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Intelligent infrastructure: Automatic number plate recognition for smart cities

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Intelligent infrastructure: Automatic number plate recognition for smart cities

BENJAMIN WATSON
3M UK&I

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3.1 INTRODUCTION

This chapter describes how optoelectronics can be used for the purpose of vehicle identification, contributing to the success of large intelligent infrastructure projects. It is illustrated with a series of case study examples for road user charging, access control, and critical infrastructure.

With the investment in smart city transportation set to yield an economic opportunity of USD 800 billion globally (Busch, 2014), it makes sense to first consider what it is that actually makes these cities “smart.”

The concept of “smart” intelligent infrastructure is not new; the basic building blocks of the technology have been available for some time, but as with all new developments, full acceptance and use involves evolution, will be described in this chapter. Our present treatment of intelligent infrastructure places a strong focus on electronic vehicle identification (EVI) through automatic number plate recognition (ANPR) and utilizes the characteristics of intelligent infrastructure required to monitor, learn, adapt, predict, protect, and self-repair (Paxman 2014).

These core traits closely align to the characteristics of intelligent infrastructure as a framework for the classification of technologies that self-monitor, while controlling their own settings. This is done according to the system input instructions, or is adaptive, responding to what the system has
detected and learnt from the aggregation of large data sets. The adoption of learning algorithms can predict the required capacity, optimize the cost and performance, and mitigate security risks.

The widespread realization of this grand vision has been slow, partly due to the inherent fragmentation across stakeholder groups, the diversity of commercial interests, and the physical size of these systems. Fortunately, however, the landscape is now changing and we are set to see an accelerated progression towards all things being connected and interoperable. This is becoming particularly important with the introduction of “autonomous” vehicles set to disrupt the current mobility platforms. In reality, these vehicles are likely, in future, to be not only fully connected to road and highway infrastructure, but also to each other, ensuring far better safety at high speeds and traffic densities, but then rendering the “autonomous” label less applicable.

These systems increasingly rely on advanced computational intelligence, open communications protocols, and shared standards that underpin the future of these technologies. Even current infrastructure to control traffic has proven to reduce journey times, ease congestion while improving safety, security, and reliability of the transport-related services shown in Figure 3.2, a process likely to become far more effective and efficient when vehicles are fully controlled by onboard sensors and driving-control software.

### 3.2 AUTOMATIC LICENSE PLATE RECOGNITION/ELECTRONIC VEHICLE IDENTIFICATION

Infrared cameras are now a widely adopted and rapidly growing application of optoelectronics used to monitor the movement of people and goods across the road network. Such cameras are frequently located on gantries or bridges above highways. These same systems can also be deployed on post structures and buildings at the side of highways or other suitable roadside locations.

This camera technology is particularly useful for law enforcement, especially if the vehicles can be classified according to type; it is even more useful if they can be individually recognized, for example, by their vehicle type, or, more exactly, from their unique number (registration) plate.

Electronic vehicle identification (EVI) through automatic license plate recognition (ALPR) includes the process of detecting a vehicle as it enters the camera’s field of view, recognizing the license plate at high speed, and uniquely identifying the vehicle. This can be applied to many applications such as road user charging, law enforcement, and the tracking of vehicles across the transport network (see Figure 3.2) for earlier examples.

The captured image is processed in real time and passed for optical character recognition, analysis, and post processing (see Figure 3.3). The initial number plate image can be detected
and normalized with various techniques, such as sharpening and improved dynamic range, to extract more detail. These normalized images can then be further subjected to noise removal and other image processing techniques, to obtain a "clean" image suitable for character segmentation, syntax checking, and character recognition. All of this happens within a fraction of a second (approximately 20 ms), taking advantage of either the powerful embedded internal processing capabilities of modern day ALPR camera technologies or using post-processing centralized systems.

For each detected vehicle, a "read event" is typically generated, which can then be compiled into a data package suitable for feeding to a software aggregator. This aggregator, equipped with analytical software, turns the data into meaningful intelligence, customized reports, or graphical representations (see Figure 3.4). This intelligence can be used to inform highways support and law enforcement activities. For example, vehicle license plate data can be used for identifying and tracking vehicles of interest in speeding enforcement, road user charging, intelligent transportation systems (ITS), vehicle recovery, campus security, critical infrastructure protection, and other applications.
enforcement agencies. Alternatively, the read event may be discarded if it is not deemed to be of interest, the decision being made (according to a series of predefined rules) within the license plate reading camera, thanks to onboard processing capabilities.

Partnering EVI technology with powerful enterprise software solutions turns the ANPR data into valuable intelligence for decision-makers. These “enterprise” software platforms enable sophisticated data aggregation, data mining, and analytics. The vehicle read event can be included as part of a time-stamped data package, with time-stamped consecutive images. These images can be taken either at one point or at geographically separated locations, which allows for measurement of velocity of an individual vehicle and/or the average traffic flow rate for precise temporal information (see Figure 3.4). Furthermore, embedded ALPR cameras can be independently time-locked using GPS time as a primary reference, with high-stability, crystal-oscillator-driven real-time clock as the secondary reference. These systems may be able to detect vehicles traveling up to 220 km/h.

3.3 DATA PROTECTION

Whenever number plate data are routinely captured, it may raise cause, for invasion of privacy concerns. For this reason, suppliers of this technology must adopt robust data privacy approaches and should be encouraged to choose the most stringent criteria for data privacy, data capture, processing, and retention.
Stored data are often encrypted such that only authorized parties are able to decrypt the data. Thus, if an unauthorized person gains access to the data, they will be unable to decipher it.

Communication between cameras and a typical back office may be encrypted to protect sensitive communications from eavesdroppers. Cryptographic techniques can be used to provide strong authentication, thus lending a high degree of mutual certainty that the communicating peers are who they say they are and have the necessary permission for the operation they are attempting.

In the event of unauthorized attempts to access the data, the system can rely on integrated firewalls with default rules that block off any port not associated with authorized and needed services.

With the appropriate handling of data, the “feed” from these systems can also be split to provide key benefits that enable ANPR technology to be used simultaneously for both law enforcement and useful civilian applications, to ease congestion while improving security and safety for the general public.

These combined applications offer a convenient way of spreading the cost of a system between several funding bodies, for example, a local authority and other organizations that may wish to share the ANPR data. The technology is designed to be extensible, easing its evolution to provide additional services if required as part of a smart cities infrastructure. Again, data privacy laws and best practice will apply.

### 3.4 CAMERA ARCHITECTURE

The embedded camera technology (see Figure 3.5) can include two cameras within a single enclosure. One provides contextual images for color overview, while the other is dedicated to ANPR for optimum performance. Images and video can be streamed via motion JPEG over hypertext transfer protocol, from either camera or the more commonly used H264 advanced video coding. These video compression formats enable the streaming of video content that is increasingly requested as part of these systems. Although not optimized for closed-circuit television streaming, the color overview camera may provide some aspects of this functionality for viewing congestion, accidents, and other incidents.

### 3.5 EMBEDDED ALPR CAMERA

In terms of communications, the latest generation of ALPR equipment can support Ethernet 3/3.5G/4G, GPRS, cloud-based technology, where no fixed optical fiber or wire links are available or accessible.

Remote communications capability encourages the wider use of mobile applications and may reduce infrastructure and installation costs. Future providers of intelligent machine vision and associated hardware platforms should also be encouraged to consider their role within wider mesh networks, connecting smart cities with self-healing, self-configuring, and non-line-of-sight communication.

In the past, ANPR systems have been sensitive to environmental conditions; however, the use of improved camera housings, often nitrogen purged and usually sealed to IP67, has overcome many of these problems and extended the operating temperature range between −40°C and +60°C. It is therefore only severe weather conditions, for example, where there is severe loss of atmospheric visibility, poorly optimized licence plate materials, or plate damage that will normally cause loss or deterioration of service.

Figure 3.5 3M P392+ Embedded ALPR Camera.
Figure 3.6 shows how ANPR systems can be integrated as part of a “total lane” solution with various third party devices such as dedicated short range communication/radio frequency identification (DSRC/RFID) readers, weigh-in motion (WiM) monitors, variable message signs (VMS), and inductive loop detectors. In the figure, the ANPR system is incorporated in the tolling and parking or ticketing system.

The ANPR system can track vehicles through complicated road networks and over long distances, with a combination of both fixed locations and mobile camera technology. This can be particularly useful as the system provides interoperability across command and control centers. This is important to flag vehicles of interest and apply appropriate rules for the vehicle passage.

3.6 INTELLIGENT TRANSPORT MATERIALS

While the remainder of this chapter focuses on optoelectronics case studies, it is also important for us to recognize the rapidly emerging demand for vehicles to also identify infrastructure by themselves.

This shift in focus is set to significantly accelerate through the introduction of autonomous and connected vehicles. It is important to transfer information from the large variety of other optical devices such as light detection and ranging, light curtains, parking sensors, infrared, and time of flight imaging techniques. These have been described in earlier sections; on-vehicle uses will also be discussed in Chapter G 2.1 on “Optoelectronics for Automobiles, Vans, and Trucks.”

As of now, there has been very little focus on improving infrastructure for the interaction between vehicles and roadside materials. This is particularly the case when compared to the significant investment made by automotive manufacturers for the development of these connected vehicles—the autonomous vehicle market is currently estimated to reach USD 42 billion by 2025 and forecasted to reach USD 77 billion by 2035.

Many companies, including 3M, are also working to reinvent the road surface and roadside materials, and their possible modes of interaction with future autonomous vehicles. These new intelligent transport materials, referred to as ITM, will support wayfinding, vehicle security, and safety to optimize journeys with greater situational awareness. Many of these will be passive optical materials, but the use of active materials may also be viable in future. It is reasonable to trust that infrastructure will be more situationally aware, sharing information, before the
vehicle approaches, on potential hazards such as level crossings and hidden junctions.

These materials will be part of our future connected infrastructure. The optoelectronics domain must not only consider how to develop the sensing technologies but also the materials being sensed that might include, for example, road markings and road signs with active handshaking between vehicles and transport infrastructure.

Toyota, for example, highlights the importance of cooperative ITS to prevent traffic accidents through supported driving. The infrastructure will bring situational awareness to road users that cannot detect them even using their vehicles’ own sensors. Figures 3.7 and 3.8 highlight the important role that infrastructure will play on road safety (see Figure 3.7 and 3.8).

According to the World Health Organization, the total number of road traffic accidents in 2013 resulted in 1.25 million deaths, globally. This can be calculated as 1 death every 25s. EVI technology is one part of the solution and ITM will follow.

3.7 INTELLIGENT INFRASTRUCTURE: ANPR FOR SMART CITIES

3.7.1 Case study examples

3.7.1.1 PUBLIC SAFETY AND SECURITY

We shall now discuss the use of vehicle identification for safety and security, possibly overlapping a little on the earlier discussions on this in the chapter that concentrates on this aspect.

Camera-based EVI-JTMS (Journey Time Measurement Systems) solutions directly contribute to safer cities through improved security, reduced road traffic accidents, and vehicle-related criminal activity. These EVI solutions provide invaluable data that may also protect the law enforcement agencies and municipal support teams with intelligence from licence plate reading cameras, prior to any intervention into potentially dangerous situations.

The intelligence generated by these optoelectronic EVI systems may also be distributed across wide networks of geographically dispersed teams to drive frontline intelligence from what may be separate data sources, such as known stolen vehicles, road closures, damages to a road network, or a public event that needs to be considered for operatives to be situationally aware.

Towards this goal of interoperable systems for public safety and security, EVI technology, such as smart ALPR cameras can distribute their data to multiple partners, to provide multiple services from the same camera network. This multimodal approach has been seen to both monitor vehicles that may have been involved in criminality in and around a city, and monitor traffic flow to help local authorities manage and optimize the flow of road users in and around the city, reducing the upfront costs of the EVI system. Furthermore, this approach significantly
Intelligent infrastructure reduces the environmental impact with a reduced number of installations and disruption to current infrastructure.

ANPR technology is widely used for security purposes to monitor vehicles of interest and for the early detection of vehicle-related crime or more serious security threats. These ANPR cameras will not only capture and read the license plates of regular cars and commercial vehicles, but they will also capture and read the license plates of motorbikes and mopeds, where the system has been configured to do so.

License plate information can be processed locally or distributed to a central application, where comparisons are made against known vehicles of special interest. If a positive comparison is made, the system owner will be notified and the system may be used to track the vehicle. These systems provide law enforcement agencies, with time and date synchronization for each of the detected vehicles that can be compared with a police national database, for example.

Integrated embedded camera systems are particularly useful to meet these challenges, often selected to limit the impact on the cityscape and neighboring infrastructure, with lower maintenance costs and “onboard” processing, with wireless capabilities. These embedded smart ANPR solutions offer remote configuration, real-time processing, and greater redundancy support when compared to distributed cameras driven and controlled by a separate processor.

With a network of embedded cameras, the downtime lost due to hardware, software failure, or even vandalism is limited to the individual camera, without impacting the entire network. Data buffering during times of communication outage can be supported to overcome poor connectivity, for a limited period of time, between the outpost ALPR camera and the in-station aggregator.

The UK National Traffic Information Service is one example of a JTMS system, with a deployment of over 4000 ANPR cameras in their national passive target flow measurement system, for travel-time monitoring.

A typical ANPR-based JTMS system is triggered when any vehicle passes the field of view. The camera then reads the number plate and sends the data
via an Ethernet connection to the back office JTMS software. The data that are received by the JTMS software can be compared against all of the other data received and a journey time can be created for each vehicle. These applications enable traffic management teams to monitor the congestion levels and vehicle flow within a city to enact early traffic control measures if congestion starts to build.

In some parts of the world, ANPR technology has been shown to offer in excess of 98% detection accuracy, with a 95% read rate for detected vehicles. The technology can function in most weather conditions unless the license plate itself is obscured. It should be made clear that these performance indicators can vary significantly from country to country due to the differences in license plate design, their composition, and maintenance.

3.7.1.2 RING OF STEEL

ALPR has been globally adopted, by many law enforcement agencies, to deal with vehicle-related crimes. These integrated systems are often referred to as a “ring of steel” to protect borders, counties, and cities monitoring movements of the vehicles as they enter in and out of the EVI perimeter. The most significant and widely known “ring of steel” is the EVI perimeter surrounding the city of London, comprising over 1500 surveillance cameras and ANPR systems that reportedly scanned 75 million vehicles in the first 3 years, as referenced in Haines (2009): “The role of automatic number plate recognition surveillance within policing and public reassurance.”

Law enforcement agencies rely on these systems, where a typical deployment may include 30+ cameras located on major routes in and out of the network. The system works by reading the number plates of all the passing vehicles and comparing them with a site-specific, regional, or police national computer database. Vehicles of interest are monitored as they pass the cameras, enabling their whereabouts to be checked and monitored for vehicles of interest. The system can be configured to discard vehicles that do not match predefined criteria.

The primary purpose of these systems is to provide ANPR capability in specific locations to obtain real-time data and information about vehicle movements throughout the city at strategic locations on arterial vehicle routes. These rings of steel can be used to identify matches to police databases to support a pro-active policing response to suspicious vehicles and to view and monitor events as they occur. (Figure 3.3 shows a typical mobile and fixed system.) EVI systems are highly scalable and open to integration with other sensing technologies due to the advances in the onboard processing capability of these “smart” embedded cameras. For example, ANPR/ALPR data can be combined with other data such as vehicle weight, to ensure safe loading as vehicles are weighed in motion, WiM.

The Dutch Ministry of Transport, the Rijkswaterstaat, was concerned about excessive damage to main roads caused by overweight trucks. In view of this, the Rijkswaterstaat awarded the PAT Company in Germany a contract to install seven weight-enforcement systems on the motorway network.

These sites capture images of overweight vehicles detected by WiM sensors. Each monitoring point has four lanes monitored by ANPR cameras and color overview cameras.

When a vehicle is detected by the WiM system and is calculated to be overweight, a set of text and image data on that vehicle can be sent from the processor to the WiM processor and forwarded to a main control office.

3.7.1.3 ROAD USER CHARGING AND JTMS

The adoption of ALPR for traffic flow optimization remains an important application for this technology, utilized by local authorities in large city centers to devise methods of reducing peak-time traffic density in the most critical areas. To help ease this problem, ALPR systems can be installed to monitor and control traffic flow, monitor the overall use of the road network, and improve safety.

Again, JTMS systems automatically read vehicle license plates at two or more points on the road network. The license plate data captured at the roadside can then be transmitted to a central computer system where the data from different sites are matched to calculate the exact travel times between pairs of sites.

Calculations of journey times across large networks can be performed at specific intervals, ranging upward from a fraction of a minute and generating accurate and detailed data of traffic conditions across the road network in near real time. This information enables traffic managers to study performance and trends over a long period of time and support the decision to spend budget
London was the world’s first major city to deploy a congestion charging scheme using ALPR in this way, thereby providing an enforcement infrastructure for the Central London Congestion Charging Scheme. Over 500 cameras were deployed without obstructing the flow of transport in and around the city and without the need for physical tollbooths, barriers, intrusive loop-based technology or supplementary RFID tags.

Embedded ALPR can provide video-based free flow tolling solutions as part of a flexible toll system without the need for physical tickets or passes. The embedded ALPR cameras read the vehicle registration as vehicles enter, drive within or exit the congestion charging zone to be checked against the Transport for London database. The network of camera sites monitor every entrance and exit to the congestion charging zone along the boundary road, and monitor journeys made within the charging zone.

Each camera site consists of both a color camera and a monochrome camera for each lane of traffic being monitored. The cameras provide digital images of the whole vehicle to the ANPR software, which then reads and records each number plate.

Before the congestion charging zone was introduced, London suffered the worst traffic congestion in the UK and among the worst in Europe, with drivers in central London spending 50% of their travel time in queues. It was estimated that the economic loss caused by congestion in London was in the order of USD 6 million every week (see Royal Geographic Society white paper). Table 3.1 shows some of the benefits achieved by the London Congestion Charging Programme.

Alternative examples of road user charging include the London Low Emission Zone (LEZ): The UK’s National Traffic Control Centre (NTCC) and the Alpine and Cross City Tunnels (CCT).

While these serve as good examples to discuss road user charging, there are of course many more deployments worldwide. These include the E470 toll highway in Denver, Colorado and the Elizabeth River Crossing in Virginia, USA (see Figure 3.9).

3.7.1.4 LOW EMISSION ZONE

The LEZ is an extension of the London congestion charging scheme that leverages ALPR as a sustainable technology, reducing emissions through optimized traffic flow, reduced congestion, and reduced journey times. Embedded ANPR technology has a low impact on the streetscape, due to their independence from external hardware and processors that may require separate roadside cabinets and associated infrastructure. These centralized systems can result in greater reconstruction of existing road surfaces and pedestrianized areas during their installation.

The aim of the Transport for London (TfL), LEZ scheme, was to improve air quality in the city by deterring the most polluting vehicles

Table 3.1 Some of the benefits achieved from the London congestion charging programme, from the consultation impact assessment (November 2012)

<table>
<thead>
<tr>
<th>Benefit Description</th>
<th>Details</th>
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<tr>
<td>Vehicle kilometers fell by almost 19% between 2000 and 2009.</td>
<td></td>
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<tr>
<td>TfL reported £136.8 m net income from congestion charging in the financial year 2011/12.</td>
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<tr>
<td>30% reduction in traffic delays within the first 12 months, within the charging zone.</td>
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<tr>
<td>Traffic levels showed a reduction of 18% in traffic entering the zone during the first year.</td>
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<tr>
<td>29,000 additional bus passengers entered the zone during morning peak periods.</td>
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<tr>
<td>Congestion charging contributes £50 m to London’s economy, mainly through quicker and more reliable journeys for road and bus users.</td>
<td></td>
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<tr>
<td>There remains no evidence of any significant adverse traffic impacts from the charge.</td>
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<tr>
<td>The number of penalty charges issued average 165,000 per month (110,000 charge-zone payments per day).</td>
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<tr>
<td>65,000 fewer car trips into or through the charging zone each day.</td>
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<tr>
<td>Taxi, bus, and coach movements have increased by 20%.</td>
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</table>
The vehicles affected by the LEZ are older diesel-engine lorries, buses, coaches, large vans, minibuses, and other heavy vehicles, derived from lorries and vans. Cars and motorcycles are not affected by the scheme.

The LEZ scheme has over 300 cameras and is applied to all roads and some motorways across the majority of the Greater London area, which is substantially larger than the congestion charging zone, which, although it has been expanded, is still confined to a relatively small area in the city center.

As with the congestion scheme, no barriers or tollbooths are required for the LEZ system; fixed ANPR cameras read the vehicle registration number plate as vehicles drive within the zone. Vehicle numbers are then checked against a database of vehicles (a) which have been tested against the LEZ emissions standards, or (b) exempt or registered for a 100% discount, or (c) for which LEZ charge has been paid.

3.7.1.5 NATIONAL TRAFFIC CONTROL CENTRE

The NTCC project is one of the largest known JTMS systems to reduce the effects of congestion on England’s motorways and major trunk roads by informing motorists about incidents and congestion.

The prime function of the NTCC project is to collect, process, and distribute strategic (wide area) traffic information, including the setting of roadside VMS and other dissemination media, using pre-agreed protocols, to assist travelers in planning their journeys.

These systems also support the UK Highways Agency and its operational partners in optimizing the use, management, and operation of the road network.

3.7.1.6 ALPINE AND CROSS CITY TUNNELS

From its opening around April 2005, Sydney’s CCT project provided a number of significant benefits to the city, including improved traffic flow, enhanced public transport, dedicated cycle ways, and improved pedestrian amenity. The CCT is a fully operational “electronic” road with no cash booths or barriers, so vehicles can travel through the tunnel without slowing down to pay.

Tolls will be collected either by detecting electronic tags on the front windscreen of vehicles or by automatic identification of the vehicles’ number plates. Windscreen tags transmit a signal to the tolling equipment as the vehicle passes one of the tolling points in the tunnel. This registers the vehicle’s use of the tunnel so that the appropriate toll can be deducted from the user’s prepaid account. Motorists without tags will pay tolls by registering the number plates of their vehicles. Images of vehicle number plates are also captured, read, and matched against registered plates. Motorists without tags will be charged the toll plus an administration fee.

A video enforcement system provides proof of passage of a vehicle at a specific tolling site. The system relies on embedded ALPR recognition processors and infrared illumination, with rear scene images in full color, when deployed with ambient light sources or directional floods for 24h color...
imaging. This system was designed to achieve high-grade ALPR results and images without distracting drivers (Figure 3.10).

3.7.1.7 CRITICAL INFRASTRUCTURE AND ACCESS CONTROL

ANPR technology is widely used to monitor and safeguard airports, gas stations, supermarket car parks, and motorway service stations. Supermarket car parks are notoriously difficult to monitor, as well as being a target for criminal activity, particularly when the supermarket is closed.

It is widely recognized that barrier-controlled systems can lead to long queues and delays on entrances and exits of car parks, which in turn deters customers from visiting. Parking attendants are not always able to effectively monitor very large-scale car parks and sometimes genuine customers cannot find a parking space. Petrol (gas) station “drive-offs” (leaving without paying for fuel) cost supermarkets and motorway service stations millions of Euros per year, with theft, fraud, and fuel smuggling, costing European governments up to €1.3 billion every year (Kennedy 2013).

The theft of fuel from supermarkets and highway service stations is an increasing problem. Many believe that the most effective way to manage this problem is through the use of ANPR systems that capture the registration details of vehicles that drive off without paying, which can then be passed to the police.

These smart cameras are also very useful for car parks of supermarkets and shopping malls, where free parking is usually allowed for genuine users of the facility. Because ANPR cameras are able to read the number plates of every vehicle as they enter and exit car parks, adding a date and a time stamp. These systems can calculate how long each vehicle has spent in the car park (see Figure 3.11). The owners of any vehicles which have not honored the “free length of stay” policy can then be sent a parking charge notice. ANPR cameras can eliminate the need for any barrier entry systems or ticket validation systems. This, in turn, vastly reduces queuing times at the entry and exit of the car park.

In this context, ANPR systems allow genuine customers to find parking spaces more easily by stopping people from using the car park for other purposes, such as while they are at work for long periods of time.

Meadowhall in Sheffield, UK is an example of a large commercial shopping center, which covers 1.5 million square ft of floor space, contains over 280 shops and caters for 24 million visitors a year, with 6 car parks holding 12,000 free parking spaces.

The Meadowhall installation has the world’s first fully integrated digital ANPR cameras that incorporate both the camera and the recognizer/processor in a single sealed enclosure. This ANPR system supplies data on traffic flow into the center’s existing security and surveillance system, giving information on vehicles entering and exiting car parks.

The enterprise software, or in-station, is an aggregator for ANPR data that also allows car park operators and management to view the times at which most customers visit the center, which of their car parks are most used, and how long customers typically spend in the center, as well as controlling access to vehicles entering and exiting their service entrances.
3.8 CONCLUSIONS

In this chapter, we have shown the growing importance of vision systems for law enforcement and the control of vehicular traffic in a wide variety of scenarios. The economic value is already evident, and the use of such systems is expanding rapidly to drive greater peace, safety, and security as part of the smart city intelligent infrastructure.

We can see that the increased focus on autonomous vehicles will also become a more central consideration for these smart cities that will drive the development of both ITS cooperative systems and ITM.

There are many more applications that could be discussed, and many more to come, particularly as these intelligent optical systems are well placed to drive the future Internet of Things megatrends, intelligent infrastructure, machine to machine, and more.

While improved traffic flow is the main impact of these solutions, advanced border security and key route surveillance help public and private sector agencies all over the world to manage complex transportation infrastructures more efficiently and to ensure smoother and safer travel experiences.

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