Smart Traffic

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ABSTRACT

A smart traffic management system refers to the combination of technologies and devices that together help reduce traffic congestion and improve passenger and vehicle safety. Smart traffic systems are crucial in minimizing accidents and improving overall road safety by reducing human error. They involve integrating IoT devices, sensors, and 5G networks into transportation infrastructure to enable seamless communication between vehicles, traffic signals, and road signs. The application of artificial intelligence has also elevated the performance of smart traffic systems where cameras capture images to conduct various analyses to derive actionable insights. The possibilities of what a camera-enabled intelligent traffic management system can do are endless. These new-age devices have helped improve passenger and pedestrian safety, reduce the number of accidents, and enhance the overall conduct of traffic management across the world. In this paper, we discuss the advantages and potential of smart traffic systems, and how they can help to revolutionize the transportation industry as a whole.

KEYWORDS: smart technologies, smart traffic, smart traffic systems, smart roads, intelligent traffic, smart cities.

INTRODUCTION

The problems plaguing our streets and highways are well known. We have more cars, bigger road networks, higher population densities, and constant traffic disruptions. Cities are facing increasing congestion due to rapid urbanization. Daily traffic congestion may be one of your city's biggest headaches. It is a catalyst for a myriad of problems beyond wait-times. Businesses suffer from delivery delays and lost productivity. Idle cars mean wasted gas and increased carbon dioxide emissions, impatient drivers, and unsafe road conditions increase the rate of potential injuries and accidents. That is why cities across the globe are seeking efficient, technically-advanced solutions to facilitate constant two-way data transfers to out-smart traffic jams.

Intelligent traffic systems are widely seen as the future of road transportation because they dramatically improve traffic flow and enhance road safety. They utilize real-time data to make dynamic decisions, leading to more efficient management and reduced congestion. Major advancements in the Internet of things (IoT) and artificial intelligence (AI) could be the key to eliminating traffic congestion once and for all [1]. A typical traffic congestion is shown in Figure 1 [2].

Traffic intelligence has proven itself vital to modern road safety. Smart traffic systems are transforming road safety beyond our wildest expectations. They do more than monitor vehicles; they predict accidents before they happen. These systems excel at detecting anomalies. They bring a new approach to road safety with measurable results [3].

WHAT IS SMART TRAFFIC?

Everything's getting smarter these days. Even our traffic lights are becoming smart in the era of artificial intelligence (AI), machine learning, big data, and the Internet of things (IoT). Smart traffic lights promise a safer, greener, and more efficient transportation world. A study concluded that smart traffic lights might reduce the time drivers spend waiting at intersections during rush hours and reduce CO2 emissions. Smart traffic lights are a system that combines traditional traffic lights with an array of sensors and AI to intelligently route vehicle and pedestrian traffic. They can form part of a bigger

intelligent transport system. Figure 2 shows how infrared sensors are used for counting vehicles [4].

One of the cornerstones in smart city design is having an integrated smart transportation solution. A city is not completely intelligent without a smart traffic management system. Smart traffic management systems are technology solutions that municipalities can integrate into their traffic cabinets and intersections today for fast, cost-effective improvements in safety and traffic flow on city streets. These systems utilize sensors, cameras, cellular routers, and automation to monitor and automatically direct traffic and reduce congestion. They will adapt and ultimately provide anticipated and real-time traffic alerts to road operators without lag time. They make it possible to increase the capacity of city streets without actually adding new roads. AI-enabled intelligent traffic management software embedded in connected devices are now advanced enough to analyze traffic patterns, weather conditions, and more, on the scale required to truly combat traffic congestion. With cameras and sensors constantly monitoring intersections, technicians can monitor the entire city from the city's traffic management center. Figure 3 shows smart traffic management system [5].

A smart traffic light is an Internet-connected vehicle traffic control system capable of adapting traffic light controls based on information collected from sensors, edge devices, and video systems. Smart traffic lights provide information on how many vehicles, delivery trucks, cyclists, pedestrians, and buses pass through an intersection, and then optimize traffic flow accordingly and autonomously. Smart traffic signals are equipped with sensing, video capture, and connectivity technologies to collect real-time data from the environment. Smart traffic light systems integrate sensor and connected video monitoring technologies to account for intersection wait times, vehicle speed, and/or pedestrian traffic. They are being developed with all road users in mind: pedestrians, cyclists, public transit, etc. The systems support advanced driver-assistance systems (ADAS) and autonomous driving technologies. These systems rely on real-time data from smart roads to make informed decisions, such as when to slow down, stop, or change lanes. Figure 4 shows some traffic lights [6]. Smart traffic cameras are the eyes of a smart traffic management system. They are installed in traffic junctions, streets, and tolls to capture images and videos of vehicles, passengers, and pedestrians. Selecting the right camera module for your smart traffic device requires meticulous analysis and evaluation. Typical smart traffic camera is shown in Figure 5 [7].

APPLICATIONS OF SMART TRAFFIC

Smart traffic solutions are already being deployed in major cities across the world. These solutions are adaptable, and because they are powered by AI. Common real-world use cases of smart traffic include the following [8,9]:

➢ *Intelligent Transportation Systems* (ITS): A smart city is not completely intelligent without a smart transportation solution. Smart transportation has emerged as a critical aspect of reshaping traffic management in modern urban centers. The integration of smart technology enhances road safety, reduces congestion and pollution, and improves travel times. ITS provide an organized, integrated approach to minimizing congestion and improving safety on city streets through connected technology. IoT sensors provide the backbone of data that intelligent transportation management systems analyze to increase actionable insights. Figure 6 shows an intelligent traffic management system [7].

➢ *Smart Transportation:* With the emergence of intelligent transportation systems and the Internet of things (IoT), the world is entering the next stage of movement — smart transportation. Smart transportation is being implemented today in several cities with their successes and failures being used to improve systems in new locations. Smart transportation not only provides detailed data points for every aspect of the transportation system, but allows administrators to better monitor operations, track maintenance needs, and identify key sources of problems that need to be fixed. For example, global hubs like New York City have embraced smart transportation for their ever increasingly intelligent city. An example of smart transportation is displayed in Figure 7 [10].

➢ *Smart Roads:* The rise of smart road technology, powered by Internet of things (IoT) sensors and 5G networks, is transforming traffic management and sustainable transportation. Smart roads are revolutionizing the way engineers, architects, and quantity surveyors work. Designed to enhance daily traffic management while accommodating the long-term needs of growing urban populations, smart roads are set to play a critical role in the future of transportation. They have the potential to improve both the efficiency and cost-effectiveness of road construction and maintenance. Smart roads are rapidly being adopted across the world. By using dynamic routing and real-time information on traffic conditions, smart roads can direct vehicles to the most efficient routes, helping to reduce journey

times and congestion. Motion sensors turn on the road lights, illuminating a specific area of the road as vehicles approach. Figure 8 shows an example of smart road [11].

➢ *Electrified Roads:* Electric engines are being recognized as a key technology to help transportation industry reduce its carbon footprint. The fundamental idea behind electric highways is straightforward: any car using the road at any one time must have access to energy, which is provided by the road infrastructure. Usually, power is transmitted to the cars directly by inductive coils or conductive rails on overhead or subsurface power lines.

➢ *Smart Street Lights:* Smart traffic lights are one of many smart city initiatives that use advanced technology to improve the management of city services and the quality of life for citizens. A smart streetlight is a type of outdoor lighting that uses technology, such as cameras, light-sensing photocells, and other sensors, to add real-time monitoring features. This kind of lighting system is regarded as a crucial advance in the creation of smart cities. Along with smart parking technology, smart traffic lights are helping to create a more intelligent traffic management system that enables smart cities to reduce congestion and travel times, to improve safety and to reduce carbon emissions.

➢ *Traffic Light Control:* Smart traffic control systems are a key component of the larger concept of smart cities. The traffic light control systems interconnect several traffic lights. Adapting traffic light controls based on data gathered from sensors, edge devices, and video systems is the function of a smart traffic light, which is an internet-connected vehicle traffic control system. Heavy traffic crossings that frequently experience congestion and accidents are the focus of traffic control. Simple traffic signals will not suffice to distribute traffic; we need systems that can change based on the conditions on the road. It is the field where AI has become widely used in both big cities and small towns, successfully preserving traffic flow in difficult driving scenarios.

➢ *Traffic Monitoring:* This is one of the most significant applications of smart road technology. This technology provides smart cities with immediate insights into traffic conditions, allowing for proactive management and timely interventions. Smart roads can monitor traffic conditions in real time by using IoT sensors and cameras embedded in the road infrastructure. This

data is then processed using edge computing, allowing traffic management systems to respond immediately to changing conditions.

BENEFITS

One of the top benefits of smart traffic management systems is the predictive insights that they offer. Predictive analytics takes smart transportation a step further by using historical and real-time data to project future traffic patterns. Data collected from smart traffic sensors can be analyzed to assist governing bodies in determining how frequently roadways are used, the daily quantity of vehicles at specific intersections, and essential urban data. Other benefits of smart traffic include the following [9,12]:

➢ *Vehicle Tracking:* Vehicle tracking on smart roads enables enhanced security and traffic management. By continuously monitoring vehicle movements, authorities can track the location of vehicles for purposes such as recovering stolen vehicles or managing traffic during emergencies. This capability is particularly useful in urban areas with higher traffic congestion and crime rates.

➢ *Autonomous Vehicles:* Autonomous vehicles represent a significant advancement in transportation, and smart roads are crucial for their operation and safety. Autonomous vehicles rely on continuous communication with smart road infrastructure to navigate safely.

➢ *Enhanced Safety:* ITS' integrated sensor technology is a next-generation life-saving solution. Smart traffic management systems enable safe transportation. Intelligent traffic systems help to limit and mitigate traffic collisions, fatalities, injuries, and property damage through its inherent advanced safety properties.

➢ *Greater Sustainability:* Traffic congestion not only affects our daily lives but also contributes to increased carbon emissions and air pollution. Smart traffic control systems play a vital role in mitigating these environmental impacts. The organic route optimization, ridesharing opportunities, and parking solutions that smart traffic management systems offer equates to environmentally friendly, sustainable technology.

CHALLENGES

In spite of their numerous benefits, the widespread adoption of smart traffic is not without challenges. The challenges center mainly around power consumption, responsible data management, high implementation costs, the need for robust data infrastructure, and privacy concerns. Traffic

managers face new challenges with keeping traffic management systems up-to-date. The priorities are to improve traffic flows, reduce congestion and increase safety. Traffic systems are chaotic by nature. The more data we can collect about the forces shaping those flows — from weather to pedestrians — the more accurately we can predict and manage traffic conditions. Other challenges include the following [10]:

➢ *Power:* The sheer number of sensors required for the world to transition to smart cities (estimated in the trillions) makes powering so many devices a daunting problem. Smart cities require a lot of sensors and those sensors all require power. For sensors attached to moving objects, this will require batteries. Stationary sensors may be able to use solar power, but more often than not will need to be wired into the city's electrical grid.

➢ *Personal Data:* There is significant debate in the world today regarding personal data online. Data is the lifeblood that smart cities need in order to operate. While much of the information needed is anonymous compared to online data, this will require a mental and behavioral shift among populations

➢ *Environmental Considerations:* From steam vehicles that burned coal and wood to today's gasoline hungry combustion engines, transportation takes a toll on the planet's resources and atmosphere. Mass transit is better for the environment than private vehicles but is not widely used across the US and other countries because it is often impractical in some regions.

➢ *Supply Chain Resiliency:* Global crises such as COVID-19 have proven that the world's supply chains are vulnerable to disruption. When workers and drivers are ill and traveling from one region to another becomes a public health hazard, autonomous transportation of goods can become a literal lifesaver.

SMART TRAFFIC AROUND THE WORLD
Despite constrained budgets for infrastructure upgrades, smart cities around the world are using smart traffic management technologies to improve the overall performance of their traffic networks and help streets and highways carry more traffic in greater safety. Many more cities are looking into modernizing their traffic controls. For example, cities like Los Angeles, London, and Singapore have already begun implementing smart traffic lights as part of their traffic management strategies. Here we consider how some nations are adopting smart traffic systems in their transportation.

➢ *United States:* Kansas City, Missouri, serves as a prime example of successful smart transportation implementation according to the US Department of Transportation. Faced with traffic challenges, the city deployed the Smart City Initiative, integrating IoT sensors, data analytics, and real-time monitoring. The tangible benefits experienced in Kansas City exemplify how smart transportation solutions can positively impact urban living in the United States [13]. Portland, Oregon is already putting intelligent traffic management systems to the test. FirstNet is a US nationwide wireless network designed to provide voice, text and data communications for emergency responders. While the use of adaptive signal control systems is gaining traction in the United States, it is still far from being universally accepted and implemented. Part of the reason may be cost.

➢ *United Kingdom:* London, in partnership with Siemens, is testing a real-time adaptive traffic signals control (ATSC) solution called Sitraffic FUSION that is powered by data from connected vehicles and connected road infrastructure. The system can detect, model, and optimize routes for all modes of transport. It also includes a traffic light algorithm for optimizing controls on signalized junctions and pedestrian crossings [14].

➢ *Netherlands:* Amsterdam is the largest city in the Netherlands, with a population of 2.4 million. The city is also one of Europe's leading tourist destinations, attracting around 6 million people a year. In 2015, the municipality of Amsterdam created its own team that was responsible for the development and operation of the data communication network that supports the Intelligent Traffic Systems (ITS) in the city. Because it is difficult, time consuming and costly to install and maintain a data network within Amsterdam, it was realized that the new network would eventually have to be able to support more than just the traffic light systems. Within five years, the industrial network will cover the whole of Amsterdam and its surrounding areas and this will almost completely rely on gigabit fiber links. There are several hundred traffic light systems throughout Amsterdam. The Amsterdam traffic is continuously monitored from the control center to help operators maintain the flow of traffic, reduce congestion and minimize the risk of accidents. The operators can redirect traffic to avoid congestion, give priority for certain traffic such as public transport and manage traffic during large

events. The traffic system in Amsterdam is shown in Figure 9 [15].

➤ *Canada:* The Canadian startup Miovision tested their smart traffic system in the Waterloo region near Ontario. The solution provided local traffic managers with real-time traffic information in the monitored area. Minutes after detecting a collision in a busy intersection, the system alerted urban planners and provided them with real-time footage from the event. The team could then issue a rapid response and reroute traffic from the affected area to prevent further congestion [16].

➤ *Singapore:* Singapore launched its ERP scheme back in the early 2010s. The local ERP consists of city-wide gantries on roads leading to Singapore's Central Area, as well as on other busy roads. Using sensors and cameras, gantries capture the license plate numbers of all entering vehicles and dispatch bills to car-installed units. Drivers can link a card to the device to get billed automatically [16].

CONCLUSION

Smart technologies are essential in revolutionizing transportation systems within smart cities. Big data analytics, machine learning, and Internet of things are revolutionizing traffic management strategies by advancing data-driven decision-making in smart cities. Fortunately, modern infrastructure systems such as traffic management are predominately IP-based, so the operation of one subsystem is often independent of other subsystems. Due to the deployment of the communications technologies, Departments of Transportation will see better traffic flow, improved emergency response, and a reduction in traffic accidents [17].

The journey toward safer roads is a multifaceted one, involving better driver education, more efficient infrastructure, and advanced technology. Smart traffic lights are poised to be a game-changer in urban mobility and road safety. These intelligent systems are transforming the way we navigate our cities, offering a plethora of benefits that extend beyond mere convenience. The future of traffic intelligence depends on algorithms and the physical infrastructure that powers them. These systems will create roads that actively prevent accidents instead of just being places where accidents happen. More information on smart traffic is available from the books in [18-21].

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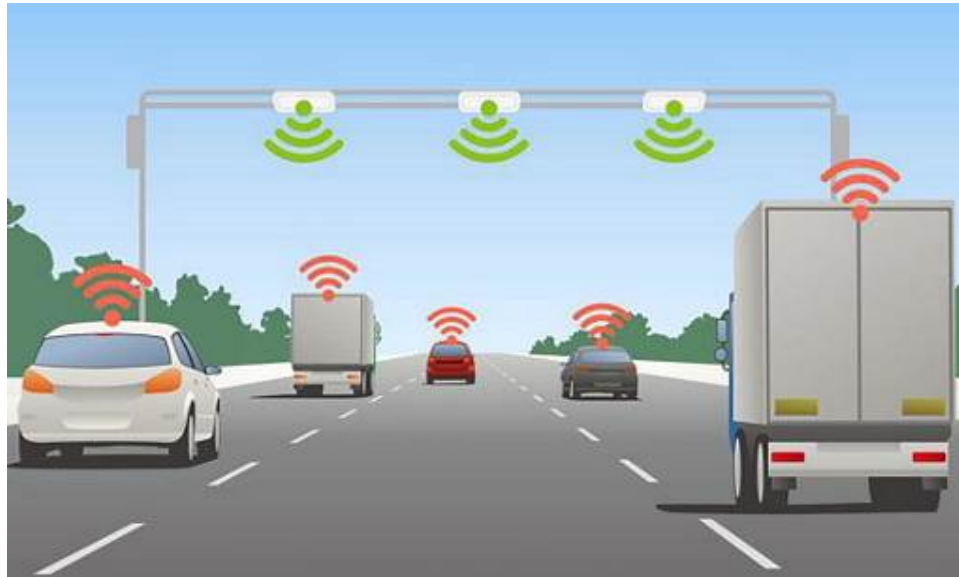
Figure 1 A typical traffic congestion [2].

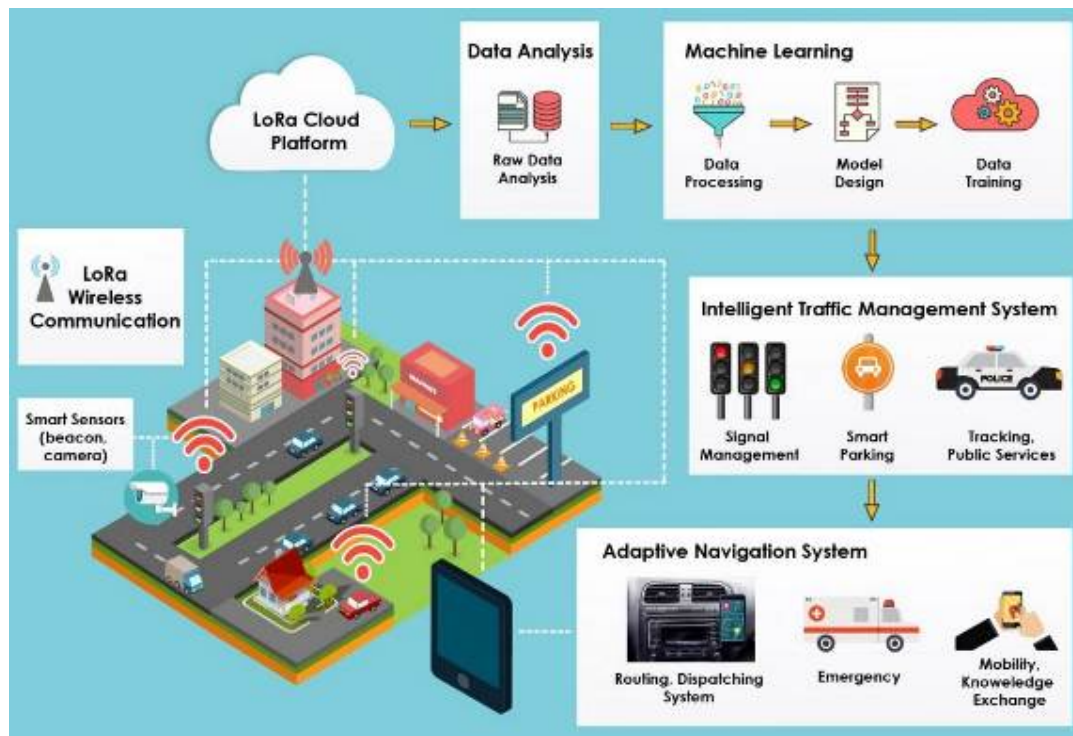**Figure 2 How infrared sensors are used for counting vehicles [5].**

Figure 3 Smart traffic management system [5].

Figure 4 Some traffic lights [6].

Figure 5 A typical smart traffic camera [7].

Figure 6 An intelligent traffic management system [7].

Figure 7 An example of smart transportation [10].
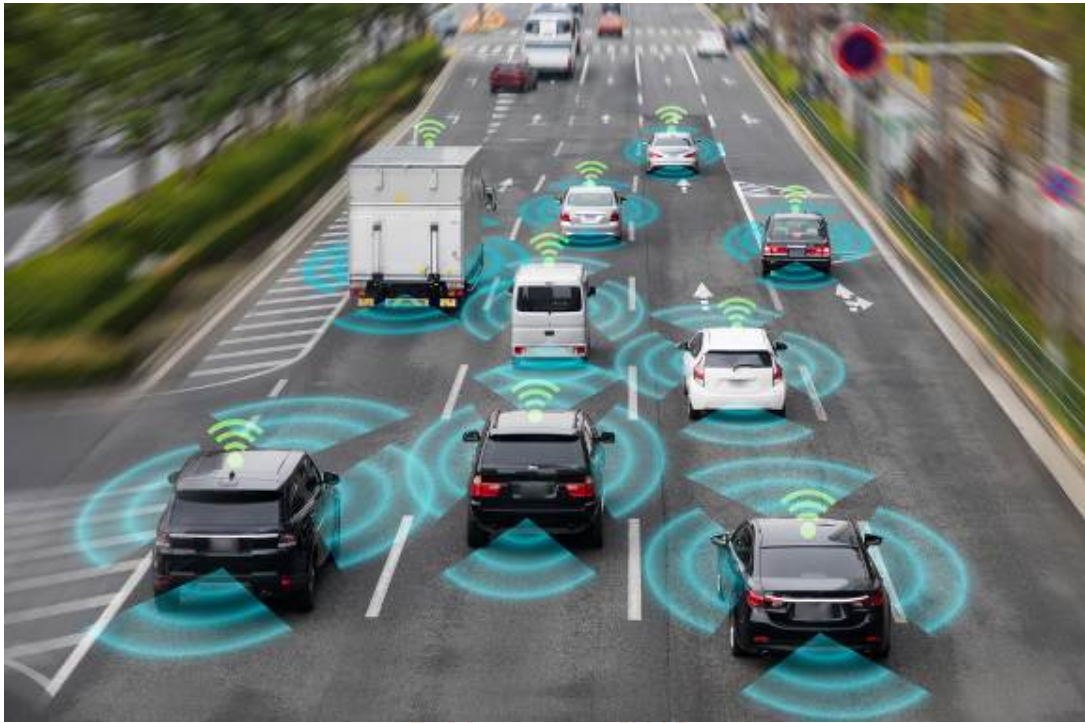
Figure 8 An example of smart road [11].

Figure 9 The traffic system in Amsterdam [15].