

Smart Urban Traffic Monitoring, Prediction and Congestion Management System

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Abstract - Traffic congestion in cities is a great problem which has impact on the time of travel, effectiveness of roads, fuel consumption, and emergencies. This paper presents a Smart Urban Traffic Monitoring, Prediction and Congestion Management System designed for Nagpur city. The proposed system integrates real-time traffic information, weather conditions, road topology, vehicle and queue parameters, incidents, road blockages, pedestrian activity, events, and public transport information to provide a comprehensive view of traffic conditions. The system monitors traffic conditions, predicts congestion for the next 15 minutes, identifies possible causes of congestion, recommends alternative routes, and dynamically suggests traffic signal adjustments. It also provides emergency vehicle priority, green corridor recommendations, Nagpur Metro alternatives, and traffic alerts through an integrated dashboard and notification system. A machine-learning-based traffic prediction approach is combined with rule-based traffic management and explainable congestion analysis. The proposed system aims to support traffic authorities and commuters by providing timely information and assisting in efficient traffic management. The system is implemented using Python, Flask, HTML, CSS, JavaScript, and external traffic, weather, and map data sources.

Key Words: Traffic Congestion, Machine Learning, Traffic Prediction, Intelligent Transportation System, Route Recommendation, Traffic Management.

1. INTRODUCTION

Fast urbanization and growth in the number of vehicles have caused traffic congestion to be a major issue in today's cities. Traffic congestion leads to increased time of journey, fuel usage, pollution, and delay in transportation. Traditional traffic management systems typically concentrate on the monitoring of existing traffic conditions, whereas traffic management demands future prediction of traffic congestion and its causes.

Traffic forecasting has increasingly incorporated both spatial and temporal relationships between different road

segments. Spatio-temporal Graph Convolutional Networks have been proposed to learn these dependencies for traffic forecasting [1]. Network-scale traffic learning approaches have also combined graph-based spatial relationships with recurrent learning to model traffic conditions across connected roads [2]. These approaches demonstrate the importance of considering the relationship between different locations rather than analyzing each road independently.

Traffic conditions are also influenced by external events and environmental factors. Research has investigated the use of traffic events extracted from social media together with traffic information for urban traffic-flow prediction [3]. Multimodal deep-learning approaches have further explored the integration of different information sources for traffic forecasting [4]. A comprehensive review of traffic forecasting methods also highlights the development of deep-learning approaches and their comparison with classical forecasting techniques [5].

The proposed system applies these concepts to an integrated urban traffic management platform for Nagpur city. It combines traffic monitoring, short-term congestion prediction, congestion-cause identification, route recommendation, traffic signal management, emergency priority, and public transport alternatives within a single system.

2. BODY OF PAPER

2.1 Methodology

The proposed system uses a Random Forest classifier and a weighted scoring algorithm for traffic-condition classification and congestion prediction. Machine-learning-based traffic forecasting is supported by previous studies on traffic prediction using deep learning and graph-based approaches [1], [2], [5]. Rule-based algorithms are used for congestion-cause detection and adaptive signal recommendations, while Breadth-First Search (BFS) identifies emergency vehicle corridors. Graph traversal is used to analyze congestion propagation between connected roads and support route recommendations [3], [4].

A. Random Forest Classifier

The Random Forest Classifier is used to classify traffic conditions using features such as car, bike, bus, truck, and total vehicle counts. It creates multiple decision trees and combines their predictions to determine the final traffic situation. In the proposed system, it forms part of the machine-learning model pipeline, although the current live dashboard does not directly call the trained Random Forest model.

B. Weighted Scoring Algorithm

The Weighted Scoring Algorithm is used for congestion prediction. It looks at traffic factors, such as slowing down the number of cars how many people are, in each car the length of the line of cars if a lane is blocked, accidents, people walking and road work. Every traffic factor gets a weight that shows how much it adds to congestion. The weighted traffic values are added together to make a congestion score. That score tells us if traffic is LOW MODERATE, HIGH or HEAVY.

C. Rule-Based Algorithm

The Rule-Based Algorithm applies predefined conditions and thresholds to traffic parameters to identify congestion causes and generate management recommendations. For example, a high queue length can indicate a vehicle-queue problem, while heavy congestion can result in an increase in recommended green-signal time. This approach allows the system to identify traffic causes and recommend actions without requiring a trained machine-learning model.

D. Breadth-First Search (BFS)

Breadth-First Search (BFS) is used to find an emergency corridor between two locations. Roads and junctions are represented as connected nodes in a graph. BFS explores neighboring nodes level by level until the destination is reached. The resulting path is then used to create a simulated green corridor for an emergency vehicle.

E. Graph Traversal for Congestion Propagation

Graph traversal is used to represent relationships between connected roads and analyze how congestion can propagate from one road to neighboring roads. The system stores road connections as a graph and examines connected locations to estimate potential congestion spillover. This information is then provided to the recommendation system to support alternate-route suggestions and traffic-management actions.

2.2 System Architecture

The proposed system follows an integrated architecture consisting of traffic data collection, data processing, traffic analysis, prediction, and traffic management. The architecture is designed to combine different traffic parameters and provide a unified platform for urban traffic monitoring and management.

Graph-based traffic research represents road networks as interconnected structures to capture spatial relationships between different road segments [1], [2]. Based on this concept, the proposed system considers connected traffic locations during congestion analysis and management.

The processed information is provided through an interactive dashboard, where current traffic conditions, predicted conditions, congestion causes, and management recommendations can be monitored. The architecture therefore connects traffic prediction with route management, signal optimization, and other traffic management functions.

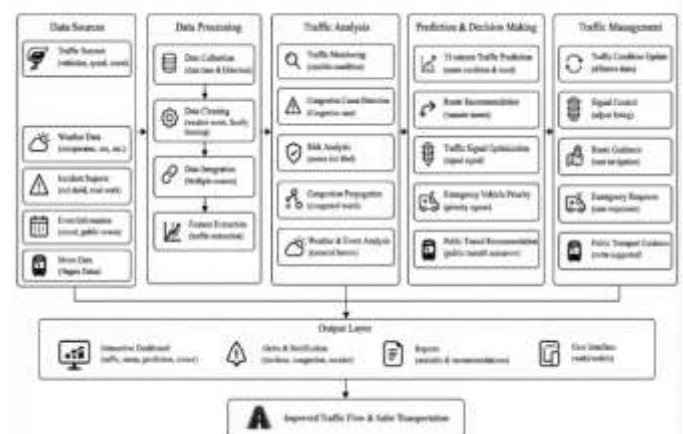


Fig.1: - System Architecture

2.3 Traffic Monitoring and Prediction

The system monitors traffic conditions using vehicle count, road capacity, vehicle speed, queue length, lane blockage, pedestrian activity, weather, incidents, and events. These parameters are processed to determine the present traffic condition and congestion level.

Traffic forecasting research has shown that traffic flow contains both spatial and temporal dependencies. Yu et al. proposed Spatio-Temporal Graph Convolutional Networks to capture these dependencies in traffic networks [1]. Cui et al. also modeled the traffic network as a graph to learn interactions between roadways and forecast network-wide traffic states [2].

The proposed system applies traffic-condition analysis to predict the traffic condition for the next 15 minutes. Deep-

learning-based traffic forecasting methods and their applications to different traffic characteristics have been comprehensively reviewed by Afandizadeh et al. [5].

2.4 Traffic Data and External Information

The system identifies major factors responsible for congestion, including high vehicle volume, reduced speed, long queues, lane blockage, pedestrian activity, incidents, road work, weather conditions, and events. These factors are analyzed to determine the possible causes of the detected congestion.

Previous research has shown that non-recurring events such as accidents, road closures, and extreme weather can affect traffic prediction. Essien et al. incorporated traffic events together with traffic and weather information to improve urban traffic flow prediction [3].

The proposed system extends this concept by identifying traffic-related causes and presenting them along with the detected congestion and risk level. This provides an interpretable view of why a particular traffic condition may occur.

2.5 Congestion Cause Detection

The system analyzes connected traffic locations to identify possible congestion propagation from one road segment to another. This allows the system to examine the relationship between traffic conditions at connected locations.

Cui et al. proposed a graph-based framework for learning interactions between roadways and forecasting network-wide traffic states [2]. Similarly, Yu et al. used graph structures to model spatial dependencies across traffic networks [1].

Based on the connected-road analysis, the proposed system provides alternative route recommendations when heavy congestion is detected. This enables traffic information to be used not only for prediction but also for route-level traffic management.

2.6 Weather and Event Analysis

The system incorporates weather conditions and event-related information into traffic analysis. Weather, incidents, road work, and event-related crowd levels are considered as factors that may influence traffic conditions.

Essien et al. demonstrated that combining traffic information with weather and event information can address the effect of non-routine events on short-term traffic prediction [3]. Their work specifically highlights

the influence of accidents, road closures, and extreme weather on traffic prediction.

The proposed system uses a similar multi-factor approach by considering weather and event conditions along with traffic parameters for congestion analysis and prediction.

2.7 Smart Traffic Signal Optimization

The proposed system includes a smart signal optimization module that analyzes traffic pressure, vehicle volume, queue length, lane blockage, and pedestrian activity before generating signal recommendations.

Traffic forecasting and intelligent transportation research emphasizes the importance of accurate and timely traffic information for traffic control and management [1], [5]. The proposed system uses the analyzed traffic condition as an input for recommending suitable signal timing.

The signal management module is connected with the congestion analysis module so that changing traffic conditions can be considered while generating signal recommendations.

2.8 Result

The developed system integrates real-time traffic monitoring, vehicle detection, congestion prediction, cause analysis, route management, and adaptive traffic signal optimization in a single platform. It detects different vehicle types and identifies congestion conditions at selected locations. The system also provides emergency green-corridor support, alternate route recommendations, Nagpur Metro suggestions, voice-based traffic advisories, and congestion propagation analysis. These features use spatial and temporal traffic relationships for traffic forecasting and management [1]. The overall results demonstrate an integrated approach for monitoring traffic conditions and providing real-time management and guidance.

A. Live route traffic and instant on-screen alert hub:



Fig.2: - Live Traffic and Instant Alerts

The developed system provides route-based traffic monitoring by allowing the user to select an origin and destination, such as Sitabuldi to Sadar. It generates instant on-screen traffic alerts and also provides an option to send the alert through WhatsApp. Such real-time traffic

information supports intelligent transportation and traffic management applications, where timely traffic information is important for congestion mitigation and safety [5]

B. Emergency vehicle green-corridor and multi-modal transit switch:

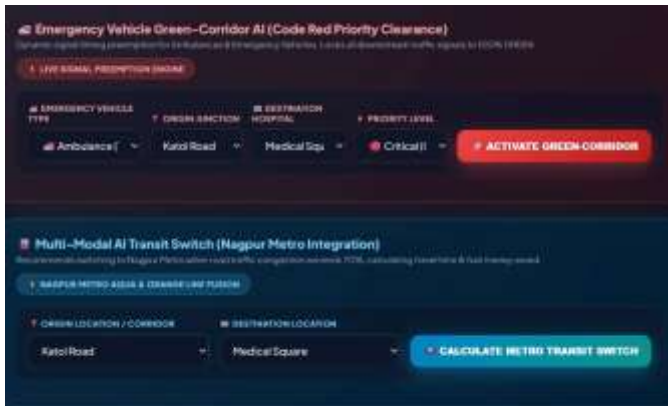


Fig.3: - Emergency Green Corridor and Transit Switch

The system provides an emergency vehicle green-corridor facility in which the emergency vehicle type, origin junction, destination hospital, and priority level can be selected before activating signal preemption. The same interface also provides Nagpur Metro as an alternative when road congestion exceeds the defined threshold, supporting multimodal transportation management. Multimodal traffic information has been explored for short-term traffic forecasting and transportation analysis [4].

C.YOLO v8 AI virtual CCTV perception pipeline:



Fig.4: - YOLOv8 AI Perception Pipeline

The system performs real-time visual vehicle detection and classification using bounding boxes for different vehicle categories. In the displayed result, 40 cars, 31 bikes, 10 autos, and 7 trucks are detected, while the system also identifies moderate lane congestion near Sitabuldi Junction. The use of traffic video and other data sources for traffic analysis is consistent with the range of data sources discussed in traffic forecasting research [5].

D. Voice AI traffic advisory:



Fig.5: - Voice AI Traffic Advisory

The system provides voice-based traffic advisories using the browser speech synthesis facility. The displayed advisory communicates the traffic condition, risk score, live speed, primary congestion cause, and recommended bypass route in Hinglish. Providing timely traffic information and guidance is an important application of traffic forecasting and intelligent transportation systems [1], [5].

E. Corridor congestion propagation:



Fig.6: - Corridor Congestion Propagation

The system identifies the relationship between a congested current junction, the connected junction hub, and the downstream road, shown as Wardha Road. It calculates the possible road-to-road spillover risk using the connected Nagpur road network. This network-based approach is related to graph-based traffic research, where roadways are represented through spatial relationships to capture traffic dependencies [1], [2].

F. Adaptive Signal Timing Optimizer:



Fig.7: - Adaptive Signal Timing

The system provides an adaptive signal optimization module that analyzes the traffic flow and generates an AI-based recommendation for signal timing. The displayed interface provides green, red, and cycle timing outputs along with a traffic-flow synchronization status. Using traffic information for intelligent traffic control is consistent with research emphasizing timely traffic forecasting for urban traffic control and management [1], [5].

G. Smart Telemetry Fusion Parameters:



Fig.8: - Smart Telemetry Fusion Parameters

The Smart Telemetry Fusion module combines important traffic parameters for traffic-condition analysis. The interface includes vehicle count, road occupancy percentage, and queue length, along with additional parameter groups for lane infrastructure, pedestrian conditions, and emergency and weather conditions.

3.CONCLUSION

The proposed Smart Urban Traffic Monitoring, Prediction and Congestion Management System integrates traffic monitoring, short-term prediction, congestion analysis, route management, signal optimization, emergency vehicle priority, and multimodal transportation support into a unified platform.

The developed system combines traffic-related parameters, connected-road information, visual vehicle detection, external conditions, and traffic management functions to provide a more comprehensive view of urban congestion. This overall approach is consistent with research emphasizing spatial-temporal traffic relationships [1], multimodal traffic information [4], and diverse traffic data sources and forecasting methods [5].

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