Smart City Traffic Control System : A Literature Review

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***Abstract*— The world is currently experiencing an unseen increase in the number of vehicles on the road, and our traffic control systems have been struggling to keep up with this rapid growth. This research paper is dedicated to addressing the complex problem of traffic management by thoroughly reviewing the existing academic literature on the topic. One important conclusion garnered is that there's no one-size-fits-all solution to the challenges of traffic. Each city has its unique traffic problems and characteristics. The primary objective, however, for this research is to contribute to the ongoing discussions about traffic management by offering valuable insights and innovative concepts. Looking at the outcome, these insights have the potential to enhance the efficiency of our cities and reduce congestion. These insights mainly relayed the outcome that for each city/road, there can only be one uniquely tailored solution. However, this paper discusses the solutions in making a generalized solution as a base for all traffic sites. Ultimately, our hope for this paper is to help pave the way for more intelligent and adaptable traffic control systems that can revolutionize the way we navigate our urban environments, making them more liveable and sustainable for everyone.**

Keywords*— *Traffic Control; Artificial Intelligence; Fuzzy Logic; Smart Cities; Adaptive intelligent

I. Introduction

Traffic congestion is one of the biggest problems major cities around the world face. Due to traffic congestion many people miss out on opportunities as well as several limited resources are wasted. Time and Fossil Fuels are some of the limited resources that are wasted due to traffic congestion. This is a major problem especially in India. India has the largest population in the world and with that comes the need of a sophisticated traffic control system which would help reduce traffic congestion in all places around the country. Our paper firstly reviews proposed solutions for other parts of the world and then proposes a solution which would fit the problem of traffic congestion in India. Our primary target cities for the implementation of this system would be major cities in India such as Mumbai, New Delhi, Bangalore, Chennai, and Kolkata. These cities rank highly according to various posts about cities around the world with the highest traffic congestion. Our eventual goal would be to roll out the solution to all traffic signals in the country.

Case Studies of cities which have implemented a smart traffic control network:

A. Los Angeles

Los Angeles has one of the country's most congested traffic networks. The city has implemented an intelligent traffic management system that incorporates unquestionable models as well as predictive analytics. To anticipate congestion and validate signal timings, rudimentary machine learning models are fed real-time data from multiple sensors and cameras. Therefore, traffic flow has improved significantly, and commuting times have been reduced.

B. Singapore

Singapore is well-known for its effective traffic management. The city-state uses proven models to estimate wait times and optimise signal timings. Predictive analytics is also utilised to forecast the unknown during peak hours and exceptional events. As a result, the traffic system is smooth and efficient, with little delays.

C. Amsterdam, Netherlands

The capital of the Netherlands uses a combination of statistical models and predictive analytics to manage its complicated municipal traffic network. The city has built a "Smart Traffic Light" system, which adjusts signal timings in real time based on traffic volume and projections. Therefore, there is reduced traffic congestion and greater air quality in the city..

II. Research Methodology

To conduct a Systematic Literature Review, some of the following questions were framed for reviewing the set of academic papers. Some of these questions are as follows:

1. What are the technologies being used by these papers to solve the problem at hand?
2. What was the methodology followed in the paper?
3. What were the limitations for the solutions used by the paper?
4. What were the outputs or outcomes of the paper?
5. What were some of the key insights that could be taken from the paper?

Our search parameter regarding these papers were relevant papers published between the year 2020 to 2023. To identify appropriate and relevant work, for this systematic literature review we found papers by using the phrases:

1. "Smart city traffic control"
2. "Adaptive intelligent traffic control systems"
3. "Intelligent traffic control systems"
4. "Traffic control system using machine learning"
5. "AI traffic control"

We accessed these papers using google scholar library which has a solid combination of several online research papers and articles and functions as an academic database. The scope of our research is to find and analyse solutions for the problem of traffic control systems using various techniques or technologies. Any paper which we felt did not fit this scope was excluded from being selected.

The papers also underwent a quality filtering process. They went through this, filtering some of the general appraisal guidelines. Some papers were even filtered through a design-based check. The papers went through thorough manual filtering as well. This manual filtering was done with regards to the clarity of the publication and the content relevancy matching with our criteria.

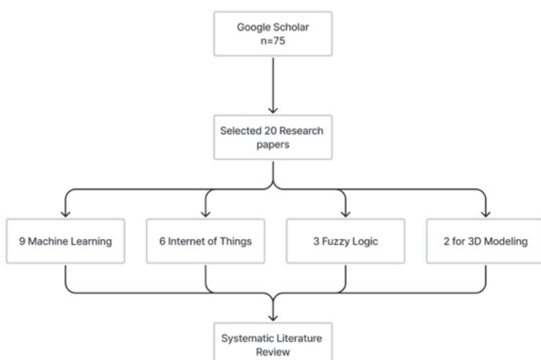

Fig.1 Paper Selection Flowchart

III. LITERATURE REVIEW

In this section, the existing literature in the domain, "Smart Traffic Control System" has been discussed. The literature has been categorized into four parts which are Machine Learning Based approaches, Internet of Things Based Approaches, Fuzzy logic and other mathematical reasoning approaches and 3D Modelling and Simulation Approaches. Each part discusses three main problems: Effectiveness of each approach, Data Requirements, and Cost of Implementation. At the end of the literature review section, we propose a possible solution combining the various approaches to answer the three above questions about Possible Effectiveness, Possible Data Collection Techniques, and Possible Cost of Implementation.

A. Machine Learning based approaches:

With the machine learning approaches the effectiveness of using machine learning approaches was analyzed. Promising results were obtained from the machine learning approach coupled with 5G networks.[1] Other approaches reduced traffic jams by either using IOT devices [2], LSTM neural networks [3], various different AI approaches [4] and Genetic Based algorithms [5]. The focus was on first identifying the traffic by using image processing through various different algorithms. [6] YOLO and SORT algorithms were also used to detect vehicles and propose adaptive solutions. [7] The techniques outperformed traditional timer based systems by dynamically adjusting traffic signals based on traffic density.[8] These approaches helped alleviate congestion and reduce pollution. [9]

The next parameter analyzed was the data requirements. A smart traffic control system would need to have information about the traffic in a city at any particular time. Real traffic data was used from Hangzhou, China and it showed promising results by optimizing how resources would be allocated.[1] The papers analyzed would also use urban traffic data and data from Indian roads to perform all the computations. [3][7] The data was primarily collected from cameras at each traffic junction by understanding the traffic density in each lane at real-time.[8] For the genetic algorithm used to solve the traffic congestion problem, the main data requirement would be the genetic algorithm factors such as traffic congestion, air quality and citizen satisfaction needed to perform the computation. [5].

The cost of each approach was not mentioned in numbers but given the above data requirements we can make certain assumptions about the cost. The cost of setting up cameras at each junction would be very high and to make sure they function in all-weather scenarios without getting damaged or losing a lot of quality for the image would make them a challenging. The cameras would need to collect data over a minimum of 2 years to establish better trends over certain days like holidays and over certain months with similar weather. Getting the consent to use the cameras from the government while not upsetting the public and maintaining their privacy would be another cost to consider. In countries with several power-cuts the cameras and systems would need to be fitted with a power source which would keep the system running even when the power was cut. This would be another cost to consider. The cost of training the machine learning models would be another cost to consider. Data accuracy and reliability is another cost to consider while designing a machine learning model for traffic control systems. These costs at the current state of technology would be very high and hence the scarce implementation of this technology. Over time if the costs were to reduce, these techniques could be used to design smart city traffic control systems as they have been proven as efficient and viable solutions.

TABLE I. MACHINE LEARNING APPROACHES

Paper Name	***Technology Used***	***Key Insights***
[1]	Deep Deterministic Policy Gradient (DDPG) based model	It outperforms existing algorithms, enhancing profits for mobile network operators, and improving smart city services.
[2]	Deep Extreme Machine Learning Model	Through its four-layer model, it effectively reduces congestion and holds promise for intelligent traffic control in smart cities, offering economic and environmental advantages.
[3]	Long Short-Term Memory (LSTM) neural networks	The research highlights the effectiveness of a neuro-inspired control framework for smart city traffic management.

Paper Name	Technology Used	Key Insights
[4]	Sensor fusion techniques, Bayesian neural networks and deep learning approaches	Enhances transportation systems and safety while emphasizing predictive modeling and individual well-being. It also addresses challenges like privacy and emotion detection
[5]	Genetic Algorithm	Fitness function based on traffic load and citizen satisfaction to find an optimal solution for urban traffic management.
[6]	Deep learning algorithms	The paper underscores the potential of image processing and deep learning for urban safety and traffic management.
[7]	YOLO (You Only Look Once) and SORT (Simple Online and Realtime Tracking) algorithms	It emphasizes the application of deep learning to adapt to dynamic traffic scenarios, addresses India's traffic congestion challenge arising from a growing number of vehicles and autos.

B. Internet of Things Based Approaches:

The effectiveness of the IOT based approaches was analyzed. These approaches had the potential to reduce waiting times, travel times and enhance traffic flow. [10][11] The results also helped reduce fuel consumption and emissions. [12] These approaches used wireless sensor networks and IOT sensors to calculate traffic density.[13] Edge Computing enabled by video segmentation helped monitor the vehicles through the Internet of Vehicles network.[14][15] The edge computing helped achieve high accuracy in vehicle detection and tracking while reducing computation, storage and network bandwidth requirements.

The data requirements are quite similar to the data requirements of the Machine Learning approaches with the difference being the accuracy of position can be achieved by IOT networks. This reduces the dependency on machine learning networks to calculate density of traffic at any point. Data must be reliable and be transmitted at all times.

The cost of this approach is not mentioned in the papers analyzed but there can be certain assumptions that can be made about the cost based on the data requirements. For successful implementation,we would need IOT sensors in cars and roads. The cost of convincing car manufacturers to install IOT sensors in vehicles needs to be considered as well as the intensive cost of setting up several IOT sensors in each junction. IOT sensors must withstand all sorts of weather and perform accurately in them. As some cars may not be IOT enabled so there is also a need to set up cameras at each junction to verify the density at each junction. Although the dependence on these cameras would serve primarily for verification. Collection of data like in Machine Learning approach would need to be done for a minimum of two years. Cost of public acceptance and protection of user data needs to be considered for this approach. Several costs such as powering sensors in power-cuts, cost of technology in current day and time to train the models must be considered like in the machine learning approach. These costs like the machine learning approach are very high and hence very scarce implementation in the real world.

TABLE II. INTERNET OF THINGS APPROACHES

Paper Name	Technology Used	Key Insights
[10]	V2X and IEEE 802.11p	Introduces a versatile Smart Traffic Signal Control (STSC) system, supporting V2X applications, compatible with existing infrastructure, and demonstrating improved traffic efficiency and reduced waiting times.
[11]	Internet-of-Things (IoT) technology, Global positioning system (GPS), EEE 802.11p, Simulation of urban mobility (SUMO) tools and Queuing theory	Introduces an IoT and game theory-based framework to mitigate traffic congestion, offering a promising solution for traffic challenges in developing countries.
[12]	Optimized Weight Elman Neural Network (OWENN) and Improved Beetle Swarm Optimization (IBSO) along with IOT technology	Emphasizes the efficacy of OWENN and IBSO methods for traffic prediction and signal control while promoting environmental considerations in traffic management.
[13]	Wireless sensor networks, Surveillance cameras, and IoT	Highlights the significance of wireless sensor networks, surveillance cameras, and IoT, in enhancing traffic management. Asks for rigorous evaluation encompassing energy consumption and network longevity for sustainability.
[14]	YOLOv3, OpenCV, Python, TensorFlow, Raspberry Pi and NVIDIA Jetson Nano	Provides edge computing's potential for real-time video analysis in challenging settings and emphasizes key frame extraction's role in data reduction. It also highlights the ongoing optimization of edge computing platforms to enhance IOV traffic monitoring.
[15]	Create IoV, using wireless access technology, routing technology, and security and privacy technology with 4G or LTE	Gives IoV's potential in routing technology. It offers valuable insights into IoV research challenges and future directions.

C. Fuzzy Logic and other mathematical reasoning approaches:

The efficiency of these approaches was studied. The approach using these mathematical models were successful in handling congestion problems, optimized resource allocation and introduced traffic signal synchronization using a combination of mathematical models and image processing. [16][17][18] Mathematical Models like Fuzzy Logic and graph theory were valuable in understanding how mathematics could be used to optimize traffic flow.[17] The combination of using image processing and fuzzy logic gave way to dynamic synchronous traffic light systems which optimized flow. [18]

The data requirements for these approaches were similar to the Machine Learning approaches as instead of using neural networks fuzzy logic was used to perform operations. Data about traffic flow over a 2 year period would need to be analyzed. All other data requirement considerations would be similar to the ones listed in the Machine Learning Approach.

The cost factors of this approach are similar to the cost factors of the machine learning approach. The cost factors which would differentiate this model from the machine learning model would be time and cost to train the model as lesser parameters would be considered. Hence it would be simpler to optimize and lesser time needed for the same. All other cost factors are the same.

TABLE III. FUZZY LOGIC APPROACHES

Paper Name	*Technology Used*	*Key Insights*
[16]	Eulerian, Lagrangian principles, IOT	Emphasizes sustainability and smart mobility for effective traffic management.
[17]	Neutrosophic sets, rough sets, graph theory, and fuzzy sets.	Emphasizes the critical role of data science researchers in precise traffic management.
[18]	Fuzzy logic and Image processing	Requires further research for broader applicability. It aims to enhance safety, reduce travel time.

D. 3D Modelling and Simulation approaches:

The effectiveness of these approaches were analyzed. The 3D Modeling technique and Code visualization techniques which can be used to study smart cities and optimize traffic flow. [19][20] These simulations are faster compared to the techniques mentioned above as they can run all possible scenarios and suggest a strategy for all of them. This gives them an upper hand in terms of training for similar accuracies in lesser time.

There is very little to no data requirements for this strategy as all possible scenarios can be simulated in this approach and a solution prepared can be used to manage traffic flow. The models were trained using Java in the Sejong city traffic simulator.

The cost of this approach is only the cost of running the simulation model and the time to train it. Although it is a fast system it cannot adapt to different cities without extra training. It can be used for one or more cities with similar features but cannot be plugged in for different cities with different approaches as the best approach for one city may not work in another city. Hence each city would need to run its own simulation which is an added cost.

TABLE IV. 3D MODELLING APPROACHES

Paper Name	*Technology Used*	*Key Insights*
[19]	GIS, BIM, and IoT technologies	Enchances traffic management and fostering sustainability in urban environments.
[20]	Java programming language, Eclipse IDE, JDT, and JFreeChart	The research emphasizes the critical role of accurate autonomous traffic and vehicle control systems in smart cities

E. Proposed Solution:

Our proposed solution which combines several of the techniques discussed above can be looked into for future research purposes. We propose to use the machine learning approach aided by the Internet of Things sensors and advanced mathematical models. We suggest that instead of heavy reliance on one source of data collection we could use various sources. In this case the cameras at each junction and the IOT sensors. This way even if one of our sensors stops working we can have a functioning traffic control system. This added redundancy increases fault tolerance in the systems. Now one would assume this would increase the cost but it would remain about the same as the cost of using only one sensor. This is because even with a redundancy and lesser dependence on only one sensor, lesser repairs would be required as well as not as robust sensors would be needed meaning lesser robust sensors would do the job as well.

We assume that the effectiveness increases as there is more data available. With the increase in data the validation of the previous models can be done easily. This is because the calculation done by the machine learning model to calculate density can be verified by the IOT sensors. The effectiveness could also benefit from using of mathematical models instead of additional layers of neural nets to boost performance and reduce response time to make it faster. These are some of the assumptions we have made in terms of effectiveness of solution.

The data requirements would be the same as the machine learning and internet of vehicles approaches. In addition data to train the mathematical models and understand which layers or how many layers to remove or replace would need to be considered. The sensors needed could be less robust as with added redundancy our model would perform better in the best case and perform significantly better than previous solutions in the worst case scenario.

The cost would be high and would not be very feasible in the current day with the current state of technology. The fear of artificial intelligence by the general public could also hamper the development of the proposed solution. All data collection would be spread over two years. The cost of all-weather scenarios as well as power-cuts needs to be considered. The time and cost to train these models would also need to be considered. The cost of training the models in terms of carbon footprint cannot be greater than the assumed gain in carbon footprint reduction which the model could offer. The cost of data accuracy would be reduced slightly as data from both sensors could verify each other's data without the need of oversight by a human. As training larger models gets cheaper the proposed solution becomes a likely candidate for traffic management in all cities around the world.

IV. FUTURE SCOPE

Creating a more generalized solution for traffic management by combining various techniques can lead to significant benefits:

A. Benefits

1. Enhanced Traffic Flow: Predictive analytics and mathematical models can forecast wait times accurately, leading to precise signal timing adjustments. This reduces wait times, alleviates congestion, and enhances traffic flow.
2. Reduced Fuel Consumption and Emissions: Efficient traffic management minimizes vehicle idle time, leading to lower fuel consumption and reduced emissions. This not only benefits the environment but also the economy by reducing the global cost of traffic congestion.
3. Heightened Safety: Proactive signal adjustments can prevent accidents and improve road safety. Smooth traffic flow reduces the likelihood of unexpected stops and rear-end collisions.
4. Economic Advantages: Reducing traffic congestion offers significant economic benefits, including increased productivity due to shorter commutes,

support for local businesses, and lower road maintenance costs.

B. Challenges and Cosideration:

1. Data Quality and Availability: The effectiveness of predictive analytics depends on the quality and availability of data. In some areas, data sources may be limited or unreliable, making accurate predictions challenging.

2. Model Accuracy: The accuracy of prediction models relies on the quality of historical data and the suitability of machine learning techniques. Continuous refinement and validation are essential for developing accurate simulations.

3. Privacy and Ethical Concerns: The use of real-time data, especially from GPS and social media sources, raises privacy and ethical concerns. Balancing traffic management benefits with privacy rights is crucial.

4. Economic Advantages: Reducing traffic congestion Infrastructure Investment: Implementing advanced traffic management systems may require significant infrastructure investments, such as installing detectors and cameras.

5. Public Awareness and Acceptance: Engaging the public and gaining approval for data-driven traffic management systems is essential. Open discussions about the benefits of this technology can alleviate concerns

V. Conclusion

This paper discusses the importance of a smart city traffic control system. It performs an Systematic Literature Review on the 20 papers that best fit our scope. In these papers we identified the methodology used and the technology used. While identifying these two we saw the insights about using these technologies and also saw the drawbacks of these technologies. From our research we realized there were several solutions each a tailored fit to the region they are designed for. There was no generalized solution to the problem of creating a smart traffic control system. We listed out the possible benefits and challenges one might face in making a more generalized solution. We hope to see future researchers make progress to create a more generalized solution.

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