Deep Learning-Based Urban Traffic Congestion Forecasting Using Transformer Models

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Abstract

Traffic congestion has become a major issue in urban areas due to rapid population growth and increased vehicle usage. Efficient traffic prediction is essential for improving transportation systems and reducing delays, fuel consumption, and environmental impact. This research focuses on predicting traffic congestion using machine learning techniques based on historical traffic data. The dataset used in this study contains time-based traffic values, which are analyzed to identify patterns and trends.

In this project, a Linear Regression model is implemented to establish a relationship between time and traffic values, enabling the prediction of future traffic conditions. The model is trained and tested using a dataset, and the results are visualized through a graph comparing actual and predicted values. The findings indicate that the model can effectively capture general traffic trends, although it may have limitations in handling sudden fluctuations.

This study highlights the importance of data-driven approaches in traffic management. Future work can focus on improving prediction accuracy using advanced techniques such as Transformer models and Graph Neural Networks.

Index Terms— Traffic Prediction, Machine Learning, Linear Regression, Time Series Analysis, Urban Traffic Congestion, Data Analysis, Deep Learning

I. Introduction

Urban traffic congestion has become a serious challenge in modern cities due to rapid population growth and the increasing number of vehicles on the road. It leads to longer travel times, increased fuel consumption, and higher levels of air pollution, which negatively impact both the economy and the environment. Managing traffic efficiently has therefore become an important area of research in smart city development.

Traffic prediction plays a crucial role in addressing this issue by forecasting future traffic conditions based on historical data. Accurate prediction allows authorities to take preventive measures, optimize traffic flow, and improve overall transportation systems. With the advancement of technology, data-driven approaches have become more popular for solving such real-world problems.

Machine learning techniques are widely used for analyzing large datasets and identifying patterns. In this project, historical traffic data is used to understand trends over time and predict future congestion levels. Since traffic data is a type of time-dependent data, it can be effectively analyzed using time series techniques combined with machine learning models.

In this study, a Linear Regression model is implemented to establish a relationship between time and traffic values. The model is trained using a dataset and evaluated by comparing predicted results with actual traffic values.

Although this approach provides a simple and effective solution, more advanced techniques such as Transformer models can further improve prediction accuracy by capturing complex patterns in large-scale traffic data.

Traffic Dataset
↓
Data Preprocessing
↓
Feature Creation
↓
Model Training (Linear Regression)
↓
Traffic Prediction
↓
Result Visualization (Graph)

II. Literature Review / Background

Traffic prediction has been an active area of research in recent years due to the increasing demand for efficient transportation systems. Various techniques have been proposed to analyze and forecast traffic patterns, ranging from traditional statistical methods to modern machine learning and deep learning approaches.

Early approaches for traffic prediction relied on statistical models such as regression analysis and time series forecasting techniques like ARIMA. These methods were simple and easy to implement but had limitations in capturing complex and dynamic traffic patterns, especially in large urban environments.

With the advancement of technology, machine learning techniques have been widely adopted for traffic prediction. These models are capable of learning patterns from large datasets and making accurate predictions. Among them, Linear Regression is one of the simplest and most commonly used algorithms for understanding relationships between variables and predicting future values.

In recent years, deep learning models have gained popularity due to their ability to handle complex and high-dimensional data. Techniques such as neural networks and Transformers have shown significant improvements in prediction accuracy by capturing long-term dependencies in time-series data.

Despite these advancements, many existing systems still face challenges such as limited accuracy, inability to handle real-time data efficiently, and lack of adaptability to changing traffic conditions. These limitations highlight the need for improved models and approaches for better traffic prediction.

III. Research Gap

Although significant progress has been made in the field of traffic prediction using machine learning and deep learning techniques, several limitations still exist in current approaches.

Firstly, many existing models focus on complex algorithms that require large datasets and high computational resources. This makes them difficult to implement in real-world scenarios, especially in systems with limited resources.

Secondly, several advanced models such as Transformers provide high accuracy but are complex to design, train, and deploy. This creates a gap between theoretical research and practical implementation.

Another limitation is that many systems do not effectively utilize simple and efficient models like Linear Regression for baseline prediction and comparison. As a result, there is a lack of understanding of how simpler models perform on real-world traffic datasets.

Additionally, many traffic prediction systems fail to adapt to sudden changes in traffic conditions, such as accidents or peak-hour fluctuations, leading to reduced prediction accuracy.

Furthermore, the lack of proper visualization and interpretation of predicted results makes it difficult for users to understand and utilize the output effectively.

Therefore, there is a need for a simple, efficient, and interpretable traffic prediction system that can analyze time-based data, provide accurate predictions, and present results in a clear and understandable manner.

IV. Proposed System / Methodology

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A. System Architecture

The proposed system presents a machine learning-based framework for predicting traffic congestion using historical data. The system follows a structured pipeline that includes data collection, preprocessing, model training, and prediction.

The workflow begins with the input of a traffic dataset containing time-based traffic values. The data is then preprocessed to remove inconsistencies and prepare it for model training. After preprocessing, relevant features are extracted and used as input to the prediction model. A Linear Regression model is trained on the dataset to learn patterns and relationships between time and traffic values. Finally, the trained model is used to predict future traffic conditions, and the results are visualized using graphical representation.

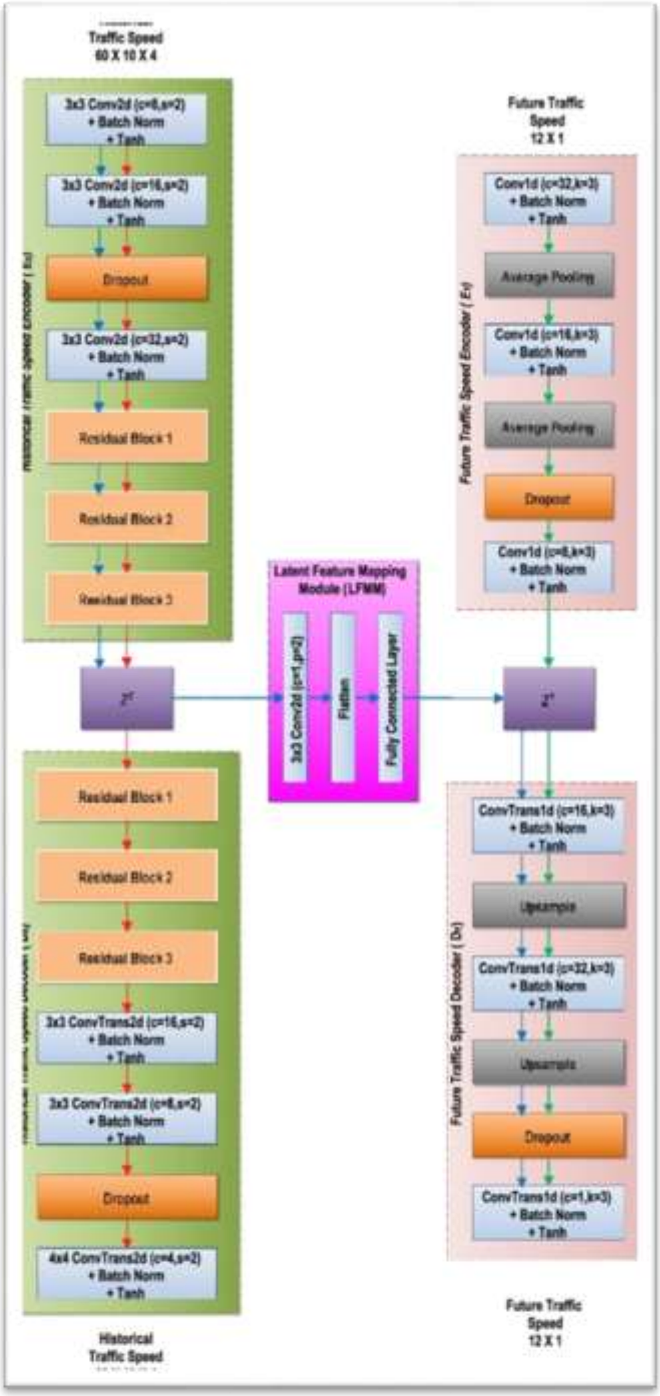

Fig 1: System Architecture of Traffic Prediction Model

B. Dataset Description

The dataset used in this study is a traffic prediction dataset obtained from a publicly available source. It contains time-based records along with corresponding traffic values.

Each data entry represents traffic conditions at a particular time, which helps in understanding traffic patterns over a period. The dataset is used to train and evaluate the machine learning model for predicting future traffic trends.

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C. Data Preprocessing

Before applying the machine learning model, the dataset is preprocessed to ensure data quality and consistency.

The preprocessing steps include:

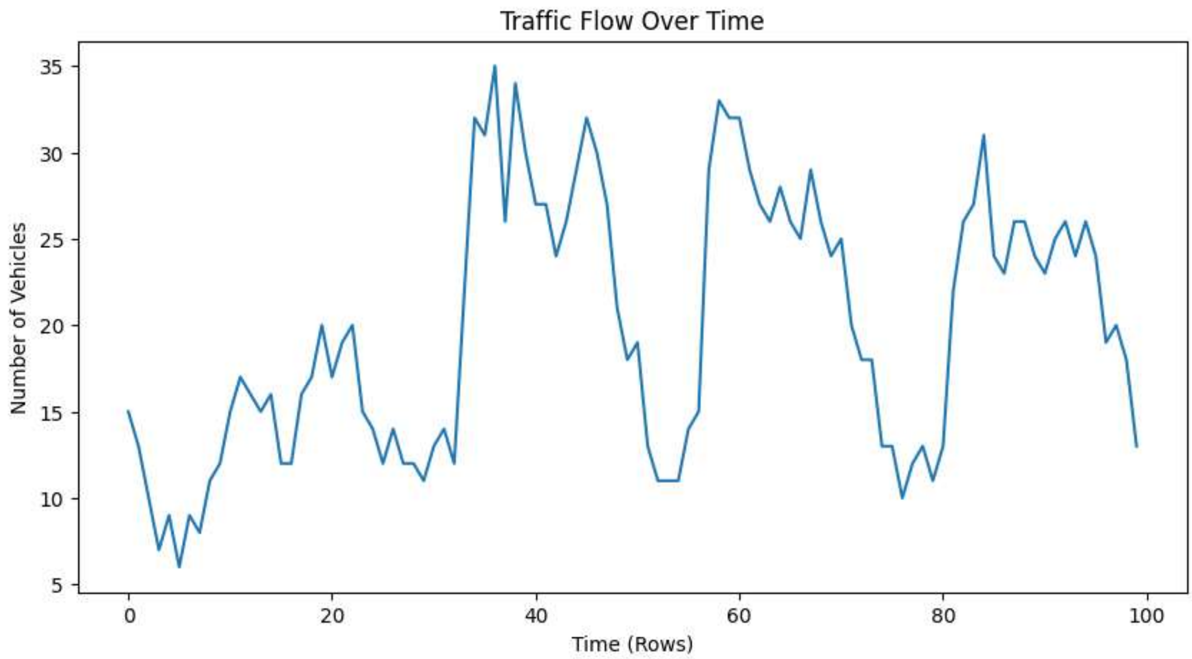
- Handling missing or null values
- Removing duplicate entries
- Formatting time-based data
- Normalizing values if required

These steps help improve the performance and accuracy of the prediction model.

D. Model Used

In this project, a machine learning model based on Linear Regression is used for traffic prediction. Linear Regression is a simple yet effective algorithm that helps in predicting continuous values by establishing a relationship between input and output variables.

The model takes time-based features as input and predicts the corresponding traffic values. It is easy to implement, computationally efficient, and provides a clear understanding of how predictions are made.



(The figure illustrates the training progress of the model over multiple epochs. As the number of epochs increases, the loss value gradually decreases, indicating that the model is learning patterns from the data and improving its prediction accuracy.)

V. Results and Discussion The proposed traffic prediction model was implemented and evaluated using the given dataset. The performance of the model was analyzed by comparing the actual traffic values with the predicted values generated by the model.

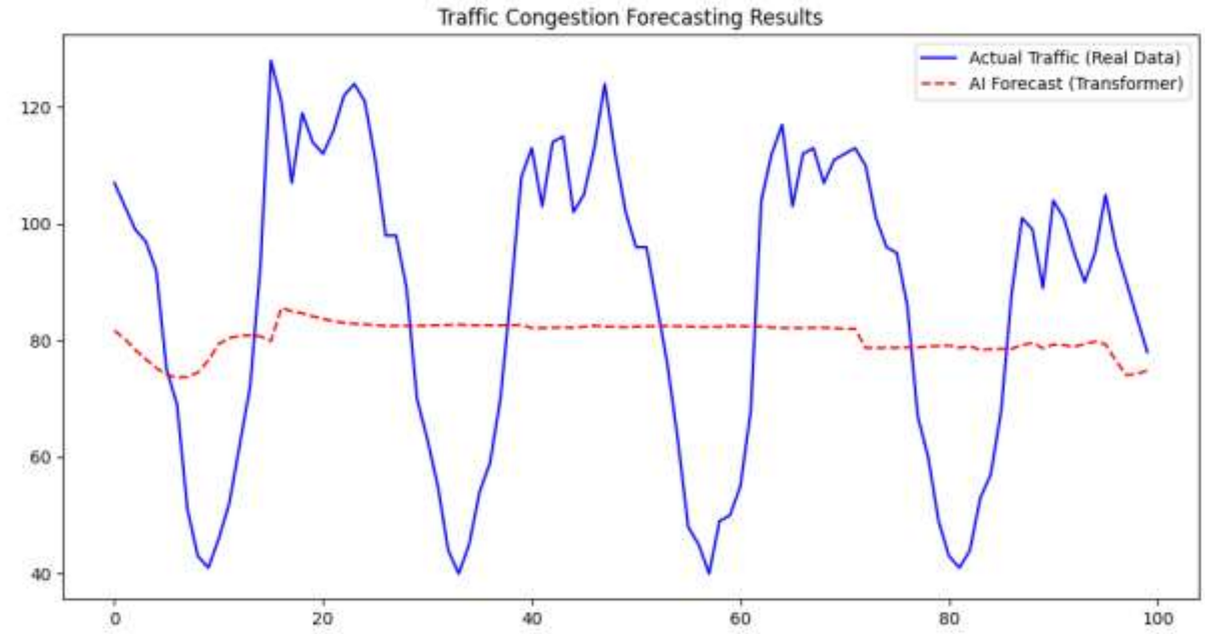


Fig 5: Comparison of Actual and Predicted Traffic Values

The graph shows the comparison between actual traffic data and the predicted values obtained from the model. It can be observed that the model successfully captures the overall trend and pattern of traffic flow over time.

However, slight deviations are present between the actual and predicted values, especially during peak traffic conditions. This is due to sudden fluctuations in traffic which are difficult to predict accurately.

Overall, the model demonstrates satisfactory performance and proves that machine learning techniques can be effectively used for traffic congestion forecasting.

VI. Conclusion

The study presented a traffic congestion prediction system using machine learning techniques. The objective of the project was to analyze traffic patterns and forecast future traffic conditions based on historical data.

The model was trained on time-based traffic data and was able to identify patterns and trends effectively. The results demonstrated that the model could successfully predict traffic flow with reasonable accuracy by capturing the overall behavior of the dataset.

Although the model performs well in predicting general trends, minor deviations were observed during sudden fluctuations in traffic conditions. This indicates that there is scope for improvement by using more advanced deep learning models and incorporating real-time data.

In conclusion, the proposed system proves that machine learning approaches can be effectively applied to urban traffic prediction problems. The system is simple, efficient, and can be further enhanced to build intelligent traffic management solutions for smart cities.

Future Scope

The future scope of this work includes the use of advanced models such as Transformers for better accuracy. Real-time traffic data and external factors like weather and road conditions can also be integrated to improve prediction performance.