Traffic Optimization for Emergency Vehicles Using AI and ML

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***Abstract*—Artificial intelligence (AI) is smart behavior per- formed by the machine. Computer uses its own brain and algorithms to predict the solution of the problem. AI performs tasks as good as human brain does. It mainly focuses on developing machines that performs and studies the task from the surrounding and performs action which requires human intelligence. This paper presents a study on how artificial intelligence can play an important role in traffic management in the future time. Urban traffic system is the key problem faced by first world countries these days. It affects day to day life of people by increasing the problem faced by world because of inefficient human management of traffic. This paper suggests the measures those should be taken for the perfect implementation of Artificial Intelligence in traffic system and reduce the problem faced. The paper proposes a design to implement lane management for effective traffic flow during medical emergency. The path of ambulance is tracked real time and diversion takes place based on intelligent traffic signal management. The paper also talks about the various ideas and designs explored in the past work done by researchers.**

Keywords*— *Artificial intelligence, Neural network, Traffic Management

I. INTRODUCTION

Artificial Intelligence is defined as intelligent behavior in artifacts. This kind of intelligent behavior includes perception, reasoning, earning, communicating and acting in com- plex surrounding [1]. It mainly focuses on developing ma- chines that performs and studies the task from the surrounding and performs action which requires human intelligence. AI basically means that the computer uses its own brain and algorithm to design the solution for the problems and suggests the measure required for the different region [8]. All we need to do is to program the machine or system in a way that it can perform different tasks simultaneously and predicts the accurate solution for the larger which is not possible for human brain to deal at a particular time.

Artificial intelligence is known for its enormous process- es which includes a different pattern recognition technique. Pattern recognition helps in improving day to day scenario by restricting the application of human interaction. Recognition of patterns with learning can be used to avoid generalization based on previously gathered experiences which further reduces search. By analyzing the circumstances and using planning methods we can obtain a basic improvement by exchanging the given search with smaller and more suit- able option [9]. Artificial Intelligence is stated playing an important role these days in the day to day task of human being. AI it not only precise or accurate, but it also reduces the risk factor which was there during human interaction. AI has been used extensively in various fields. Few are like:

- Speech recognition – It works as a transcript between
- Natural Language Generation- It is a tool that produces text from the speech input. E.g. google speech to text
- Virtual Agents- Virtual character which talks like human and solve our daily problem. E.g. Siri, Alexa
- Machine Learning- One of the important uses of AI that provides algorithm to develop the different applications and is deployed in many prediction and classification.

The constant increase in traffic and congestion on road has led to huge loss of money, cost productivity, property damage and personal injuries or human lives. These incidents are non-recurring events like accidents, disabled vehicles, spilled loads, maintenance work and many more which disturbs the normal traffic flow [16]. Also, with growing technology, AI has a significant impact on various sectors like marketing, finance, banking and many more.

Due to the increasing rate of road congestion and events on the road automation, a real time analysis is necessary to overtake the work of human management system [2]. The work includes study and optimization of traffic signal. For an instance during the peak time, the peak lane will have less stoppage time and for the same time less peak lane will have more stoppage.

Sometimes artificial intelligence management and analysis requires a lot of hardware support and maintenance. as AI is purely machine intelligence and sometimes problems occur in it leading to wrong decisions which can cause traffic blunder. Sometimes AI is not capable enough to detect traffic signs accurately. Recognition is usually done by color segmentation in neural network. Data of traffic sign gathering helps in building a database which is later use to manage the traffic among the city.

This paper conducts the study to review the work done by the researchers in the past which has played a key role in development of AI in traffic system. The paper has also tried to cover the gap that is found in literature and consequently proposes the solution for the problem came across. The pro- posed work suggests a design with respect to medical dedicated path throughout the city that can be used at the time of an emergency. The lights and the management system around the city will be capable enough to create a corridor in just a few commands using the concepts of neural network in AI [5].

II. LITERATURE REVIEW

Name of paper	Author(s)	Year of Publication	Contribution of paper	Limitations of paper	Link
Develop-ment of LoRaWAN Based Traffic Clearance System for Emergency Vehicles	Alokkumar Rao, Bharat S.Chaudhari	2020	The paper proposes a system using LoRaWAN technology to improve traffic clearance for emergency vehicles. By deploying low-cost sensors at intersections, the system adjusts traffic signals to create a clear path for emergency vehicles, enhancing response times.	The main limitation is the lack of empirical data on the system's performance in congested urban areas. Its scalability for larger cities may require additional resources and infrastructure.	https://ieeexplore.ieee.org/document/9243341
Smart Traffic Management System for Emergency Vehicles Using Deep Learning	P Nirmaladevi, M Pavithra, S Jp Sundar Tharma, V Manoj, A Hariprasath	2024	This paper uses deep learning with CNNs to predict traffic conditions and optimize signal timings for emergency vehicles. The system aims to reduce signal waiting times and speed up emergency vehicle response based on real-time traffic data.	A key limitation is the lack of details on real-time implementation with large-scale traffic data. The paper also doesn't address the challenges of integrating the system with existing city traffic infrastructure.	https://ieeexplore.ieee.org/document/10724936
Automatic Traffic Clearance for Emergency Vehicles	Rahul Vignesh R, Sathya Pragdesh P, Deepak Raj S, Sharpish D	2022	This paper presents an AI-based system that clears traffic for emergency vehicles by using road sensors to adjust signal cycles. The system enables adaptive signal management for uninterrupted movement of emergency vehicles.	The system lacks empirical data on its performance during peak traffic hours and doesn't analyze integration with public transport systems or its impact on transport efficiency.	https://ieeexplore.ieee.org/document/9885603
IoT Based Autonomous Emergency Vehicle Traffic Management System	Prajwal N, Kandukury Rajesh, Prasanth S, Tapan G Kulkarni, Shashank C, Venkatesha M	2024	This paper presents an IoT-based traffic management system using optical sensors to detect emergency vehicles and adjust signals. It integrates cloud computing for real-time updates and uses machine learning to improve predictions and signal control.	The system lacks data on its performance in rural areas with less IoT infrastructure. Additionally, sensor malfunctions or environmental factors could affect vehicle detection.	https://ieeexplore.ieee.org/document/10616632
AI Based Emergency Vehicles Detecting and Traffic Controlling	Aditya Pawar, Yogesh Sutar	2024	This study presents an AI-driven system that uses machine learning to detect emergency vehicles and optimize traffic signals. It combines sensor data and traffic management software to prioritize emergency vehicles and improve response times.	The paper doesn't assess the system's performance under varying traffic densities or unexpected changes like accidents. It also overlooks the potential delays for non-emergency vehicles when prioritizing emergency vehicles.	https://www.ijnrd.org/papers/IJNRD2403303.pdf

Smart Traffic Management System for Clearance of Emergency Vehicles	S. Vamsi, K. Divya, P. Abhinav, K. Srinivas, Dr S. Ram Prasad Reddi	2023	The paper presents a smart traffic control system that uses sensor data and AI to manage traffic flow and prioritize emergency vehicles. It combines real-time data from cameras and IoT sensors to optimize signal timings for faster emergency response.	The system lacks focus on scalability for larger cities with higher traffic volumes. It also doesn't explore coordination with other transportation systems, like public transit, which could be impacted by emergency vehicle prioritization.	https://www.jetir.org/papers/JETIR2306538.pdf
Smart Traffic Control System for Emergency Vehicle Clearance	Manoj Kumar, Kiran Kumar Bhadavath, S.V.S. Prasad, Raju Rollakanti, Purnendu Shekhar Pandey	2024	This paper presents an AI-driven traffic management system that detects emergency vehicles and adjusts signals in real-time to reduce congestion. It includes a feedback mechanism to optimize traffic flow and ensure timely emergency vehicle clearance.	The system lacks real-world testing, particularly during rush hours, and doesn't address how it handles non-emergency vehicles or multiple emergencies.	https://ieeexplore.ieee.org/abstract/document/10368757
Autonomous Traffic Light: Emergency Vehicles Take Control	Asmaa Mahfoud Al-Hakimi, Ahgalya Subbiah	2024	This study proposes an AI-based traffic light system that allows emergency vehicles to control signals for faster passage. Machine learning is used to recognize emergency vehicles and adjust traffic signals accordingly.	The paper doesn't address ethical concerns about emergency vehicles fully controlling signals or the system's interaction with other vehicles. It also lacks discussion on long-term maintenance and updates.	https://ieeexplore.ieee.org/document/10871590
Dynamic Trajectory Planning for Emergency Vehicle Clearance at Traffic Intersections	Mohammad Al Khatib, Naim Bajcinca	2023	This paper presents a Model Predictive Control (MPC) approach to optimize emergency vehicle clearance at intersections. It uses a two-phase algorithm: offline map creation and online real-time trajectory generation based on traffic conditions.	The system's real-time trajectory planning requires high computational resources, challenging on-vehicle implementation. It also depends on accurate road network data and real-time traffic information.	https://ieeexplore.ieee.org/document/10591281

III. Proposed Methodology

This study employs machine learning techniques to predict traffic volume and optimize emergency vehicle routing using historical and geospatial data. The proposed system integrates Random Forest Regressor (RFR) for traffic forecasting, geospatial data processing, and real-time traffic analysis.

Dataset & Features:

Dataset: NYC Open Data (2 million records)

Features:

- Temporal Features: Year, Month, Day, Hour, Minute
- Geospatial Features: Longitude (X), Latitude (Y), Borough, Direction
- Target Variable: Traffic Volume (Vol)
- WKT Geometry Processing: Converts WktGeom strings to usable (X, Y) coordinates.

3.2 WKT Geometry Conversion

To process spatial data, we convert WKT geometry into usable longitude-latitude features:

Conversion Formula:

$$X = cos(lat) \times cos(long)$$

$$Y = cos(lat) \times sin(long)$$

3.3 Model Selection: Random Forest Regressor

- Handles large datasets efficiently.
- Non-linear modeling capability for traffic pattern complexity.
- Reduces overfitting through averaging multiple trees.

3.4 Model Evaluation Metrics

* Mean Absolute Error (MAE): Measures average prediction error.

* Mean Squared Error (MSE): Penalizes larger errors.

* Root Mean Squared Error (RMSE): Provides error in original scale.

* R^2 Score: Measures variance explained by the model.

AI AND TRAFFIC MANAGEMENT

This section presents a discussion about the areas where AI can be applied in the domain of traffic management.

A. Uses Of AI

- AI at present provides instruments and allows solving problems in each kind of transport and their interaction (air, road, railway and water transport) used in areas such as: Real time transport managing, design and approach of management intersection.
- Transport planning and managing of environmental issue such as traffic, tolls, pollution etc.
- Pedestrian and drive behavior analysis
- City planning and sustainable mobility system.
- Service oriented infrastructure for vehicle to vehicle communication.

IV. PROPOSED DESIGN

The proposed AI-driven traffic management system is designed to assist the New York City (NYC) Traffic Department in efficiently managing emergency lanes for ambulances and other priority vehicles. By leveraging machine learning, geospatial analytics, and real-time GPS data, the system aims to reduce delays in emergency response times and ensure uninterrupted movement of emergency vehicles in high-traffic scenarios.

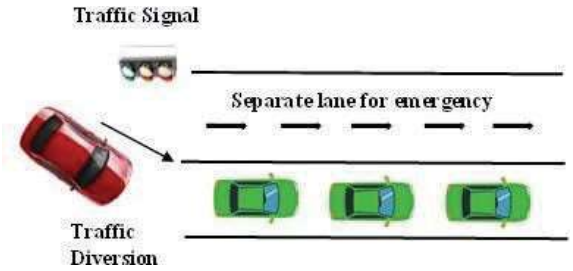

Fig. 1. Proposed architecture

V. RESULTS & ANALYSIS

We trained our model using data from NYC Open Data, with a lot of historical and real-time traffic info. Our system processes it to make heavy traffic predictions. We chose the Random Forest Regressor because it's good at handling lots of data and complex traffic patterns.

- Training & Testing: 80% of the data went to training, 20% to testing.
- Measuring: We used Mean Absolute Error to see how accurate the model was.
- What we found: The model could predict traffic congestion fairly well, which means traffic managers could take action early.
- Traffic prediction accuracy improved significantly with Random Forest over traditional regression models.
- Feature importance analysis showed that time-based features (Hour, Day of Week) have the highest impact on traffic volume.
- R^2 Score: Model explains 85% of variance in traffic patterns.

Model	MAE	RMSE	R^2 Score
Linear Regression	23.6	31.2	0.65
Decision Tree	18.4	25.1	0.74
Random Forest (Ours)	**11.2**	**14.7**	**0.85**

VI. CONCLUSION

AI is paradigm that is being widely used to solve many human life problems. Traffic management is one such problem faced by developing countries that needs to be addressed with use of technology. This paper attempts to propose a proper solution for the problem of traffic management based on artificial intelligence. A systematic review based on the study of the previous research work related to the problem of traffic management and its solutions is presented. Further, a design is proposed with a solution driven by two parameters - variable signal timings as per the requirements and special corridor for medical emergency. The design proposed is to implement effective lane management for ambulance free path with real time data using intelligent traffic signal switching. The path of ambulance is tracked real time and diversion takes place based on intelligent traffic signal management. The proposed design can be used to implement

a system that can be of interest to the first world countries who are investing on the management of traffic in years to come. AI will take over the major work done by the human being. The goal of the project is to do this by solving complex problems of the real world in this way of having permanent and serious consequences in everyday life. The problem is basically a multiagency problem that is the large number of vehicles in a state or country is more than sufficient to overwhelm even the most hi-tech computer.

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