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Intelligent Traffic Management Systems: A review

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Abstract

Recent years have witnessed a colossal increase of vehicles on the roads; unfortunately, the infrastructure of roads and traffic systems has not kept pace with this growth, resulting in inefficient traffic management. Owing to this imbalance, traffic jams on roads, congestions, and pollution have shown a marked increase. The management of growing traffic is a major issue across the world. Traffic management is a key branch within logistics. It concerns the planning, control and purchasing of transport services needed to physically move vehicles (for example aircraft, road vehicles, rolling stock and watercraft) and freight. Intelligent Transportation Systems (ITS) have a great potential in offering solutions to such issues by using novel technologies. The ITS-based traffic management and control solutions in this evaluation have been divided into four categories: solutions for managing traffic, preventing congestion, and predicting trip times. The solutions, together with the underlying technology, benefits, and limitations, have been described.

Keywords: Intelligent Traffic Systems, Traffic Management, Traffic jam

Introduction

As robotics, the Internet of Things (IoT), and artificial intelligence (AI) advance, so are the ways in which they might lessen the stress of city traffic. Major cities continue to struggle with infrastructural issues, traffic congestion, pollution, accidents, and other issues. The same problems expanded more extensively with the growth of smaller urban centres. Fortunately, urban centres all around the world are beginning to realise how important it is to spend money on cutting-edge technology to enhance traffic flow. Over the past ten years, local governments have launched dozens of audacious projects, ranging from dynamic management to advanced development planning [1].

Projects that were started in 2011 as experiments are now becoming best practises for advanced traffic management. Mobile device tracking, fully automated parking garages, and smart traffic lights have all shown to be quite effective. On the other hand, there are upcoming concerns that must be handled right away, including the expanding usage of autonomous vehicles [2].

Traffic management systems today are under pressure to evolve and become leaner, greener, and more connected. But what type of technology goes into designing such systems? This article provides details.

Benefits of Smart Traffic Management Systems

It could be argued that a smart city isn't completely intelligent without a smart transportation solution. Additionally, many ITS benefits extend past roadways to optimize city infrastructure as a whole [3]. We've outlined the top 5 benefits of smart traffic management systems below.

1. Predictive Insights

One of the top benefits of smart traffic management systems is the predictive insights that they offer. 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. Ultimately, ITS can provide crucial preventative roadway insights.

2. Enhanced Safety

According to the Governors Highway Safety Association (GHSA), drivers struck and killed an estimated 7,485 people on foot in 2021. ITS' integrated sensor technology is a next-generation life-saving solution. Portland, Oregon is already putting intelligent traffic management systems to the test. Their public transit agency, TriMet, has their fleet of busses equipped with infrared meters (Fig. 1) that communicate with traffic light receivers to appropriately time stops. While these meters offer a safe transportation solution, it also enables faster transportation.

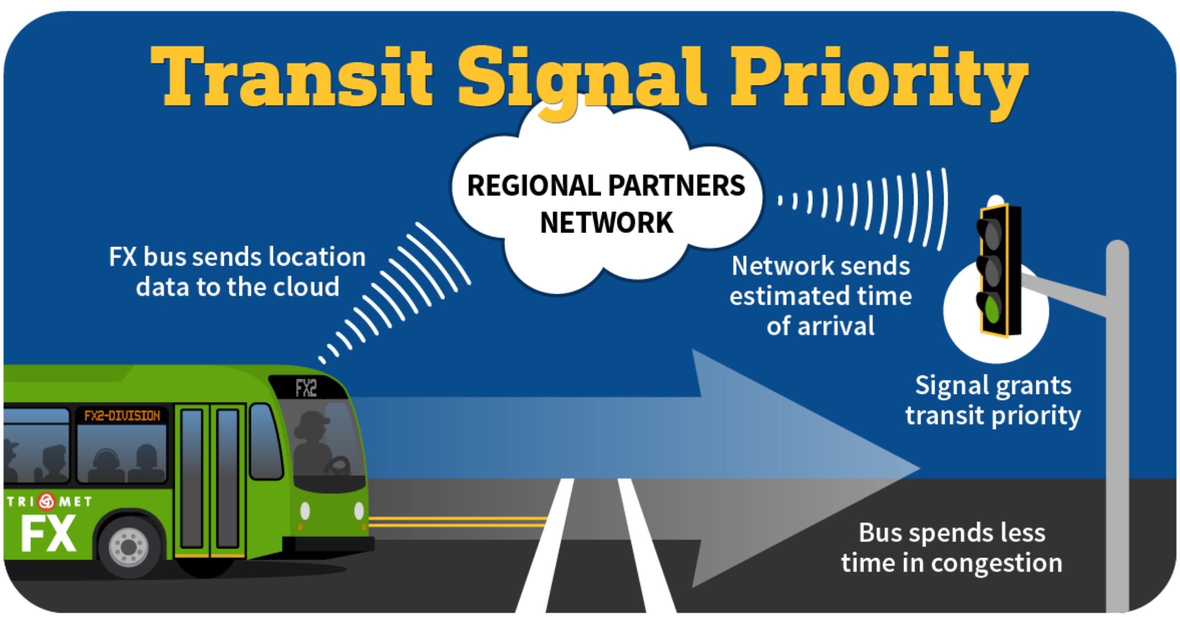

Fig. 1 Example of Portland, Oregon smart traffic solution [4].

3. Cost Reduction

The National Highway and Traffic Safety Administration reported that traffic collisions cost the United States $340 billion in 2019 [4]. 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.

4. Improved Emergency Response

Behind every smart traffic management system is route optimization. When roadways provide ideal traffic conditions, cities are better prepared for emergencies. Minimized congestion enables improved emergency vehicle response time and the real-time insights provided by smart traffic management systems allow for enhanced flexibility, action, and organization in the event of a large-scale public emergency (tornado, earthquake, flood, etc.).

5. Minimized Emissions

The organic route optimization, ridesharing opportunities, and parking solutions that smart traffic management systems offer equates to environmentally friendly, sustainable technology [5], [6]. Juniper Research predicts that continued smart traffic management systems could potentially cut 205 million metric tons of CO_2 emissions by 2027. It's clear that smart solutions can play a large role in reducing our carbon footprint [7], [8].

Elements of an intelligent traffic management system

Once upon a time, the swing of a traffic safety baton was enough to manage a busy intersection. But with more vehicles on the road, we need smarter systems.

An advanced traffic management system (TMS) is a context-aware solution that relies on real-time data from connected road infrastructure and predictive analytics to effectively coordinate traffic across city arteries. Such traffic management software, coupled with wireless urban connectivity, acts as a backbone for the implementation of an intelligent transportation management system.

ITS traffic systems focus specifically on improving the throughput and safety of urban roads through adaptive controls and analytics. But as the last over than 50 years of targeted effort have proven, managing traffic congestion isn't an easy task. From city layouts to unplanned protests, a lot of familiar and unpredictable factors make urban transportation planning an uphill battle.

As a concept, intelligent traffic systems were designed to provide traffic managers with real-time and predictive insights about traffic flow speeds and traffic congestion/incidents. In practice, however, the success of such projects strongly depends on a city's ability to place a virtual management layer on top of physical traffic infrastructure.

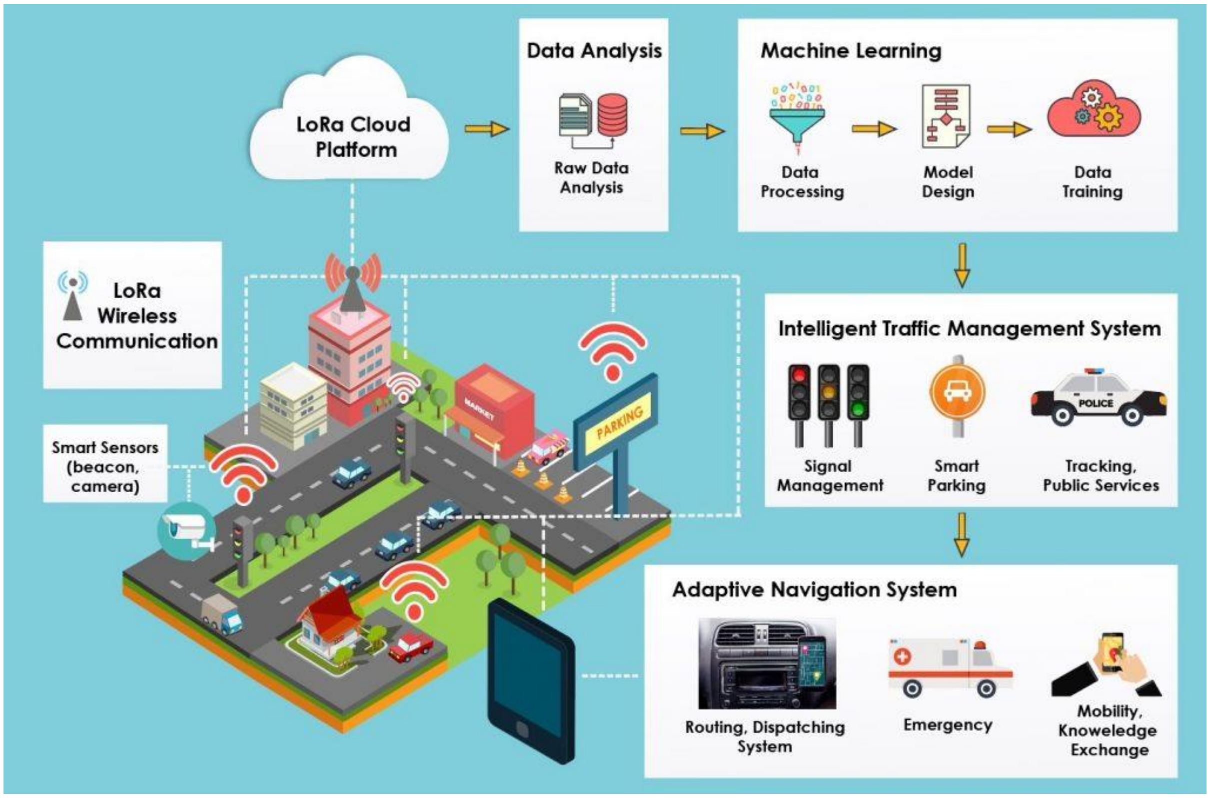

Fig. 2 Smart Town Traffic Management System Using LoRa and Machine Learning Mechanism [9]

Table 1 Main elements of an intelligent traffic system

Hardware	**software**
Lot road sensors including: ● RFID (radio frequency identification) or AIDC (automatic identification and data collection) tags ● Temperature sensors Air quality sensors	Cloud computing and edge processing capabilities: • Traffic data platform/data lake • Cloud-based traffic control systems • Geographic information systems (GIS) All supporting transportation apps
Connected CCTV cameras	Big data and predictive analytics
Connected traffic light systems	Al/ML: • Computer vision • Optical character recognition (OCR) • Reinforcement learning
Smart toll gates / electronic road pricing gantry systems	Location-based services
Edge devices - chips on edge nodes for faster data processing	

Implementing all of the above is a lot of work. But this progressive digitization also opens opportunities for startups and private companies to pitch their intelligent road traffic solutions to authorities.

Features global cities seek in traffic management systems

The need for transportation won't abate any time soon (unless we rewrite the fundamental laws of physics and invent teleportation). But even in that unlikely scenario, someone will have to transport and install the portals around town.

More realistically, the latest prognosis on population growth suggests that urban areas will become even denser and span into megacities with population counts of over than 20 million in the next 50 years. And all those people will want to have multimodal transportation options. McKinsey estimates that between now and 2040, approximately $2 trillion in transport infrastructure investments will be needed every year.

These investments will go into:

- Expansion and modernization of physical road infrastructure — road connectivity projects, electric charging infrastructure development, and maintenance.
- Public transportation sector decarbonization and improvement, paired with urban mobility as a service solution.
- Logistics and freight route improvements and better solutions for the booming last-mile delivery sector.
- Smart city traffic management solutions to battle congestion and pollution on the streets.

Here are the top intelligent traffic management capabilities urban planners will seek to acquire in the next decades.

1. Video traffic detection systems with edge processing capabilities

Traffic management is prone to the butterfly effect a phenomenon in chaotic systems (urban traffic) where a tiny change in conditions (one jaywalker) can cause a ripple effect across the entire system (major congestion across town).

Urban planners need more eyes around town to:

- Get real-time information on traffic conditions
- Detect and rapidly respond to incidents
- Proactively implement preventive measures

You can't catch all the butterflies (or force everyone to respect the traffic rules). But you can create an environment where one casual incident doesn't bring the entire traffic system to a standstill.

One viable way to accomplish the above is to implement connected video detection systems in critical areas around town. Then pair them with real-time traffic management systems.

Modern traffic incident management systems (TIMs) are powered by:

- Connected CCTV cameras with HD footage.
- Computer vision capabilities for image detection and recognition.
- Edge chips for local video processing, which reduces latency.
- Cloud connectivity and GPS-based communication to receive updates.

Such a setup allows you to:

- Detect incidents when they happen such as car crashes, road blockages, illegal parking, careless bike riders or pedestrians
- Transmit alerts to the intelligent traffic management system in seconds
- Program or automatically execute a sequence of follow-up actions such as dispatch emergency services, adjust traffic signal controls in the area, re-route public transport, and update nearby drivers

The Canadian startup Monovision tested a similar 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.

At Intellias, we also worked on an IoT-enabled traffic management solution for one of our clients. The pilot system we designed aggregates data from in-car sensors, road cameras, public traffic feeds, and user devices. After being processed locally on the edge device, this information is dispatched to the cloud system for further analysis. Then it is made available to road users and regional traffic management centers as real-time updates on traffic conditions.

Arguably, the best part about building out such edge data processing capabilities (paired with live video) is that you can reuse the collected data for other intelligent traffic analytics use cases. These include:

- **Multimodal traffic counts** to understand the most-used modalities in the area and their average cruising speeds
- **Road safety analytics** — using pattern detection, your systems can flag inappropriate driver and pedestrian behaviour in different areas
- **Programmatic alerting of response units** (police, ambulance, tow trucks/maintenance teams) after detecting an incident
- **Public transport detection** across the city to monitor on-time performance and implement adaptive controls (e.g. priority passage)
- **Origin–destinations traffic analysis** to develop better traffic management plans and update controls in line with the most common journeys

2. Advanced safety and pollution analytics

A smart traffic management system can do more than just flash the green light on time. It can also help to design greener and safer urban environments [10].

Such solutions can help urban planners reach bold carbon-neutral transportation targets faster by supplying them with real-time impact data such as:

- Air quality/pollution in the area
- CO_2 emissions per journey
- Traffic throughput and speeds during different weather conditions
- Road infrastructure damage post-hurricane, flooding, etc.
- Asset performance under severe conditions — heat waves or icing
- Dangerous driving behaviour such as harsh braking or excessive acceleration

The above data can be collected via sensors and pre-processed on edge devices. Then it can be dissipated to a cloud-based traffic center for further analysis. Based on the obtained intelligence, you can issue better policies and controls to improve the sustainability of transportation.

Copenhagen is already testing a similar solution as part of its mission to become the first CO_2-neutral European city by 2025. Local authorities have reprogrammed their traffic management system to prioritize public transport during rush hour. They are also testing dynamic traffic light programming to reduce the number of idle, fuming cars at intersections.

Copenhagen has not only cut pollution but also made travel faster — the average speed for cars increased by 4% and for buses by 9%. Ultimately, the implementation of high-performing and sustainable traffic management systems boils down to your ability to procure real-time traffic feeds and comb through them with advanced analytics. This is a technologically complex but feasible task.

3. Predictive traffic planning

At first sight, traffic systems may seem chaotic. But an experienced manager can notice repetitive patterns:

- Regular origin–destination trips
- Problematic intersections
- Narrow, congestion-prone lanes
- Overparked streets with low throughput
- And other corners of the city where navigation gets tough

An advanced traffic management system can help you locate those troublesome areas faster and predict where traffic congestion can occur under certain conditions, such as during a heavy snowfall, after a planned event, or due to a likely road accident.

Likewise, predictive traffic planning capabilities are essential to model traffic network performance during planned events such as scheduled construction work or major public events. That's the beauty of big data analytics in urban planning: You can estimate the capacity of your traffic network and model different response scenarios to day-to-day occurrences and unplanned events.

NoTraffic, for example, has brokered deals with a handful of cities in Arizona, Ohio, and California to install their smart traffic light systems. Using a combination of sensors, V2X connectivity, and computer vision, the NoTraffic device analyzes current road conditions. The controller can count and categorize all road users, calculate how many cars will arrive from the previous intersection, and determine how this will impact congestion at the next.

Then the traffic light dispatches data to a nearby edge device, where it's analyzed and translated into real-time action. But traffic light synchronization happens in the cloud, allowing the entire grid to react to real-time road conditions.

If you're interested in engaging in more long-term planning, you can pair collected traffic insights with GIS tools and mapping data to create 3D city models and simulate condition-based traffic flows. For example, how will new bridge construction impact traffic flows? You can learn more about such solutions from our case study.

4. Smart junction management

Road junctions are the biggest locus of pressure in cities because that's where congestion and accidents frequently happen. Once again, a combination of sensing technology and AI algorithms for transportation can help you make intersections safer [11]. To accomplish that, add the following controls to your intelligent traffic systems:

- **Turning movement counts on intersections**. This data can help you better interpret traffic flows and optimize signals. Plus, it can help you figure out when and why accidents occur and design alternative controls to minimize the temptation of rule-breaking.

- **Dynamic traffic light signal optimization**. With numbers in place, you can implement dynamic controls during rush hours and seasonal events, and you can enable users to program custom controls in line with city rules or safety planning decisions.

Case in point: Vivacity Labs helped Manchester city design and deploy an AI-controlled smart junction system. Using sensors and cameras, Manchester authorities can anonymously identify different types of road users and optimize traffic signals at junctions. They can choose to prioritize different transport modes — public transport, bikes, or pedestrians — as needed. Also, the obtained data can be reused to run traffic simulations on a range of junction layouts.

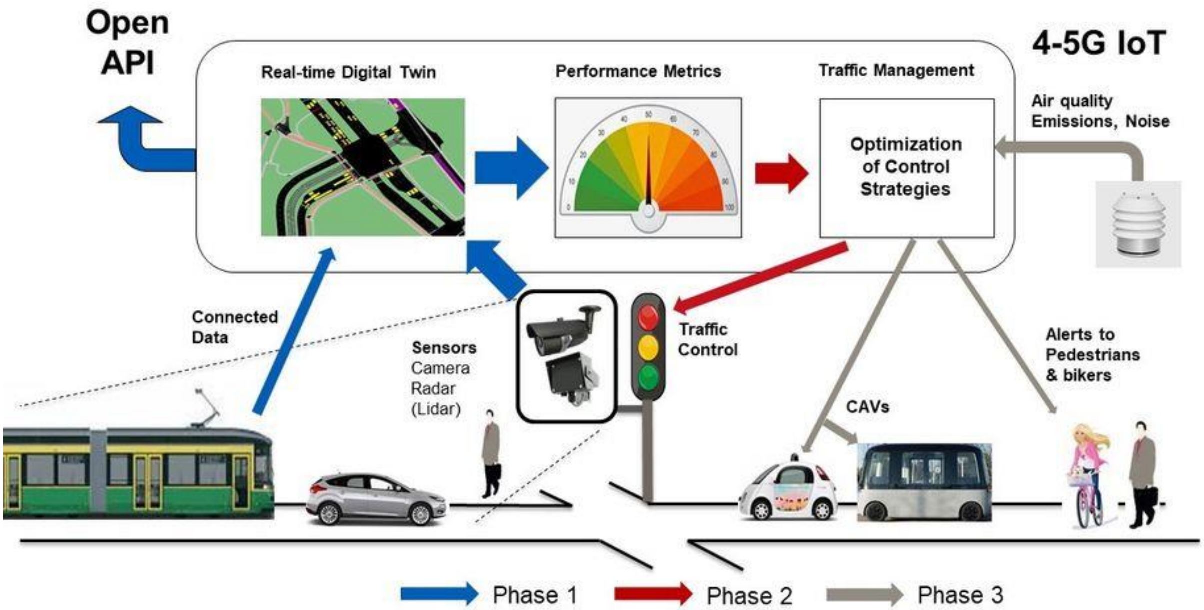

Fig. 3 An overview of the Smart Junction project [12]

5. Electronic Road pricing and toll collection

Congestion can be reduced by optimising traffic flow. However, if the number of single-occupancy vehicles on the road continues to increase, this method will fall short.

So far, urban planners have come up with two strategies for reducing car counts on the streets:

- Entice more people to public transport by designing a better MaaS transit experience
- Put a higher price tag on cruising busy streets in a private car

This is known as electronic road pricing (ERP). It's a popular second-level method for persuading consumers to choose public transport over private cars.

To identify and bill cars entering a certain city area, an ERP system uses road infrastructure (cameras, gates, gantry systems) and in-car hardware (separate devices or onboard computers).

Advanced models are linked to a sophisticated traffic management system, which generates dynamic pricing for different regions based on the time of day, vehicle size, traffic congestion, and other criteria.

Singapore launched its ERP scheme back in the early 2010s. The local ERP consists of city-wide gantries on roadways heading to Singapore's Central Area as well as other important arteries. Gantries use sensors and cameras to capture the licence plate numbers of all entering vehicles and send invoices to car-installed equipment. Drivers can link a card to the device to be automatically billed.

ERP controls are dynamic, and pricing is designed to discourage road use during peak hours. Using this system, Singapore can keep traffic moving at optimal speeds of 20 to 30 km/h on arterial roads and 45 to 65 km/h on motorways.

Since 2015, Hong Kong has been conducting ERP pilots in central and adjacent areas. Many European cities are the same way. Such projects first raise public concern. However, the benefits of reduced travel time, less congestion, and lower pollution compel authorities to act.

Table 2 Traffic effects of different congestion charging schemes [13]

	London	Singapore	Stockholm	Milan	Gothenburg	Rome
Traffic volume	-16% (2006) -30% charge-able vehicles, +25% busses, +15% taxis, +49% bicycle -21% (2002-2008)	-44% after ALS -10%-15% after ERP compared to ALS - 20%-30% for other extensions of the system	-20% across the cordon	-34% (-49% in user of heavy polluting vehicles)	-10% across cordon, -2.5% vehicle-km in Gothenburg	-20% over cordon +15% motor-cycles
Travel times	30% delays	speed criteria charge levels between 20-30 kph and 45-65 kph	-33% in delays	-17% in congestion +7% bus speed, +4.7% tram speed	-10-20% reduction median travel time on corridors	+4% in speeds +5% speeds PT
Public transit ridership	More than 18%	n.a.	+5%	n.a.	+6%	+5%

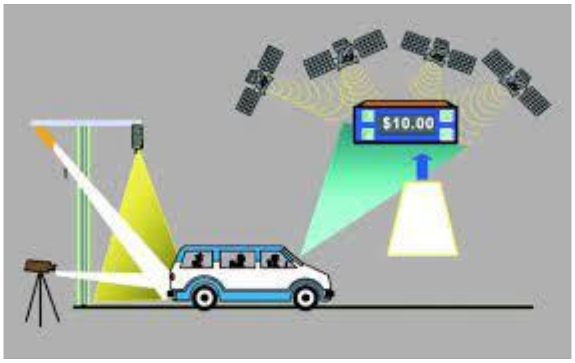

Fig. 4 Congestion Charging [14]

6. Parking areas

Municipalities may make better use of public space by making parking zones more efficient, and this field is gradually incorporating cutting-edge technologies. Simply avoid driving around the block looking for an odd open slot if you know exactly where to go to drop off your car safely. When the network of devices connects significant data that is subsequently processed by AI, local authorities will be able to recognise trends and use them in the construction of a transit system. Take, for example, automatic valet parking. Stanley Robotics initially used it at the Lyon-Saint Exupéry Airport in France in 2018. The method adds 50% more parking places while reducing CO_2 emissions [15], [16].

If you are flying from this airport, you can reserve a parking space on their website. When you get there, you put your car in a box and wait for the robotic valet to take it and park it efficiently. However, if you include a system of ramps, shelves, slabs, and lifts, robot-based automation can do even more. Connect this system to a computer, instruct AI to orchestrate it, and you will benefit from more room and happy car drivers who can book parking spaces and get their automobiles on the fly by phoning or using a mobile app.

In spite of a parking area's level of robotization, one sort of IoT device can significantly increase its efficiency: smart sensors. These wireless sensors are often installed in the ground. They have access to real-time parking lot surveillance and notify vehicles when spaces become available. Sensor choices include smart cameras and overhead radars/lidars. The former is less expensive but less accurate, whereas the latter is far more accurate but more expensive.

PayBySky, established in the United Kingdom, takes a fresh perspective to parking, making the procedure even more dynamic. They integrate satellite vehicle locating algorithms with a database of parking places, which includes information such as rules, times, and rates.

Skymeter, the gadget that makes your car visible to satellites and other linked devices, is plugged into the OBD-II port. Once you've parked, the system will pay for you, and you'll be charged quarterly. And if you choose to park in an illegal or inconvenient location, the system will notify you.

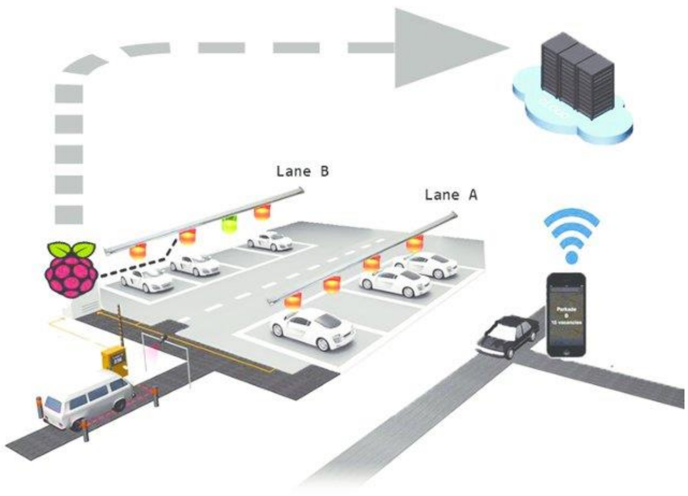

Fig. 5 Smart Parking System [17]

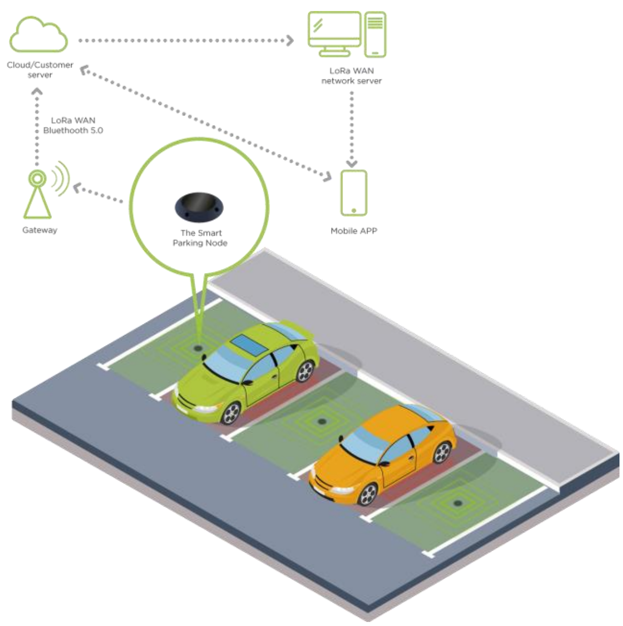

Fig. 6 Smart Parking Solution with Cloud, Mobile App and Web [18]

7. Traffic lights

Traffic light systems play an important part in municipal infrastructure. Countries around the world have long attempted to make them more dependable and controllable in order to prevent casualties and generally improve the quality of life for their populations. Here is where IoT and AI working together can really make a difference [14].

In 2018, a collaboration between the city of Dallas and Ericsson led in the real-time adjustment of traffic signals at hundreds of junctions. They also employed this technology to prioritise buses on the road by using tailored greenlight timing.

The city of Vienna has indicated the installation of a smart traffic light system in 2019. It was preceded by a testing period during which engineers from Graz University of Technology's Institute of Computer Graphics and Vision educated the AI. The system consists of 200 lights outfitted with small cameras that employ computer vision, an AI method, to recognise a pedestrian's desire to cross the street. When the intent is determined, the light turns green, giving the pedestrian priority. Furthermore, these lights have their own fault monitoring system. If anything goes wrong, it immediately reports the situation. This helps to decrease and, in some cases, avert those moments of street pandemonium that everyone despises.

8. Personal devices

Mobile device connectivity has grown dramatically during the last decade. Municipalities can analyse traffic patterns around the city using tracking devices to establish efficient public passenger flow and minimise bottlenecks that could otherwise contribute to traffic delays and accidents.

Cities can utilise network-based localization algorithms that receive radio signals from nearby base stations to find connected mobile device users. A paper published in the EURASIP Journal on Wireless Communications and Networking in 2019 suggested an intriguing mobile device tracking algorithm: antenna, map, and timing information-based tracking (AMT). This method is particularly well suited for automated traffic monitoring because it does not necessitate collaboration from mobile device users or server upgrades. AMT tracks mobile devices by utilising "enriched open map data, a mode of transportation estimator, and advanced tracking algorithms."

Denmark, one of the world pioneers in Smart City Initiatives, has already begun to use a range of mobile tracking technology. Copenhagen Connecting illustrates how this might aid in traffic optimisation and congestion reduction [19].

The Portland City Council unanimously approved an agreement among the Portland Bureau of Transportation, TriMet, and the regional agency Metro to fund testing of Replica, a programme developed by Alphabet subsidiary Sidewalk Labs, in 2018. This application creates a digital twin of the Portland metro area by combining precise location data from smartphones with data from the United States Census Bureau. This is a terrific method for Portland's transportation planners to "dramatically improve their ability to understand and monitor how people use streets, sidewalks, and transit."

9. Autonomous vehicle systems

Driverless automobiles are making inroads into our cities. They bring numerous benefits, such as reduced accidents and congestion, but they also introduce new obstacles.

According to a paper published in Transport Policy in 2019, driverless cars may possibly create congestion if they continue to circle about to avoid paying expensive parking costs in large cities [20], [21].

Self-driving cars must be managed. In an interview at the CES 2020 in Las Vegas, Siemens Mobility CEO Marcus Welz stated, "Frankly, thousands of self-driving vehicles are still thousands of vehicles in a traffic jam whether there's a human driver or not."

What happens if people without licences, who have never owned a car and have no plans to do so, increasingly buy self-driving cars as they become more affordable? The burden on the highways will reach an all-time high, and our cities will be paralysed by traffic.

Autonomous vehicles are IoT devices that work with the larger traffic management system. This opens up the possibility of developing a smart management system for such cars. Municipalities should consider it now, before driverless cars take over the streets.

The public and private sectors should collaborate in two directions: The intelligent application of vehicle-to-infrastructure (V2I) technologies, which include road sensors and connected road signs that communicate with autonomous vehicles. Local and national governments should decide whether dedicated short-range communications (DSRC) or cellular vehicle-to-everything (C-V2X) systems are preferable in each circumstance.

Creating a linked network of static and mobile sensors and mobile apps to encourage shared autonomous mobility (SAM). It's worth noting that experts have been working on carpooling with autonomous vehicles for a few years already.

A study led by Professor Daniela Rus of MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) was released in 2016. The researchers created an algorithm that reroutes cars in real-time in response to incoming requests and sends idle cars to locations where demand is high [22], [23].

According to Professor Rus, "the system is particularly suited to autonomous cars, because it can continuously reroute vehicles based on real-time requests."

10. Traffic Intelligence from Video: Patented Algorithms for Real-Time Detection

TrafficVision software transforms any traffic monitoring camera into an intelligent sensor for AID and real-time data collection. Traffic Vision, designed exclusively for Intelligent Transportation Systems (ITS), watches digitally encoded video feeds from highway traffic cameras to spot incidents quickly and continuously collect real-time traffic data.

Traffic Vision, which uses current camera infrastructure, assists traffic management in making proactive decisions based on immediate, visually verifiable incident alerts, delivering more information about what is happening on highways, bridges, and tunnels.

Traffic Vision assists organisations in making the most of their ITS investment by utilising both existing and new video assets. Traffic Vision assists traffic management in ensuring safer and more efficient travel for the public by giving the information required to decrease the impact of incidents and recurring congestion on roadways [24], [25].

Conclusion

By definition, traffic systems are chaotic. The more information we have about the forces that shape those flows, from weather to pedestrians, the better we can predict and manage traffic circumstances.

A single technology, however, is insufficient to provide a thorough understanding of a system as complicated as a rising city. Intelligent transportation management systems, in fact, necessitate a network of connectivity, hardware, and software technologies. And, as we all know, an ecosystem is always looking for new partners.

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