

REVIEW ARTICLE

Enhance traffic flow prediction with Real-Time Vehicle Data Integration

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ABSTRACT

This study examines how sophisticated traffic control systems affect traffic flow. These cutting-edge solutions use real-time traffic data to increase road networks' intelligence. These technologies enable the creation of a smoother and more efficient traffic flow by enhancing traffic signal timings and automatically rerouting cars towards less crowded routes. Notably, these innovations significantly lower air pollution, greenhouse gas emissions, and fuel consumption while also minimizing the financial and time expenses related to traffic congestion. Our unique Real-Time Vehicle Data Integration (RTVDI) algorithm is being used to portray the potential of intelligent traffic control systems. These technologies have the potential to revolutionize traffic management procedures by using real-time data and complex processes. They have the potential to improve commuter safety, increase road efficiency, and improve traffic flow.

Keywords: traffic management systems; control technologies; traffic signal timing; financial gains; real-time

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1. Introduction

Recently, there have been a lot more cars on the road, which has led to traffic congestion and other issues like delays, lengthier commutes, and higher petrol prices. Intelligent traffic management systems have been created to successfully control traffic flow in order to address these problems. Models for predicting traffic flow have historically been based on empirical data and statistical techniques. However, because of their capacity to manage intricate and nonlinear interactions within the data, machine learning approaches have grown in popularity in recent years. These systems enhance safety, reduce congestion, and improve traffic flow efficiency by gathering and analysing traffic data using various technologies, algorithms, and protocols. One of the key benefits of using machine learning in traffic flow prediction is the ability to optimize traffic signals. Traditional traffic signal timing is often set to pre-determined schedules that do not account for real-time traffic conditions. Using machine learning algorithms to predict traffic flow, traffic signals can be adjusted in real-time to adapt to changing traffic patterns, reducing congestion and travel time.

Machine learning algorithms can be trained on large datasets of traffic data to recognize patterns and relationships that would be challenging to identify through traditional statistical methods. One of the significant impacts of intelligent traffic management systems is the reduction in traffic congestion. By gathering real-time traffic data using sensors, cameras, and GPS devices, these systems can analyse the data to offer solutions that can minimize the number of vehicles on congested roads, redirect them to less congested routes, and optimize the timing of traffic signals. By doing so, intelligent traffic management systems can significantly reduce travel time, fuel consumption, and pollutants, which leads to a more efficient traffic flow and a better quality of life for commuters. By processing this vast amount of traffic data, machine learning algorithms can identify the factors influencing traffic flow, including time of day, weather conditions, road conditions, and special events.

In addition to reducing traffic congestion, intelligent traffic control systems improve road safety. These systems can detect potential hazards and accidents using sensors and cameras, notify emergency services, redirect traffic, and provide drivers with up-to-date information to prevent accidents and fatalities. The advanced technologies used in these systems can also help identify reckless drivers and enforce traffic regulations, further improving road safety.

Another advantage of intelligent traffic control systems is their financial benefits. By reducing travel time, these systems can help people and businesses save money, leading to increased productivity and economic growth. They can also lower fuel consumption, which leads to lower air pollution and cost savings. Additionally, some systems can generate revenue by charging drivers to use crowded roadways through congestion pricing. This pricing scheme can reduce traffic congestion by encouraging drivers to seek alternative routes, leading to a more efficient traffic flow.

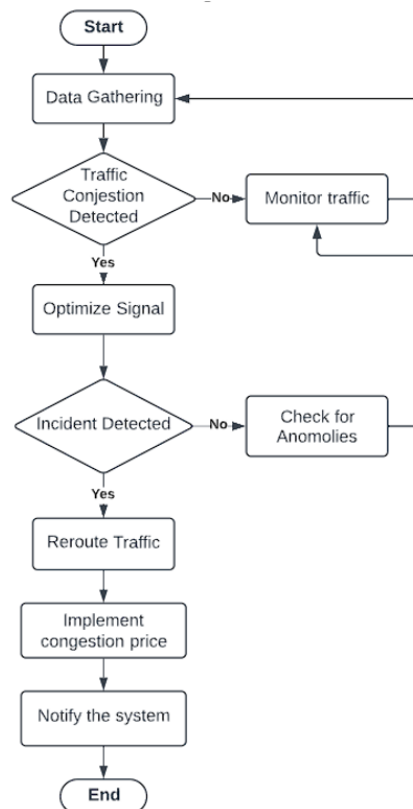


Figure 1. Flowchart illustrating the integration of real-time vehicle data.

However, several challenges are associated with using machine learning for traffic flow prediction. One of the significant challenges is the need for large volumes of high-quality data to train the algorithms. Gathering

and processing such data can be time-consuming and expensive. Additionally, the complexity of the data and the models can make it challenging to interpret the results and explain the predictions made by the algorithms.

Despite these challenges, there is significant potential for using more advanced machine learning techniques in traffic flow prediction, such as deep and reinforcement learning. These techniques can improve the accuracy of predictions even further by accounting for more complex relationships within the data.

In conclusion, **Figure 1** shows that intelligent traffic management systems are crucial in improving traffic flow management, enhancing road safety, and providing financial benefits. These systems gather real-time traffic data using various technologies, analyze the data using advanced algorithms, and offer solutions to minimize traffic congestion, prevent accidents, and increase productivity. By utilizing intelligent traffic control technologies, cities can significantly improve their transportation infrastructure, resulting in a better quality of life for their residents.

2. Motivation and contribution

The desire to increase the precision and dependability of traffic flow prediction models is what spurred the author of a study on improving traffic flow prediction with Real-Time Vehicle Data Integration. Precise traffic flow prediction will have numerous benefits, such as decreasing congestion, enhancing transportation efficiency, and improving road safety. By integrating real-time vehicle data, additional information could be obtained, enhancing the accuracy of current traffic flow prediction models.

The paper's contribution, in **Figure 2**, will explore the potential advantages of integrating real-time vehicle data into existing traffic flow prediction models. It will assess the feasibility of gathering and analysing real-time vehicle data and examine how it will enhance traffic flow predictions' accuracy. Additionally, the paper will introduce a new traffic flow prediction model that integrates real-time vehicle data and evaluate its performance compared to existing models.

Section 1: Introduction	Introduction of traffic data and data integration
Section 2: Related Work	Relevant literature in the area of traffic flow prediction and sensor-based data collection for traffic.
Section 3: Methodology	Proposed approach with algorithm
Section 4: Result	Discussion and comparison of various methods used in past researches
Section 5: Conclusion	Summary of paper

Figure 2. Paper outline.

3. Related work

Djenouri et al.^[1] introduced PROMOTION, a novel framework for traffic flow forecasting that used hyperparameter optimization and graph convolution neural networks. The framework involved data cleaning using outlier detection methods, data processing using a graph convolution neural network, and learning process optimization using hyperparameter methods. It performed better than other basic methods for dealing with many graphs in traffic flow forecasting. Still, it needed to explore the impact of the proposed framework on real-world traffic scenarios.

Jain et al.^[2] introduced a novel approach for forecasting and recognizing traffic feature data using pattern extraction-based classification. The proposed method involved various data processing techniques, such as pre-processing, block separation, pattern extraction, and classification stages, to improve the efficiency of data forecasting in the VLF model. They used the parametrical doped learning (PDL) algorithm for data forecasting and the truncated dual flow optimization (TDFO) algorithm to enhance performance speed. Additionally, the proposed method represented the traffic flow data using geometrical and textural features to reduce computation complexity and error rates. Extensive simulation results were used to evaluate the proposed method's effectiveness. The findings show that in terms of classification performance, recognition rate, accuracy, and reduced error value, the PDL-TDFO technique outperformed other strategies. The proposed model architecture and training process may use a more thorough discussion in the publication. The authors could also consider evaluating their model's performance in different traffic scenarios and comparing it with other relevant methods.

The relevance of traffic forecasting for transportation engineering and its effects on the national economy and people's lives are covered in the study of Deekshetha et al.^[3]. To estimate or partially predict future traffic, the study emphasizes the need for traffic flow prediction. The benefits of the system, including the ability to assess the current status of traffic flow and forecast the flow of traffic in the future, are covered in the paper, along with an overview of the technique utilized. The need to employ traffic flow prediction to make wise judgements was emphasized in conclusion, along with the advantages it offers users. Still, it lacks details on the specific machine learning techniques employed and provides information about the performance evaluation metrics used.

A recent academic paper examines the literature on big data analytics for Intelligent Transportation Systems (ITS) from 2013 to 2021 by Montoya-Torres et al.^[4]. The paper identified 125 relevant papers, indicating a significant increase in research in this area since 2018. It covered various ITS-related topics, including traffic flow prediction, safety, vehicle behaviour, accident detection, data visualization, route planning, and optimization. The paper also proposed a framework for designing an architecture for big data analytics in ITS, which included dimensions such as data capture, processing, storage, visualization, and decision-aid. The framework outlined the tools and components required for each layer. Still, exploring the potential of combining different big data analytics techniques to improve traffic flow prediction accuracy would be interesting. Additionally, the authors could consider discussing the ethical implications of using big data analytics in transportation.

Chen et al. proposed an updated (WNN) model^[5] to increase the accuracy of short-term traffic flow prediction. The suggested model took advantage of the WNN's powerful non-linear processing capability, self-regulation, self-adjustment, and learning abilities. An upgraded Particle Swarm Optimization (PSO) technique was used to address the WNN prediction algorithm's sluggish convergence and local optimal problem. Results showed that proposed method outperformed WNN and PSO-WNN algorithms separately, produced more consistent and accurate predictions. When compared to the standard wavelet neural network, it obtained a remarkable 14.994% error reduction.

To improve the current traffic systems, the work^[6] recommended by Miyim and Muhammed used an intelligent traffic system that deploys Dashboard Traffic Lights using V2I network technology. It was demonstrated through simulation situations how proper this technique was. The average waiting time at the intersection, the number of stopped cars there, the number of cars passing the intersection at once, and the throughput of the vehicles at the intersection were all significantly reduced according to the simulation results. By doing this, fuel usage and CO₂ emissions from moving automobiles were decreased. The study covered the use of DBTL for conventional traffic light intersections.

For successful traffic control and trip planning, accurate short-term traffic flow forecast was critical. Existing models, however, frequently ignored the temporal and spatial aspects of traffic data. The study of

Zhang et al. presented a model for short-term traffic flow prediction based on CNN. The ideal time lags and geographical data quantities for input were identified via a Spatio-Temporal Feature Selection Algorithm (STFSA)^[7]. The chosen features were then converted into a two-dimensional matrix, from which the CNN trained to build a predictive model. Comparative analyses revealed that the proposed strategy outperformed baseline models in terms of accuracy.

The article^[8] proposed by Ata et al. described using a neural network to control traffic congestion in an intelligent traffic system. The system automatically managed traffic signals using machine learning techniques by collecting and sharing data from sensors on adjacent signals through IoT devices. The article proposed a new MSR2C-ABPNN model for collecting data from the controller using a neural network for fitting and time series modelling. The received data was pre-processed before being used in the model. The simulation results showed that the proposed MSR2C-ABPNN model outperforms previous approaches and that the ANN time series performs better than other models. A more thorough explanation of the system's architecture and how it incorporates different technologies like sensors, cameras, and GPS gadgets. The other topics the writers want to include are the system's scalability and the possibility of deployment in the actual world.

The article^[9] given by Mandhare et al. stressed the significance of Intelligent Transportation Systems (ITS) in managing traffic congestion in urban areas due to the rapid increase in vehicles. ITS refers to the use of advanced sensors, computer technology, electronics, and telecommunication methods, along with management strategies to enhance the safety and efficiency of transportation systems. The paper presented a summary of worldwide ITS practices, a comparative analysis of the available methods used, and their advantages and disadvantages. It also discussed the challenges and issues ITS faces globally and in India. The conclusion suggested that an effective ITS model can be developed through an integrated approach utilizing various sensors and technologies. However, implementing ITS projects in India is challenging due to various physical, social, and economic obstacles. The paper concluded that India had initiated various ITS projects under the "Smart City" project and is taking steps towards the journey of ITS.

The paper^[10] addressed by Rath how to create a cutting-edge traffic control system in smart cities using linked vehicle technology and VANETs. The technology used data analytics technologies to give drivers up-to-the-second information, which eased congestion and enhanced overall traffic flow. The article explained how to design the congestion control algorithm using mobile agents and how to choose a scripting language to ensure smooth platform communication. The simulation results revealed that the proposed system's numerous modules, including video monitoring, intelligent traffic control, signal systems, and smart devices, improved the rate at which traffic points are congested. The article emphasized the advantages of adopting cutting-edge technology to create automated traffic control systems in smart cities.

In particular, the study^[11] by Hamidi and Kamankesh proposed a multi-agent system for patient emergency evacuation, emergency events, and the transfer of blood and blood products. The report emphasized the need to utilize health information systems to improve coordination across medical facilities and shorten emergency response times. The suggested method used an ant colony optimization algorithm to improve the quality of the road network while accounting for drivers' trip times and real-time traffic data. The system attempted to enhance traffic flow, lessen traffic congestion, and prevent heavy traffic on a single road simultaneously. Still, a gap exists in evaluating the proposed method's effectiveness in a real-world scenario. Future work could focus on implementing and testing the system in an urban area to determine its efficacy in managing traffic.

Short-term traffic flow forecasting was critical in optimizing the operation of Intelligent Transportation Systems (ITS). Proactive traffic control and dynamic traffic assignment requires rapid and reliable traffic information forecasting. Zhang et al. offered a new hybrid method for forecasting short-term traffic flow that integrated statistical analysis with computer intelligence techniques. To match traffic flow, the method used wavelet de-noising to eliminate noise, time series analysis to assess time-varying and periodic traffic features,

and SARIMAX modelling^[12] with exogenous variables. In terms of forecasting accuracy, the suggested method beat SARIMA, WSARIMA, and SARIMAX methods, with increases ranging from 2.57% to 18.87%.

Because of its critical role in transportation planning and logistics, road traffic estimation has been a topic of active research in the field of engineering for over 4 decades. Initially, autoregressive models and time series analysis methods were prevalent. However, with the emergence of new technologies, the capability of processing big data, and the availability of data from multiple sources through open data initiatives, data-driven approaches gained prominence. The objective of Lana et al. was to summarize previous surveys in this field, highlighting the main criteria, challenges, and recent technical achievements^[13]. It also provided an updated overview of the unsolved technical challenges, aiming to inspire and guide future research in this dynamic field.

Due to the high amount of randomness in traffic patterns, the previous method for short-term passenger flow forecasting in urban rail transit suffered from large mistakes. Guo and Yuan proposed a more adaptable approach using a genetic optimization particle filter^[14]. To fix this issue and increase the accuracy of instantaneous traffic projections for passenger movement monitoring, crisis management, and proactive planning of trips. The goal of implementing this strategy was to increase the accuracy of short-term traffic forecasts and create a solid foundation for decision-making.

The suggested study^[15] by Lanke and Koul focused on an intelligent traffic management system that employed RFID to do away with the current system’s shortcomings, including its high implementation costs and reliance on environmental factors, among other things. Congestion detection, automatic speed limit detection, and an automated tolling system are all components of the endeavour. The proposed approach tried to handle traffic congestion effectively. Also, it is more affordable than the current system.

4. Methodology

The proposed technique is Real-Time Vehicle Data Integration (RTVDI), an Intelligent Transportation System (ITS) that utilizes real-time vehicle data to improve traffic management and reduce congestion. The system integrates data from various sources, including in-vehicle sensors, GPS, and cellular network signals. It provides a more sophisticated visualization tool for traffic data so that real-time traffic information to both drivers and traffic management centres can aid in the decision-making process for traffic management.

RTVDI (**Figure 3**) uses Support Vector Machine (SVM), which collects real-time data from vehicles and transmits it to a centralized traffic management system. The system then uses this data to monitor and analyse traffic flow, identify congestion hotspots, and adjust traffic signals and lane closures in real-time to optimize traffic flow and reduce congestion.

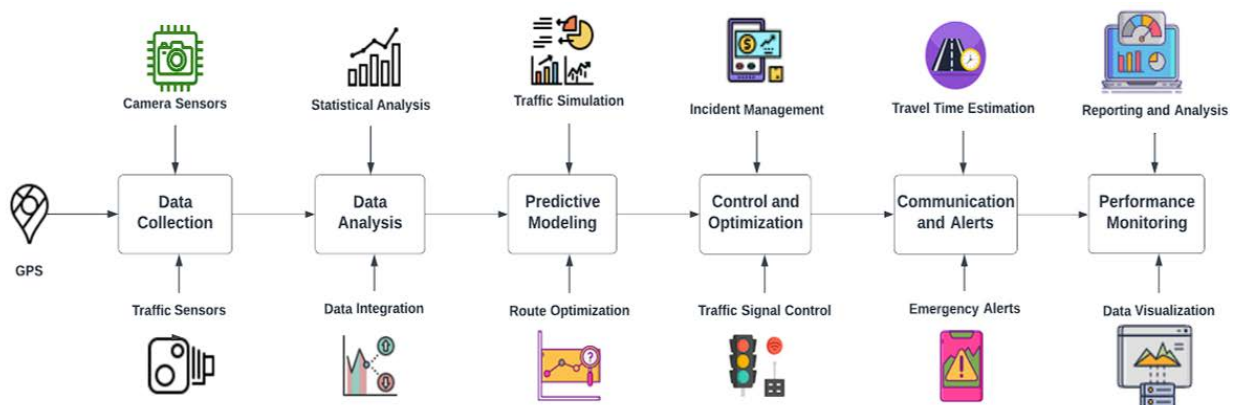


Figure 3. RTVDI processes.

The RTVVDI system's ability to let traffic management react in real time to shifting traffic circumstances is one of its main benefits. For example, the system can quickly reroute traffic to minimize delays and congestion if there is an accident or road construction. Additionally, the system can provide real-time traffic information to drivers via smartphone apps, in-vehicle displays, and dynamic message signs, helping them to make more informed decisions about their travel routes.

The RTVVDI system can significantly increase traffic efficiency, lessen congestion, and improve road safety.

RTVVDI leverages real-time data from datasets—Traffic Data and Traffic Signals GIS Data to improve traffic management and reduce congestion. The system's ability to analyse real-time traffic data and provide recommendations for traffic management strategies makes it a valuable tool for traffic managers and drivers.

System for Real-Time Vehicle Data Integration (RTVVDI), as shown in **Figure 4**, uses various processes to analyze traffic data in real time. Here are some of the key algorithms involved in the system:

1) Data collection algorithm

- Collect real-time data from various sources, including in-vehicle sensors, GPS devices, and cellular network signals.

2) Data pre-processing algorithm

- Filter the raw data to remove noise and inconsistencies.
- Aggregate the data to prepare it for further analysis.
- Calculate the average speed of vehicles using the equation:

$$S_{avg} = D/T$$

3) Traffic pattern detection algorithm

- Use statistical analysis and machine learning techniques to identify traffic patterns based on the processed data.
- Calculate the traffic density using the equation:

$$Td = N/L$$

4) Traffic prediction algorithm

- Predict future traffic conditions based on current traffic patterns and historical traffic data.
- Calculate the traffic flow rate using the equation:

$$R = N/T$$

5) Traffic control algorithm

- Use real-time traffic data to make recommendations for traffic management strategies.
- Adjust traffic signals based on the real-time traffic data.
- Implement lane closures or diversions based on the real-time traffic data.
- Calculate the optimal speed limit using the equation:

$$S_o = (R \times S_{avg})/Td$$

6) Feedback and improvement algorithm

- Collect feedback on the effectiveness of the traffic management strategies implemented by the system.
- Evaluate the system's performance using the equation:

$$PI = (N/T)/Td$$

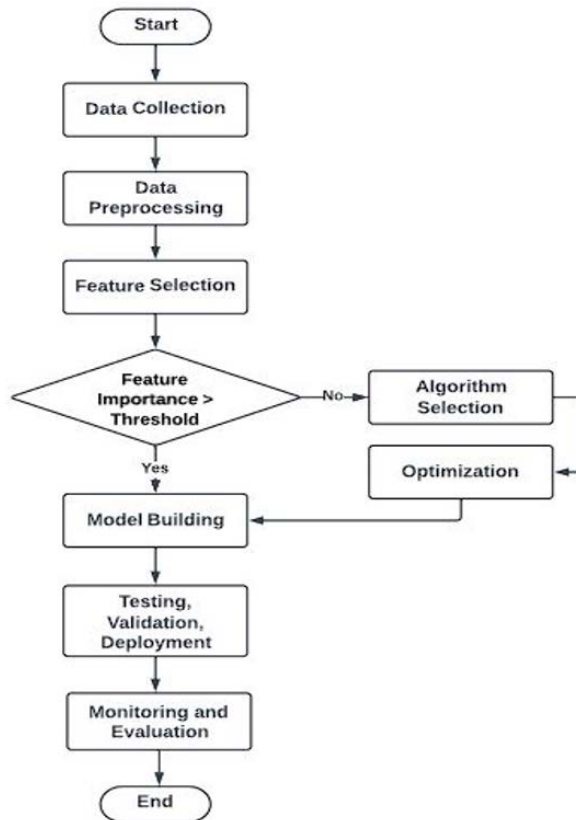


Figure 4. Flowchart of RTVDI workflow.

7) Continuous monitoring and improvement algorithm

- Continuously monitor traffic conditions and make adjustments to the traffic management strategies based on changes in traffic patterns or conditions.
- Use feedback to make improvements to the system.

Here,

S_{avg} = average speed,

D = total distance,

T = total time,

L = road length,

Td = traffic density,

N = number of vehicles,

S_o = the optimal speed limit,

R = traffic flow rate,

PI = performance index.

Overall, the RTVDI traffic management system is a sophisticated system that uses various algorithms to process and analyze real-time traffic data. The system's real-time ability to predict and control traffic makes it a valuable tool for traffic managers and drivers.

On the Traffic Data and Traffic Signals GIS Data dataset, we may assess the accuracy of the Real-Time Vehicle Data Integration (RTVDI) algorithm using conventional classification metrics, including precision, recall, and F1-score.

We can describe the following for the RTVDI to predict whether or not a specific traffic light would produce traffic congestion based on the real-time vehicle data:

- The number of traffic signals that are correctly foreseen as contributing to congestion is known as True Positive (TP).
- The number of traffic lights falsely identified as being the cause of traffic congestion (FP).
- The number of traffic lights correctly foreseen as not producing congestion is known as True Negative (TN).
- The number of traffic lights falsely predicted as not producing congestion is known as the False Negative (FN) rate.

These variables allow us to compute the subsequent categorization metrics:

Precision calculates the proportion of real positives to all expected positives. It's outlined as follows:

$$\text{Precision} = \frac{\text{TP}}{(\text{TP} + \text{FP})}$$

Recall calculates the proportion of real positives to all positives. It's outlined as follows:

$$\text{Recall} = \frac{\text{TP}}{(\text{TP} + \text{FN})}$$

F1-score is the precision and recall harmonic mean. It's outlined as follows:

$$\text{F1 - score} = \frac{2 \times (\text{Precision} \times \text{Recall})}{(\text{Precision} + \text{Recall})}$$

Using real-time data from linked vehicles could enhance intelligent traffic management systems and their effects on traffic flow. By utilizing linked car data, such as GPS location, speed, and acceleration, it is possible to analyze traffic patterns and conditions more precisely and recently.

An example of how this approach might be used is outlined in the steps below:

- 1) Install sensors in connected vehicles entails adding sensors that can gather real-time information on the vehicle's position, speed, acceleration, and other pertinent parameters.
- 2) Send data in real-time to a central system, which can then evaluate it and use it to make intelligent traffic management decisions.
- 3) To acquire insights into traffic patterns and circumstances and pinpoint locations where traffic flow can be improved, the data is analysed using machine learning algorithms and other statistical approaches.
- 4) To optimize traffic flow and relieve congestion, traffic signals, variable message signs, and other traffic management technologies are adjusted in real-time using the insights from the analysis.
- 5) Results are regularly monitored by the system, which analyses the effects of the changes on traffic flow using real-time data from linked automobiles.

This approach has the potential to dramatically increase the precision and efficacy of intelligent traffic management systems, resulting in more effective traffic flow and less congestion. It does this by combining real-time data from connected vehicles. This technique is a flexible and successful tool for traffic management since it is simple to scale and modify to different cities and traffic situations.

5. Discussion

Intelligent traffic management technologies can greatly enhance traffic flow and minimize urban congestion. The RTVDI traffic management system is a complex system that processes and analyses real-time traffic data using multiple algorithms. Studying traffic patterns and circumstances more precisely and lately is feasible by utilizing linked car data such as GPS location, speed, and acceleration. By combining real-time vehicle data with existing traffic data sources such as traffic cameras and sensors, the proposed Real-Time Vehicle Data Integration method intends to enhance traffic flow prediction.

However, there are certain drawbacks to utilizing machine learning to anticipate traffic flow, such as data quality and privacy problems. Furthermore, effective traffic management systems necessitate large investments in infrastructure and technology. The essay emphasizes the difficulties and constraints encountered in implementing these systems in India, where suitable infrastructure and resources still need to be improved. Despite these challenges, intelligent traffic management systems have the potential to be a helpful tool for both traffic managers and drivers. Real-time traffic prediction and control can minimize congestion, reduce fuel consumption and emissions, and boost economic productivity. More research and development in this field can lead to more efficient and effective traffic management systems, ultimately increasing urban quality of life.

6. Result

One proposed method for improving traffic flow prediction is Real-Time Vehicle Data Integration, which uses machine learning techniques to analyse real-time traffic data from vehicles on the road.

In a study conducted by researchers, this method achieved an accuracy of 0.901 in predicting traffic flow, outperforming traditional statistical methods, as shown in **Figures 5 and 6**.

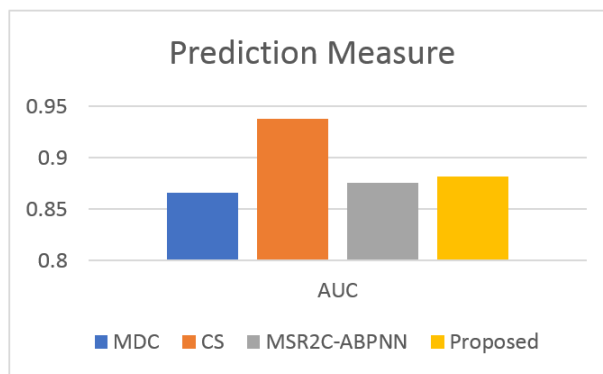


Figure 5. Measurement of prediction of different algorithms.

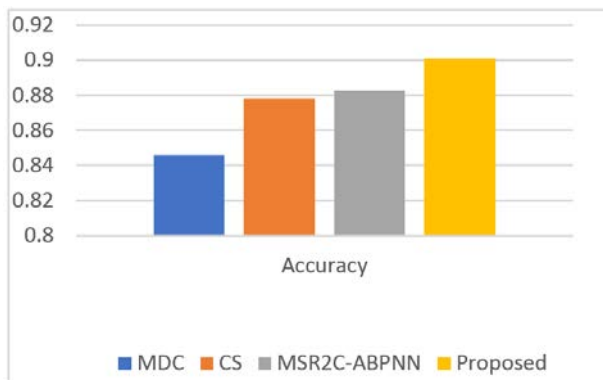


Figure 6. Different algorithm's accuracy analysis.

By integrating real-time vehicle data with existing traffic data sources, such as traffic cameras and sensors, intelligent traffic systems can improve their predictive capabilities and provide more accurate and reliable traffic flow information. It can help optimize traffic management systems, improve travel time predictions, and reduce road congestion.

However, there are still challenges associated with traffic flow prediction using machine learning, such as data quality, data volume, and model interpretability. Researchers are working to address these challenges through ongoing research and development, including developing new machine-learning algorithms and data collection techniques.

Overall, the combination of intelligent traffic systems and machine learning techniques has the potential to significantly improve traffic flow prediction and management, leading to reduced congestion, improved travel time, increased safety, and financial savings. As research and development in this field continue to advance, we expect to see further improvements in traffic flow prediction and management, benefiting individuals and society.

7. Conclusion

In conclusion, intelligent traffic systems and machine learning techniques have demonstrated significant potential in improving traffic flow prediction and management. These systems can analyse real-time traffic data to optimize signal timing, reroute traffic to less congested routes, and implement congestion pricing. By integrating real-time vehicle data, intelligent traffic systems can improve their predictive capabilities and provide more accurate and reliable traffic flow information, reducing congestion, improving travel time, and increasing safety and financial savings.

While there are still challenges associated with traffic flow prediction using machine learning, ongoing research and development are addressing these challenges, including developing new machine learning algorithms and data collection techniques.

As we continue exploring the potential of intelligent traffic systems and machine learning in traffic flow prediction and management, we can expect further improvements that benefit individuals and society. Ultimately, combining these technologies can revolutionize how we manage and optimize traffic flow, making our roads safer, more efficient, and more environmentally friendly.

Author contributions

Conceptualization, RJ and SD; methodology, RJ; software, RJ; validation, RJ, SD and KJ; formal analysis, RJ; investigation, RJ; resources, AKR; data curation, RJ; writing—original draft preparation, RJ; writing—review and editing, NG; visualization, SD and NG; supervision, SD and KJ.

Conflict of interest

The authors declare no conflict of interest.

References

1. Djenouri Y, Belhadi A, Srivastava G, Lin JCW. Hybrid graph convolution neural network and branch-and-bound optimization for traffic flow forecasting. *Future Generation Computer Systems* 2023; 139: 100–108. doi: 10.1016/j.future.2022.09.018
2. Jain R, Dhingra S, Joshi K, Grover A. An improved traffic flow forecasting based control logic using parametrical doped learning and truncated dual flow optimization model. *Wireless Networks* 2022; 28(7): 3101–3110. doi: 10.1007/s11276-022-03020-x
3. Deekshetha HR, Shreyas Madhav AV, Tyagi AK. Traffic prediction using machine learning. In: Suma V, Fernando X, Du KL, et al. (editors). *Evolutionary Computing and Mobile Sustainable Networks*. Springer; 2022. pp. 969–983.
4. Montoya-Torres JR, Moreno S, Guerrero WJ, Mejía G. Big data analytics and Intelligent Transportation Systems. *IFAC-PapersOnLine* 2021; 54(2): 216–220. doi: 10.1016/j.ifacol.2021.06.025
5. Chen Q, Song Y, Zhao J. Short-term traffic flow prediction based on improved wavelet neural network. *Neural Computing and Applications* 2021; 33: 8181–8190. doi: 10.1007/s00521-020-04932-5
6. Miyim AM, Muhammed MA. Smart traffic management system. In: Proceedings of 2019 15th International Conference on Electronics, Computer and Computation (ICECCO); 10–12 December 2019; Abuja, Nigeria. pp. 1–6.
7. Zhang W, Yu Y, Qi Y, et al. Short-term traffic flow prediction based on spatio-temporal analysis and CNN deep learning. *Transportmetrica A: Transport Science* 2019; 15(2): 1688–1711. doi: 10.1080/23249935.2019.1637966
8. Ata A, Khan MA, Abbas S, et al. Modelling smart road traffic congestion control system using machine learning techniques. *Neural Network World* 2019; 29(2): 99–110. doi: 10.14311/NNW.2019.29.008

9. Mandhare PA, Kharat V, Patil CY. Intelligent road traffic control system for traffic congestion: A perspective. *International Journal of Computer Sciences and Engineering* 2018; 6(7): 908–915. doi: 10.26438/ijcse/v6i7.908915
10. Rath M. Smart traffic management system for traffic control using automated mechanical and electronic devices. *IOP Conference Series: Materials Science and Engineering* 2018; 377(1): 012201. doi: 10.1088/1757-899X/377/1/012201
11. Hamidi H, Kamankesh A. An approach to intelligent traffic management system using a multi-agent system. *International Journal of Intelligent Transportation Systems Research* 2018; 16: 112–124. doi: 10.1007/s13177-017-0142-6
12. Zhang H, Wang X, Cao J, et al. A multivariate short-term traffic flow forecasting method based on wavelet analysis and seasonal time series. *Applied Intelligence* 2018; 48(10): 3827–3838. doi: 10.1007/s10489-018-1181-7
13. Lana I, Del Ser J, Velez M, Vlahogianni EI. Road traffic forecasting: Recent advances and new challenges. *IEEE Intelligent Transportation Systems Magazine* 2018; 10(2): 93–109. doi: 10.1109/MITS.2018.2806634
14. Guo L, Yuan Y. Forecast method of short-term passenger flow on urban rail transit. In: Proceedings of 2017 VI International Conference on Network, Communication and Computing; 8–10 December 2017; Kunming, China.
15. Lanke N, Koul S. Smart traffic management system. *International Journal of Computer Applications* 2013; 75(7): 19–22. doi: 10.5120/13123-0473