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Solving Traffic congestion using Artificial Intelligence: A review

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Abstract

This research articles explores the integration of AI, computer vision, IoT, and autonomous vehicles for optimized urban traffic management. Computer vision enables real-time traffic monitoring, while IoT facilitates dynamic data collection. Autonomous vehicles, driven by AI algorithms, contribute to traffic optimization. The study reviews successful implementations, addresses challenges, and emphasizes collaborative efforts for widespread adoption. This research highlights the potential of these technologies to revolutionize urban mobility, mitigating congestion and fostering smart transportation ecosystems.

Keywords: Intelligent transportation system, Artificial intelligence, Traffic flow management, Autonomous Car, Internet of things (IoT), Traffic Congestion, Smart Traffic Light

1. Introduction

In recent years, a huge surge in the number of vehicles roaming on the roads of major cities has been witnessed.[3] The increase in traffic is attributed to the increase in population, deficient infrastructure, and poor economy. The increase in traffic has in turn raised the issue of traffic congestion, a traffic condition characterized by slow speed, long vehicle queues, and long trip times.

Research conducted in Istanbul, Moscow, Boston, and Jakarta highlighted several economic problems and health issues caused by traffic congestion[1]. The outdated traffic management system is not capable of managing traffic congestion i.e. it operates independently as a result, it does not respond to variations in traffic [3,4]. This means many developing countries with outdated technology have to spend a high percentage of GDP on logistics [2].

To tackle these issues, authorities have suggested various solutions over time. Recently with the development of various scientific fields humans have been offered various opportunities [5]. In this paper, we discuss four technologies which use AI to help in reducing traffic congestion:

Artificial intelligence (AI) Algorithms: Artificial intelligence (AI) refers to the intelligence of computers using various methods to make decisions. It's the most recent and efficient technology available to mankind at this time, capable of dealing with social and economic challenges [6]. AI cannot physically change the existing system, but it can help in managing traffic [7].

Computer Vision (CV): Computer vision (CV) is a field of AI, that can help computers process videos and images to get meaningful data from them. CV can detect objects on road and then operates the traffic light accordingly [14].

Internet of Things (IoT): The Internet of Things (IoT) is an interrelated system of devices and objects, with unique identifiers. These objects and devices can communicate with each other without human interaction [12]. IoT allows vehicles and roads to communicate and then manage the traffic with the help of AI.

Autonomous vehicles (AV): An autonomous vehicle (AV) is a kind of vehicle that can operate without a human driver using its sensing capabilities. Research has shown that if AVs operated in coordination, the average traffic flow is better than human traffic flow [21].

The main contribution of this article is that it provides a comprehensive survey of the state-of-the-art research where AI assisted technologies such as CV, IoT and AV are used for traffic management alongwith the highlighting the practical difficulties. This can be a starting point for someone that wants to research in this field.

2. Traffic Management with AI Algorithm

2.1 AI Controlled Traffic Light

The system presented in this paper has the objective of enhancing traffic flow and decreasing the average waiting time of the vehicles on the road. This system is applied to the typical traffic light without much modification to the old infrastructure [3].

The system receives information on the whole traffic network and then the decision is made at the intersection according to the traffic volume and priority vehicles. This minimizes both the waiting time of the vehicles and the traffic jams [3]. The whole process is shown in the fig. 1.

The results of the systems show that the waiting time was reduced by 34.16%. It not only decreases the need for new infrastructure but also reduces fuel consumption and gas emissions. It has a positive effect on the environment and human health [3]. The signal can also be modified with Markov Decision Process (MDP) which optimizes the interpretable signal control policies and manages the traffic control flow [9].

This system is only designed for a single traffic light at a junction and is not connected to other traffic lights in the city, as a result, they do not coordinate with each other. This system can solve traffic jams at one junction but may lead to traffic at other junction.

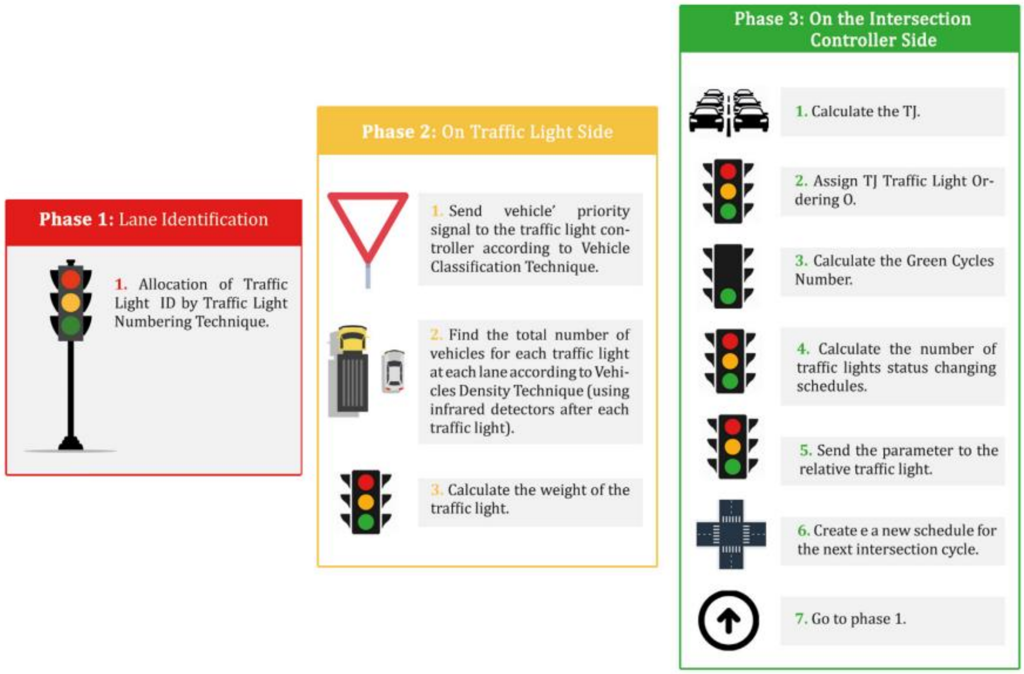

Figure 1: Phases of the system [3]

2.2 Neural Network vs Fuzzy logic based traffic light

The system is designed for the city of Bogota, Colombia, which has a focus on the flow of vehicles and its prediction. In a simulation environment, the Levenberg-Marquardt method was used to explore various network architectures, but the results were not satisfying. The lowest mean squared error (MSE) indicated that the neural network isn't suitable for this job [4]. The results are shown in table 1:

Table 1: Results of neural network[4]

Architecture with Levenberg Marquadt for traffic with 40 vehicles.

Size	Number of neurons	MSE	Regression
(2 3)	5	0.007	0.905
(5 3)	8	0.005	0.93
(1 0 3)	13	0.002	0.969
(5 5 3)	13	0.003	0.958
(15 15 3)	33	0.001	0.982
(20 20 3)	43	0.001	0.982
(5 5 5 3)	18	0.001	0.977
(10 10 10 3)	33	0.001	0.983

The researchers then studied an algorithm powered by fuzzy inference systems with adaptive networks. This algorithm considered various aspects of the cars and the road and was tested in a simulated environment and the results were better than the neural network [4]. The results are presented in the table 2:

Table 2: Results of the algorithm [4]

Avenida Caracas	Longitud entre cruces (m)	Trojo(s)	Tverde(s)	Temporary offset of green
No 45	281	49	66	–
No 47	212	47	68	4.5

It was observed that the system produced very good results when the system was provided with appropriate inputs and a good amount of data [4]. In another study, it was noted that if deep reinforcement learning is implemented in a traffic light the results can further be improved [10].

2.3 Best Route based on AI

Best Route based on AI is a solution suggested to minimize the problem of traffic congestion in the form of an app that diverts traffic to alternate routes with fewer vehicles. For this, graph theory based on the best first search algorithm is used which works on the method to expand the nodes in a graph prioritizing those nodes that have the lowest cost from the starting point to the destination. The app is implemented as a web app using JavaScript and Google map API, with 154 nodes in Medan city [11].

The experiment result demonstrated that different routes were suggested from start to end and vice versa directions. As the algorithm doesn't consider the total time, so in some cases the distance and travel time were the same, it should also be noted that the routes suggested by the algorithm are not always optimal [11]. The process is described in the flow chart, fig. 2:

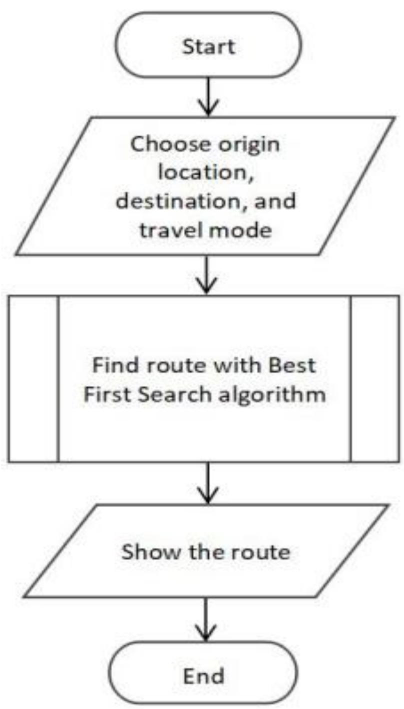

Figure 2: Process of best route based on AI[11]

In another study which took into account both traffic records and climate conditions. The optimal route was suggested for logistic transportation, based on the MLP model. The results indicated that the system is feasible with an accuracy rate of 88%, provided sufficient data is fed [12].

2.4 Challenges faced by implementing Reinforcement learning (RL) in Traffic Control

Reinforcement learning is a field of machine learning which is based on a feedback mechanism. The agent learns by itself by performing an action and improving according to the feedback.

There are always two sides of a picture, same goes with AI. AI faces challenges that hamper its implementation in the real world.

- Safety concerns: Reinforcement learning which is implemented in traffic control has no safe policy leading to serious traffic violations and therefore it’s not safe to be implemented in traffic control in a real scenario [13].
- Predictability: RL-based controller make decisions based on the current state of the environment which is a single step. They are not committed to future actions which makes them unpredictable in nature. [13]
- Efficient Controller Training: RL controllers are very slow to train which makes them expensive when it comes to traffic control applications [13].

Due to the above mentioned challenges, some people think AI is not trustworthy and does not consider its implementation in traffic control safe. Due to these trust issues, most people and governments are not willing to implement AI in real-life traffic control [13].

3. AI Traffic Surveillance Cameras

3.1 CCTV control traffic light

The system is shown in the figure.2 utilizes the power of CCTV cameras to obtain images and calculate traffic density in real time through image processing and object detection [14]. The system uses the Yolo algorithm that identifies the type and number of vehicles leading to the calculation of traffic density. Afterwards, the signal switching algorithm calculates the density of traffic and determines the timing of traffic lights. The simulation results suggest that the system is effective and gives better results as compared to the existing system [14].

The system was tested in a simulation environment created with the help of Pygame. The simulation consists of a four way intersection with four traffic lights. The results of the simulation show that the system can detect vehicles with 75% – 80% accuracy and also performs better than the present static system as shown in fig. 4:

3.2 AI enabled CCTV:

This system is implemented using deep CNN which is trained using a GPU at the back end. Various object detection algorithms are used to detect and classify the vehicles in the images which are captured by the CCTV. The system not only finds the volumes but also can detect the queuing of vehicles, crashes, and other problems associated with traffic flow [15].

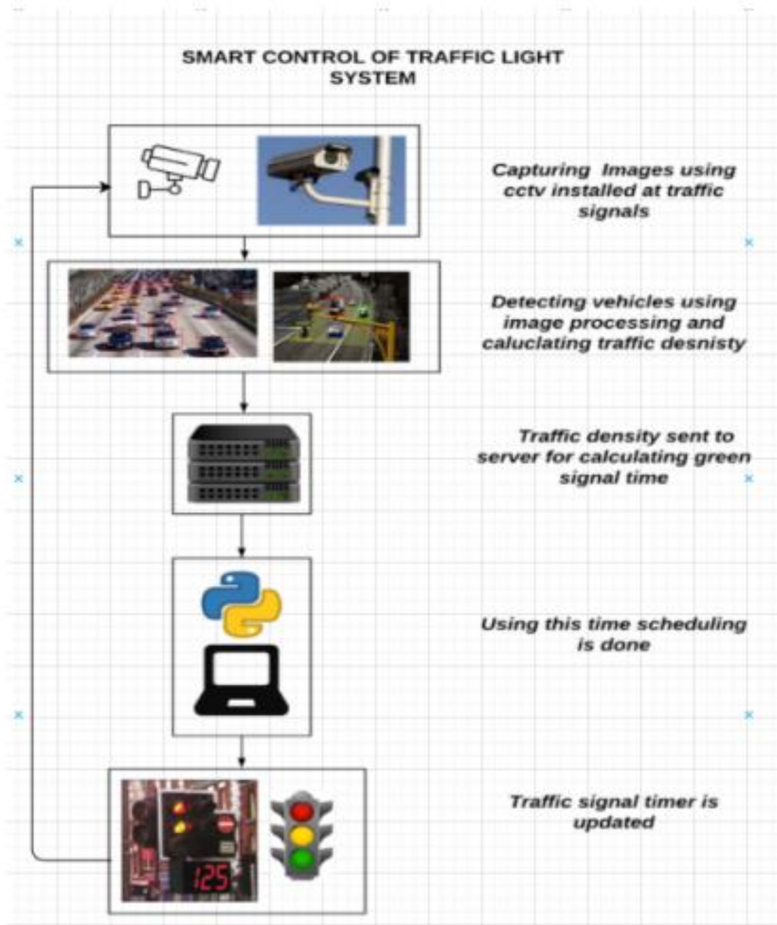

Figure 3: Smart control of traffic light system[14]

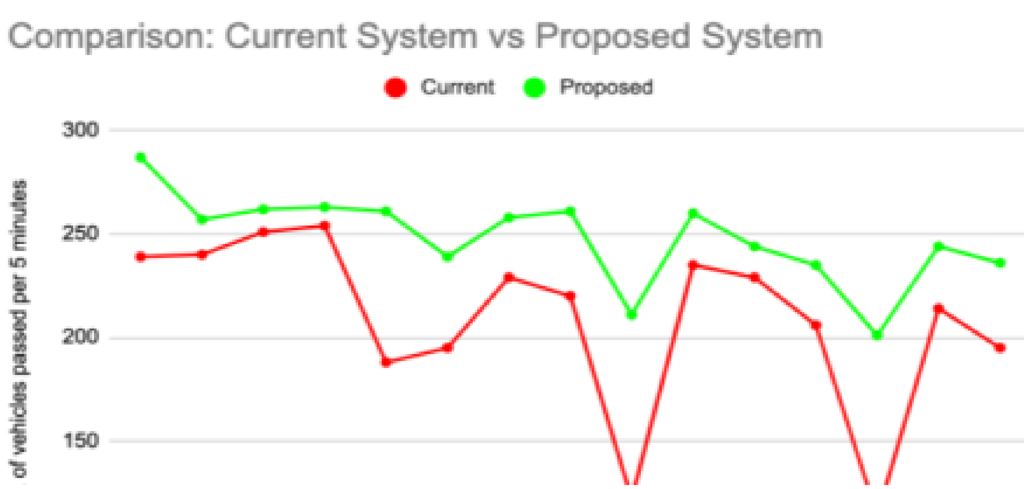

Figure 4: Comparing the current system vs proposed system [14]

The following methodology is adopted by the system:

This system uses Mask R-CNN, Faster R-CNN, YOLO, and CenterNet for object classification and detection. Faster R-CNN is a detection algorithm and is further enhanced by its extension Mask R-CNN which adds masks to pixels. YOLO is an object detection algorithm, while CenterNet uses low computational power for detection in cropped images [15].

The system uses YOLO and Mask R-CNN for monitoring the traffic, the result detection is then tracked by Intersection over Union (IOU) system. The result is then used to decide the travel direction. The system also detects vehicle speed and the road type to detect any inconsistency on the road . The Fig. 5 shows the working of the system. The system performed at more than 90% accuracy but still faces challenges of blurred images caused by glare effects or long distances[15].

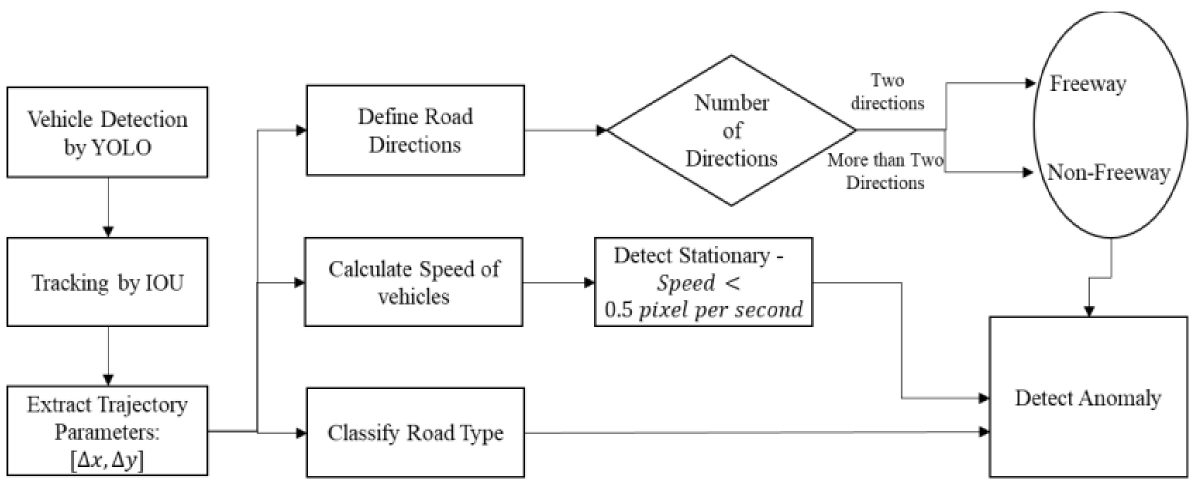

Figure 5: System using YOLO & Mask R-CNN[15]

4. Managing traffic congestion with IoT

4.1 On-Board Unit (OBU) based monitoring

The OBU-based system assumes that each vehicle on the road has an onboard unit installed in it, to obtain the 105 vehicles' velocity and location. The system then utilizes an ensemble of classifiers : (i) Fuzzy logic; (ii) KNN; and (iii) ANN-MLP to detect the congestion at a specific point. The congestion information is then shared among the regions of interest (RIs), as shown in Fig. 6.

If congestion in an area is detected then the vehicles are notified, if a vehicle confirms that it wants to travel to the congested area. Then the vehicle route is updated with the Dijkstra algorithm to suggest the best route as demonstrated in Fig. 7.

The system was tested in a simulation environment and the results were promising. The results demonstrated that traffic congestion can be controlled. The travel time, fuel consumption, and CO2 emission from the vehicles were decreased [16].

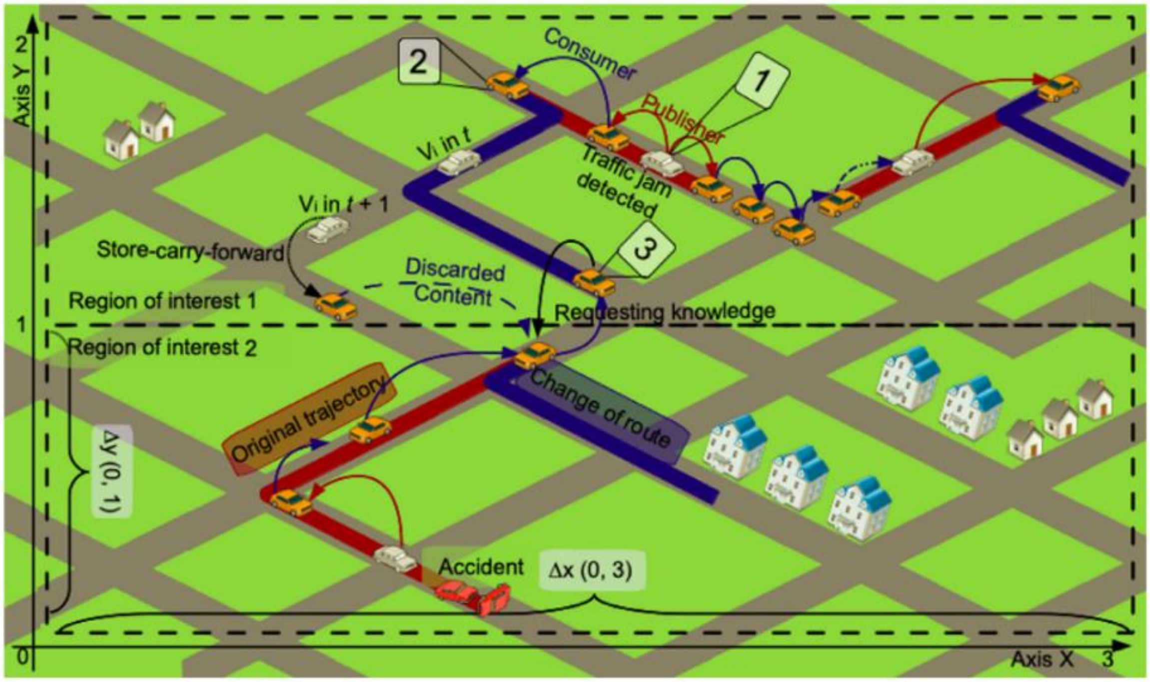

Figure 6:suggested best route by Dijkstra algorithm[16]

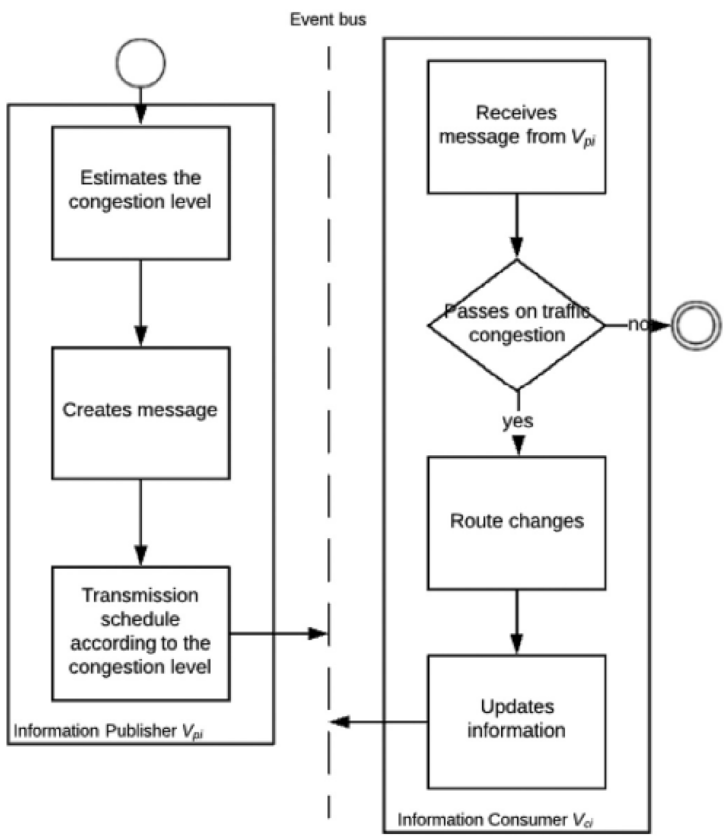

Figure 7: Suggested best route by Dijkstra algorithm[16]

4.2 Smart Road Traffic Management System

The SRTMS (Smart Road Traffic Management System) uses physical hardware and software programs to collect and transmit data to the network. The vehicles have onboard diagnostics (OBD) and sensors to monitor the driver and also interact with all the other IoT devices on the road such as traffic signals, electronic message boards, etc. These devices collect data and also inform the driver [17]. The details of the system are shown in the Fig. 8.

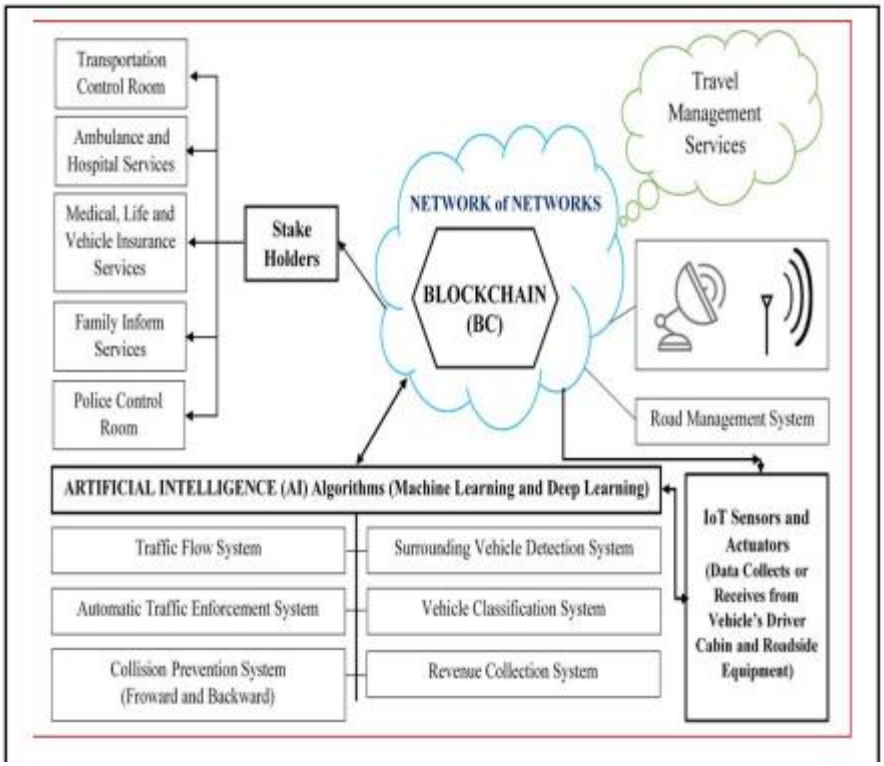

Figure 8: Intelligent traffic control system with sensor in wireless network [17]

The second part of the system is the decision making which comprises of machine learning and deep learning. Machine learning makes real time decisions from the data collected by the IOT while deep learning optimizes the performance of the system [17].

The system is equipped with blockchain technology to share information without any third-party involvement. The system also makes use of digital devices such as GPS or CCTV to identify objects and the level of congestion on the roads. In an emergency, the system can contact the emergency department. It's concluded that the system contains all the necessary requirements to monitor traffic and deal with congestion but the implementation of the system is not easy and it contains a lot of complexity [17].

4.3 Fusion-based intelligent traffic congestion control system

The control system relies on Vehicular Network (VN) which is a multipurpose communication network, which helps vehicles to converse with one another and with the road infrastructure [18]. The data is collected from the vehicles via the sensors present in the vehicles and on the road. The vehicles then share the information with other vehicles and the infrastructure [18].

The data flows through a multi-layered system which consists of a sensory layer to collect data, a preprocessing layer to clean data, a training and performance layer where ML models (ANN and SVM) and new model FITCCS-VN used to make congestion prediction, and finally a validation phase to confirm accuracy [18].

To conclude the network collects data using the Internet of Vehicles (IoV) and then processes the data with fusion-based techniques and then utilizes machine learning to predict and control traffic congestion. The system was tested using simulation and during the test, accuracy was 95% with a 5% miss rate was achieved. Researchers suggest that further improvement can be made using models like Alexanet [18].

The results of fusion based FITCCS-VN suggests that it is better than other models as shown in the Fig. 9:

	ANN	SVM	Fusion based FITCCS-VN
Accuracy (%)	94.0	90.3	95
Miss Rate (%)	6.0	9.7	5

Figure 9: Results of fusion based FITCCS-VN [18]

4.4 Adaptive Traffic-Management (ATM) System

The Adaptive Traffic-Management (ATM) proposes an intelligent transport system that is not only able to tackle traffic congestion but also helps in managing traffic [8]. This system consists of a few modules as discussed below:

Vehicle location and route selection:

The system tracks the location of the vehicle, the selects all the possible routes to travel from the start to the end point. The routes are then compared to the precision value, all the routes that are below this value are removed and the rest are suggested to users. If no route meets the requirement of the precision value then the critical path is suggested to the user [8].

Accident module: The system can detect accidents using sensors and then save the data. The data is then processed and models are trained to prevent similar types of accidents in the future [8].

Image processing: The images from the road are captured, and processed and object detection is applied to detect the level of congestion. The traffic light then operates accordingly [8].

*Vehicle communication module:*The sensors present in the vehicle collect data and then notify the drivers on that specific route of any incoming unsafe situation ahead [8].

*ML module:*The last module is of machine learning, which gets its data from the vehicles and roadside. The model is trained using the DBSCAN clustering method. The details are shown in Fig. 10.

Finally the system was tested on a simulator in MATLAB and the simulation results demonstrated that the performance was better than that of conventional system.

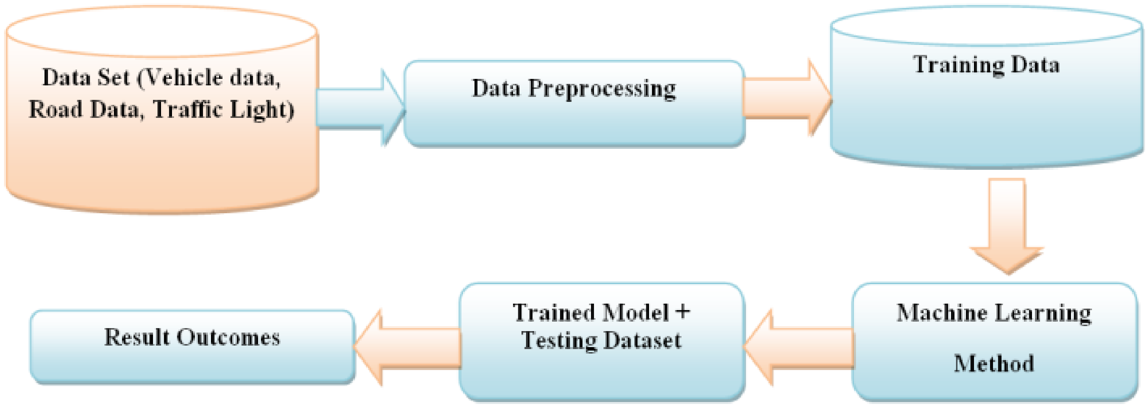

Figure 10: Machine learning model [8]

4.5 Mivar control system

The Mivar control system(MCS) is a theoretical approach designed for cars, it can be installed into any car manned or unmanned. The system monitors the drivers and enforces traffic regulations to improve road safety. The Mivar system collects data using the car sensor, vision systems, and navigator then converts the data into an object format in the mirror system [5]. The system uses a software called Razumator to create an algorithm, the steps of the algorithm are then added into a stack. The steps are compared with the driver's actions and finally, a conclusion is made [5]. The Mivar system manages to provide the drivers with prompts and notify them of the traffic violations they make. The system suggests that it is a cost effective solution and can work in any environment and speed. The system is shown in the Fig. 11.

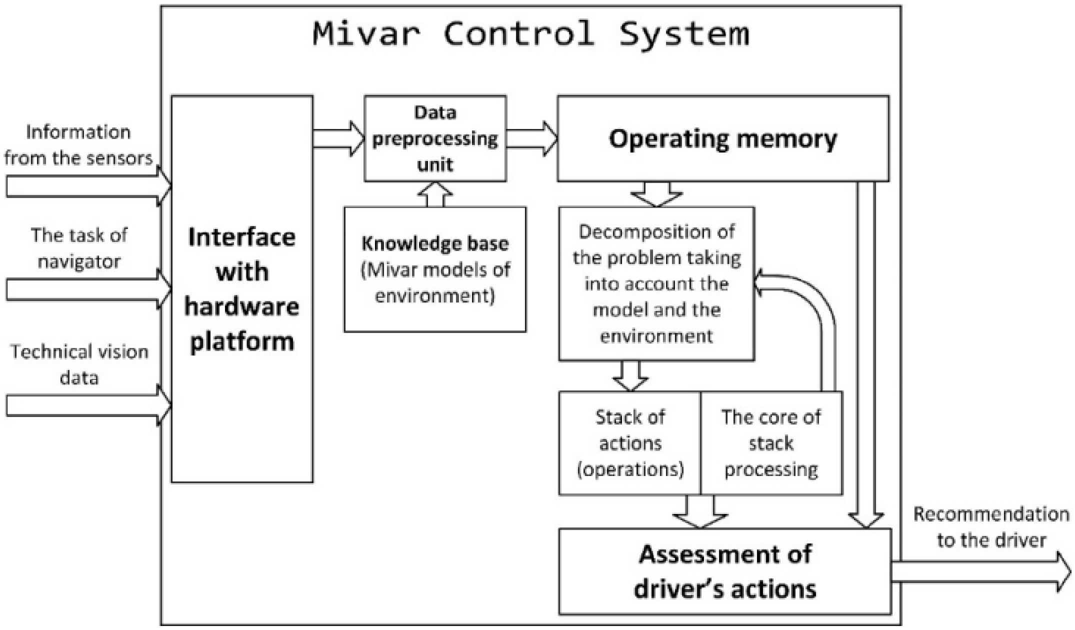

Figure 11: Mivar control system [5]

5. Autonomous vehicle's role in traffic management

5.1 The role of AV in traffic flow

The authors of this paper conducted a theoretical analysis of autonomous vehicles(AV). They studied the controllability, stability, and reachability of autonomous vehicles in a traffic system [19]. They assumed that the AV has access to the global traffic state which is opposite to reality. They also studied time delays in traffic and focused on a single lane road [19].

The analysis is described in detail below:

Controllability and stability: The study of autonomous vehicles(AV) proved that a single AV can stabilize a traffic flow, control its velocity, and brings it to a specific value. Hence proved that AV can have a role in controlling traffic congestion [19]. The Fig. 12 demonstrates the results:

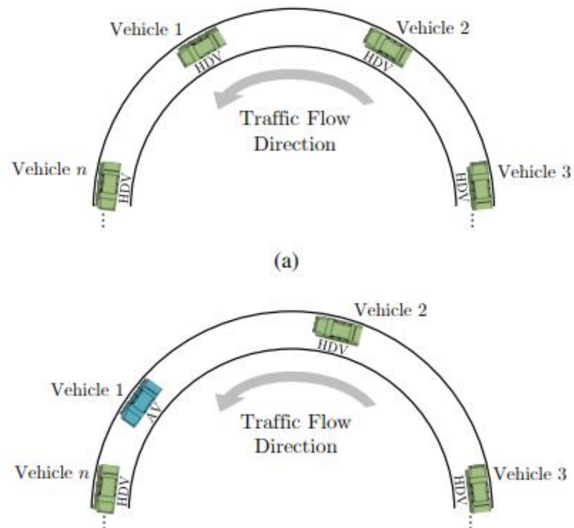

Figure 12: Results of AV[19]

System-level optimal control: This is a strategy of H2 optimal control, which considers the whole traffic flow instead of a single autonomous vehicle (AV). This can make the flow smooth and improve fuel consumption as compared to the normal traffic flow method.

Reachability analysis: This is the analysis of a single autonomous vehicle (AV), which demonstrated that by including only 5% of AV in a system the velocity can be improved by 6%.

Multiple autonomous vehicles: After analyzing a single AV, the analysis was extended to multi autonomous vehicles (AV). The results demonstrated that controllability, stability, and reachability were similar but the coordination of the vehicles reduced the time and energy for handling perturbations and also improved traffic flow [20]. AV also needs a uniform policy to operate under it for which researchers used RL to generate policy for AV using the data collected from AVs [21].

Another study suggests that applying deep reinforcement learning (DRL), which uses the power of both machine learning and deep learning to help autonomous vehicles make decisions. This approach will help improve the decision making capabilities of autonomous vehicles [20].

6. Conclusion

In this paper, we have discussed four technologies of traffic management to deal with traffic congestion. Of the four technologies, AI algorithms can be implemented in any city to upgrade old traffic light system or help drivers with a smartphone to use alternative routes. Followed by CV and IOT which can also be used to upgrade older system but are more expensive, complicated, and can work only in smart cities. Finally comes autonomous vehicles which can be seen in a limited number in developed countries, so they have a limited role in reducing traffic congestion.

Key challenges for AI-enhanced traffic management include addressing privacy concerns, cybersecurity risks, and ensuring data integrity. Additionally, overcoming interoperability challenges, establishing a robust regulatory framework, and gaining public trust are crucial for successful implementation. Socioeconomic impacts and the need for standardized practices further contribute to the complexity of integrating these technologies.

The implementation of AI is still a challenge for developing countries, while for developed countries it's the best solution to reduce traffic congestion, improve economy, and decrease pollution.

References

[1] A. S. Arifin and F. Y. J. I. I. J. o. A. I. Zulkifli, "Recent development of smart traffic lights," vol. 10, no. 1, p. 224, 2021.

[2] M. Lopez Conde and I. Twinn, "How artificial intelligence is making transport safer, cleaner, more reliable and efficient in emerging markets," 2019.

[3] A. A. Alkhatib, K. A. Maria, S. AlZu'bi, and E. A. J. E. I. J. Maria, "Smart traffic scheduling for crowded cities road networks," vol. 23, no. 4, pp. 163-176, 2022.

[4] R. A. Gonzalez, R. E. Ferro, and D. J. A. S. E. J. Liberona, "Government and governance in intelligent cities, smart transportation study case in Bogotá Colombia," vol. 11, no. 1, pp. 25-34, 2020.

[5] D. Aladin, O. Varlamov, D. Chuvikov, V. Chernenkiy, E. Smelkova, and A. Baldin, "Logic-based artificial intelligence in systems for monitoring the enforcing traffic regulations," in *IOP Conference Series: Materials Science and Engineering*, 2019, vol. 534, no. 1, p. 012025: IOP Publishing.

[6] N. J. I. P. Kshetri, "Artificial Intelligence in Developing Countries," vol. 22, no. 4, pp. 63-68, 2020.

[7] J. J. E. j. o. e. Hu and m. sciences, "EXPLORING THE USE OF ARTIFICIAL INTELLIGENCE TO SOLVE TRAFFIC CONGESTION," no. 1, pp. 3-10, 2020.

[8] U. K. Lilhore *et al.*, "Design and implementation of an ML and IoT based adaptive traffic-management system for smart cities," vol. 22, no. 8, p. 2908, 2022.

[9] J. Ault, J. P. Hanna, and G. J. a. p. a. Sharon, "Learning an interpretable traffic signal control policy," 2019.

[10] C. Chen *et al.*, "Toward a thousand lights: Decentralized deep reinforcement learning for large-scale traffic signal control," in *Proceedings of the AAAI Conference on Artificial Intelligence*, 2020, vol. 34, no. 04, pp. 3414-3421.

[11] D. Rachmawati, P. Sihombing, and B. Halim, "Implementation of best first search algorithm in determining best route based on traffic jam level in medan city," in *2020 International Conference on Data Science, Artificial Intelligence, and Business Analytics (DATABIA)*, 2020, pp. 5-12: IEEE.

[12] W.-C. Hu, H.-T. Wu, H.-H. Cho, and F.-H. J. J. o. I. T. Tseng, "Optimal route planning system for logistics vehicles based on artificial intelligence," vol. 21, no. 3, pp. 757-764, 2020.

[13] G. Sharon, "Alleviating Road Traffic Congestion with Artificial Intelligence," in *IJCAI*, 2021, pp. 4965-4969.

[14] M. M. Gandhi, D. S. Solanki, R. S. Daptardar, and N. S. Baloorkar, "Smart control of traffic light using artificial intelligence," in *2020 5th IEEE international conference on recent advances and innovations in engineering (ICRAIE)*, 2020, pp. 1-6: IEEE.

[15] V. Mandal, A. R. Mussah, P. Jin, and Y. J. S. Adu-Gyamfi, "Artificial intelligence-enabled traffic monitoring system," vol. 12, no. 21, p. 9177, 2020.

[16] G. P. Rocha Filho *et al.*, "Enhancing intelligence in traffic management systems to aid in vehicle traffic congestion problems in smart cities," vol. 107, p. 102265, 2020.

[17] A. Sharma, Y. Awasthi, and S. Kumar, "The role of blockchain, AI and IoT for smart road traffic management system," in *2020 IEEE India Council International Subsections Conference (INDISCON)*, 2020, pp. 289-296: IEEE.

[18] M. Saleem, S. Abbas, T. M. Ghazal, M. A. Khan, N. Sahawneh, and M. J. E. I. J. Ahmad, "Smart cities: Fusion-based intelligent traffic congestion control system for vehicular networks using machine learning techniques," vol. 23, no. 3, pp. 417-426, 2022.

[19] Y. Zheng, J. Wang, and K. J. I. I. o. T. J. Li, "Smoothing traffic flow via control of autonomous vehicles," vol. 7, no. 5, pp. 3882-3896, 2020.

[20] S. J. I. T. o. I. T. S. Aradi, "Survey of deep reinforcement learning for motion planning of autonomous vehicles," vol. 23, no. 2, pp. 740-759, 2020.

[21] J. Cui, W. Macke, H. Yedidsion, D. Urieli, and P. J. a. p. a. Stone, "Scalable multiagent driving policies for reducing traffic congestion," 2021.