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Traffic Congestion Analysis and Route Optimization in an Urban Road Network Using Geographic Information System (GIS)

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Abstract: Traffic congestion is a critical challenge in urban transportation systems leading to longer travel times, higher fuel consumption, and increased environmental pollution. This study examines traffic congestion along the major urban road corridor in Thiruvananthapuram, Kerala, India, by Geographic Information Systems (GIS). Travel time data were collected from Google Maps under varying conditions, including weekdays, weekends, holidays, festivals, in different weather conditions, and special events, to capture temporal and situational variations in traffic flow. The collected data were analyzed to identify congestion zones based on speed across different road segments. QGIS software was utilized to perform Optimal Route Analysis by Contraction Hierarchies (CH) within the study area using the OpenRouteService (ORS) Directions API with the driving car profile, based on OpenStreetMap road network data. The study demonstrates that GIS provides an effective framework for traffic congestion analysis, route optimization, supporting improved urban traffic management and planning.
Keywords: Travel Time, Optimal Route Analysis, Traffic Management, Geographic Information System.

I. INTRODUCTION

Traffic congestion has emerged as one of the most significant challenges in rapidly urbanizing cities particularly in developing countries, where increasing vehicle ownership, limited road capacity, and unplanned land use place substantial pressure on existing road networks. Persistent congestion results in increased travel time, higher fuel consumption, environmental pollution, and economic losses, while also negatively affecting emergency response and overall urban mobility. Geographic Information Systems (GIS) have become an effective tool for analyzing urban traffic conditions due to their ability to integrate spatial and non spatial data, perform network based analyses, and visualize congestion patterns across complex road networks[7]. Several studies have demonstrated the use of digitized road networks, travel time estimation from Google Maps, and speed based congestion classification to identify traffic congestion hotspots in cities such as Bhopal [7], Coimbatore [6], and Attingal [2]. In addition route optimization using OpenStreetMap (OSM) data and opensource routing engines such as OpenRouteService has gained importance for identifying shortest and fastest paths under varying traffic conditions [5]. Building on these approaches the present study analyzes traffic congestion along the selected Road Network, one of the road networks most affected by congestion in Thiruvananthapuram city, by segmenting the road network, estimating travel time and speed, identifying congestion zones, and determining optimal routes using Geographical Information System (GIS).

II. LITERATURE REVIEW

Several researchers have highlighted the importance of GIS in identifying and mapping traffic congestion zones. [7] conducted a GIS based traffic flow analysis using real time open source data from Google Maps to identify congestion prone road segments in Bhopal city. The study involved digitizing the road network, estimating travel time and speed for individual road links, and classifying congestion levels based on speed reduction. The findings demonstrated that open source traffic data can serve as a reliable input for urban traffic congestion analysis. [6] applied GIS tools such as network analysis, overlay analysis, and kernel density estimation to evaluate traffic congestion spots in Coimbatore city. The results demonstrated that GIS based spatial analysis is effective in identifying congestion hotspots and supporting traffic diversion strategies to reduce congestion during peak hours.

Similarly, [2] examined traffic congestion in Attingal town using QGIS by mapping roadside friction points such as parking activity, pedestrian movement, and landuse characteristics. The study emphasized that integrating spatial factors influencing vehicle speed is crucial for effective congestion assessment and management in medium sized urban areas.

Speed and travel time have been widely used as primary indicators for congestion analysis. [1] employed a fuzzy inference system integrated with GIS to classify traffic congestion levels based on speed reduction, speed ratio, and average traffic speed. The study demonstrated that speed based indices are effective in identifying congestion hotspots and categorizing urban road segments into free flow, moderate, heavy, and blocked traffic conditions.

[3] analyzed traffic congestion on an arterial road in Indore city by evaluating average speed, traffic volume, and level of service. The findings indicated that speed reduction during peak hours is a direct indicator of congestion severity and can be used to identify critical bottlenecks in urban corridors. In addition, route optimization has emerged as a key component of urban traffic studies, particularly for identifying shortest and fastest routes under congested conditions. [4] assessed optimal routes in the complex traffic environment of Kolkata using GIS based network analysis and graph theory. The study highlighted that the shortest distance route is not always the fastest due to spatial variation in traffic speed, emphasizing the importance of travel time based routing in urban networks.

[5] focused on improving travel time estimation in OpenRouteService by integrating modeled traffic speed data derived from OpenStreetMap and other open data sources. The study demonstrated that incorporating traffic speed information significantly enhances routing accuracy and enables more reliable identification of fastest routes within urban road networks.

III. STUDY AREA

The study area comprises the road network extending from Chavadimukku Junction to Thampanoor, as shown in Fig. 1, forming an important urban corridor in Thiruvananthapuram, Kerala, India. Geographically, the area is located at approximately 8°29′7.80″ N latitude and 76°56′57.26″ E longitude. The selected corridor has a total length of about 10 km and serves as a major route connecting residential, commercial, and administrative zones within the city.

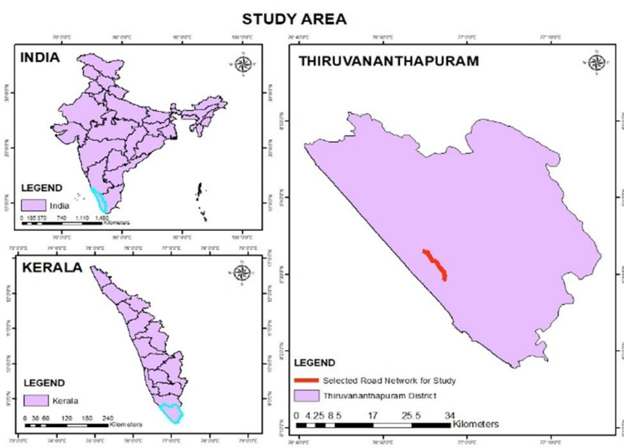

Fig 1: Study Area

Due to its strategic importance and high traffic demand, as shown in Fig. 3, the corridor experiences varying traffic conditions throughout the day, making it well suited for analyzing traffic congestion patterns and route efficiency using GIS based techniques.

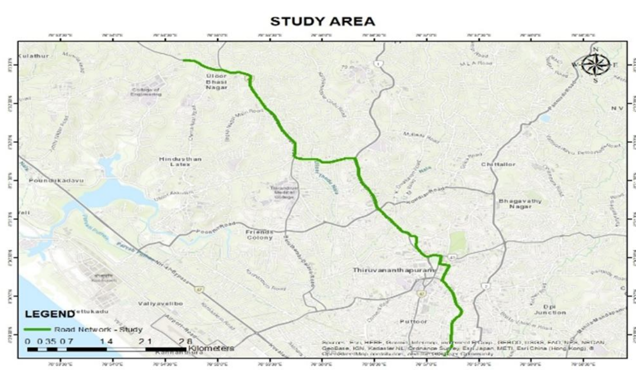

Fig 2: Road Network selected for Study.

Fig 3: Traffic congestion near Pattom.

IV. METHODOLOGY

This study employs a GIS based approach to analyze traffic congestion and route optimization along the selected urban road network. A summary of the study is presented below, and the methodological workflow is illustrated in Fig. 4.

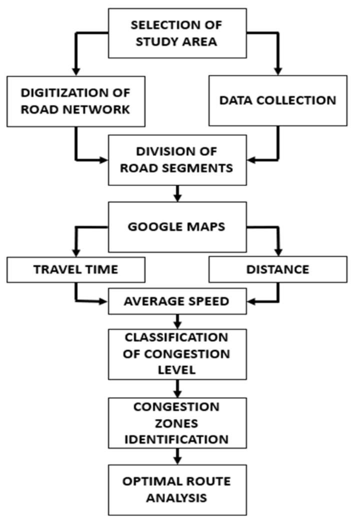

Fig 4: Flow Chart

The road network within the study area was digitized using high resolution satellite imagery from Google Earth Pro, as shown in Fig. 2, to create a topologically correct network dataset. The digitized network was subsequently divided into thirteen road segments, as illustrated in Fig. 5, to facilitate the collection of speed data for each segment and to comprehensively capture traffic conditions across the study area. For each road segment, road length and travel time data were collected from Google Maps during representative time periods between 08:00 and 20:00 h. Data were obtained for weekdays, weekends, and holidays, as well as under varying weather conditions, including rainy, cloudy, and sunny periods, and during special situations such as festivals and events. Based on the collected road length and travel time, the speed for each segment was calculated in kilometers per hour (kmph).

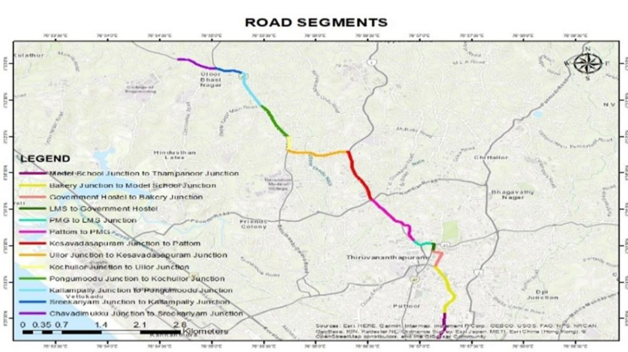

Fig 5: Division of Road Segments.

Speed data obtained for each road segment were averaged across all observed days providing a representative measure of typical traffic conditions for each segment. The different color codes indicate the speed of traffic on the road. According to Google Maps, the official color classifications are as follows: green indicates no traffic delays with speeds of at least 80 kmph; yellow represents a medium level of traffic with speeds ranging from 40 to 80 kmph, red signifies traffic delays with speeds below 40 kmph and dark red indicates extremely slow traffic conditions with speeds of less than 10 kmph. Based on these criteria, the collected speed data were classified into corresponding congestion levels, enabling the identification of road segments experiencing high traffic congestion.

V. RESULTS AND DISCUSSION

The results and discussion presented below examine the spatial patterns of traffic congestion and the outcomes of route optimization along the study corridor.

A. *Traffic Congestion Analysis*

After classifying the road segments based on average travel speed, it was observed that all thirteen segments experienced traffic delays, with average speeds below 40 kmph, as shown in Fig. 6.

Fig 6: Traffic congestion in the selected Road Network.

This consistently low level of operating speed across all segments clearly indicates severe congestion and underscores the need for effective congestion management strategies. Optimal route identification was performed to determine the shortest and fastest distance between Orgin and Destination. QGIS was selected for this study because it is an open source, cost effective Geographic Information System that provides reliable tools for shortest and fastest route analysis, utilizing OpenStreetMap and OpenRouteService data.

B. *Fastest Route*

The fastest route is computed by minimizing estimated travel time, where each road segment is assigned an assumed speed based on its functional class from OpenStreetMap data, travel time is calculated as the ratio of segment length to speed, and the optimal path is identified using a shortest path algorithm based on Contraction Hierarchies. The resulting fastest route has a length of 10.391 km and an estimated travel time of 0.237 h (14.22 minutes).

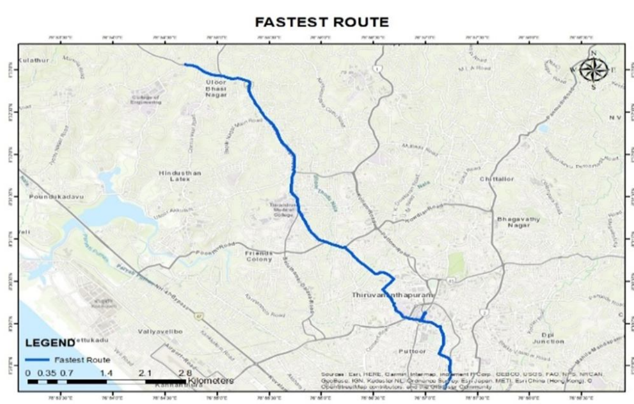

Fig 7: Fastest Route.

C. Shortest Route

The shortest route between Orgin and Destination was generated using the OpenRouteService (ORS) Directions API with the driving car profile. The route minimizes cumulative road length by selecting the most direct routable segments derived from OpenStreetMap data, and the optimal path is identified using the Contraction Hierarchies shortest path algorithm. The resulting shortest route has a total length of 9.973 km with an estimated travel time of 0.34 h (20.4 minutes).

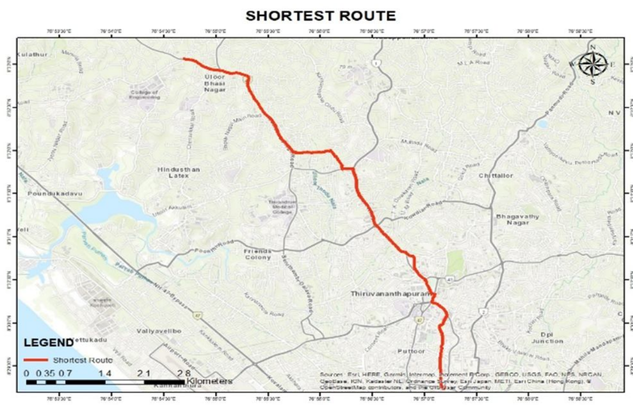

Fig 8: Shortest Route.

VI. CONCLUSION

This study confirms the effectiveness of a GIS based approach for congestion analysis and route optimization along the corridor. The results indicate widespread congestion, with average speeds below 40 kmph across all road segments, and highlight critical congestion hotspots affecting travel efficiency. Optimal Route analysis using OpenRouteService shows clear differences between shortest and fastest routes where fastest route often reduce travel time by avoiding congested sections. These findings underscore the value of integrating congestion assessment with route optimization to support efficient urban traffic management and transportation planning.

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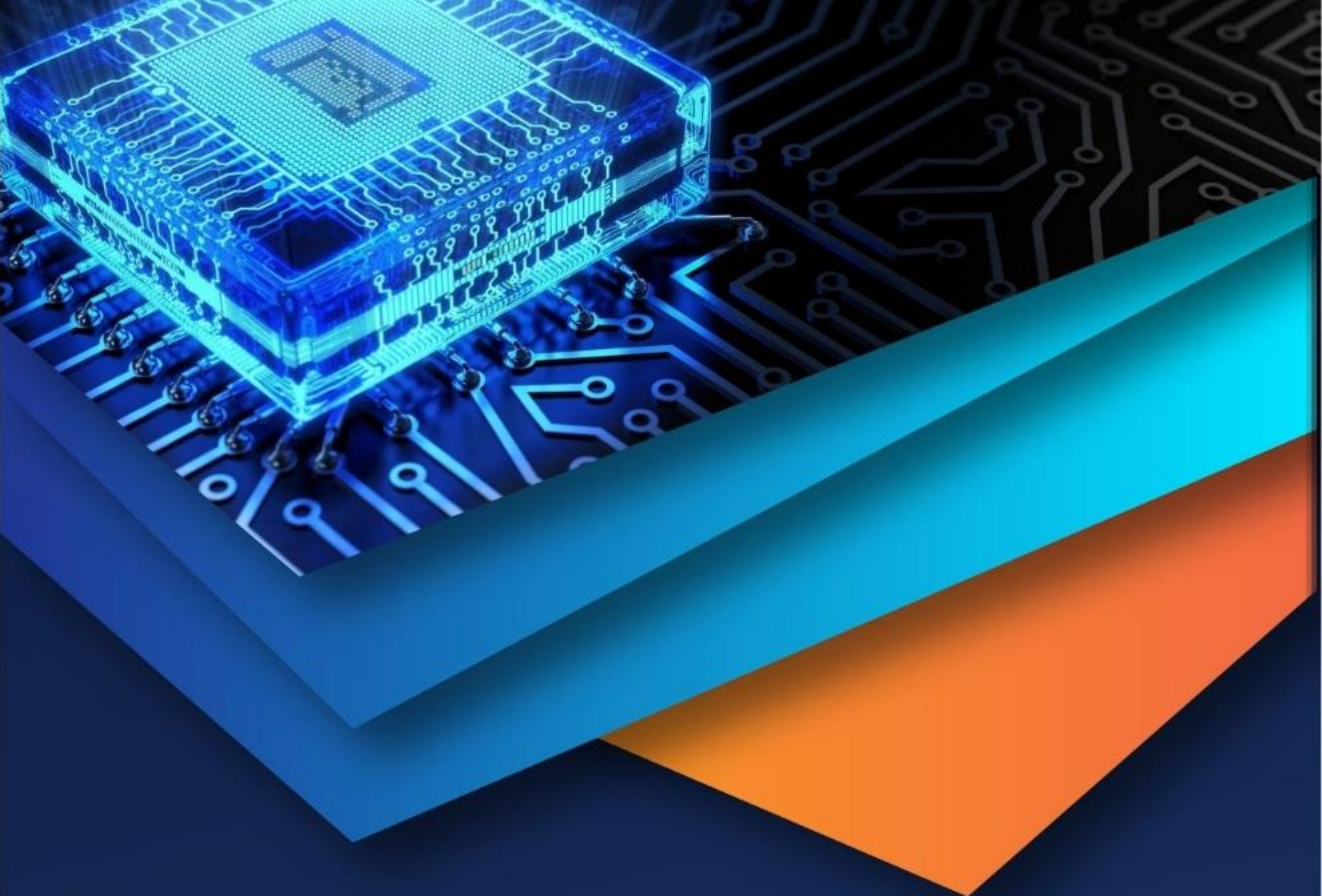

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