 Background

The transportation infrastructure is a vital component of any state's economic backbone, and California, being one of the most populous states in the US, has one of the most complex and busy road networks. Efficient, safe, and reliable transportation routes are crucial for the mobility of goods and people. As urban areas expand and traffic congestion becomes a more pressing issue, there is a growing need to analyze, optimize, and visualize the existing infrastructure to ensure safe and smooth transportation.

1.2 Motivation

With the increasing population and traffic congestion in California, ensuring the safety and efficiency of its road network is paramount. By visualizing the state's road network in 3D, we aim to provide a comprehensive view of traffic patterns, high-risk zones, and bottlenecks. This visualization would serve as a valuable tool for urban planners, local authorities, and the general public, making them aware of potential hazards and areas in need of improvement. The 3D model also aims to facilitate more informed decision-making regarding road expansions, traffic management, and urban planning.

1.3 Main Contribution

Our project's primary contribution is the development of an interactive 3D model of California's road network, integrated with Google Earth. This model incorporates various data layers, traffic congestion, accident hotspots, and roads with elevations. The use of advanced visualization techniques allows for a detailed and dynamic representation of the road network, providing insights that are not easily discernible from traditional 2D maps. Additionally, our project introduces data integration of road networks[OSM dataset link] , elevation data [DEM dataset link] , digital surface model [DSM dataset link]

1.4 Overview of Results

The results of our project demonstrate the effectiveness of 3D visualization in understanding complex road networks. Preliminary findings indicate that the 3D model significantly enhances the ability to identify problem areas, such as regions with high accident rates or severe traffic congestion. The model also reveals the impact of various factors like road design and traffic signals on overall traffic flow. These insights are instrumental in proposing targeted interventions for traffic management and road safety improvements.

1.5 Structure of the Report

The remainder of this report is organized as follows: The next section provides a detailed literature survey, placing our work in the context of existing research. Following that, we delve into the methodology, describing the technical aspects of creating the 3D visualization and the data sources used. The subsequent section presents a thorough evaluation of the model, including the datasets, performance metrics, and analysis of the results. The report concludes with a summary of our findings, a discussion of potential future directions for this research, and a detailed breakdown of each author's contributions to the project. References are provided at the end of the report to support our research and findings.

2 Literature survey

In preparation for this project, a literature survey is vital to ground the work in existing research and to glean insights from similar initiatives. This survey will be segmented into three topical pillars that form the project's foundation: 3D Visualization Road Network, Highlighting Accident-Prone Areas, and Areas of Frequent Traffic Congestion. The ensuing collection of scholarly papers mentioned below will be instrumental in guiding the project through proven methodologies, innovative approaches, and analytical techniques

2.1 3D Visualisation Road Network

2.1.1 An Automatic Approach to Extracting Large-Scale Three-Dimensional Road Networks Using Open-Source Data

2.1.1.1 The study[1] presents a 3D road network extraction method aligning with terrain and road engineering standards for large-scale urban environments.

2.1.1.2 It corrects nodes and edges with excessive grades and enhances topological accuracy, particularly for features like tunnels and interchanges, ensuring they match engineering specifications.

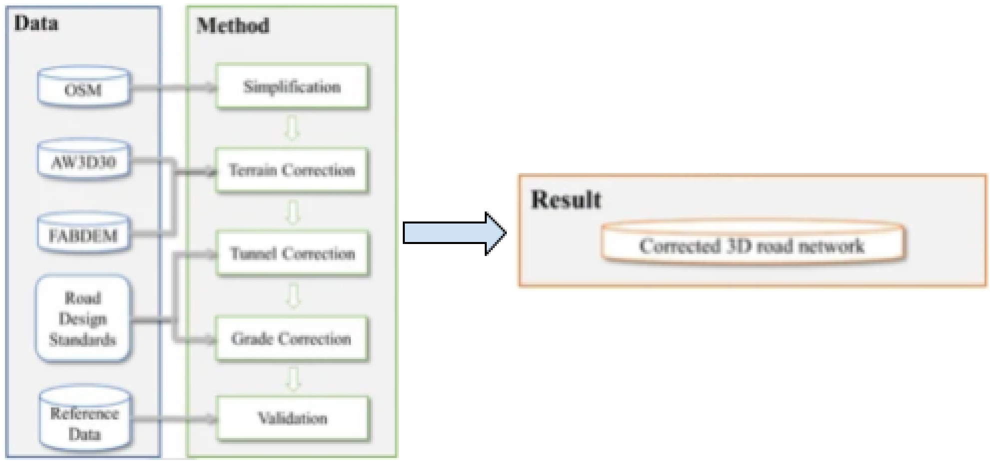

Figure 1: High-Level Overview of 3D road network

2.1.1.3 The method capitalizes on multi-source data, yielding accurate and reliable elevation datasets. Validation across three cities showed a mean absolute error (MAE) of 1.94 m, confirming the approach's efficacy.

2.1.1.4 The study's tools and code are aligned with OpenStreetMap standards, broadening its utility for urban research and applications such as traffic congestion modeling and urban planning.

Relevance to the Topic : This paper is highly relevant as it directly addresses the challenges of creating accurate 3D visualizations of urban road networks, which is a core component. The methodologies for correcting and validating 3D road network data can be integral to our approach, especially for analyzing traffic congestion and accident-prone areas. The study's techniques for ensuring data accuracy and topological correctness can significantly contribute to the reliability of our visualizations and analyses.

2.1.2 Automatic Generation of Large-scale 3D Road Networks based on GIS Data

2.1.2.1 The study[2] proposes an automated method to generate complex, large-scale 3D road networks using open-source GIS data, including satellite imagery, elevation data, and 2D road center axis data.

2.1.2.2 The paper[2] introduces a semantic structure for road networks to achieve high-detail and well-formed networks within a 3D scene.

2.1.2.3 The paper[2] applies method segments elevation data and applies smooth processing to create realistic road surfaces, supporting the automatic generation of diverse intersection types.

2.1.2.4 The Fig 2 displays the validation done by the author[2] for the methods he suggested.

Fig 2: (a)3D intersections and reconstruction of road generated and (b)displays the validation done

Relevance to the Topic: The paper uses GIS data to generate 3D networks, which can be used in our project for generating california road network in high-detailed manner whether it is intersection or mountain area using authors method. Also as suggested by author[2] this approach can also be used for traffic simulation of california.

2.1.3 A General Framework for 3-D Parameters Estimation of Roads Using GPS, OSM and DEM Data

2.1.3.1 The study[3] presents a method to estimate road inclinations using statistical modelingOpenStreetMap (OSM) and ASTER GDEM2 data to account for map inaccuracies.

2.1.3.2 This paper[3] utilizes sigma-points for dynamic sampling and prediction of state-space vectors and sequential processing of sensor data for correction, focusing on road engineering standards.

2.1.3.3 This paper[3] uses triangulated irregular correction(TIN) modeling for DEM to create a continuous surface that informs the filtering solution.

2.1.3.4 As a result, this paper is able to estimate road inclination accurately and refines from terrain models while enhancing OSM database automatically with estimated road segment slopes.

- **Relevance to the Topic:** This research is relevant to our project as it demonstrates a practical implementation of integrating various data sources to enhance road network data with elevation information[20]. The techniques for road slope computation and the fusion of GPS, OSM, and DEM data can be adapted to our project to accurately visualize 3D road networks and analyze traffic congestion and accident-prone areas[21][22].

2.1.4 BIM AND GIS: WHEN PARAMETRIC MODELING MEETS GEOSPATIAL DATA

2.1.4.1 The paper[6] discusses the potential of integrating BIM and GIS technologies for AECOO (Architecture, Engineering, Construction, Owner and Operator) projects. BIM (Building Information Modeling) is a process for creating and managing digital representations of physical and functional characteristics of places. GIS (Geographic Information System) is a tool that allows users to create, visualize, and analyze spatial data.

2.1.4.2 The authors argue that BIM and GIS are complementary technologies that can be used to improve the efficiency and effectiveness of AECOO projects. BIM can be used to create detailed 3D models of buildings and infrastructure, while GIS can be used to analyze and manage geospatial data such as land use, topography, and transportation networks.

2.1.4.3 The paper presents several case studies that demonstrate the benefits of integrating BIM and GIS. In one case study, BIM and GIS were used to coordinate the design and construction of a new airport. This collaboration helped to avoid costly conflicts between different design disciplines.

2.1.4.4 In another case study, BIM and GIS were used to manage the maintenance of a large infrastructure project. This integration allowed for the creation of a centralized database of asset information that could be used to track and schedule maintenance activities.

2.1.4.5 The authors conclude that the integration of BIM and GIS is a promising trend that has the potential to revolutionize the AECOO industry. They call for further research and development to improve the interoperability of these two technologies

- **Relevance to the Topic:** This paper converts the GIS data into a 3D visualized Model. One of the outcomes of our topic is to visualize road networks in 3D space. Hence the paper helps in achieving the goal.

2.1.5 Automating 3D graphics generation using GIS data - Terrain and Road reproduction

2.1.5.1 The paper[7] explores the use of GIS data to generate 3D environments. Specifically, it focuses on the generation of terrain and roads. The author evaluates different types of GIS data and their use cases in the context of 3D graphics generation.

2.1.5.2 The paper also presents a software prototype that can be used to generate 3D environments from GIS data. The prototype uses a novel technique for extracting roads from LiDAR data. This technique is based on shape analysis of LiDAR-backed road cross-sections.

2.1.5.3 The prototype was evaluated on a dataset of real-world data. The results show that the prototype can generate satisfactory terrain and roads. However, the texturing of the terrain was observably flawed as a consequence of the choice of source data. The road extraction typically worked well, allowing for a visually pleasing and correct reproduction of roads.

2.1.5.4 The author concludes that the use of GIS data for the purpose of generating 3D environments is a promising area of research. The prototype developed in this thesis demonstrates the feasibility of this approach. However, further research is needed to improve the quality of the generated 3D environments.

- **Relevance to the Topic:** This paper automates the process of converting the GIS data into a 3D visualized Model. This will help us in case of scalability if we want to apply this project to a larger geographical area.

2.1.6 Realistic urban road network modeling from GIS data

2.1.6.1 The paper[8][18] presents a method for reconstructing urban road networks with respect to important geometric constraints of real-world roads. The authors start with GIS data, which is often sampled and inaccurate. They then propose a mathematical road surface model based on road axes and properties. They also introduce a process to produce a mesh representing the roads and the terrain so that roads and terrain match.

2.1.6.2 The authors evaluate their method on a dataset of real-world data. The results show that their method can reconstruct realistic urban road networks. The reconstructed roads are accurate and have the correct geometry.

2.1.6.3 The authors conclude that their method is a promising tool for reconstructing urban road networks. They call for further research to improve the accuracy and efficiency Of their method.

- **Relevance to the Topic:** This paper helps in converting the GIS data into road Network Model. This can help us to build the network to analyze the traffic.

2.1.7 Fast 3D Visualization of Road Product Models

2.1.7.1 The implementation of the visualization software, RoadVi, and its integration into the road life-cycle environment are covered in detail. The paper concludes with a discussion on the potential of using Java applets for visualization, which would eliminate the need for local software installations and allow for dynamic, web-based visualization of road models.

2.1.7.2 This paper[4] is relevant for any project aiming to develop comprehensive 3D visualizations of road networks, particularly those that require the integration of complex datasets and aim to provide a tool for a wide range of users. The methodologies and technologies discussed in the paper could inform the development of scalable, efficient, and user-friendly visualization tools within the context of big data management and infrastructure planning.

- **Relevance to the Topic:** 3D Visualization of Roads: The paper[4] discusses the development of 3D visualization software for roads, which is directly related to the project's goal of creating a 3D visualization of California's road network.
- Integration with Road Product Models: The paper[4] mentions the integration of visualization software with road product models, which gives us insights into how to structure our datasets and integrate them into a comprehensive visualization system.

2.1.8 Template-Based 3D Road Network Modeling

2.1.8.1 The paper[5] presents a novel method to address the limitations of existing 3D road modeling techniques, specifically their inflexibility, subpar visual effects, and inefficiency when dealing with large-scale models. The authors propose a template-based approach to construct and simulate 3D road networks by pre-processing GIS data to enhance the accuracy of road path models and match them to the terrain.

2.1.8.2 The paper[5] focuses on a method for 3D road modeling based on road GIS data, which is directly applicable to your project's objective of creating a 3D visualization of traffic patterns and high-risk zones.

- **Relevance to the Topic:** Performance and Scalability: The paper[5] discusses the performance and scalability of the proposed method, addressing the challenge of visualizing extensive road networks without compromising on efficiency.
- Simulation of Traffic Conditions: The paper[5] not only discusses road modeling but also the simulation of traffic conditions, which aligns with our goal to display traffic bottlenecks and areas of frequent congestion.
- Real-World Application and Testing: The method has been tested using real-world data, demonstrating its practical application, which can provide confidence in its relevance to our own real-world application.

2.1.9 Template-Based 3D Road Network Modeling

2.1.9.1 The authors address the limitations of traditional two-dimensional roadway design processes and propose an innovative single-stage method for 3D roadway design utilizing visualization techniques. This method integrates both horizontal and vertical alignment designs, thereby reducing the risk of critical design errors that are not apparent in 2D designs, such as the underestimation of curve sharpness due to illusions created at the intersection of vertical valley curves and sharp horizontal curves.

2.1.9.2 The methodology presented by Karri and Jha involves using elements like 3D lines and splines to create a roadway design that passes through identified control points on a given terrain. Mathematical formulations are provided to calculate these 3D lines and splines, and the paper emphasizes the advantages of 3D visualization techniques in identifying errors that cannot be spotted in traditional horizontal or vertical alignments. This approach allows designers to adjust the roadway geometry more effectively by adding or modifying control points, thereby improving the accuracy and safety of the road design.

2.1.9.3 This paper is relevant to our project aimed at visualizing complex road networks in 3D as it provides a potential framework for improving design accuracy and efficiency through advanced visualization techniques. The proposed method's ability to create more intuitive and error-free road designs by considering all dimensions simultaneously is particularly beneficial for large-scale visualization projects, such as the comprehensive visualization of California's road network

- **Relevance to the Topic:** 3D Roadway Design:- It proposes a methodology for designing roadways in three dimensions, which directly applies to our project's need to visualize road networks in 3D.
- Visualization Techniques: The authors advocate the use of visualization techniques to identify and correct potential errors in road design, which is beneficial for ensuring the accuracy and safety of the road network visualization in our project.
- Design Elements: The paper discusses the use of 3D straight lines and spline curves as design elements in creating roadways, which can provide a framework for how to approach modeling different road types in California.

2.2 Highlight Accident Prone Area

2.2.1 To Find Accident Prone Zones and Nearest Health Facility by GIS Based Spatial and Network Analysis in Amritsar, Punjab

2.2.1.1 The study[10] employs GIS for real-time monitoring and management of road traffic accidents (RTAs).

2.2.1.2 It identifies accident-prone areas using spatial analysis and locates the nearest health facilities through network analysis.

2.2.1.3 Data from 2015, including accident specifics, were analyzed using Moran's I for spatial clustering and cluster and outlier analysis for hotspot identification.

2.2.1.4 Fortis Hospital was identified as the nearest health facility to severe accident clusters.

- **Relevance to the Topic :** This study's[10] approach to identifying accident-prone zones using GIS-based spatial analysis aligns with the project's goal to analyze accident-prone areas in urban road networks.
- The network analysis for locating health facilities can be integrated into the project to enhance emergency response strategies.
- Techniques from this paper[10] could be applied to the project to visualize accident hotspots and related healthcare facilities, contributing to smarter city planning and traffic safety management

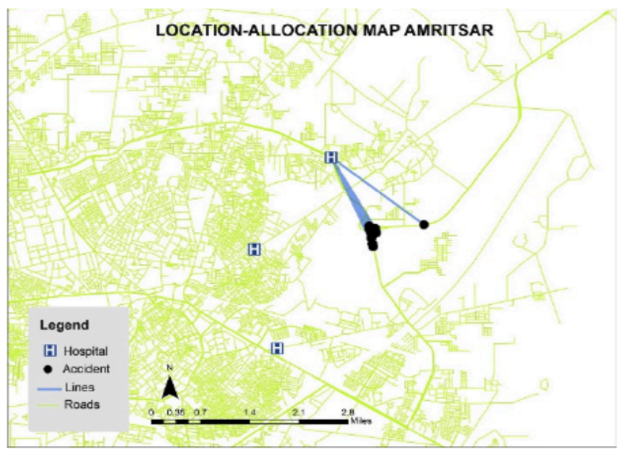

Figure 3: Location allocation output

2.2.2 Big Data Analytics and Visualization with Spatio-Temporal Correlations for Traffic Accidents

2.2.2.1 The paper[9] proposes a novel accident occurrences analytics and visualization method in spatio-temporal dimension to predict when and where an accident-prone crash type will occur.

2.2.2.2 The method is applied to a dataset of 38,674 accident records from Xiamen City in China, and the results are illustrated through two case studies in multiple road segments.

2.2.2.3 The findings of accident occurrences analysis and visualization would not only help the traffic police department implement instant personnel assignments among simultaneous accidents, but also inform individual drivers about accident-prone sections and the time span which requires their most attention.

- **Relevance to the Topic :** The paper's[9] exploration of spatio-temporal correlations aligns seamlessly with our project's goal of adopting a dynamic approach to understanding traffic patterns. This resonates with our emphasis on real-time analysis and proactive congestion management.
- Visualization Synergy: The paper's[9] emphasis on visualization techniques perfectly aligns with our project's objective of creating a comprehensive representation of traffic congestion. This synergy strengthens our approach to 3D visualization, enhancing our capacity to communicate complex traffic data effectively.
- The paper[9] introduces specific techniques or algorithms for spatio-temporal analysis, it could significantly fortify our project's analytical capabilities. This potential addition, coupled with insights into big data analytics, promises methodological enhancements that align with our project's data-driven focus and diverse data sources.

2.2.3 Overview of the identification of traffic accident-prone locations driven by big data

2.2.3.1 The management of road safety has evolved from focusing on accident-prone locations to road network safety management, but the theories, methods, and techniques of accident-prone location identification are not yet systematic and perfect.

2.2.3.2 This paper[11] systematically reviews the existing research theories and methods in terms of common identification indicators, identification methods, and future development directions, and analyzes the hot issues and challenges faced by big data-driven research.

2.2.3.3 The current research hotspots can be summarized as GIS, cluster analysis, and expressway, and clarifying future research priorities and breakthrough directions can provide support for further improving road safety and enriching the theoretical system of traffic safety.

- **Relevance to topic:** The paper[11] provides a comprehensive overview of leveraging big data for the identification of traffic accident-prone locations. By delving into methodologies driven by advanced analytics, machine learning, and data mining, it offers insights into the proactive identification and mitigation of potential accident hotspots.
- It delves into advanced analytics, machine learning, and data mining techniques, providing insights into the methods employed for proactive identification and mitigation of potential accident hotspots.

2.3 Highlight Areas of Frequent Traffic Congestion

2.3.1 Traffic congestion analysis at the turn level using Taxis' GPS trajectory data

2.3.1.1 The paper[12] proposes an approach for detecting traffic congestion at the turn level using taxis' GPS trajectories. The approach analyzes features of taxis' GPS trajectories and identifies valid trajectory segments to detect congested road segments of three different intensities.

2.3.1.2 The proposed approach is effective in detecting congestion of different intensities and analyzing congestion at the turn level. The approach is demonstrated using taxis' GPS trajectory data and a road network in Wuhan, China.

2.3.1.3 The proposed approach has advantages over other approaches in analyzing turn-level congestion. The paper[23] compares the results of the proposed turn-level congestion detection approach with the speed fluctuations of each turn at the Zhongnan Intersection and identifies some advantages of the proposed approach in analyzing turn-level congestion.

- **Relevance to the topic:** Fine-Grained Traffic Information: The paper[12] emphasizes the importance of sensing turn-level traffic conditions for providing detailed and fine-grained information. This aligns with our project's goal of identifying accident-prone locations with precision.
- GPS Trajectory Analysis: The proposed approach utilizes GPS trajectory data from taxis to detect and analyze traffic congestion at the turn level. This methodology could be relevant to our project's exploration of big data for understanding traffic patterns and accident-prone areas.
- Cost-Effective Approach: The paper[23] addresses the challenge of high data collection costs in previous studies. Our project can benefit from the proposed approach that detects congestion at a finer-grained level while covering a larger area and at a lower cost, contributing to the practicality of implementation.

2.3.2 A Survey of Road Traffic Congestion Measures towards a Sustainable and Resilient Transportation System

2.3.2.1 The study analyzes traffic congestion's impact on sustainability and reviews current congestion measurement methods.

2.3.2.2 Using Chicago's real-time traffic data, various congestion metrics were compared, revealing consistent trends despite different measures.

2.3.2.3 The study emphasizes the complexity of measuring congestion and the need for standardized methods.

2.3.2.4 Future research directions include resilient traffic management systems and analysis of non-recurring congestion.

- **Relevance to the Topic:** This paper's[13] comprehensive review of congestion measures aligns with your project's aim to incorporate traffic data in 3D road network visualization.
- Insights from this study can inform the development of more sustainable and efficient traffic analysis methods within your smart city framework.
- The discussed methodologies and future directions can guide your project's approach to analyzing traffic congestion and integrating it with road safety analyses.

2.3.3 Big Data Analysis and Prediction of Traffic in Los Angeles

2.3.3.1 The study[14][24] analyzes traffic congestion's impact on sustainability and reviews current congestion measurement methods.

2.3.3.2 It utilizes Hadoop for data management, Azure ML for traffic predictions, and Business Intelligence tools for data visualization.

2.3.3.3 The research assesses traffic predictions using metrics such as accuracy, precision, and recall.

- **Relevance to the Topic:** Provides a methodology for analyzing and predicting traffic patterns, essential for managing congestion.
- Demonstrates the use of Big Data tools and machine learning, which can be applied to traffic

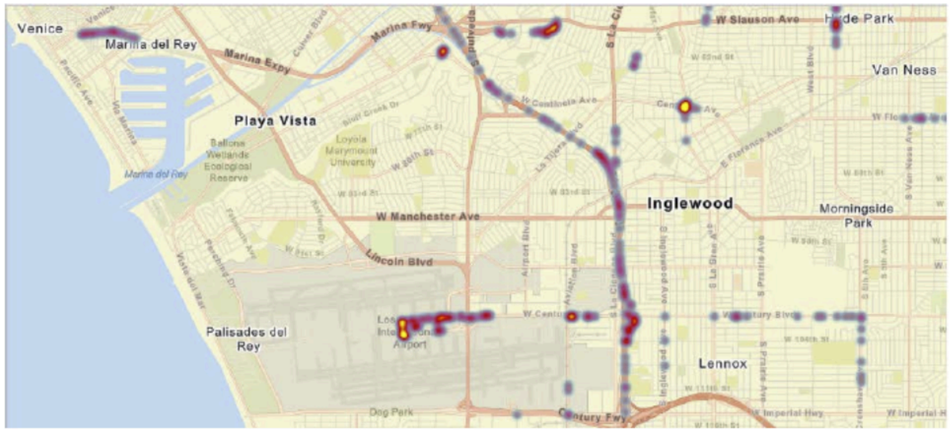

Figure 4: Jams tracked from users' devices around LAX at 6:30 - 7am

3 METHODOLOGY

3.1 High-Level Overview

The methodology of our project revolves around the integration of geospatial data to create a 3D visualization of California's road network. Key technologies employed include:

- **Geographic Information System (GIS):** Utilized for mapping and spatial analysis.
- **Python Libraries:** We used libraries such as OSMnx for retrieving, constructing, and visualizing street networks, and Rasterio and GDAL for processing raster data.
- **Google Earth and FABDEM Data:** For elevation[20] and topographical details to enhance the 3D model.

Main Components

In this section, we will delve into the specifics of our project's methodology, focusing on how we collected and processed the data, and the techniques we employed to develop the 3D model[15][16]. This will include a description of the data sources used, such as road network data from OpenStreetMap and elevation data from FABDEM datasets, and the processes involved in integrating these datasets. Additionally, we will elaborate on the technical steps involved in creating the 3D visualization, highlighting the use of Python libraries and the integration of this data with Google Earth for an enhanced geographic representation.

3.1.1 Data Collection

3.1.1.1 Road Network Data: We utilized OpenStreetMap (OSM), accessed through the OSMnx Python library, to obtain comprehensive data on California's road network. This dataset provided detailed information on road types, layouts, and connectivity, crucial for constructing an accurate representation of the state's transportation infrastructure.

3.1.1.2 **Elevation Data:** The elevation data was sourced from the FABDEM dataset. This high-resolution digital elevation model (DEM) offered the necessary topographical details to create a realistic 3D landscape on which the road network was overlaid.

3.1.2 Data Processing

3.1.2.1 **Elevation Data Handling:** Using the GDAL and Rasterio libraries, we processed the elevation data to align with the road network coordinates. This involved geospatial transformations and raster data manipulations to ensure seamless integration of the elevation data with the road network.

3.1.2.2 **Network Analysis and Enhancement:** NetworkX, a powerful library for network analysis, was employed to analyze the road network for various aspects such as traffic flow, congestion points, and potential accident hotspots. This analysis helped in enhancing the road network data with additional attributes relevant to traffic dynamics and safety.

3.1.3 3D Modeling Techniques

3.1.3.1 **Integration with Google Earth:** The processed and enhanced road network, along with the elevation data, was then integrated into Google Earth. This step was pivotal in transforming the traditional 2D GIS data into a dynamic 3D model[17][19], enabling users to visualize the road network in the context of the actual landscape.

Figure 5 (a): 3D road networks

Figure 5 (b): Traffic Congestion roads

3.1.3.2 **Visualization and Interactivity:** Advanced visualization techniques were employed to render the network in 3D. Special attention was given to interactive features, allowing users to explore different layers of data such as traffic densities, accident hotspots, and elevation profiles. These interactive elements make the model not just a static representation but a tool for exploration and analysis.

3.1.3.2.1 Elevation profiles: In the visualization, particular emphasis is placed on the interactive elevation profiles, which detail the vertical dimension of roadways as they connect to larger highways. Users can seamlessly navigate through the road network to extract precise elevation data.

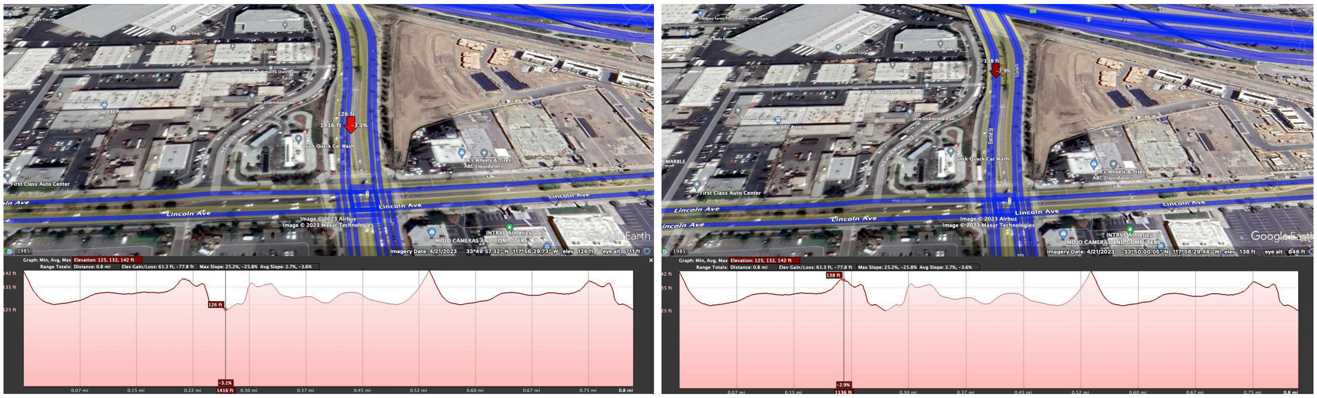

Figure 6: (a) and (b) Detailed Elevation Analysis demonstrates a descent from 138 ft to 126 ft

3.1.3.2.2 Traffic densities: Figure 6(a) and 6(b) enhances our 3D model with a traffic density layer, where the deepening red hue along Florence Avenue signifies heavier congestion, correlating with known bottleneck locations. The accompanying table pops up upon interaction, revealing specific data such as the type of bottleneck as shown in Figure 7, its frequency, and duration. This intersection of 3D visualization and real-time traffic data empowers urban planners with actionable insights to address congestion and improve traffic flow.

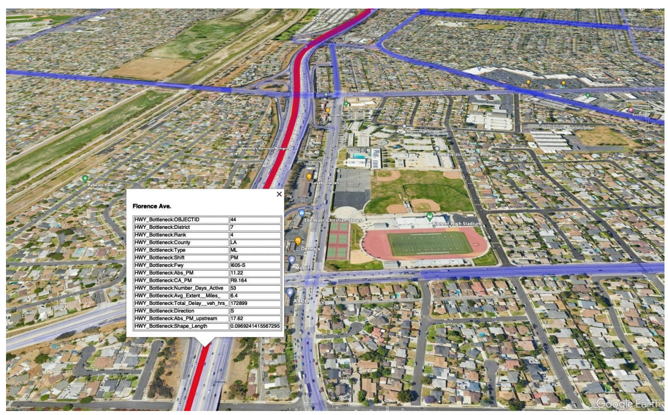

Figure 7 : Traffic Density and Bottleneck Visualization

3.1.3.2.3 Accident hotspots: Figure 7 highlights accident-prone zones along a key stretch of road, where each red triangle represents a hotspot. The clustering of symbols indicates sections with higher frequencies of accidents, drawing attention to potential safety concerns. This visual tool is integral for traffic safety analysis, providing a clear indication of where interventions such as improved signage, road modifications, or increased traffic enforcement may be necessary to enhance road safety.

Figure 8: Accident Hotspots Visualization

4 Evaluation and Results

Our evaluation focused on two primary performance metrics:

4.1 **Scalability**: We assessed the model's scalability by testing the consistency of visualizations from a small bounding box (bbox) to a larger area within the same location. This was crucial to ensure that the model could handle different scales of geographic data without losing detail or accuracy.

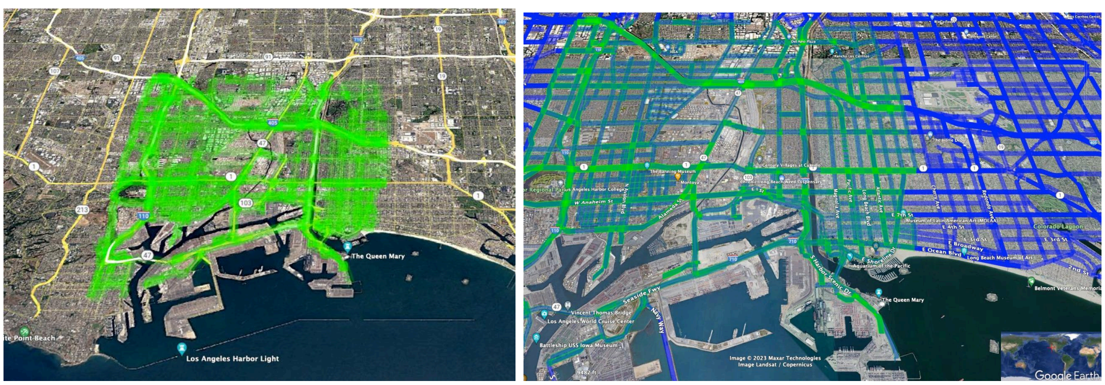

Figure 9: Scalability Demonstration - (a) Small Bounding Box and (b) Expanded Area

Our performance evaluation of the 3D visualization model's scalability was rigorously conducted to ensure that as the geographic scope expands, the model retains its consistency and accuracy. In Figure 9(a) , we observe the model's detailed rendering of traffic patterns within a small, concentrated bounding box, delineated in green. This demonstrates the model's precision in handling granular data. Transitioning to Figure 9(b), the model illustrates its scalability by encompassing a larger area represented in blue. Despite the increase in scope, there is no compromise on the clarity and detail of the traffic data, suggesting that the model adeptly handles data expansion.

Figure 10 further cements this finding with a graph that quantitatively measures scalability: the data size, quantified by the count of nodes and edges, scales linearly with the increase in region size. This proportional scalability is indicative of the model's robustness, ensuring that data integrity and visual quality remain intact even as the visualization extends to encompass larger geographic regions. Such scalability is imperative for versatile applications, enabling thorough analysis at multiple spatial resolutions, ranging from the intricacies of local street-level patterns to the expansive requirements

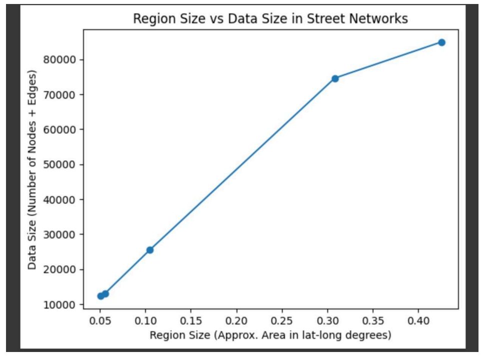

Figure 10: Data Size Scaling with Region Size

4.2 **Correctness**: To verify the correctness of our data integration, we overlaid our visualization on Google Earth Pro. The key indicator of success was the precise overlap of our model with the existing infrastructure on Google Earth, demonstrating that our elevation and traffic data accurately reflected the real-world environment.

Figure 11: Road Network Visualization (a) Without Google Earth Layer (b) With Google Earth Layer

In the evaluation of our visualization model's correctness, Figure 11(a) and 11(b) offer a comparative view before and after the integration of Google Earth imagery. Figure 11(a) depicts the 3D visualization derived solely from the OpenStreetMap dataset, with the road network prominently highlighted in blue, serving as a standalone representation of the infrastructure. Transitioning to Figure 11(b), we see the same visualization overlaid onto the detailed backdrop of Google Earth. The precise alignment of the blue road overlays with the actual streets and highways captured in the satellite imagery validates the geospatial accuracy of our model, confirming the successful integration of multiple data layers and the fidelity of our visualization to real-world geography. This juxtaposition not only demonstrates the correctness of our approach but also underscores the model's potential as a reliable tool for urban planning and traffic management.

These metrics were pivotal in validating the reliability and accuracy of our 3D visualization model, ensuring it serves as an effective tool for urban planners and traffic safety officials.

4.3 Analysis

Our findings reveal that certain stretches of the road network have experienced a significant increase in traffic congestion, as evidenced by the transition from white lines in 2011 to red lines in 2020. These areas, particularly those marked with red danger signals, suggest a correlation between increased traffic congestion and the frequency of accident hotspots. The visualization confirms our hypothesis that road segments with heightened congestion are more prone to accidents. However, it also challenges the assumption that traffic bottlenecks remain static over time, showing that infrastructure changes and urban development can alter traffic dynamics significantly. This analysis provides urban planners with a visual tool to prioritize interventions in traffic management and infrastructure development to address the evolving patterns of congestion and enhance road safety.

Figure 12: Composite visualization of the road network data (in blue), juxtaposed with traffic congestion data from two distinct years—2011 (in white) and 2020 (in red), accident hotspots (red warning symbols).

5 Conclusion

This project concluded with several key findings: First, the integration of multi-source geospatial data into a single 3D visualization model was successful, as evidenced by the accurate overlay of the model with real-world geography. Second, the model's scalability was validated, with its performance remaining consistent across varying scales of geographic data. Lastly, the interactive features provided clear insights into traffic density changes and accident hotspots, supporting urban planning and infrastructure development efforts. For future research, there is potential to incorporate real-time traffic data, enhancing the model's utility for immediate traffic management. Additionally, exploring the integration of machine learning algorithms could predict traffic changes and suggest proactive measures for traffic and safety management.

6 Author Contributions

Shrey Sinha: Led the data collection process, orchestrating the sourcing and integration of OpenStreetMap and FABDEM datasets. Also managed the documentation and reporting, ensuring that the project's findings were clearly communicated and supported by visual evidence.

Anish More: Focused on the data processing and analysis aspect, handling the elevation data alignment and ensuring the accuracy of traffic and accident data. Played a pivotal role in the implementation of scalability tests and the optimization of the model's performance across different geographic scales.

Ajay Wayase: Took charge of the project's technical infrastructure, setting up the visualization platform on Google Earth and ensuring seamless integration of the various data layers. Contributed to the development of the interactive features that allow for exploration of traffic densities, accident hotspots, and elevation profiles.

Akash Bilgi: Was instrumental in the evaluation phase, designing the performance metrics and conducting a thorough analysis of the model's correctness and scalability.

Siddhant Poojary: Contributed to the development of the interactive features that allow for exploration of traffic densities, accident hotspots, and elevation profiles.

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