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***Original Article***

# Intelligent Traffic Management Systems for Smart Cities

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***ABSTRACT***

*The high rate of urbanization has caused a high growth in the number of vehicles, which has produced a congestion, wastage on time, and fuel, as well as pollution to the environment. No longer applicable because of the dynamic character of modern urban traffic, the traditional traffic management systems based on the use of the non-informative control mechanisms and low real-time flexibility. The Intelligent Traffic Management Systems (ITMS) have become a very important part of an intelligent city system, as it intends to use the latest technologies that include Artificial Intelligence (AI), Internet of Things (IoT), machine learning, cloud computing and big data analysis to make traffic flow in the city more efficient and safer. In this paper, complete research on Intelligent Traffic Management Systems in smart cities has been made. It dwells upon the development of traffic management, the enabling technologies, system architecture, and methodologies. An elaborate literature review indicates the latest developments and outlines the gaps in research. The proposed approach will combine real-time data collection, predictive analysis, and responsive signal modulation to improve the traffic flow. The mathematical models and performance evaluation measures have been addressed to measure the system effectiveness. The findings indicate that intelligent systems are very effective in minimizing congestion, travelling time as well as emissions over traditional methods. Lastly, issues, constraints, and research prospects are given to facilitate long-term and viable implementation of ITMS in intelligent city setups.*

***KEYWORDS***

*Intelligent Traffic Management, Smart Cities, Internet Of Things (Iot), Artificial Intelligence, Machine Learning, Adaptive Traffic Control, Urban Mobility, Big Data Analytics.*

# 1. INTRODUCTION

## 1.1. Background

The modern cities have gone under tremendous restructuring with over 60 per cent of global population being estimated to live in towns by 2050 following his rapid global urbanization. The enhanced urbanization has put so much strain on the already available transportation facilities leading to severe congestion, travel delays, and fuel waste, as well as air pollution. Traffic congestion does not only lead to significant economic losses in terms of time and fuel wastage but also leads to environmental destruction and deteriorated life in general in the urban areas. Conventional forms of traffic management systems that largely feature static-time signal plans and manual traffic control are becoming increasingly less efficient in treating these issues. This type of systems works according to historical traffic modes and cannot change dynamically to the changes occurring in the real-time demand of traffic or accidents or other unforeseen events. Addressing these issues, the idea of smart cities has surfaced, aiming to rely on the use of digital means, data analysis, and smart systems in urban infrastructure to make it more efficient, sustainable, and livable. In this context, Intelligent Traffic Management Systems (ITMS) have a significant role to play in terms of optimization in urban mobility. ITMS facilitate real-time data processing, predictive and reactive control of signals, which allows identifying traffic constantly, even with such technologies as the Internet of Things, artificial intelligence, and real-time data processing. These features enable the traffic systems to act proactively to dynamic traffic conditions, minimize congestions, enhance road safety, and environmental impact. Thus, intelligent traffic management has now been implemented as a constituent element of smart city projects, to contribute to sustainable urban development and better quality of life of the urban population.

## 1.2. Role of Intelligent Traffic Management Systems


**Fig 1- Role of Intelligent Traffic Management Systems**

Intelligent Traffic Management Systems (ITMS) is a technology that combines a combination of high-technology sensing, communication as well as computer technologies to meet the increasing demands of urban transportation. The use of ITMS facilitates effective, secure, and sensible traffic operations through the use of real-time information and clever algorithms.

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*1.2.1. Monitor Traffic Flow in Real Time*

ITMS allows tracking of real time traffic conditions by the usage of sensors, cameras, GPS equipped vehicles, and mobile applications. This live presence gives authorities on traffic to monitor traffic flow, traffic density and speed changes along road system. The continuous monitoring assists in identifying congestion, incidents, and abnormal traffic patterns in time and it is the basis of proactive management of the traffic.

*1.2.2. Predict Congestion Patterns*

ITMS has the capability to forecast the pattern of congestion and demand variations of traffic based on historical and real time traffic data. The machine learning and data analytics are used to predict the number of people in a traffic in the hours of peak time, or special events, or some unforeseen disruptions. Congestion prediction can be developed to enhance reliability and efficiency of networks by predicting correctly the congestions at the beginning of the situation, thus providing measures that prevent the worsening of the situation.

*1.2.3. Optimize Signal Timings Dynamically*

ITMS dynamically optimizes signal functions, which is one of its fundamental functions, that is, the dynamism of the traffic signals themselves. ITMS uses variable green time, phase sequences, and offsets unlike fixed-time systems, which apply set times, regardless of the actual demand at a specific time. This is an adaptive strategy that reduces the time loss, minimizes queues, and increases intersection throughput thus resulting into a better traffic flow.

*1.2.4. Enhance Road Safety*

ITMS plays a vital role in enhancing road safety because it helps to detect an occurrence quickly and control traffic. Live tracking and analytics allow detecting accidents, stalled cars, and risky situations and reacting to them fast and redirecting the traffic. Also, adaptive signal control may assign a higher priority of priority over emergency vehicles, and less conflict point will take place at the intersection which will greatly decrease the chances of an accident.

*1.2.5. Reduce Emissions and Fuel Consumption*

ITMS helps to prevent congestion, idle time, and stop and go to reduce the fuel consumption and vehicular emissions which will be crucial in reducing the fuel consumption. The flow of traffic becomes easier and cars are more efficient in their work, which leads to the reduction of greenhouse gas emissions and improved air quality. This is an environmental advantage that makes ITMS compliant with sustainability and smart city projects that focus on establishing a more eco-friendly city.

**1.3. Limitations of Traditional Traffic Systems**

Conventional traffic management systems are becoming less and less effective as used to manage the complexity and dynamism of today transportation networks in cities. The fact that these systems rely on set of signal timing plans, which are developed according to historical traffic and based on presumed traffic patterns is one of the main limitations of these systems. These fixed-time timetables are unable to conform to the reality of the traffic demand that alters in real-time due to peak hours, special occasions, accidents, or weather conditions resulting in an inefficient usage of the signals and a greater amount of congestion. Moreover, the traditional systems experience inaccessibility to the full real-time data in traffic due to their high reliance on manual monitoring or little sensing facilities. It means that the lack of the timely and accurate data limits the capability of the traffic authorities to track the prevailing conditions in the road and make the informed decisions. Lack of responsiveness to the incidents or emergencies by traditional systems is also another major weak point. Traffic lights cannot give priority to emergency vehicles, reroute traffic and reduce the effects of accidents without real-time detection and adaptive controllers, thus causing a delaying traffic and exposing people to greater risks. Also, conventional traffic systems are not very scalable, since it can be costly to expand coverage area or incorporations of new intersections and necessitate the upgrade of extensive hardware and manual change settings. This renders it hard to absorb the increasing traffic levels and urbanization. Another significant issue is the high operational and maintenance costs because manual control over traffic means that human control must be exercised continuously, the signal timing must be reset periodically, and that ancient infrastructure should be maintained as well. All these restrictions lead to poor traffic congestion, more time wastage, use of more fuel and more emissions. Since the number of urban residents keeps rising, the flaws in dealing with conventional traffic management systems indicate how crucial the issue of intelligent, data-driven, and adaptable solutions is that can possibly fit the dynamic needs of the new metropolis.

## *2. LITERATURE SURVEY*

### 2.1. Evolution of Traffic Management Systems

The development of traffic regulation systems indicates the increase of the complexity of the urban transportation systems. The early systems used were overly dependent on manual traffic policing and fixed time plans to be used on traffic lights failed to respond to the dynamic traffic environment. The use of electronic controllers and simple communication infrastructure gave way to semi-automated systems with the possibility to have pre-proscribed signal coordination, but with restricted responsiveness. Sensing technologies, wireless communication and computational power have since promoted the shift to fully autonomous and intelligent traffic management systems. These new systems focus on maximizing the composition of traffic in real time by constantly adjusting to the variations in traffic and this has minimized congestion, traveling time and impact on the environment.

### 2.2. Sensor-Based Traffic Monitoring

The intelligent traffic systems have had sensor-based traffic monitoring as one of their pillars. Inductive loop detectors, video cameras, radar sensors and GPS-enabled devices have been extensively covered in terms of their use in gathering traffic parameters (count of vehicles, their speed, density and time of travel). Inductive loop detectors provide good quality information although they are typically expensive and difficult to install. Systems based on cameras are rich in visual data, but can be easily affected by weather and light conditions. Solutions based on radar and

GPS enhance their coverage and flexibility but can experience accuracy and privacy constraints. Although these sensing strategies have been effective, the implementation of these forms of sensing in the long-term has been frequently criticized due to high costs of operation, heavy reliance on infrastructure as well as data reliability.

### 2.3. Iot-Based Traffic Management

With the incorporation of the Internet of Things (IoT) into traffic management systems, it has become possible to collect and communicate real-time heterogeneous data in a distributed manner. The IoT-based architectures enable sensor interaction, control centers with traffic lights, vehicles, and control centers through their seamless interaction to enhance the scalability and flexibility of the system. The studies state that IoT enhances situational awareness and assists in making decision-supported by the data to reduce congestion and to plan the routes. Yet, the extensive usages of IoT in the traffic systems provoke the issue of data security, network latency, interoperability, and fault tolerance. Providing reliable communication and ensuring data security is confidential in transportation management solutions with the help of IoT is also a major worry.

### 2.4. Artificial Intelligence and Machine Learning Approaches

The reason behind the popularity of artificial intelligence (AI) and machine learning (ML) methods is the capability to model complex and non-linear processes of traffic. Tasks that have seen the use of neural networks, deep learning models, and reinforcement learning algorithms by researchers include prediction of traffic flows, adaptive signal control, and incident identification. Reinforcement learning based adaptive signal control systems are some of these that have shown significant gains in terms of minimizing average waiting time and queue length compared to the origin fixed-time or actuated control systems. Although AI-driven systems can be promising to work with, they typically demand a vast amount of data of high quality and significant computing power that casts doubt on their ability to be generally applicable and use them in resource-limited settings.

### 2.5. Cloud and Edge Computing

The use of cloud computing in intelligent traffic management is a highly used application in storing of large data and data analytics as well as making decisions centrally. It is able to train complex models and analyze historical data due to its high level of computation. Nevertheless, there can also be latency introduced by cloud-only architecture and this is not wanted in applications of time-responsive traffic control. To overcome this weakness, edge computing has been created as one of the complementary frameworks, enabling the processing and decision-making of data nearer to the source of data. Recent researches promote a hybrid cloud-edge design that balances both the computational efficiency and low latency, and is, therefore, appropriate to implement in intelligent cities as real-time traffic monitoring and traffic control.

### 2.6. Research Gaps

Although the current status of the intelligent traffic management systems has been highly advanced, there are still various gaps in the research. A lot of research is verified with simulation or small-scale deployment and not so many researches are made to determine the scalability and long-term performance in the real-life world. Instead, the combination of multi-modal means of transport, including public transit, pedestrians and Cyclists, and autonomous vehicles is not deeply considered. Also, there is the lack of strong cybersecurity systems designed specifically to operate in traffic infrastructure that expose systems to data breaches, and malicious attacks. Lack of standardized assessment metrics also adds to the lack of the comparison and benchmarking of proposed solutions underpremised by large-scale and integrated research.

## *3.METHODOLOGY*

### 3.1. System Architecture

The Intelligent Traffic Management System (ITMS) that has been proposed has a layered architecture to provide modularity, scalability and effective data flow. The system is structured into four functional layers which are dedicated to accomplish certain tasks such as collecting data to controlling traffic and dealing with users.

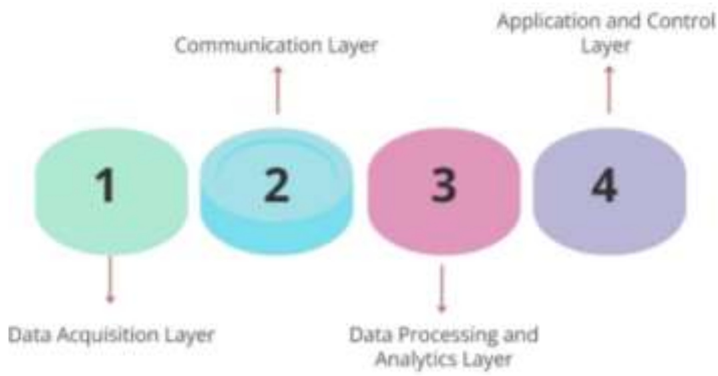


**Fig 2 - System Architecture**

#### *3.1.1. Data Acquisition Layer*

The Data Acquisition Layer will ensure that real-time traffic data are gathered in various sources that are installed throughout the transportation network. Sensors fitted to this layer comprise camera, inductive loop detectors, radar devices, GPS fitted cars, and environmental sensors. The data that is usually collected comprises of the number of vehicles, their speeds, the occupancy of the lanes, and the level of congestion. This layer is the basis of successful traffic monitoring and decision-making because it ensures that the necessary data is supplied by both owing to the correct and consistent input.

#### *3.1.2. Communication Layer*

The Communication Layer permits a secure and dependable data transmission between the field devices and centralized or distributed processing units. It uses wireline and wireless technology of communication like fiber optics, cellular network, Wi-Fi communication, and dedicated short range communication (DSRC). This layer means low-latency data transfer; interoperability between

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heterogeneous devices, data security issues including challenges that may occur due to network reliability, bandwidth control, and management.

*3.1.3. Data Processing and Analytics Layer*

The Data Processing and Analytics Layer will be used to aggregate, filter, and analyze data so that significant information about the raw traffic data can be derived. The highest level of analytics, machine learning and statistical models, are utilized to make predictions of traffic and identify traffic incidents, as well as set traffic signals within optimal time frames. This layer can take advantage of cloud computing to scale its computations and edge computing to ensure time responsiveness needs, hence a balance between cost-effectiveness in computations and real-time responsiveness.

*3.1.4. Application and Control Layer*

Application and Control Layer transforms the results of analytics into practical traffic management plans. It encompasses traffic signal instructions, static message boards, route directional systems, and surveillance boards among the traffic officials. This layer can be used to assist the automated and adaptive traffic control to make real-time adjustments to signals, alert congestion and operator decision support. It also offers smart city integration interfaces with traveler information systems.

**3.2. Data Acquisition Layer**

The Data Acquisition Layer is expected to receive real and near real time traffic data on various and heterogeneous sources. This layer will cover all areas of traffic conditions on the road network, by integrating bio-persistent infrastructure sensors with mobile and user-generated data.

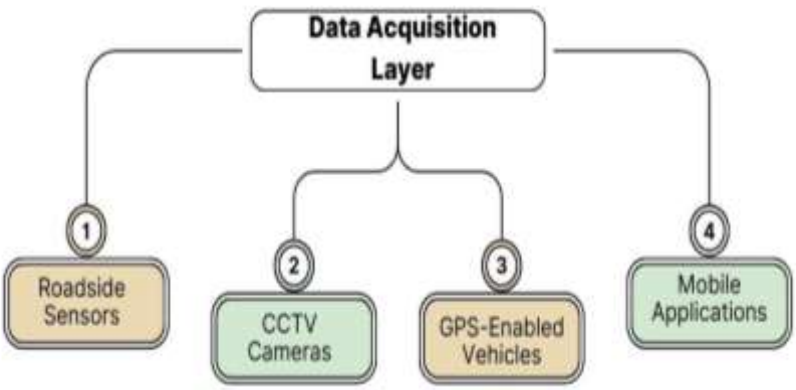


**Fig 3 - Data Acquisition Layer**

*3.2.1. Roadside Sensors*

Inductive loop detectors, radar sensors and infrared sensors are road side sensors that are installed along the roadways and intersections to constantly monitor the traffic parameters. These types of sensor give precise information about the number of vehicles, speed, and occupancy of the lane and traffic congestion. Roadside sensors provide localized data because of their fixed installation, but can be very expensive to install and maintain.

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*3.2.2. CCTV Cameras*

The CCTV cameras mostly find application as surveillance cameras on visual traffic and monitoring of incidents. They also record video streams that can be analyzed by use of computer vision methods to identify the movement of vehicles, congestion, accidents, and traffic offences. The CCTV based surveillance delivers high contextual knowledge and can be used to understand the situational awareness in real time, but the system is subject to weather, lighting, and occlusions.

*3.2.3. GPS-Enabled Vehicles*

The GPS based vehicles provide mobile sensing units because they send the location, speed and travel-time to the traffic management system. The probe vehicle information allows the scaling of traffic movement without the need to install a lot of roadside infrastructure. GPS techniques are quite useful in data collection, especially the estimation of travel times and the congestion patterns but the accuracy of the data collected by these methods is dependent on the availability of the signal and the rate of vehicle penetration.

*3.2.4. Mobile Applications*

Mobile apps can provide crowd-sourced traffic information in the form of the anonymized user data, including the location, speed, and route selections. Such aids help to increase the range of spatial coverage and deliver real-time information about traffic conditions, incidences and closures. Although the mobile app data enhances the responsiveness and scalability of the system, they also create issues regarding data privacy, user consent and reliability of the data.

**3.3. Communication Layer**

Communication Layer is an important factor when it comes to ensuring a smooth, reliable, and low-latency communication between the data acquisition and components of the Intelligent Traffic Management System (ITMS) and the higher-level processing and control modules. This layer incorporates various communication technologies that provide heterogeneous devices and diverse communication needs of the data transmission. The most popular applications of wireless sensor networks (WSNs) include the interconnection of roadside sensors and monitoring devices as it is flexible and scalable with low costs. These networks allow sensors to exchange traffic information on the number of vehicles, speed and environment among other information to other nearby gateways or edge nodes. Nonetheless, there are drawbacks of WSNs associated with insufficient bandwidth, power, and ease of interference, and effective strategies should be suggested using routing and power management. Modern cellular networks like 4G LTE and 5G networks are becoming more popular in order to support high-speed and large data transmission. They have extensive geographical coverage, high data rates and low latency which makes them suitable in real time monitoring of traffic, video streaming by CCTV cameras and vehicle to infrastructure communication. Specifically, the 5G technology makes the system more responsive as it allows connecting such a technology option as ultra-reliable low-latency communication that is indispensable to time-sensitive traffic regulation and safety solutions. There is also Dedicated Short-range Communication (DSRC) which is immediately applied to direct communication between roadside units and vehicles in short ranges. DSRC facilitates the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, and supports quick transfer of data to applications which include the most recent collision avoidance, signal priority, and cooperative traffic management. The Communication Layer combines WSNs, cellular networks and DSRC so that the data transmission is robust, secure and real-time hence allowing effective coordination of the system elements and also decision-making processes in an intelligent manner across the traffic management infrastructure.

### 3.4. Data Processing and Analytics Layer

The Data Processing and Analytics Layer is an entity that converts raw traffic information into meaningful information that can assist in the intelligent decision making and adaptive traffic control. This layer extends data management procedures with more advanced ways of analysis to process massive quantity of heterogeneous traffic data effectively.

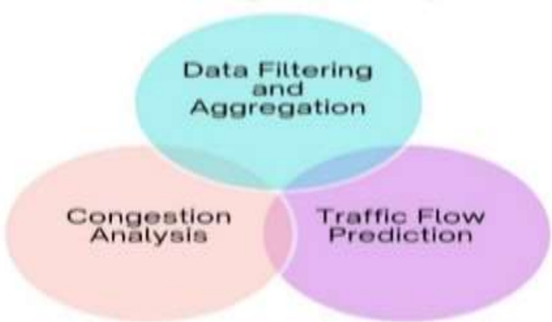


**Fig 4 - Data Processing and Analytics Layer**

#### *3.4.1. Data Filtering and Aggregation*

Task processing Data filtering and aggregation are necessary processes to enhance the quality and usefulness of traffic data collected. The filtering methods are used to eliminate noise, outliers and incomplete records due to sensors errors, communication lags or external interference. Aggregation takes data of different sources and periods of the day to come up with cohesive traffic indicators like speed average, vehicle density, and flow rates. The processes eliminate data redundancy, increase the accuracy and make sure that processes that follow are based on reliable and consistent data.

#### *3.4.2. Traffic Flow Prediction*

Traffic flow prediction aims at predicting the future state of traffic in terms of the historic and live traffic data. The parameters that are predicted using machine learning and statistical models include the volume of traffic, speed, and travel time in various road segments. By making proper predictions of traffic, it is possible to make expected predictions of traffic and therefore manage the traffic proactively by enabling systems to predict the congestion, correct signal timings ahead of time and guide users of routes. This feature plays an important role in enhancing the traffic efficiency and eliminating delays at rush hours.

*3.4.3. Congestion Analysis*

Congestion analysis is the process of identifying, assessing, and overseeing the traffic jams in the transport network. This process can be used to get an idea of severity and the causes of congestion by examining traffic density, queue length, and change in travel time. Mature analytics also be able to differentiate recurring congestion to non-recurring congestion caused by incidents or roadworks. The knowledge acquired in the course of congestion analysis can be used to implement effective traffic control policies, including traffic diversion and dynamic signal optimization, which eventually improves the performance of the network as well as end-user experience.

**3.5. Adaptive Signal Control Algorithm**

The Adaptive Signal Control Algorithm is an algorithm that aims to optimize dynamically timings of traffic signals according to the dynamics of traffic environment based on the reinforcement learning (RL) strategy. The closer is in comparison to the traditional methods of signal control which is fixed-time, actuated, or based on a predetermined plan of control, the proposed method of signal control allows the traffic signals to learn the best approaches to the control strategies due to the constant interaction of the traffic environment with the traffic signals. With this method, every traffic signal is represented as a smart agent and it monitors the current state of traffic as the length of vehicle queues, waiting time and flow rate of traffic on various approaches. With these observations, the agent chooses the correct actions, such as varying the time of green lights, the sequence of phases or the timing of the signals, and the aim is to reduce the time delay and congestion. Reinforcement learning enables the system to compare the efficacy of each move with the help of some rewarding program which reflect indicators of the performance of traffic like decrease of waiting time, elevated throughput, and reduced in the line of queues. As time goes by, the algorithm develops adaptive policies, which react well to the recurring or un-recurring traffic trends such as peak-hour traffic jams and unexpected accidents. Adaptation to changes in demand is done quickly by use of real-time data so that the final decision of the signal control can be known to be responsive to the prevailing traffic conditions. Also, reinforcement learning provides decentralized or coordinated control where a number of crossings work together to optimize the network-wide level of traffic flow. This dynamic style induces better robustness, scalability and minimizes human interference to the system. Through the constant learning of the environment, Adaptive Signal Control Algorithm can greatly enhance efficiency of traffic, less fuel consumption and general road user experience, and is a major element of intelligent traffic management systems.

**3.6. Performance Metrics**

Quantitative measures of effectiveness of the proposed Intelligent Traffic Management System (ITMS) are performance metrics. These metrics are an indication of the efficiency of traffic and a measure of the environmental impact which gives a holistic view of the performance of the system under different traffic volumes.


**Fig 5 - Performance Metrics**

*3.6.1. Average Travel Time*

Average travel time is the average length of time of vehicles which transfer through a definite section of road or cross a journey within the traffic system. It is one of the main means of traffic efficiency and user experience. Fewer calories consumed in average travel time will indicate a better traffic flow, optimal signal coordination, and congestion that is controlled using adaptive control techniques.

*3.6.2. Queue Length*

The queue length measures the amount of vehicles in a traffic intersection or roadways at a particular time slot. This measure proves to be especially helpful to evaluate the intersection performance and pinpoint the bottlenecks. Short queue is a sign of good signal timing and achieves less congestion whereas long queues can be a repetition that there is not enough capacity or the coordination of traffic signals.

*3.6.3. Intersection Delay*

The time that vehicles get stuck at an intersection after leaving in a free-flow situation is what is called intersection delay. It is a key metric of intersection efficiency and one that measures the effect signal control has on the movement of vehicles. Reduced intersection delays even show the usefulness of adaptive signal control algorithms, reducing unnecessary stops and increasing throughput.

*3.6.4. Fuel Consumption*

Fuel consumption is the assessment of volume of fuel which is utilized in vehicles during the network. Unnecessary stops, holding, and stop and go ensures that a lot of fuel is highly consumed. The proposed system helps in smoother traffic flow by maximizing the signal timings and minimizing delays resulting in a minimum fuel usage and energy efficiency.

*3.6.5. Emission Levels*

Emission levels refer to the quantity of the pollutant that is emitted by the vehicles in the form of carbon dioxide ($CO_2$), nitrogen oxide ($NO_2$) as well as particulate matter. An expanded traffic and

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long idle periods raise the rate of emissions. Ensuring environmental sustainability by decreasing emissions with an enhanced flow of traffic would be a goal towards smart city and green transportation.

## *4. RESULT AND DISCUSSION*

### 4.1. Experimental Setup

The experimental design was aimed at strictly testing the work of the suggested Intelligent Traffic Management System in the conditions of realistic traffic. The experiments were done on real life traffic data gathered on urban road systems so that the test running environment is as close as possible to the actual traffic mechanisms. These data sets contained the time stamped data on vehicle flow, speed and density collected along various sources that comprised roadside sensors, GPS enabled vehicles and traffic surveillance units. The simulations also included real traffic data, which made them to capture peak and off-peak variations of traffic in addition to the recurrent congestion planning that is often witnessed in an urban setting. The simulation environment has been designed with comprehensive urban intersections layouts, such as using multi-lane approach, signalized intersection and using different traffic demand rates. Such intersection models included realistic restrictions like lane patterns, turning, pedestrian crossing, and signal phase regulations. The suggested algorithm of adaptive signal control on the basis of reinforcement learning was compiled into the simulation framework and trained with the help of historical traffic data prior to being tested in real-time simulation settings. Relative performance improvements were done in the form of baseline comparisons versus traditional fixed time and actuated signal control strategies. System parameters, such as the traffic demands, arrival rates and the incident scenario were carefully varied to ensure the test of the strength and flexibility of the proposed approach. Measures of performance time, the length and width of the queue, intersection delay, the fuel consumptions and the level of emissions were documented during the simulation runs. Several simulation cycles were carried out to discard any statistical unreliability and minimize random variations. Such an extensive experimental plan allowed a fair and consistent assessment of the presented system, which presented viable information about its suitability, scalability, and applicability to the real-life urban traffic management practices.

### 4.2. Performance Comparison

**Table 1: Performance Comparison**

| Metric | Traditional System | Proposed ITMS |
|---|---|---|
| Average Delay (s) | 85 | 42 |
| Travel Time (min) | 32 | 21 |
| Fuel Consumption (%) | 100 | 78 |
| $CO_2$ Emissions (%) | 100 | 72 |

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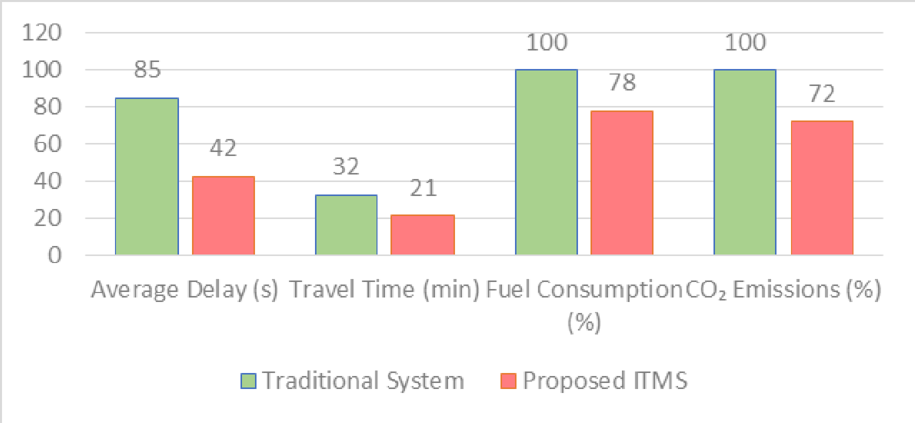


**Fig 6 - Performance Comparison**

*4.2.1. Average Delay*

Average delay is simply an indication of the average amount of time that vehicles spend at the intersection because of signal control and congestion. Under the conventional system, the mean delay time was counted to be 85 seconds, which was mostly caused by determined signal timings that could not adjust to the changes in the beautifully running traffic. Conversely, the suggested ITMS minimized the average delay to 42 seconds by varying dynamically the signal phase according to the existing traffic need. This significant decrease indicates the efficiency of an adaptive control based on reinforcement learning to reduce unwanted waiting times.

*4.2.2. Travel Time*

The travel time is the amount of time taken by vehicles to travel using the road network. The conventional system had an average passenger travel of 32 minutes, which denoted the high level of stops, as well as poor coordination of the signals. Using the suggested ITMS, the average travel time was reduced to 21 minutes which showed that the traffic had been smoother and coordination of intersections enhanced. This will boost the general user experience and efficiency of the network.

*4.2.3. Fuel Consumption*

The fuel used is measured as a percentage of the traditional one where the baseline of 100 would be a system used long before the liberalization process. The traditional system had consumed more fuel because of the time wastages due to idling and stop and go traffic. Saving fuel consumption of 78% was achieved with the proposed ITMS because it minimized delays and allowed easier movement of vehicles. The result of a low fuel consumption means that there would be less operating cost to the road users.

*4.2.4. $CO_2$ Emissions*

The CO 2 emissions were also compared with the traditional system of 100% as the baseline. The congestion rates in the conventional system were high and this resulted in high level of emissions due to the idling and ineffective driving habits. Proposed ITMS led to a decrease in CO 2 emission to 72 percent through enhancement of traffic flow with decreased stop times. The consequence of this outcome indicates the environmental advantages of smart and dynamic traffic light control systems.

**4.3. Discussion**

The outcomes of the experiment prove by far that the Intelligent Traffic Management System (ITMS) proposed is far superior in comparison with the traditional methods of traffic control in all the performance parameters considered. This huge decrease in the average delay as well as travel time shows that adaptive signal control is efficient in responding to real time changes in traffic as compared to old systems that are based on fixed time assumptions and operated using a fixed set of assumptions. Through repetitive learning of traffic conditions using reinforcement learning methods, the system dynamically manages the timings of the signals to optimise the ability to adapt the traffic demand with a high degree of manipulation and therefore, minimise the development of queue and optimise intersection throughput. All these enhancements bring about a smooth traffic flow and efficiency of the road network. The fact that fuel consumption has reduced is another step that supports the operations advantage of the proposed system. This decreases idling time and stop and go patterns of running the vehicle hence making vehicle operation more efficient, reducing fuel consumption and operations expenses to commuters. Besides the efficiency in traffic, the proposed ITMS has significant environmental benefits. The drastic decrease of the $CO_2$ emissions supports the system in the perspective of supporting the ecologically viable urban transportation projects as it alleviates the adverse environmental impact of the traffic jam. It is especially applicable in probably populated cities where the emissions of vehicles are the primary cause of air pollution. Moreover, the findings indicate that adaptive signal control does not only have beneficial impact at the intersection level, but also has beneficial network-based impacts when implemented at more than one intersection. The stability of the system in different traffic demands signifies it to be appropriate to be implemented in the real world. Nevertheless, simulation-based analyses are helpful, but actual application is likely to bring a new factor of disturbances like communication delays, failure of sensors, and cyber threats. These challenges will also require the design of strong systems and field test to make a large scale adoption. On the whole, this discussion proves that smart, data-driven traffic control systems represent a potential remedy to enhancing city mobility, alleviating congestions, and ensuring the environment in a sustainable way.

**4.4. Limitations**

Although the suggested Intelligent Traffic Management System (ITMS) proved its efficiency, a number of limitations ought to be admitted. Among the major problems is the fact that deployment cost of installing advanced sensing devices, communication and computing facilities is relatively high at the beginning. Individual units like roadside sensors, high-resolution CCTV cameras, edge computing units, and communication modules cost a lot of capital to apply, and may not be adopted in the developing areas or municipalities with low budgets. On top of hardware expenses, the cost of system integration, software development and highly skilled personnel also create a significant added expense to an overall cost of deployment. The heavy reliance of the system on availability of efficient communication is another weakness that stands out. Real-time operation requires continuous data flow among sensors and processing units as well as control systems. Failure of network or latency problems, as well as insufficient coverage, may adversely affect performance of systems and decrease the efficiency of adaptive ability of signal control. At locations with low connectivity, or network instability, it can be difficult to ensure that the systems are responsive. Moreover, the gathering and manipulation of big data volume that is generated by traffic also represent serious data privacy and security issues. The data obtained through Gps enabled cars and mobile applications can consist of sensitive location information that can be abused when not secured well. User anonymity, encryption of data, and adherence to data protection laws are essential both in terms of complexity and design and functionality of the system. To overcome such restraints, specific planning and support of the policies implemented, as well as the implementation of sound cybersecurity and privacy protection strategies, should be taken. Although these issues cannot be claimed to be more significant than the advantages of intelligent traffic management, they serve to point out the crucial matters that need to be considered in order to facilitate the implementation of ITMS solutions on a sustainable and large-scale basis translating to practical application.

## *5. CONCLUSION*

The paper has made an overall study of Intelligent Traffic Management Systems (ITMS) as an enabling factor of smart city transport infrastructure. The proposed ITMS framework will include the Internet of Things (IoT) technologies, artificial intelligence, and improved data analytics to focus on crucial issues related to traffic jams in urban areas, ineffective signal control, and environmental pollution present. The layered system architecture allows the acquisition of data to be done without any complications, the data transmission is accurate, the processing of the data is intelligent, and the control is adaptive to the changing traffic conditions in real-time. Simulation findings based on real data of the traffic prove that, the proposed system greatly performs when compared to the conventional traffic management strategies. It was noted that significant gains were made in regard to minimal average travel duration, reduced intersection delays, short queue length, and increase in traffic flow efficiency. Besides operational advantages, the system also helps in improving environmental sustainability through saving of fuel consumption and emitted carbon dioxide, hence green transportation and enhances the general air quality of the urban areas. These results prove that smart, evidence-based traffic control systems can improve the safety, efficiency, and user experience in multi-faceted urban settings. In the future, there are multiple research topics that can be used to advance the functionality and usability of ITMS. The combination of intelligent traffic management systems with autonomous and connected vehicles is one of these important areas. Such integration would provide real-time vehicle to infrastructure communication so that traffic lights would act ahead of vehicles based on their movement and give better coordination among all other intersections. The other major direction is the development of multi-modal and traffic management strategies, which should not be based on the individual vehicles only, but also on the use of the transport, people, bicycles and ambulance. Multi-modal data could provide a more inclusive and effective traffic control policy. Furthermore, data security protocols using blockchains can be used as a possible solution to the problem of data integrity, privacy, and trust in distributed traffic management systems. Blockchain can guarantee safe information exchange among stakeholders and eliminate hacking and data violation. Lastly, extensive real-life implementations and field tests are also vital as they will test the resilience of the system, its scalability and how it will perform with various traffic and environments. Further research and development of intelligent traffic management is also essential and relevant in the efforts of the academia, industrial and government agencies, as a pillar of smart city development to provide safer, greener, and more efficient urban movements to the coming generations.

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