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WHITE PAPER

IBTTA Technology Matrix

Identifying key innovations for the tolling industry

January 14, 2021

Abstract

The Technology Innovation Matrix was developed as a resource for members of the International Bridge and Tunnel Association (IBTTA) in identifying and tracking new and emerging technologies with the potential to impact the toll industry. This white paper introduces the matrix, discusses how it was developed, summarizes key technologies, and provides recommendations on future IBTTA research activities.

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Executive Summary

Since the advent of all electronic tolling (AET), electronic toll collection (ETC) and open road tolling (ORT), the tolling industry has undergone immense change due to technology innovation. These innovations have helped agencies reduce their costs, improve operations, and provide higher quality services to their customers. However, adopting new innovations and business practices can be a significant challenge, particularly given the rapid pace of technology development. Tolling agencies may find it difficult to assess what technologies are worth pursuing. Even when an opportunity to innovate is identified, there are challenges with integrating technologies into existing operations and legacy systems while maintaining flexibility to adapt to the future.

The International Bridge, Tunnel and Turnpike Association (IBTTA) developed the Technology Matrix and this white paper as a resource for association members who wish to learn about emerging technology innovations and their potential implementation within a tolling environment. It was developed with the collaborative input of IBTTA membership who identified technologies and prioritized them for consideration by the tolling industry. Furthermore, members provided their perspective on how priority technologies may soon impact the industry, which are captured in this report and summarized in subsequent sections of this executive summary.

Overall trend towards generating, communicating, sharing and analyzing data

One of the most predominant technology trends is that of connectivity and Big Data analytics; foundational building blocks for the Internet of Things (IoT). The IoT describes a future system where everyday objects are embedded with sensors, software and other computing technologies within a network, thus allowing them to generate, transmit and receive data. Within a tolling context, the IoT would entail everything from basic roadside infrastructure (like pavement, signs, and concrete structures) to vehicles, pedestrians and other system users; all generating and transmitting data to the tolling agency in real time. This would support real time operations improvements as well as more efficient, data-based asset lifecycle management. Furthermore, the development of artificial intelligence (AI) technologies will enable agencies to better manage and analyze data in real time and further automate the transportation system. The general timeline for development of data enabled tolling systems is shown in Figure 1. These observations are supported by technology research from outside of the tolling industry. For example, in its 2019 report on the “Hype Cycle for Transportation Industry,” Gartner concludes that the IoT and AI in transportation will have a transformational impact on the transportation industry within the next 5 to 10 years.

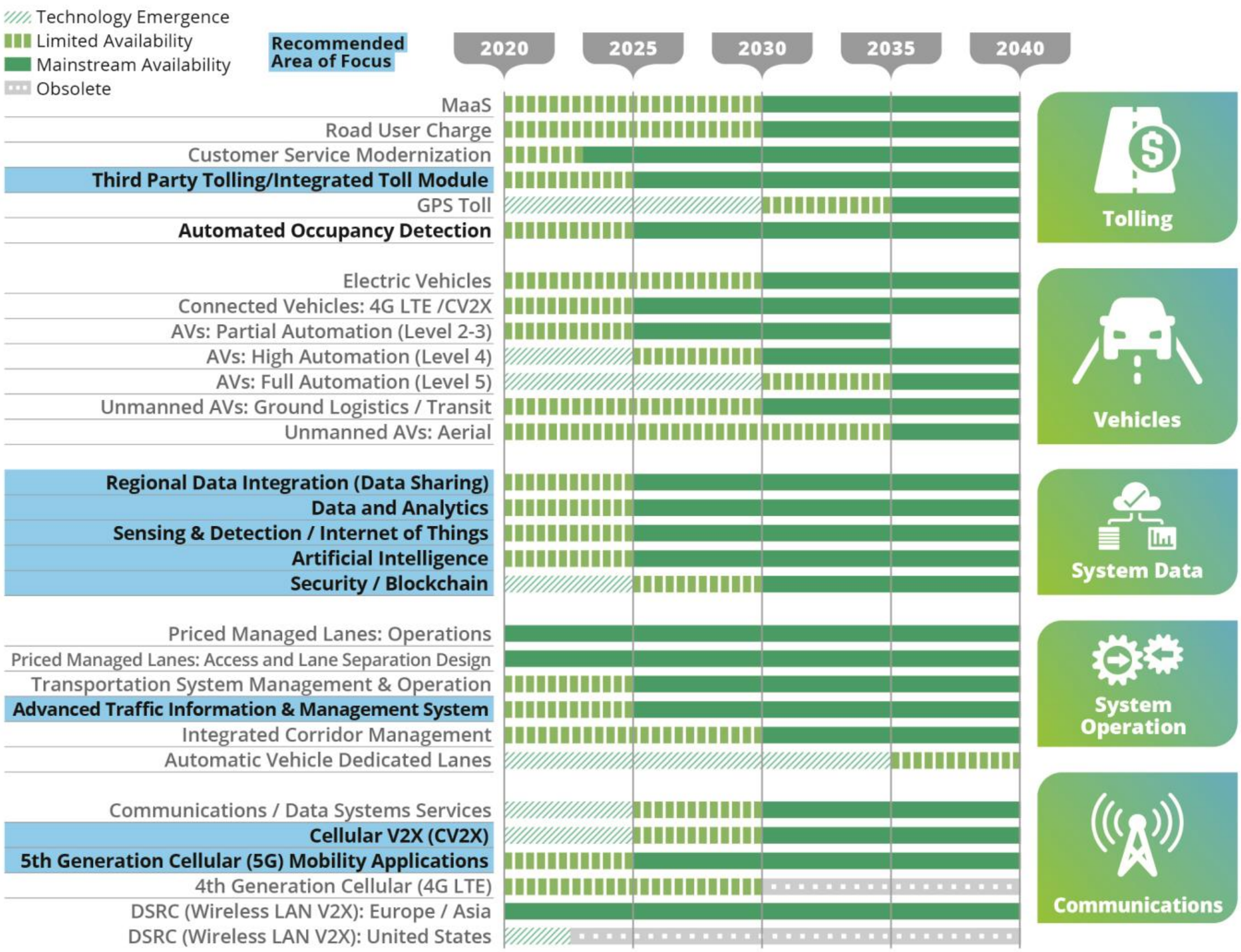

Figure 1: Summary of innovative tolling technology trends and priority technologies

What can agencies be doing now?

- **Collaborate and share data with regional partners.** Data can be shared with system users as well as partner agencies as part of regional Transportation System Management and Operations (TSMO) programs. TSMO represents a set of strategies focused on various operational improvements that maximize performance of the existing transportation system and reduces the need for extra capacity. Many agencies are already engaged in TSMO programs and participation in regional programs is strongly encouraged by the Federal Highway Administration (FHWA). Data enabled TSMO integrates and manages the transportation network as a unified whole, making all transportation modes work together and ultimately perform better. As high quality, high resolution vehicle and infrastructure data becomes more widely available, advanced TSMO applications for situational awareness, data archiving, and analytics become available for transportation agencies, first responders, planners, and researchers. For example, the Regional Information Transportation Information System (RITIS) service fuses data from numerous agencies, transportation systems, and the private sector and provides various analytical and monitoring tools. RITIS features a performance dashboard displaying metrics for highway, transit, aviation, and port-related modes of transportation. Regional data sharing approaches can also enable the coordination of Active Traffic Management applications like adaptive ramp metering, signal priority, speed harmonization, and dynamic rerouting across numerous facilities and jurisdictions.

- **Explore new services for users.** Smartphone tolling applications, which allow users to access and pay for tolled facilities without the need for a tag/transponder or agency account, are already on the market and active on facilities in numerous countries and states. They expand the potential pool of toll road users and could potentially lower operations and enforcement costs to agencies by promoting interoperability and supporting an alternative customer experience. Toll authorities should already be considering how their back-office systems (BOS) and business rules can integrate with mobile payment platforms and smartphone-based tolling applications. This includes advancing their existing customer experience.

What about the near term (within the next three years)?

- **Increase vehicle and infrastructure connectivity.** The tolling industry is well positioned to leverage the IoT as it already features the basic communications infrastructure in the form of RFID and 4G LTE cellular. Such communications technologies enable real-time, location-specific data and notifications to be generated on road conditions and vehicular activity. In a few years, cellular-based connected vehicle applications will become standard market features on new vehicles, and with the advent of 5G mobility services, even higher speed and higher quality transmission can occur without the need for roadside equipment. Agencies should continue to test dual band roadside units as well as vehicular on-board units (OBU) until there is a definitive standard. The fifth generation of cellular technology (5G) is likely to significantly expand the number and speed of services available to travelers and toll agencies. Already present in urban areas as a telecommunications platform, 5G transmitters and receivers strategically placed along the transportation network could enable the collection of vast amounts of in-vehicle data and broadcast data for numerous safety and operations-related applications. Agencies should continue to monitor developments in 5G with a particular focus on those associated with cellular-based vehicle to vehicle/infrastructure (CV2X) applications.

What to plan for in the mid-term? (3 to 5 years)

- **Improve data management and analytics:** As vehicles and infrastructure become more connected, there is an increasing array of data being generated for use in facility operations. A key challenge is identifying what data needs to be collected and how it can be used and maintained. Advancements in Big Data, sensor fusion, Artificial Intelligence

(AI) and Machine Learning (ML) will be a force-multiplier as operational and customer service-related functions can become more automated, freeing human resources to tackle less predictable and more dynamic challenges. Agencies should continue pilot testing data integration and advanced data management approaches while evaluating requirements against legacy systems and considering new requirements as legacy systems are replaced.

- **Increase agency awareness through sensor enhancement and sensor fusion.** The basic sensor technologies needed for IoT realization are already available and continually improving. Agencies use a number of sensors for in-lane vehicle detection and improvements to video and emergence of technologies like LiDar will enable higher resolution and further automation of routine operations. Furthermore, sensor fusion technologies will soon be tested and implemented on roadways that allow for an array of infrastructure-based data to be read, interpreted and acted on by artificial intelligence and machine learning based technologies in a back office or transportation management center setting.
- **Explore ways to improve construction and maintenance activities.** High resolution surface and subsurface surveying can improve quality assurance (QA) and quality control (QC) activities within agency engineering groups. Universities and state departments of transportation are continually evaluating new methods for generating quick, high quality, high resolution survey data that does not require the destruction of pavement through traditional means such as core sampling. Agencies should monitor these developments and work with university or research sector partners to test the potential implementation of these technologies.

What to watch for on the long term (5 to 10 years or more)

- **Monitor developments in transportation system funding alternatives and identify opportunities for the toll industry:** States and the federal government are not only grappling with transportation funding shortfalls but face a significant funding challenge in the long term through reduced fuel tax payments. Road Usage Charges (RUC), Mileage-based User Fees and Vehicle Miles Travelled (VMT) fees all levy a charge based on distance travelled and are being studied by states as a possible funding replacement. While many states have studied RUC, and Oregon has a limited deployment, it is likely to be many years before these systems become more widespread. However, when they do, they will functionally affect every road including toll roads, and there is likely to be overlap in terms of policy and technology. Tolling agencies may need to work with RUC system operators towards some form of integration. RUC account managers may need to act as toll collectors for their users, but it is also possible that tolling systems play a significant role in RUC back-office operations. Furthermore, refinements in RUC assessment technologies could enable satellite tolling applications, reducing the need to construct and maintain roadside tolling equipment. If RUC is not implemented, then it is possible that ongoing revenue shortages will push states to expand tolling.

Introduction

The IBTTA Technology Matrix was initially developed by the Emerging Technologies Committee in conjunction with the research activities aimed at identifying innovation best practices for the tolling industry. At the time of that 2019 research effort, IBTTA sought to develop a resource to identify and track developments in key technologies and business innovations.[1] Such a tool would be valuable for IBTTA members in evaluating the need for future investment and planning for future innovations. An initial Technology Matrix was thus developed that identified key emerging technologies as well as existing technologies for which new tolling applications were being developed.

That initial matrix was subsequently refined throughout 2020 with the input of IBTTA members and the dedication of IBTTA member research resources. The Innovation Subcommittee scheduled and facilitated bi-weekly meetings to solicit volunteers, hear from subject matter experts, and discuss emerging technologies and make updates to the matrix. IBTTA volunteers developed and contributed content for the matrix and this white paper within their own areas of knowledge with representation from agencies, consultant firms, and vendors. IBTTA Technology Matrix Task Force members who contributed to this effort are shown in Table 1.

Table 1: IBTTA Technology Matrix Task Force membership

Trey Baker	WSP
Steven Bird	Red Fox
Mary Biswell	OTC
George Christopher	Douglas Stuart
Jeff Dailey	CTRMA
Michael Davis	RS&H
Al Gerayeli	AECOM
Thomas Greiner	ASFINAG
Brennan Hamilton	Ford
Kathryn Hartzell	PTC
Rick Herrington	HNTB
Sean Hill	DRJTBC
Adam Horn	HNTB
Brian Kelley	OTC
Geoff Korfin	Innovative Prod
Juan Kuthy-Saenger	Atkins

Tyler MIlligan	Milligan
Claudio Occhipinti	Fagan
John O'Neill	MTA
Lev Pinelis	Transurban
Carl Pro	RJ Lee
David Raines	RKK
Laura Rogers	The Ray
Michael Sexton	CTRMA
Jeff Siegel	HNTB
Chris Swenson	WSP
Robert Taylor	PTC
Stephen Taylor	i77 Partners
Mario Toscano	Drive Engineering
Justin Word	CTRMA
Mia Zmud	CTRMA

Following completion of the initial draft of the matrix, IBTTA volunteers conducted a prioritization exercise to identify those technologies with a high level of maturity and potentially significant

[1] IBTTA Emerging Technology Committee, “Strategies for Innovation and Technology White Paper,” November 27, 2019, Section 4 Next Steps, page 15.

application within the tolling industry. The objective of this exercise was to differentiate those technologies that may only be theoretical or with little known application to the tolling industry versus those that are close to market ready with potentially significant impacts to one or more aspects of the tolling industry.

The matrix and associated prioritization are intended to be a living document that is updated periodically by IBTTA with contributions from its membership as part of ongoing Emerging Technologies Committee activities. This document should thus be considered a snapshot of a current environment that is subject to rapid change.

Technology Matrix Overview

The following sections provide an overview of the technology categories comprising the matrix and the specific technologies comprising those categories. These categories include:

- Communications
- Sensing and detection
- Construction and civil engineering
- Analytics, data processing, and information technology
- Automation and connectivity
- Consumer applications
- Transportation demand management

Each innovation is described briefly followed by discussion of use cases. In this report, use cases are summarized based on whether they are current or future. Current use cases are those applications of technology that are well established within the tolling industry or that are being pilot tested or implemented on a limited basis. Future use cases are applications that are theoretical, experimental, or for which the tolling industry is only on the cusp of pilot testing. Depending on how technologies are developed and brought to market, some future cases may never be realized. The differentiation of current and future use cases and the placing of technology innovations within multiple use cases was deemed necessary because many existing technologies are finding new applications while retaining their traditional role in operations. Bluetooth, for example, is commonly used to monitor facility speeds but can also potentially be used in traffic signalization applications.

Although not discussed within this white paper, the matrix identifies potential impact categories for innovative technologies as follows**:**

- **System Automation.** Technologies that facilitate the automation of various system activities such as operations or maintenance. Examples include license plate image processing, vehicle classification, dynamic rerouting, and wrong way driver warnings.
- **Vehicle Automation.** Technologies that facilitate automated vehicle operation such as lane keeping assist, navigation, collision warning, and platooning.

- **Revenue Assurance.** Technologies that impact typical business operations such as maintenance and administration.
- **Alternative Revenue.** Technologies that potentially provide new sources of revenue for toll agencies.
- **Safety.** Technologies with the potential to improve system safety for users, pedestrians, agency personnel, etc.
- **Regional Mobilit**y. Technologies with the potential to achieve regional mobility goals outside of tolled facilities.
- **External Market.** Technologies applicable to markets that fall outside of the tolling industry but with significant potential to impact the industry.

Each technology was scored within its category based on its applicability to the tolling industry and market maturity using a scale of 1 to 5, as shown in Table 2. Scores for each technology were compiled to derive the average applicability and maturity scores. Applicability and maturity scores are presented with each technology description.

Table 2: Technology Prioritization

Applicability	
1	None
2	Low
3	Potential
4	Somewhat
5	High

Maturity	
1	Conceptual: No product, undefined or unknown use cases
2	Experimental: Initial development of units, applications, etc.; initial use case development
3	Prototype: Initial units developed, limited trials, potential use cases established, beta testing
4	System tested: Multiple pilot tests, limited deployments in an operational environment
5	Mature/Operational: Deployed in multiple operational environments

Technologies within each category were arrayed on a matrix, with those scoring very high in terms of both applicability and maturity residing in the upper right hand quadrant of the matrix, as shown in Figure 2. These are the technologies most likely to be of interest to the toll industry and warrant consideration, although other factors were considered, leading to the featured technologies in this report.

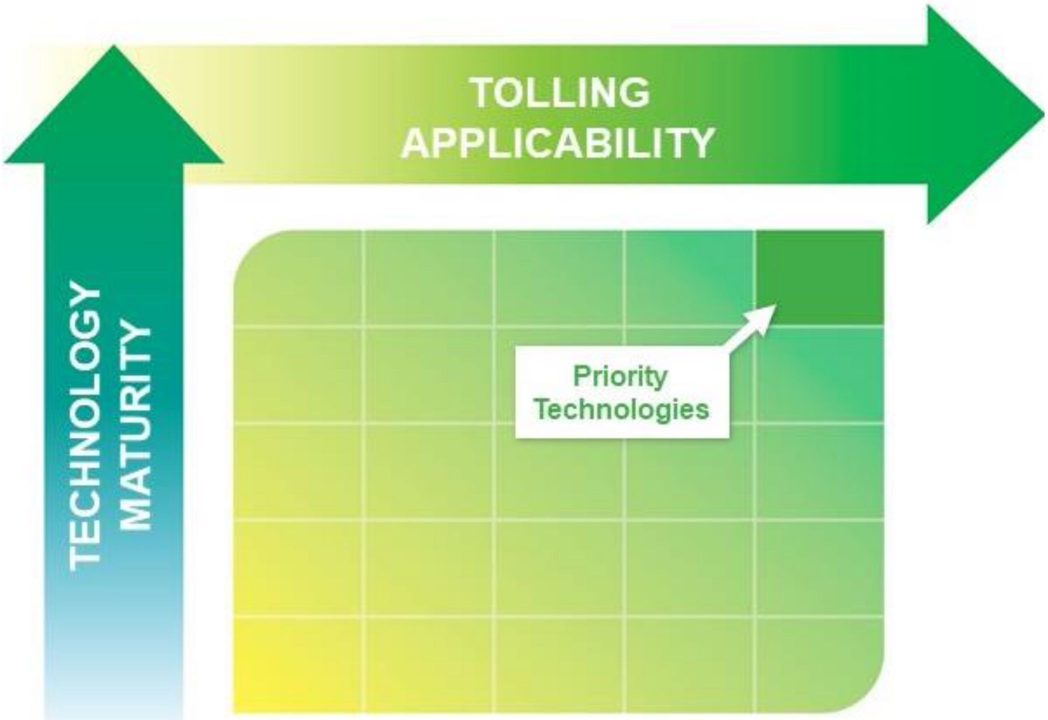

Figure 2: Technology Prioritization Matrix

Each section of the report concludes with a brief discussion on one or more of the technologies that were determined to be highly mature and/or with particularly high applicability to the tolling industry. These technologies include:

- 5G Cellular
- Sensor fusion
- Dielectric profiling systems (DPS)
- Artificial Intelligence (AI) and Machine Learning (ML) for call center automation
- Connected Vehicles
- Smartphone/Mobile tolling
- Active Traffic Management (ATM) and Integrated Corridor Management (ICM)
- Road Usage Charging (RUC)

Recommendations

This report does not make recommendations on what technology innovations should be pursued. Rather, it was intended to "cast a wide net" to illustrate the wide range of technology innovations available to the tolling industry and provide an initial assessment of which should be prioritized for tracking and monitoring. However, the IBTTA Innovation Subcommittee makes the following recommendations for leveraging the information contained in this white paper and advancing industry knowledge:

- IBTTA should develop SmartBriefs, white papers, etc. on the topics highlighted in this white paper. Specific technologies, such as 5G or cellular connected vehicles systems might be featured. IBTTA should also consider cross-cutting topics such as:
  - Best practices and lessons learned in pilot testing
  - Overcoming contracting and/or procurement challenges
  - Developing a successful business case for exploration and/or implementation
- IBTTA has, in the past, done an effective job of identifying and approaching subject matter experts to provide information on emerging technologies in the form of webinars, online videos, and special conference sessions or presentations. The technologies and innovations identified in this paper should be included as topics of interest moving forward.
- IBTTA should use the information contained in this white paper to inform the development of special sessions at appropriate events. For example, emerging innovations in the area of construction and civil engineering, and specifically dielectric profiling, might be discussed at a special session at maintenance-related events.
- A separate Technology Matrix Subcommittee should be spun-off from the Innovation Subcommittee. The new subcommittee would be focused primarily on research supporting updates to the Technology Matrix and assisting IBTTA in identifying future priority technologies. An initial activity for the new subcommittee would be developing a formal process for refining, maintaining, updating and disseminating the IBTA Technology Matrix. The Innovation Subcommittee would then focus primarily on organizational aspects of innovation.
- Members should begin considering how these technologies might impact their own operations and strategic plans pursuant to guidance in other Emerging Technology Committee and Innovation Working Group white papers. IBTTA reports on Big Data, blockchain applications, and Connected, Automated, Shared, and Electric (CASE) vehicles are all available for review by members and this white paper should be considered a supplemental reference/resource to those efforts.

Communications

Communications technologies are used for the transmission of information between vehicles, roadway infrastructure and toll system users. With the continued growth of electronic toll systems and the increasing connectivity of infrastructure, vehicles, and users, communications technologies will be critical components of the tolling industry well into the future and will be a primary building block for the Internet of Things (IoT). Developments in communications technology are likely to increase the range of services that can be provided, such as connected vehicle safety applications and may reduce the need to install and maintain expensive roadside equipment. Specific communications technologies reviewed by the IBTTA Technology Matrix subgroup are shown in Table 3:

Table 3: Communications technologies

Technology	Description	Toll Applicability	Maturity
Bluetooth	A standard wireless technology for two-way data transmission over short to medium range distances. Operates with Ultra High Frequency (UHF) radio waves in the unlicensed ISM band at a frequency of 2.4 GHz and in the bandwidth of 2.402 – 2.48 GHz. A common feature in electronic devices including mobile phones, laptops, tablets, etc.	**4.3**	**4.5**
Wireless Fidelity (Wi-Fi)	An IEEE 802.11 communication standard for wireless local area network targeting high-speed data transmission for work and homes. Generally, operates on one of two frequencies – 2.4 GHz or 5 GHz ISM Band. Wi-Fi is a side-channel (or non-carrier enterprise owned) for data communications.	**4.0**	**4.5**
Dedicated Short Range Communications (DSRC)	A member of the Radio Frequency Identification (RFID) family of technologies. Tolling applications communicate over the 915 Mhz frequency and are prevalent internationally but have limited application within the United States. The US federal government has set aside the 5.9 Gigahertz (GHz) frequency band, which is specifically designated for medium range (100-300 ft.) wireless communications, for automotive and transportation safety applications. These applications are discussed in in the Automation and Connectivity section of this report.	**4.3**	**4.0**
5th Generation Cellular (5G)	Represents the next advancement in mobile technologies from the current 4G/3G network. Is anticipated to produce high throughput and connection density for mobile systems with fewer transmission delays and low latency rates. This is strictly a carrier provided communications channel between a tower and a receiving device such as a car or mobile phone. Also used for C-V2X communications.	**4.6**	**3.5**

Electronic tolling system applications commonly rely on many of these well-established communications technologies. Current tolling system use cases for communications technologies include the following:

- **Traffic data.** Various RFID technologies as well as Bluetooth are commonly used on roadways for the collection of travel time and speed data. In the case of Bluetooth, specialized roadside readers detect the unique Bluetooth identification of equipped devices in vehicles and calculate travel times/speeds based on successive reads. The data is anonymous and does not cover all vehicles on the roadway and is therefore not useful for determining volumes. Unique IDs are collected and could potentially be used for origin destination studies, but such an approach would be limited by the need for extensive reader coverage of the network.
- **Roadside and vehicle connectivity.** Bluetooth, Wi-Fi, RFID and DSRC support the transmission of various information sets between vehicles and roadside equipment. In the US, 75 megahertz of spectrum in the 5.9 GHz band for DSRC was designated for traffic safety applications. DSRC was viewed as a primary communications enabler for connected vehicle (CV) safety applications. However, due to slow development, the Federal Communications Commission (FCC) in 2020 opened up 45 megahertz of spectrum for other uses. The remainder of the 5.9 GHz band is still designated for auto safety. The development of 5G cellular may take over many of the CV communications functions envisioned for DSRC. Connected vehicle applications are discussed in later sections of this report.
- **Infrastructure connectivity.** Wi-Fi is commonly used for communications between various roadside infrastructure systems including tolling equipment and intelligent transportation systems.
- **In-lane vehicle and account identification.** DSRC is the primary (and defining) electronic tolling technology in Europe and other international tolling applications. The technology enables low power communications between systems through vehicle mounted On-Board Units (OBUs) that communicate with readers mounted on tolling gantries to transmit information.
- **Third party tolling services.** Mobile-based applications currently rely on the existing 4G/LTE cellular network to provide various alternative tolling services such as smartphone tolling, which is discussed in the Consumer Applications section of this paper. The growth of the 5G cellular network is likely to expand the number of service offerings. Agencies are currently pilot testing the communications medium with third party vendors.
- **Occupancy Verification.** Smartphone applications may be employed to verify vehicle occupancy for HOV and HOT facilities. Users, drivers as well as other occupants, download the app. Drivers provide the transponder and license plate number. Prior to each trip, the driver and all occupants must declare their status for the trip on the HOV/HOT facility to be accepted as eligible. The North Central Texas Council of Governments (NCTCOG) currently uses the GoCarma system for its facilities in the

Dallas-Fort Worth region. NCTCOG estimates there have been 35,000 users representing 30,000 vehicles using the system and that the violation rate is 2.7 percent.

Future use cases will be influenced by several factors including federal legislation and rulemaking and the adoption and incorporation of certain technologies by the automotive and telecommunications industry. Future communications-based tolling use cases include:

- **Vehicle Detection and Positioning.** DSRC tolling applications are capable of detecting vehicles as well as positioning them within the toll zone. Wi-Fi may also be used for vehicle detection and positioning through the use of multiple radios within open road tolling zones. Information from these radios can be used to triangulate precise vehicle ground positioning. The University of VA and other academic institutions have conducted research in this area tracking vehicles at signalized intersections using Wi-Fi.
- **Roadside and vehicle connectivity.** DSRC will enable high-speed communication of safety, weather, and other information through connected vehicle applications (V2V/V2X). However, this will require factory installed or aftermarket devices within vehicles until such technologies are standard features. 5G cellular may also be used for highspeed data communications in lieu of DSRC or other networked, media-to-media communications channels. 5G will likely require localized transmitters but could reduce the need for extensive overhead/roadside equipment relative to existing DSRC and other RFID-based technologies.
- **Sensing and detection.** A 5G-based high-speed wireless network covering the roadway system supports the deployment of sensors without the need to lay fiberoptic cable or otherwise hard-wire them into the agency's ITS systems. The historic growth of 4G, development of 5G, and widescale deployment of sensors and other data collection technologies will support the Internet of Things (IoT), a vision of the future where everyday objects are embedded with sensors, software and other computing technologies in a network, thus allowing them to generate, transmit and receive data.

As can be seen in Figure 3, communications technologies were rated highly in terms of maturity and applicability to the tolling industry. 5G cellular as seen as having a potentially significant impact in the long term, even though mobility-related applications are still being studied and developed. It is thus discussed in more detail in the next section.

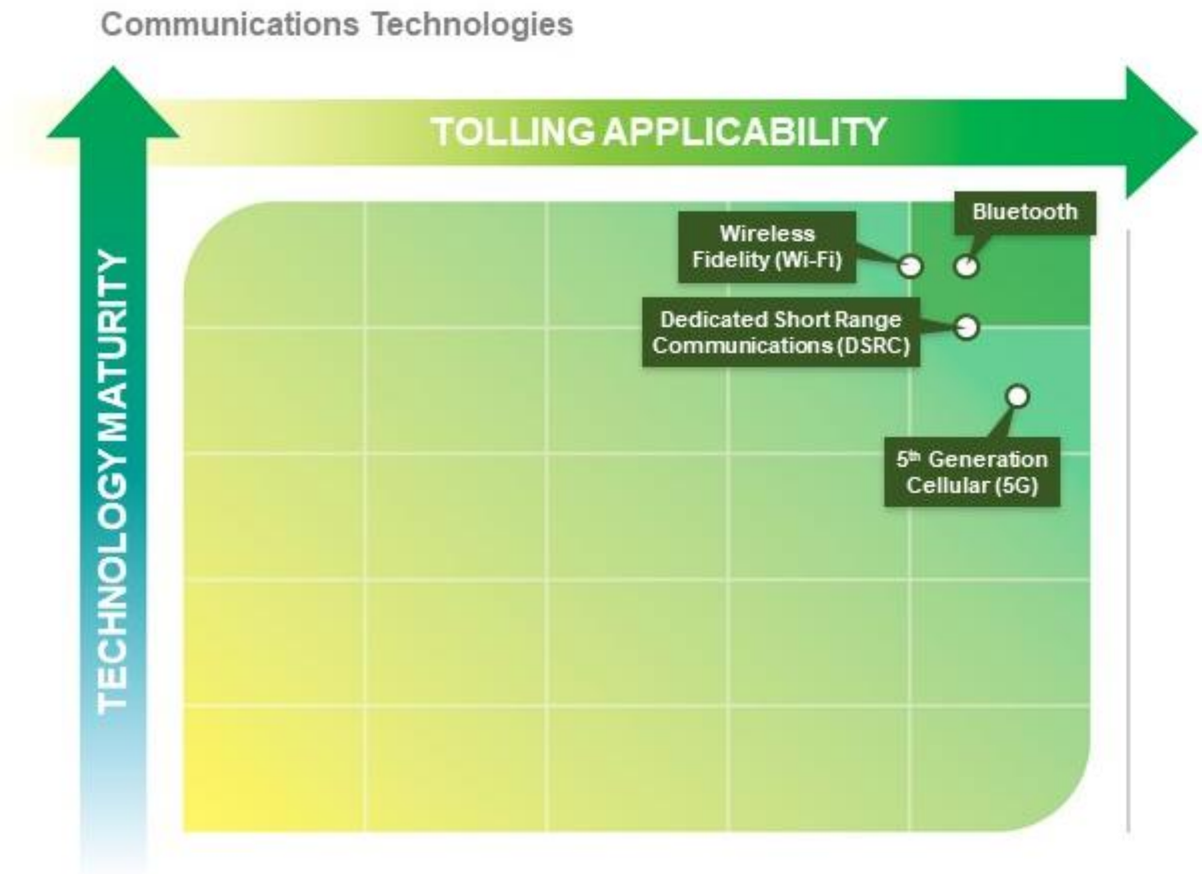

Figure 3:Prioritization of communications technologies

5G Cellular

Fifth generation cellular technology (5G) represents the next evolution over the current, nationwide 4G/LTE network. 5G offers higher data throughput, higher connection density, fewer transmission delays, and lower latency rates relative to 4G. In addition to improving the quality of consumer telecommunications services, 5G's improved operating parameters could likely support connected and automated vehicle (CAV) applications without the need for extensive network of roadside infrastructure such as existing DSRC roadside units. Because of 5G's higher speed and lower latency, it has a smaller transmission range relative to 4G/LTE and would therefore require more transceiver towers to cover the same geographic "cell." CAV applications reliant on 5G would therefore require the placement of some 5G communications infrastructure near, or perhaps even within existing, rights-of-way.

Depending on technology development and market trends, 5G may eventually serve as the primary enabling and supporting technology for the Internet of Things (IoT); a global network of everyday objects embedded with computer technology connected to the internet. The IoT would enable the collection and analysis of vast amounts of data that, in a tolling context, could be used for proactive asset management and predictive modeling.

Initial deployment of 5G is occurring through telecommunications and in-home consumer services. The next step will be development of enterprise and mobile services. Initial deployment is also centered primarily in urban areas with penetration in more rural areas likely to take longer. 5G enabled devices will rely on connections with the existing 4G/LTE network to ensure continuous coverage.

While service providers have launched various 5G technologies around the United States and the globe, the opportunities for the Tolling Industry and the role the Industry will play in the buildout of 5G networks are uncertain. Due to greatly improved data transfer and increased bandwidth anticipated with 5G, the transportation industry considers 5G one of the most likely contenders for the connected vehicle market. If 5G becomes the primary communications medium of connected vehicles, the Tolling Industry should consider accommodating the technology and benefiting from the revolutionary impacts, such as improved safety applications and connected vehicle related services.

5G will increase data transfer speeds by a factor of as much as 100 compared to 4G, which would enable connected vehicles to transmit large amounts of critical vehicle data in real time. However, while 5G millimeter radio waves are capable of faster data transfer and larger bandwidth, they are easily impeded. Millimeter radio waves can be impeded by rain, blocked by roadway structures, and cannot transmit over long distances. 5G small cells are capable of transmission distances of up to 1,000ft., while longer range 5G would require the installation of large Multi-Input Multi-Output (MIMO) 5G arrays on radio towers.

Currently, Right-of-Ways (ROW) along interstates and toll roads are premium resources for installation of fiber backbone to improve connectivity for tolling authorities and the public. Similarly, tolling authorities may expect to play a role in providing ubiquitous 5G coverage by allowing 5G deployment within the ROW. Tolling authorities could support the buildout of 5G small cell and MIMO arrays to expand service provider coverage while benefitting from the connectivity provided to the toll road.

5G can present tolling authorities with innumerable benefits for safety and data by connecting with customers on the roadway. Additionally, 5G technology may help to accelerate the deployment and adoption of connected vehicle technologies, expand broadband services to rural areas and underprivileged areas, and present the tolling industry with a paradigm shift in data-driven tolling operations. There are, however, questions about who will provide, implement, maintain and manage these 5G systems. One possible approach is through the public-private partnerships (P3) on a corridor-by-corridor basis. Tolling agencies can wait to see what develops, but they are also in a position to proactively explore potential partnership approaches in advance of more wide scale 5G deployment. The private sector is likely to be attracted to the tolling industry’s extensive right-of-way and fiber optic and wireless networks.

Sensing and detection

Sensing and detection technologies, like communications technologies, are a common feature of modern electronic tolling systems. They enable the detection of vehicles within a tolling zone and, in some cases the identification and classification of vehicles. These technologies differ from communications technologies in that they do not facilitate the exchange of information between infrastructure, vehicles and users but, rather, generate much of the information to be communicated. Information that is provided by these technologies typically covers all vehicles within a lane or a facility and they are therefore used extensively for operations and enforcement activities. Sensing and detection technologies are another critical aspect of the IoT as they will supply the information needed for future operations and asset management activities. Technologies examined by the Technology Matrix Task Force are shown in Table 4.

Table 4: Sensing and detection technologies

Technology	Description	Toll Applicability	Maturity
Light Detection and Ranging (LiDAR)	Also known as laser scanning, LiDAR utilizes a pulsated laser beam to measure the distance to a target object. The speed and wavelength of the laser beam, and the return times are used to make three-dimensional representations of the object. The technology uses wavelengths in the range of ultraviolet, visible, or near infrared spectrum to image objects depending on the applications and the nature of the objects.	**3.6**	**4.3**
Infrared	Sensors that detect and convert energy from vehicles, roadways, and other objects into electrical signals that can be used for signal control, and vehicle volume, speed, and classification detection.	**4.2**	**4.5**
Microwave	Roadside mounted sensors that emit electromagnetic waves to detect vehicle presence and measure vehicle speed.	**3.5**	**4.0**
Optical	Convert light rays from the visible spectrum to electronic signals for various purposes including non-intrusive detection and counting of objects.	**4.3**	**4.7**
Pneumatic Systems	Consist of a pressure hose that registers changes in air pressure through a membrane. Vehicles are detected as they pass over the pressure hoses, which are mostly built into artificial thresholds.	**2.7**	**4.2**
Blending plate Systems	Blending plate systems consist of a metal plate on the underside of sensors such as strain gauges. When a vehicle drives over the measuring plate, expansion caused by the movement of the tire over the plate is measured and the dynamic load is calculated.	**3.5**	**3.6**
Piezoelectric	When a vehicle drives over a piezoelectric sensor, the system detects the electrical charge generated by the sensor and calculates the dynamic load. Piezo elements are attached to a thin carrier cable that generate a voltage signal depending on the contact pressure (axle load) of vehicles passing over them. This is based on the functional principle that certain crystals release electrical charges when subjected to mechanical action.	**3.5**	**3.5**

Technology	Description	Toll Applicability	Maturity
Sound detector	Sound / acoustic detectors are, in principle, selective microphones which analyze the vehicle noise (especially the rolling engine and passing noise) of vehicles. Directional microphones receive the sound and evaluate the threshold value, which is used to count the vehicle or to detect fire or tire burst and screaming people.	**2.6**	**3.4**
Fiber Optic	Fine light disturbances caused by vehicular vibrations allows traffic conditions to be measured along a route	**4.4**	**4.2**
Magnetic field detector	React changes in the earth's magnetic field due to the iron mass of the vehicles. The magnetic field detector can also be mounted directly next to the road, but has limited ranges of approximately 1 m to 3 m. Low energy consumption and the future increasing efficiency of the photovoltaic modules, which is now about 18%, could increase its current low level of use.	**3.7**	**4.7**
Loops	This is a conductor loop through which alternating current (frequency from 10 kHz to 200 kHz) flows. In practice, the induction loop inserted in the pavement is the most widely used detector. Smart loops are in development that allow for a wider array of data to be collected and analyzed.	**4.0**	**5.0**
Video	In addition to the lane-related collection of local parameters, video image processing systems also offer the possibility of recording and evaluating traffic conditions on a spatially limited route section. The detection algorithm is essentially based on the difference image method.	**4.9**	**4.8**
Radar	Radar (Radio Detection and Ranging) is a process that uses electromagnetic waves in the highest frequency range (microwaves) to detect objects. Technically used microwaves range from 1 GHz to 120 GHz. Frequencies from 1 GHz to 30 GHz are used for traffic data acquisition. Electromagnetic waves are only reflected by objects whose dimensions are larger than their wavelength. For this reason, the radar measurements are not influenced by the weather.	**4.0**	**4.8**
Sensor Fusion	The best sensors are intelligently linked. The disadvantages of individual sensors is reduced.	**3.0**	**2.6**
Landscape Management Sensors (or Nature Tech Sensors)	Sensors installed into the landscapes surrounding roadways to manage the health and safety of those spaces. Sensors can be configured to monitor a range of issues including water level and flow, plant growth, soil moisture, and storm events. The data produced from these sensors allows transportation managers to respond in real-time to the landscape's needs and can prevent destructive events from occurring such as soil erosion and flooding.	**2.6**	**3.4**

Sensing and detection technologies are used extensively as part of operations and enforcement activities on electronic toll systems. They are also commonly featured with new safety applications. Existing use cases for sensing and detection technologies in tolling systems include the following:

- **Surveying.** LiDAR is often used in surveying for construction, land development, and environmental assessment related activities. In many applications it is paired with unmanned aerial devices (drones).
- **Vehicle detection and identification.** Infrared and microwave sensors as well inductive loops are used for in-lane vehicle detection and, in some cases, classification. Optical detectors can also be deployed for vehicle detection but are less reliable and therefore much less prevalent than infrared or microwave.
- **Roadway safety applications.** Infrared sensors are an emerging vehicle detection method in wrong way driving applications. Inductive loops have also been used in such applications.
- **Traffic data.** Pneumatic sensors are the traditional source of traffic count data. Smart pneumatic sensors have the potential to provide more detail on traffic.
- **Vehicle weight assessment.** Blending plate systems with capacitive measuring strips can be embedded in the road surface for weight assessment on commercial vehicles.
- **Traffic signalization.** Induction loops are mainly used for traffic light signalization and barrier control. They may also be used for pedestrian and incident detection systems.
- **Facility observation.** Video detection systems and cameras are the primary facility observation mechanism and support webcam services for facility users.
- **Occupancy enforcement.** Infrared cameras can be used to enforce occupancy requirements on High Occupancy Toll (HOT) and High Occupancy Vehicle (HOV) lanes.LA Metro installed infrared cameras on the I-10 and I-110 ExpressLanes and estimates that the system accurately detects violators 90 percent of the time. However, photos must be reviewed by a Metro staffer.

Although sensing and detection technologies are well established in electronic tolling systems, there are a number of new and emerging use cases that could be supported by refinements to existing technologies or the development of new technologies, such as:

- **In-lane vehicle detection and identification.** LiDAR offers potential for higher resolution vehicle detection, measurement, and identification. Piezoelectric sensors may also be used for such applications and, due to the high time resolution of these sensors, could provide exact speed and axle counts. Piezoelectric sensors may also be used for dynamic weight determination due to the voltage amplitude increases resulting from the load.
- **Traffic data.** LiDAR can potentially be used to gather high resolution traffic data for monitoring and other data collection activities. Fiberoptic sensors could enable the use of existing infrastructure to detect congestion without installing sensors along the route. The growth in drone technologies could expand the methods available to collect traffic data without investing in fixed infrastructure assets or static sensors.
- **Roadway safety applications** -The potential coupling of in-vehicle LiDAR applications and vehicle-to-infrastructure (V2X) applications could enable the detection of pedestrians, vehicles, and roadway obstructions for use in safety applications. Sound sensors may be

used to generate danger warnings in front of tunnels or if incidents occur at toll stations. Landscape management sensors can ensure the landscapes surrounding roadways and HOT lane systems remain clear from debris and safe for drivers.

- **Automated vehicle occupancy detection.** Infrared and piezoelectric sensors could enable automated vehicle occupancy detection, thus reducing the need for visual enforcement on HOT lane systems. Drones can potentially be used for vehicle occupancy enforcement depending on their on-board systems and capabilities.
- **Infrastructure data.** Landscape management sensors can be used to monitor stormwater infrastructure and its performance in real-time.

The prioritization of sensing and detection technologies is shown in Figure 4. Although the technology is still being developed within a tolling context, and its ultimate application within tolling systems is still being explored, sensor fusion technologies are likely be critical as more and more sensing and detection technologies are deployed along roadways. The Innovation Subcommittee anticipates that the assessment of maturity and applicability of sensor fusion technologies is likely to increase significantly in the future, so that technology is discussed in more detail in the following section.

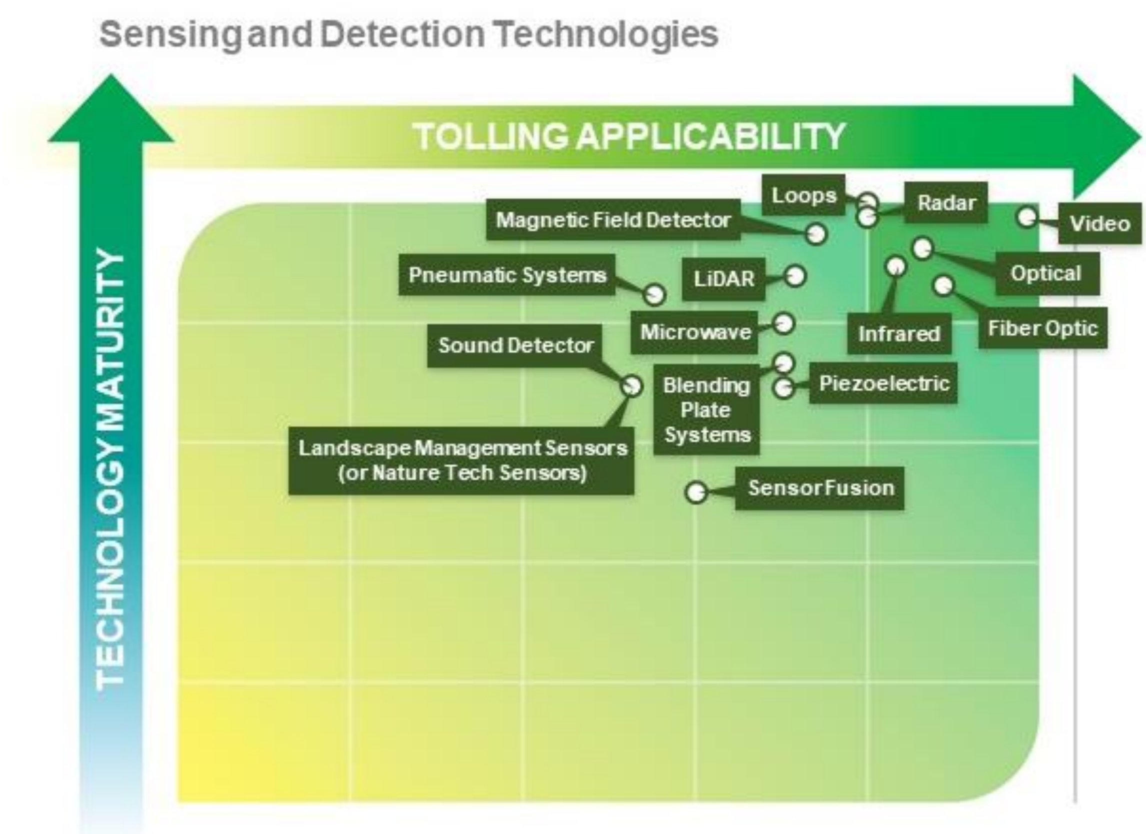

Figure 4: Prioritization of sensing and detection technologies

Sensor Fusion

Many different sensing and detection technologies, including video cameras, traffic detectors, environmental sensors and radar, are already used in toll systems throughout the world. Each technology has its advantages and disadvantages, depending on the application. Sensor fusion technologies connect these existing sensors with one another and utilize algorithms to leverage the advantages of each sensor type to improve situational awareness and provide higher quality data.

Sensor fusion hardware and associated software enable increased detection quality while generating an “overall picture” of the environment on the facility. In a tolling environment, sensor fusion applications are likely to be found in front of toll stations. One significant advantage of adopting sensor fusion applications is the reduction of false alarms and erroneous data, increasing the reliability of event detections at toll stations. Initial tests at ASFINAG have already shown that there is a significant reduction in false alarms and a significant increase in the reliability of event detection for motorway operators.

If certain sensors or detections have a “blind spot,” artificial intelligence (AI) and machine learning can use sensor fusion to supplement missing or inaccurate data with information from other sensors. For example, a laser-based fog sensor might be able to detect fog on roadway, but video cameras (with an algorithm) are also able to detect fog. In the event that the laser-based fog sensor becomes inoperable or faulty, sensor fusion would allow the operator to still automatically identify the presence of fog as identified by the video cameras. Sensor fusion thus provides sensing and detection redundancy without the need for additional hardware on the roadway, thus allowing agencies to focus installation and operations efforts only essential sensing and detection approaches.

Sensor fusion also plays a critical role in connected, automated, shared and electric (CASE) applications, particularly in terms of precision location determination in automated vehicle systems. Most systems rely on the Global Navigation Satellite System (GNSS) to determine geographic location, often with a very high level of precision. However, in spite of the ubiquitous nature of the GNSS network, it still operates on a “line of site” basis, meaning that urban environments with tall buildings or tunnels can result in a loss of signal. Sensor fusion technologies by companies such as Xsens and U-blox enable AV systems to “dead reckon” and supplement lost GNSS data by accessing sensors such as gyroscopes and accelerometers to determine the direction of travel and distance.

Furthermore, sensor fusion is a critical element for access by artificial intelligence systems to advance visual and radar-based detection systems, enabling a much higher level of situational awareness by vehicles. For example, sensor fusion may allow automated driving applications to maintain travel within the lane, on a very limited basis, even if external machine vision-based cameras suffer a failure.

Construction and civil engineering

These technologies and innovations are used in construction and maintenance activities and include a broad range of materials and surveying related innovations. In general, these technologies have the potential to extend the existing lifecycle of facility assets and reduce construction and maintenance costs. Construction and civil engineering technologies examined by the Technology Matrix Task subgroup are shown in Table 5.

Table 5: Construction and civil engineering technologies

Technology	Description	Tolling Applicability	Maturity
Smart Pavement	Highly durable and unobtrusive sensors installed directly into pavement and other roadway surfaces.	**3.2**	**2.3**
Smart Structures	Highly durable and unobtrusive sensors installed directly into roadway structures such as bridges and columns.	**3.8**	**2.3**
Rubberized Asphalt	The incorporation of recycled tires into asphalt mixtures.	**3.4**	**3.5**
Nanomaterials	Materials in which a single unit typically measures between 1 and 1,000 nanometers (10-9 meters).	**3.4**	**1.7**
Piezoelectric Pavement	Surfaces that convert the mechanical energy of a vehicle passing over the roadway into electrical energy.	**3.6**	**2.5**
Shape Memory Metal	Materials (often nanomaterials) that are highly durable and capable of retaining their shape after impacts.	**2.5**	**1.5**
Self-healing Pavements	Special pavement mixtures that can be repaired through electrical induction	**3.4**	**2.5**
High contrast pavement markings	New methods for striping of roadways such as increasing the luminance of markings over a range of conditions and by placing a low luminance contrast stripe adjacent to the pavement marking. A contrast stripe adjacent to a white marking reduces dependence on illumination levels and enables higher Sobel contrast gradient values for darker (e.g. soiled, aged) markings.	**5.0**	**4.5**
Dielectric profiling	Dielectric profiling is used to assess the quality of asphalt pavement compaction at the time of paving by measuring the pavement's dielectric constant. Dielectrics are insulating materials that can be polarized in an electric field but do not conduct electricity. Typically, the measured dielectric constant of asphalt in the field is compared to laboratory compacted specimens.	**4.8**	**3.3**
Electrical resistivity imaging	The measurement of the apparent electrical resistivity of subsurface materials. Electrical resistivity imaging (ERI) is subsurface investigation measure that rapidly produces high-resolution profiles of the shallow subsurface under most field conditions.	**4.2**	**3.3**
Solar Photovoltaic	Technologies to collect and convert solar power into electrical power.	**3.8**	**4.5**

Deformable and Cut Resistant Metal	Materials that are highly deformable and ultra-resistant to dynamic point loads. Based on a bio-inspired metallic ceramic structure that derives its extreme hardness from the local resonance between the embedded ceramics in a flexible cellular matrix and the attacking tool, which produces high-frequency vibrations at the interface.	**3.3**	**2.0**

Current use cases include the following:

- **Roadway safety applications.** Smart road reflectors can provide enhanced safety by giving drivers an immediate visual signal that an incident has occurred, or some other roadway condition requires that they slow down. Connected beacons can be user-activated from a remote location with activation of one reflector triggering all the reflectors in a designated vicinity. These technologies may be useful in blind curves where drivers may have insufficient braking time.
- **Asset management.** The placement of sensors in major infrastructure assets through smart pavement applications allows for the ongoing collection and analysis of asset health data and the modeling of remaining life.
- **Pavement and construction.** The application of rubberized asphalt mixture increases road durability, resistance to cracking and rutting, improves traction, reduces spray during wet conditions, maintains the black color longer (which provides contrast for pavement markings used by autonomous vehicles), while extending the life of pavement by 30 percent or more. These durability benefits have lifecycle cost savings by reducing certain maintenance needs over the life of the road such as filling cracks. Rubberized asphalt also reduces tire noise from the roadway and reuses scrap tire rubber that would otherwise be sent to the landfill or stockpiled, resulting in environmental benefits.
- **Vehicle automation.** High contrast pavement markings facilitate vehicle automation functions, such as lane keeping assist and lane departure warnings, by improving the ability of automotive machine vision cameras to detect roadway markings. Machine vision cameras commonly rely on edge detection systems and algorithms that look for contrast, which is easier to assess with a high contrast pavement marking approach.
- **Pavement quality assessment.** Dielectric profiling supports the continuous assessment of asphalt pavement compaction quality by measuring the pavement dielectric constant. The technology allows for highly precise and accurate assessments without the need for destructive core sampling which only provides a spot assessment. Electrical resistivity imaging (ERI) is another non-destructive subsurface imaging application for engineering investigations. Soils and bedrocks generally have different resistivities, so ERI can be used to delineate soil-bedrock interfaces. Useful in identifying voids.
- **Alternative services.** The placement of solar photovoltaic systems in available right-of-way enhances agency assets by generating clean renewable electricity that can be transmitted to the regional grid or used locally to power agency buildings, lighting, and electric vehicles.

Future use cases include the following:

- **Infrastructure data.** Smart studs can be installed along the roadway to collect and transmit data in real-time on roadways, pavement and weather conditions to local receiving stations.
- **Roadside and vehicle connectivity.** Emerging smart stud technologies are capable of **providing** real-time information to drivers and self-driving vehicles. Examples include merging vehicle alerts, risk notifications (like icy conditions), and navigation recommendations with lane-by-lane traffic updates.
- **Roadway structures.** Nanomaterials have the potential to provide strong and durable sign coverings and roadside structures. Similarly, shape memory metals can be used to manufacture highly durable signs and similar roadway structures that retain their shape and do not require replacement after being struck by a vehicle.
- **Pavement and construction.** Piezoelectric pavements could be used to provide special lanes that support in-road charging of electric vehicles. Self-healing pavement technologies could result in roadways that can be quickly repaired without the need for replacement. Transparent material laid over electricity generating solar panels could result in roadways that generate and transmit electricity to the regional grid or used locally by the agency.
- **Safety.** Deformable and cut resistant metals could extend the life of equipment which may continually be used in areas where there is constant friction. They may also be used to develop safety equipment to protect users where high speed cutting tools are used and could come in contact with users.

The prioritization of construction and civil engineering technologies, as shown in Figure 5, shows much more uncertainty than other emerging technologies evaluated by IBTTA members. Much of this is due to the still experimental nature of many of the innovations. However, dielectric profiling systems are already being used by transportation agencies to provide high-quality subsurface data without the use of destructive surveying methods. This technology thus has the potential to make a very near-term impact on how toll agencies undertake routine maintenance and surveying activities and is therefore discussed in more detail in the next section.

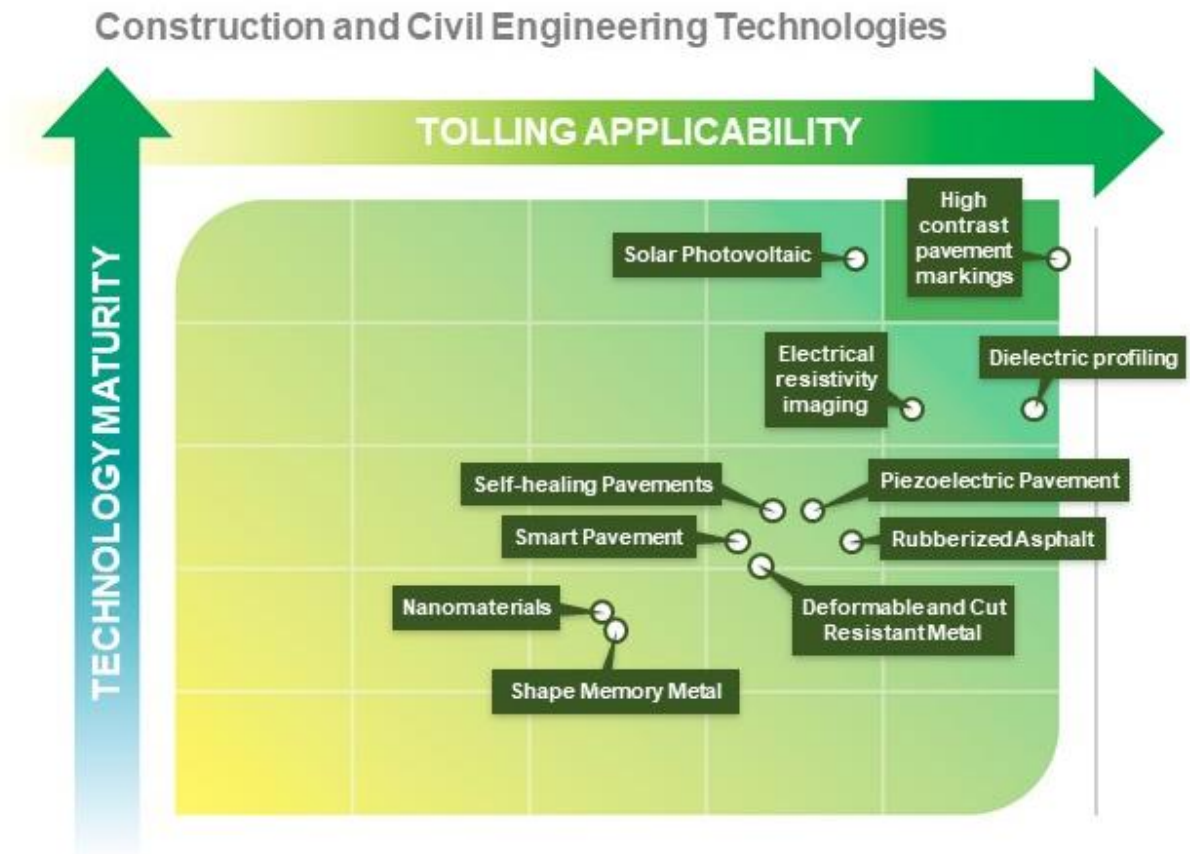

Figure 5: Prioritization of construction and civil engineering technologies

Dielectric Profiling Systems (DPS)

Subsurface investigations for asphalt pavement quality control and quality assurance are often based on destructive coring samples that may represent less than 1 percent of the in-service pavement. Furthermore, quality control with core samples requires waiting for asphalt to cool, drilling the core and then initiating performance tests, a process that requires at least 24 hours for results and may not allow agencies to make changes to the pavement following installation. Dielectric profiling systems (DPS) represent an emerging strategy for continuous assessment of asphalt pavement compaction quality that provide a much wider assessment of the area in less time and with no pavement destruction. These approaches work by measuring the pavement's dielectric constant, which is the ratio of the pavement's electric permeability relative to the electric permeability of free space (a vacuum). Figure 6 shows DPS device being used on a new roadway surface.

Figure 6: Dielectric Profiling System being used on new pavement (photo credit: Minnesota Department of Transportation)

The Minnesota Department of Transportation (MnDOT) began evaluating DPS approaches in 2015 as part of the federal Strategic Highway Research Program 2 (SHRP2). MnDOT conducted a series of field trials to assess the coreless calibration prediction by comparing DPS measurements with field core samples. These tests ultimately showed that DPS provided the equivalent of approximately 100,000 core samples per mile in terms of coverage. Researchers concluded that DPS can provide comprehensive asphalt compaction evaluations to inform construction-related decisions and has significant potential as a future quality assurance tool.

Analytics, data processing, and information technologies

An increasing array of data is available for agencies and the tolling industry at large for use in operations, administration and business intelligence related activities. As infrastructure, vehicles and users become more connected over time through the IoT and connected vehicle systems, the amount of data available will increase exponentially, posing challenges for agencies in terms of managing and transmitting that data internally and with partners and stakeholders within the tolling industry. The technology applications in this section of the report represent only a small slice of the innovations currently available and emerging within the tolling industry but are generally representative of those that have the highest likelihood of immediate and significant impact. IBTTA members are encouraged to review the IBTTA Emerging Technology Committee's various reports on Big Data for more information on these particular topics. Analytics, data processing and information technologies examined by the task force are shown in Table 6.

Table 6: Analytics, data processing, and information technologies

Technology	Description	Toll Applicability	Maturity
Distributed Ledger-based data sharing	Consists of a decentralized database. Each node within the distributed ledger maintains a ledger of the database, and updating the ledger occurs independently. Blockchain is a type of distributed ledger which consists of an interconnected and growing list of records, known as blocks, which are linked and protected using cryptography. Some systems do not use actual blocks, but benefit from the consensus model, internal system governance, reduced costs, and increased security.	**4.1**	**3.3**
Blockchain-based token payment and transfers	Consists of a blockchain based ledger of interconnected and growing list of records for purposes of tracking transfer of assets between parties. Each block includes a cryptographic hash that links to the previous block in the chain, a timestamp that establishes the creation or modification time of the block, and associated transaction data.	**3.8**	**3.4**
Artificial Intelligence and Machine Learning	The simulation of human intelligence processes by machines, especially computer systems, that include learning (the acquisition of information and rules for using the information), reasoning (using rules to reach approximate or definite conclusions) and self-correction.	**4.8**	**3.9**
Tokenization	Substitutes sensitive data elements associated with payment (like account details of the cardholder) with a non-sensitive equivalent, referred to as a token, that has no tangible meaning or value to external users (including merchants or hackers). Supports access to sensitive systems without the need to encrypt data for transmission.	**3.9**	**4.4**
Geofencing	The creation of virtual geographic boundaries, often using information from the Global Navigation Satellite System (GNSS) to establish boundaries pertaining to various jurisdictional boundaries such as cities, counties or states.	**4.5**	**4.1**

Current use cases include the following:

- **Vehicle classification.** Basic artificial intelligence and machine learning systems coupled with machine vision and vehicle imagery are used to validate vehicle attributes such as axle counts. This technology combination is also used for automated license plate analysis for either additional ID validation or audits.
- **Business processes.** Tokenization is currently used to enable high security customer data transmission in the financial sector. Tokenization is increasingly common for various business processes within the tolling industry and will become more prevalent with the increase in third-party tolling services.
- **Toll zone detection.** GNSS in conjunction with geofencing applications currently support truck tolling systems in Europe. Such technology approaches are also used to delineate state and other jurisdictional boundaries in location-based road usage charging systems. Smartphone tolling applications, such as those discussed in the Consumer Applications section of this report, often use GNSS and geofencing to notify the smartphone application that it is approaching a toll zone.

Future tolling use cases include the following:

- **Interoperability.** Blockchain-based data sharing may eventually serve as a platform for high-security, highly auditable interoperability processes.
- **Additional payment options.** Customers may use digital currency for account funding, which would likely be supported through blockchain-based token payments and transfers. They may also enable more secure and auditable transfer value between systems without using payment processors to validate transactions.
- **Business processes.** Artificial intelligence and machine learning could significantly improve automated image review processes.
- **Predictive analytics.** When coupled with advanced computing technologies, artificial intelligence and machine learning applications could support very detailed modeling of transportation events and long-term scenario building and evaluation.
- **Safety applications.** The processing of data in Basic Safety Messages (BSM) from connected and automated vehicle applications to identify potential safety and performance issues in real time will likely be supported by artificial intelligence and machine learning. This is likely to modify the role of traditional ITS systems.
- **Automated vehicle occupancy detection.** Artificial intelligence and machine learning will likely support automated vehicle occupancy detection through enhanced interpretation of various data elements such as in-vehicle or roadside sensing and detection systems. Such developments could reduce the need for visual enforcement on HOT lane systems. Agencies and companies like Transurban are looking at how this can be accomplished with cameras, infrared and similar equipment. However, in the future, vehicles may report occupancy automatically through connected and automated vehicle systems.

- **Alternative tolling services.** Geofencing could enable satellite tolling systems in the US and reduce the need for roadside infrastructure.

The prioritization of analytics, data processing and information technologies is shown in Figure 7. Artificial intelligence and machine learning are seen as having a high level of applicability in the tolling industry. A near term application of these technologies that can be explored by tolling agencies right now is that of call center modernization and automation, which is discussed in the next section.

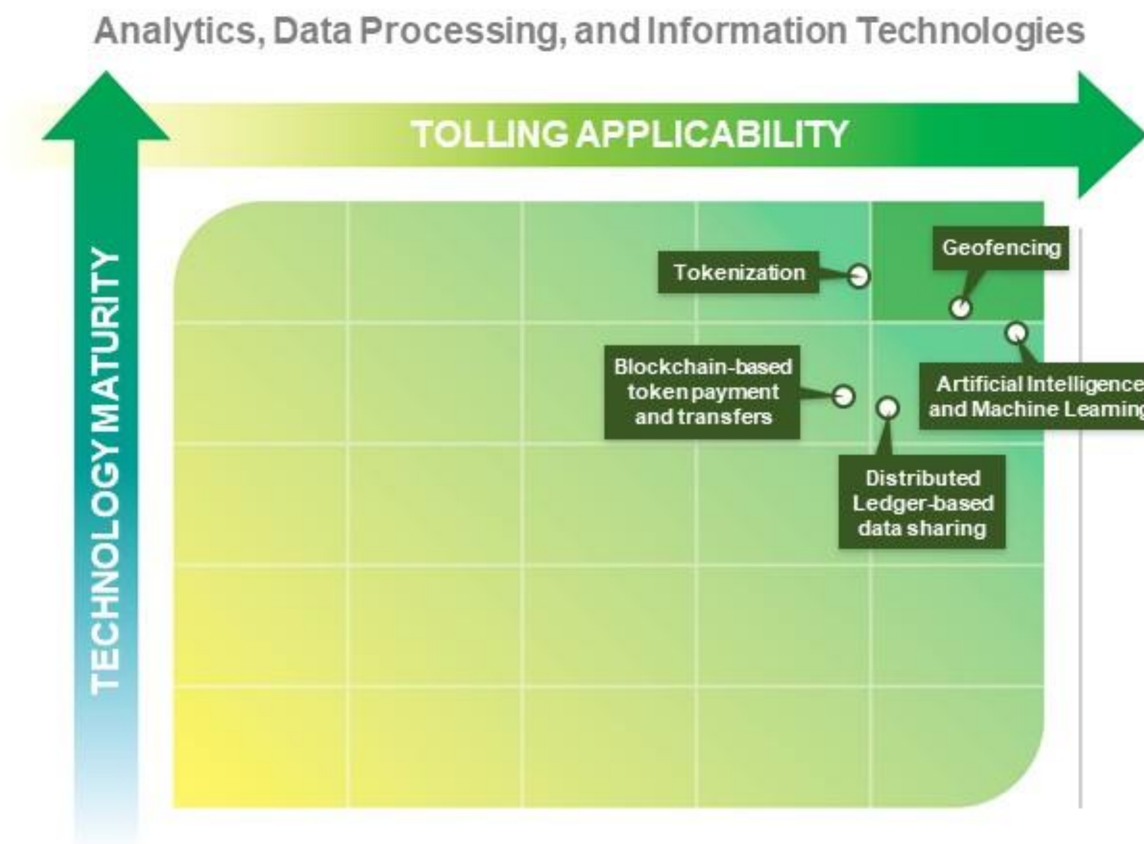

Figure 7: Prioritization of analytics, data processing, and information technologies

Contact Center Modernization and the Customer Experience (CX)

AI and machine learning applications are anticipated to significantly improve the operation of call centers and other tolling-related customer services. An intelligent call center (ICC) is already an important element of improving the customer experience (CX) while reducing costs to maximize return on investment (ROI).

A 2017 study by the Harvard Business Review concluded that "*81% of customers across all industries attempt to solve problems themselves prior to reaching out to a live representative*". Although this study is 3-years old, the number of customers expressing this sentiment has likely increased due to do demographics and specifically the entrance of younger, more tech savvy generations into the workplace. The same study went on to note that "*the cost of a do-it-yourself transaction is measured in pennies, while the average cost of a live service interaction (phone, email, or webchat) is more than $7 for a B2C company and more than $13 for a B2B company."*

While phone support is still important and necessary for resolving certain types of issues, it can be inefficient and costly. Contact centers that offer only phone and/or email support risk frustrating customers — or even losing them. As such, desired outcomes for an ICC are: first contact resolution, fast resolution speed, knowledgeable agents, easy experience, and reduced hold times. These objectives can be achieved by utilizing and/or integrating various technologies to create an "Omni Channel" approach. Some of these technologies are customer facing while others improve efficiencies in the back office and management. With the abundance of both technology options and system providers available, a thoughtful and strategic approach is required. The following are examples of how various technologies, including AI and machine learning, can be incorporated into future ICC systems for improved CX:

Self Service Efficiency

Applications that enable customers to resolve issues without interacting with an operator include:

- **Interactive Voice Response (IVR).** Routes calls to the appropriate queue for faster service, and can also allow customers to solve simple issues without an agent.
- **Automated Call Distributor (ACD).** Distributes calls to available agents and collects important analytics, like wait time, call length and call volume.
- **Intelligent Call Routing / Skills-Based Routing.** Uses predetermined parameters to prequalify and route calls to the most appropriate agent.
- **Artificial Intelligence (AI).** Uses tools like chatbots to automate routine support processes and capture predictive analytics. Common AI uses include:
    - Automated responses to initial customer contact, including information on next steps
    - Improving call routing
    - Handling simple transactional matters
    - Monitoring and analyzing trends in agent performance
    - Helping to tailor individual agent training
- **Robotic Process Automation (RPA).** The use of software bots to automate highly repetitive, routine tasks. This application overlaps with AI systems.
- **Agent Performance.** Applications that improve the performance of human operators.

- **Workflow Management.** Beyond agent scripting, full workflow management guides agents quickly to exactly where they need to be and automates tasks, saving each agent hundreds of hours per year.
- **Call Recording Systems.** Records all calls and stores them in case you need to review a particular call or use it for training purposes.
- **Speech Analytics.** Analyzes all interactions to identify insights and trends, as well as uncover inefficiency and service issues.
- **Real-Time Speech Analytics (RTSA).** Allows supervisors to monitor calls as they happen and to intervene as necessary.
- **Gamification.** Increases productivity and reduces turnover across the organization through recognition, competition and collaboration, and transforms daily routines into rewarding rivalries.

Customer Engagement

Applications that improve human-to-human interactions include:

- **Auto Responders.** Allows customers know their request is being actively worked on and when they can expect a response.
- **Call-Backs.** Gives customers the option to have an agent call them back so they don't have to sit on hold.
- **Self-Service Options.** Provides quick access to common issue solutions to improve customer satisfaction and reduce call volume.

Data Integration

Applications that support the integration of various back office and customer service center data systems include:

- **Customer Relationship Management (CRM).** Provides agents with a unified customer view to improve service and eliminate customer frustration of repeating personal information and issues.
- **Knowledge Management (KM).** Central information repository that agents can quickly and easily access to solve common issues.

Compliance and Security

Applications that improve compliance, reporting, and data security approaches include:

- **Voice Biometrics.** Uses the intricacies of the human voice to authenticate callers.
- **Regulatory Compliance.** Helps manage operations in accordance with government legislation and industry guidelines nationally and globally.
- **TCPA Compliance Solutions.** Requires manual dialing and prohibits adding software that can use a random or sequential number generator to predictive dial or automatic dial from a list.

- **PCI-DSS Compliance.** Secure hosting with a PCI-compliant provider is required for all companies that accept credit card payments and store, process and transmit cardholder data

Vehicle automation and connectivity

These technologies support the automation of vehicles and communications between vehicles, roadside infrastructure, and pedestrians and other potential user groups. They also support the automation of an array of services. This category includes some of the highest profile and most highly anticipated transportation innovations in the nation and agencies are currently testing and deploying numerous connected vehicle applications to support improved operations and safety. As automated vehicle technologies become refined and adopted, agencies will have to consider how they should be accommodated within their existing infrastructure network. This section provides only a very cursory overview of automation and connectivity technologies and readers are encouraged to read the various publications of the Emerging Technology Committee's Connected, Automated, Shared and Electric (CASE) Working Group for more detailed information. Technologies examined by the Technology Matrix Task Force are summarized in Table 7.

Table 7: Automation and connectivity technologies

Technology	Description	Toll Applicability	Maturity
Automated Vehicles	Refers to a range of sensors, communications, and data processing systems that enable vehicles to be piloted with little to no interaction from a human driver.	**4.1**	**3.0**
Wireless LAN V2X	Vehicle-to-everything (V2X) connectivity based on wireless local area network (WLAN) technology. Typically relies on media-to-media communication technologies such as DSRC for connection with the vehicle and does not require a cellular network for communications. Includes vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) applications.	**3.6**	**3.7**
Cellular V2X (CV2X)	Vehicle-to-everything (V2X) connectivity based on cellular technology. Requires connection to a cellular network and, in the case of 5G, localized cellular transmitters and receivers. Includes vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) applications.	**4.0**	**4.1**
Unmanned Aerial Vehicles (Drones)	Devices capable of flying by remote control that can be equipped with an array of cameras and sensing equipment	**3.6**	**4.4**

Current use cases for this group of technologies includes the following:

- **Traffic data.** Wireless LAN V2X and Cellular V2X (CV2X) applications both support collection of data transmitted by connected vehicles, such as basic safety messages (BSM), for use in various operations-related activities.

- **Traffic operations.** Wireless LAN V2X and Cellular V2X (CV2X) applications both support the transmission of signal phase and timing (SPaT) data from equipment at signalized intersections to equipped vehicles.
- **Maintenance.** Drones are currently used to support the unmanned inspection of bridges and other infrastructure. Such technologies are often coupled with LiDAR.
- **Surveying.** Drones, coupled with LiDAR, may be used for unmanned aerial surveying for construction and land development activities.

Potential future use cases for these technologies include the following:

- **Alternative tolling services.** Connected vehicle applications will be the primary technology supporting vehicle platooning. This may be a valuable service for agencies with long tollways or extensive networks featuring a significant amount of freight traffic.
- **Vehicle-to-vehicle (V2V) connectivity.** Connected vehicle applications will support the transmission of traffic conditions and events (such as slow downs, hard braking, forward collision warning, etc.) in real time among a platoon of connected vehicles.
- **Roadside and vehicle connectivity.** Connected vehicle applications will support the transmission of toll system information (such as rates, speed limits, incidents, construction zones, etc.) to the vehicle.
- **Roadway safety applications.** Connected vehicle applications will support safety services via communication between vehicles and infrastructure, including wrong-way driver detection and notification, bicycle and pedestrian detection, etc.
- **Incident detection, response, and clearance:** Drones, coupled with sensing and detection technologies, may provide highly accurate remote identification of incidents and other safety and performance related roadway situations.
- **Data security and privacy.** Security certificates for secure communications between vehicles and roadside infrastructure as part of connected vehicle applications are essential. In the future, tolling agencies may need to implement Security Certificate Management Systems (SCMS), particularly for services that depend on pulling and processing data from vehicles (as opposed to pushing data to vehicles). SCMS allows agencies to confirm that data received from vehicles and other sources can be trusted. INTEGRITY Security Services (ISS) is the primary issuer of security certificates in the US and issues about 51 billion a year. New York, Wyoming, Florida, and The Ray all use ISS' SCMS service. Furthermore, vehicle manufacturers obtain security certificates for their various CV applications from ISS. Most vehicles on the roadways are not currently equipped with the DSRC-based OBUs that would support CV applications and their associated security approaches. However, if the USDOT were to mandate all vehicles have onboard radios, tolling could become an optional service in future model vehicles without the need for purchasing tags or transponders.

The prioritization of automation and connectivity technologies is shown in Figure 8. Connected vehicles and, in particular, cellular V2X, were seen by the committee has having the highest potential impact to the tolling industry and is therefore discussed in more detail in the next section.

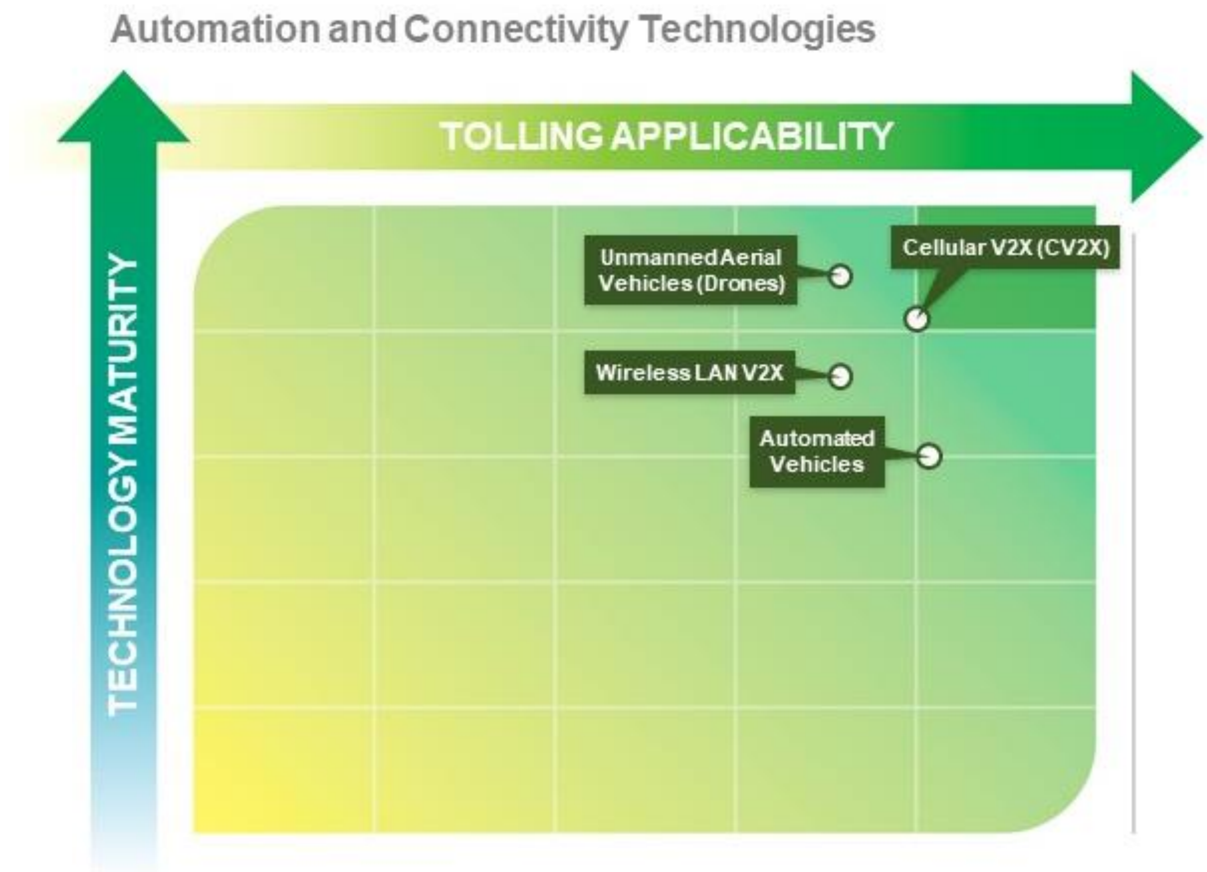

Figure 8: Prioritization of automation and connectivity technologies

Connected Vehicles and Cellular V2X

The Tampa Hillsborough Expressway Authority (THEA) was an early leader in the exploration of connected vehicle applications within a tolling environment. With funding from the US Department of Transportation's Connected Vehicle Pilot Deployment Program, THEA deployed 47 Roadside Units (RSUs) along the agency's Reversible Express Lane (REL) and within central Tampa. THEA also deployed over 1,000 Onboard Units (OBUs) in personal vehicles, buses, and streetcars as part of the pilot. Vendors were invited to demonstrate basic applications such as Forward Collision Warning (FCW), Emergency Electronic Brake Light (EEBL), Intersection Movement Assist (IMA), and some Vehicle to Infrastructure (V2I) applications. USDOT and THEA found that many vendors had difficulty demonstrating their applications within THEA's environment relative to their own test facilities, indicating a strong need for agencies to exercise caution and be conservative in evaluating potential CV partners.

Three vendors were eventually selected for the pilot, and an OBU specification was developed by the project's onboard vehicle integrator in cooperation with the vendors. USDOT and THEA observed that during development, vendors often struggled with the number of applications offered and the challenges of debugging at THEA as opposed to their facilities. At one point a vendor was dropped from the pilot due to vendor staff limitations, inability to support the pilot from outside the US, and a lack of industry footprint in the US. The remaining vendors collaborated along with the onboard vehicle integrator and infrastructure integrator to revolve remaining pilot issues. USDOT and THEA have noted that field testing and integration requirements were significantly underestimated and that more testing in a deployment situation, rather than a laboratory, was needed.

The pilot is ongoing, and a number of applications are being tested. Over 1,000 drivers had an enhanced rearview mirror installed in their cars to display safety messages and issue audio alerts. Vehicles communicate with other participating connected vehicles, traffic signals and other infrastructure. THEA is also testing pedestrian safety applications using advanced LIDAR sensors to detect pedestrians in crosswalks with roadside equipment broadcasting that information to nearby connected vehicles.

Developers and OEMs are, in many cases, moving beyond the wireless local area network (WLAN)-based applications that typified earlier CV initiative and focusing on development of cellular-based connected vehicle systems (CV2X). These approaches rely on the use of cellular communications channels in lieu of roadside units, expanding the range within which CV applications can be offered and reducing the need for technology hardware for agencies. Ford, for example, recently announced that it will include CV2X in all new vehicles starting in 2022 and is already working with agencies such as the Central Texas Regional Mobility Authority to test safety and toll processing-related applications using factory installed on-board equipment.

Consumer applications

Consumer applications are technologies and innovations that may impact the tolling industry due to their use by end-users, either through integration within a vehicle or through use on a smartphone. Typically, full engagement with the product requires integration to a tolling agency's back office systems. New applications are also being developed which tolling agencies may consider creating an interface or modifying systems to either produce or consume data associated with the consumer products. These are not necessarily technologies that a tolling agency would implement and operate but they should be accounted for in future operations and business practices. These applications are shown in Table 8.

Table 8: Consumer applications

Technology	Description	Toll Applicability	Maturity
Smartphone Tolling	The integration of required tolling communications protocols and technologies within smartphones.	**4.8**	**4.2**
Immersive Interfaces (heads-up displays)	Technologies that allow for the display of information on the interior windshield or other in-vehicle surface that eliminates the need to look away from the roadway.	**3.3**	**4.0**
Integrated Toll Modules (ITM)	Integration of required tolling communications protocols/ technologies as a standard feature on new model vehicles.	**4.2**	**3.6**
Electronic License Plates	License plates that incorporate Global Navigation Satellite System (GNSS) and wireless (cellular and DSRC) communications technology within a digital display.	**4.0**	**3.4**
Shared Mobility	Smartphone-based and other personal device-based applications that allow users to access various modes of travel from a registered service provider.	**3.7**	**4.0**
In-vehicle Telematics	Various sensor, telecommunications and data processing systems installed by the manufacturer as a standard feature on new model vehicles.	**4.3**	**3.4**
Mobility-as-a-Service / Mobility on Demand	Refers to a family of applications that allow transportation system users to access and pay for any number of alternative mobility services through an integrated platform.	**3.5**	**3.8**

Current tolling use cases include the following:

- **Alternative toll account management services.** Specialized tolling smartphone apps can be linked to license plate tolling accounts that preclude the need for a transponder. Furthermore, integrated tolling modules or similar communications devices are becoming more common as a standard feature in new model vehicles, precluding the need for aftermarket tags. Current designs for electronic license plates incorporate RFID equipment that could be detected in-lieu of windshield mounted tags or transponders.
- **Vehicle identification.** Current designs for electronic license plates incorporate RFID equipment that could be detected in-lieu of tags. Although untested, this could improve

the ability to read and recognize license plate imagery captured by roadside cameras. Furthermore, smartphone apps linked to license plate tolling accounts can help reduce the need for a transponder by users.

- **Automated Vehicle Occupancy Detection.** Smartphone-based occupancy detection approaches can be used to increase the accuracy of reported vehicle occupancy and reduce revenue risk and cost of roadside enforcement.

Future tolling cases include the following:

- **Alternative tolling services.** Immersive interfaces are being explored by auto manufacturers like Ford to display the current toll rate, speed information, vehicle navigation, and downstream congestion notifications broadcast in a heads-up display.
- **Virtual support.** Personnel equipped with augmented reality glasses or video can access support as needed for certain investigation, survey, operation, maintenance or repair, or construction tasks. Personnel may perform remote support and expertise to field staff through the platform as support personnel can observe and share information in real time through the field personnel's AR glasses or other video.

The prioritization of technologies associated with consumer applications is shown in Figure 9. Smartphone-based tolling applications are already on the market and used to varying degrees. As such, they are discussed in more detail in the next section.

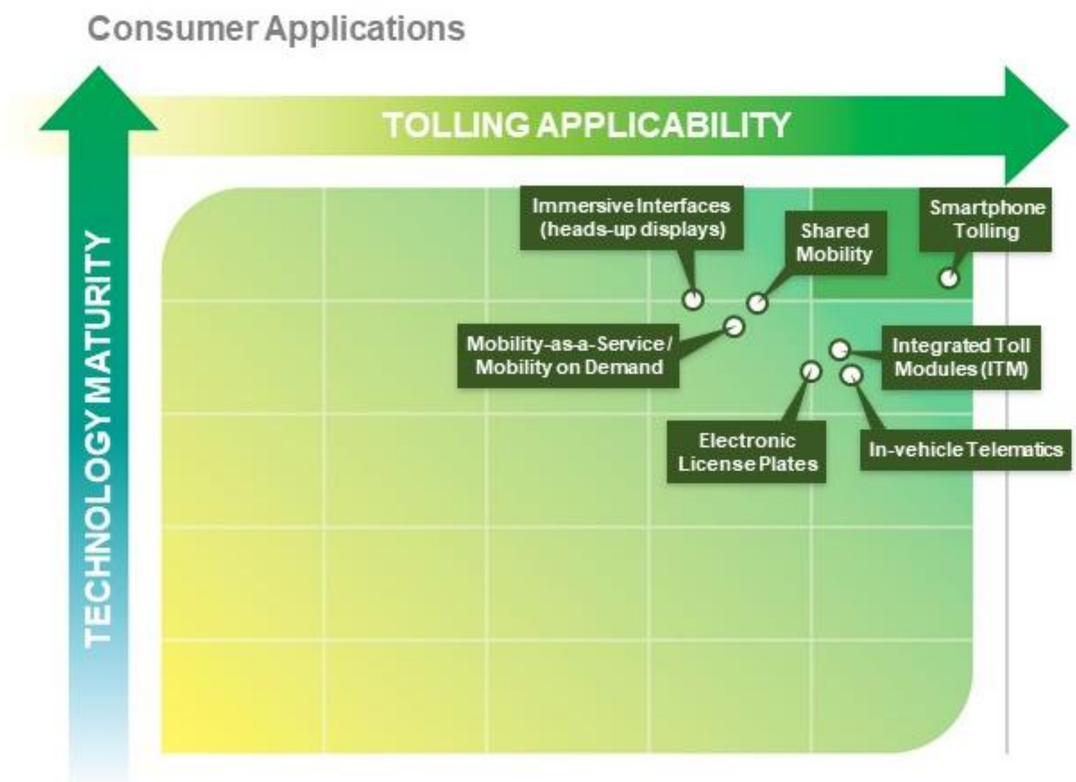

Figure 9: Prioritization of consumer applications

Smartphone/Mobile Tolling

Smartphone tolling applications allow users to access a number of different facilities without having the necessary transponder. For toll road users, a smartphone tolling account can be a convenient payment option that allows them to use a wider array of facilities and pay for them through an interface they are familiar with. For agencies, these applications represent a significant opportunity to expand their customer base, with over 3.5 billion smartphone users worldwide, and potentially shifting enforcement and some transaction processing costs to the private sector.

Smartphone tolling applications typically function like pay-by-plate accounts, in that they rely on the capture of license plate images at the roadside to track the transaction (from the agency/operator side). Typically, users establish an account with the service provider, capture the license plate and vehicle information either by photo or by manual entry, and fund the account or pay for transactions through various means. Image capture occurs in the lane at the time of transaction, and image review/OCR analysis occurs to identify vehicle/account association.

Some service providers couple their app with a sticker transponder, which is then affixed to the vehicle. The transponder is either issued directly to the service provider or the service provider is authorized to purchase approved transponders from a transponder manufacturer. The toll transaction in the lane occurs through reading the transponder at the time of the transaction. The toll operator validates the association of the transponder to the smartphone service provider, notifies the service provider of the transaction event, the service provider debits the customer's account, and transmits payment to the toll operator. At some point, these types of applications might not be necessary as automated vehicle systems may automatically initiate the necessary transactions.

GNSS is also used by some service providers to create transaction events on the customer side, however reconciliation with the toll agency must still occur to validate the transaction event recorded at the lane.

Smartphone tolling applications currently do not allow users to access all toll facilities. Each smartphone service provider must first coordinate with the relevant agency to facilitate the necessary exchange of information, and also establish a contractual agreement as the service provider in essence becomes an extension of the toll operator. The lack of ubiquity requires users check with their service provider and/or toll operator to ensure that a smartphone tolling application will function on a specific toll road.

Toll operators are encouraged to assess whether their current operational approach can support the necessary exchange of data with service providers. These services provide both an alternative user experience and payment options, which potentially improve customer satisfaction and reach alternative customer types. These services also have the potential to offload operational costs and increase transaction processing efficiency.

One current constraint on integration of these services is that toll operators still must maintain some infrastructure as a back-up to the smartphone tolling application services. If for some reason a smartphone customer's account is not funded, the tolling operator is still responsible for receiving payment for the transaction. Some service providers are guaranteeing payment of their customers transactions, which helps alleviate this issue, however this still requires that the smartphone or associate technology captures relevant data to represent the transaction event.

Innovations and developments in smartphone tolling are very much a near term issue for the tolling industry, as there are already a number of high-profile service providers operating within the tolling industry. These include, but are not limited to:

- **PayTollo.** Supported on facilities in California, Colorado, Florida, Georgia, Illinois, Massachusetts, New York, North Carolina, and Washington State.
- **PlusPass.** Supported on facilities in Texas, Florida, Washington State, Georgia, North Carolina, Illinois, Massachusetts and Colorado.
- **Peasy.** California, Colorado, Delaware, Florida, Georgia, Illinois, Kentucky, Massachusetts, Maryland, Maine, North Carolina, New Hampshire, New Jersey, New York, Texas, Virginia, Washington State
- **Uproads.** California and Texas
- **tapNpay.** North Texas

Transportation demand management

Transportation Demand Management (TDM) strategies focus on the management of traffic without the need for investing in additional roadway capacity. They focus on influencing driving behavior through strategies such as pricing and incentives to shift travel to different periods of the day, different routes, or different modes. Congestion pricing is among the most popular and effective of TDM strategies and is a common feature on the high occupancy toll lanes operated by many IBTTA member agencies. With transportation agencies facing growing funding shortfalls, TDM is an increasingly attractive option for addressing congestion. TDM applications of relevance to the tolling industry include those shown in Table 9.

Table 9: Transportation demand management applications

Technology	Description	Toll Applicability	Maturity
Cordon / Area Pricing	Establishing a geographic boundary and charging for crossing that boundary (cordon) or for travel on roads within that boundary (area).	**4.3**	**4.2**
Road Usage Charging	Charging vehicles for each mile driven as a transportation funding source.	**4.3**	**3.7**
Active Traffic Management	Dynamically managing recurrent and non-recurrent congestion based on prevailing and predicted traffic conditions to improve trip reliability. Increases throughput and safety with integrated systems incorporating new technology including automated dynamic deployment to quickly optimize performance.	**4.3**	**4.7**
Integrated Corridor Management	Bundling of ITS technologies and applications that improve transportation network performance in the efficient movement of people and goods through institutional collaboration and aggressive, proactive integration of existing infrastructure along major corridors.	**4.6**	**4.5**

Current tolling use cases for TDM are generally within the **traffic flow management** category. Active Traffic Management approaches are mostly used by local and regional agencies on their facilities but could find application within a tolling environment. These strategies include non-pricing options to improve system performance such as: Dynamic Lane Use / Shoulder Control, Dynamic Lane Reversal, Speed Harmonization / Dynamic Speed Limits, Dynamic Merge Control, Queue Warning, Signal Priority, Adaptive Ramp Metering / Managed Motorways, Dynamic Rerouting, Dynamic Junction Control, Adaptive Signal Control. Furthermore, ICM can be implemented as a means of better managing heavily used toll facilities in congested urban regions.

TDM applications within a tolling context will likely retain use cases in the **traffic flow management** category into the future. Advancements in the technologies discussed in this report will lead to improvements in the ability of TDM systems to improve traffic flows and manage congestion.

In the future, TDM applications will also likely see use cases in the realm of **alternative tolling services.** With an increasing focus on the use on congestion pricing to address traffic outside of the typical freeway/corridor context, such as in New York and Los Angeles, there is likely a strategic role for tolling vendors and agencies as part of operations and administration of future cordon or similar pricing approaches. Furthermore, although RUC systems are currently under development as a revenue alternative, they could facilitate widespread freeway tolling through their reliance on satellite technology. Finally, a national or regional RUC systems could facilitate more widespread **interoperability** through the promulgation of standards for technology, data transfer, etc.

The prioritization of Transportation Demand Management innovations is shown in Figure 10. ATM and ICM may be integrated as a package, have significant potential within a tolling context, but have not been well explored by the tolling industry. As such, they are covered in the next section of this paper. Additionally, RUC is discussed in more detail as it may have significant implications for the tolling industry in the long term due to the technology opportunities it affords and the institutional challenges it entails.

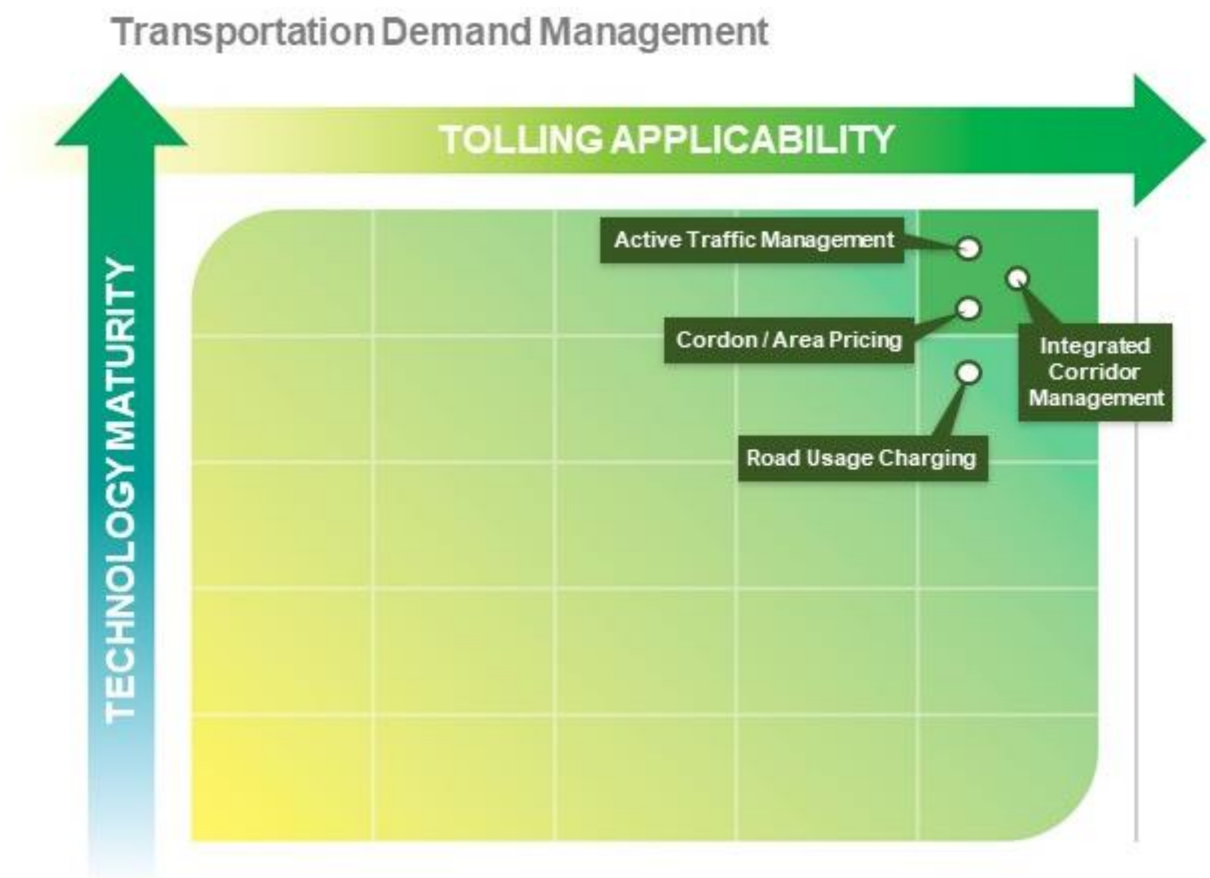

Figure 10: Prioritization of transportation demand management applications

Active Traffic Management (ATM) and Integrated Corridor Management (ICM)

Integrated Corridor Management involves the application of Active Traffic Management (ATM) strategies across multiple facilities, enabling dynamic network operation in response to real time conditions. Specific ATM strategies that might be implemented as part of an ICM approach include:

- **Dynamic lane use/shoulder control**. Involves opening roadway shoulders for use by vehicles in response to traffic volumes or the closing of mainline travel lanes to traffic in response to traffic incidents. Opening shoulders creates an additional travel lane for increased volume while closing mainlines allows vehicles to shift lanes in advance of an incident, reducing shocks to traffic flows.
- **Dynamic lane reversal / Contraflow lane reversal.** Involves reversing the direction of traffic flow on a dynamic basis to better control and allocate capacity during congested conditions. Lanes are switched to flow in the direction with the heaviest traffic volumes.
- **Dynamic speed limits/Speed Harmonization.** Involves the changing of speed limits on a dynamic basis based in response to roadway conditions, traffic levels, and/or weather conditions. Speed harmonization uses dynamic speed limits in order to slow traffic down well in advance of bottlenecks and queues, reducing sudden shocks to traffic flow caused by these slowdowns and reducing the chance of an incident.
- **Dynamic Merge Control.** Involves managing vehicular entry into merging areas on a dynamic basis with the use of dynamic message signs or lane control signs. Signs notify drivers that a merging maneuver is imminent and encourages drivers to make the maneuver quicker and reducing shockwaves to traffic flows upstream from the merge point.
- **Queue warning.** Involves using dynamic roadway warning signs to alert drivers that congestion or vehicular queues are ahead, reducing the chance of rear end collisions when traffic has slowed significantly or stopped on an otherwise fast-moving highway.
- **Signal Priority.** Involves managing traffic signals with sensor equipment so as to provide priority to special vehicle classes, most commonly transit vehicles. These vehicles are afforded a shorter wait time, longer green signals, or priority during left turn maneuvers.
- **Adaptive ramp metering.** Involves the dynamic adjustment of traffic signals located near roadway ramp entrances to manage vehicle flow onto major roadways. This requires algorithms, as opposed to traditional pre-determined static metering schedules, that take information from any number of sources to determine optimal flow rates onto the metered facility.
- **Dynamic rerouting.** Involves providing drivers with alternative route information in response to traffic or roadway incidents or conditions that impact travel times on a dynamic basis, allowing them to bypass congestion.
- **Dynamic junction control.** Manages access on mainlines and ramp lanes based on traffic conditions such that priority at roadway junctions is given to facilities with higher traffic volume so as to minimize the impact of merging/diverging movements. This can be done through dynamic lane assignment or opening shoulders.

- **Adaptive traffic signal control.** Involves maximizing vehicle throughput at traffic signals by dynamically adjusting phasing and timing based on prevailing traffic conditions.

As state agencies continue to grapple with transportation funding shortfalls and unmet maintenance needs, it is likely that local and regional agencies will have to find ways to better manage existing infrastructure in the absence of new funds for capacity expansion. Heavily congested urban regions are likely to turn to ATM and, eventually, ICM strategies that are likely to include toll and managed lanes facilities as part of a region-wide network approach to management. The gradual increase in transportation system management and operations (TSMO) among regional transportation partners is an initial step in this process. Table 10 shows locations where ATM strategies are already in place.

Table 10: ATM strategies in the US

Location	ATM Strategies
Mobile County, AL / Flagstaff, AZ / Portland, ME / Truckee River, NV / Pittsburgh, PA / Knoxville, TN / Cheyenne, WY	Dynamic Speed Limits (weather based)
Los Angeles, CA / Minneapolis, MN / Portland, OR / Houston, TX	Adaptive Ramp Metering
Seattle, WA	Dynamic Lane Use Control, Dynamic Speed Limits, Queue Warning, Adaptive Ramp Metering
Northern Virginia, New Jersey	Dynamic Lane Use Control, Dynamic Speed Limits, Queue Warning, Dynamic Shoulder Use
Los Angeles, CA	Dynamic Junction Control
Chicago, IL	Shoulder Use
St. Louis, MO / Staley's Junction, OR	Dynamic Speed Limits
Manhattan, NY	Adaptive Signal Control

As noted earlier, ICM involves the integration of various ATM applications across numerous facilities for broader roadway network management. This integration occurs along three dimensions:

- **Institutional Integration.** Coordination of and collaboration between various agencies, jurisdictions and system stakeholders. During institutional integration, operational roles and responsibilities are assigned and/or shared in a manner that crosses traditional institutional boundaries.
- **Operational Integration.** Implementation of multi-agency transportation management strategies to promote information sharing and coordinated operations across the various transportation networks, thus aiding in the management of capacity and demand.
- **Technical Integration.** Sharing of information, system operations, and control functions accomplished through communications links between agencies, system interfaces, and

associated standards. Technical integration allows all affected agencies to view, monitor and evaluate the impact of operational decisions, which can only be accomplished following institutional and operational integration.

ICM is currently applied along a 20-mile section of I-15 from the City of San Diego to the City of Escondido. First implemented in 2013, the system uses advanced technology to operate and manage freeway, surface streets, and transit networks in a coordinated manner to improve system efficiency and maximize mobility for travelers. This includes predictive algorithms and real-time modeling tools to forecast traffic across the managed networks and recommend strategies to manage anticipated congestion. Such strategies include coordinating freeway ramp meters and arterial traffic signals as well as providing possible routing information for travelers to detour around major incidents.

Road Usage Charging (RUC)

Many states are exploring Road Usage Charging (RUC) as an alternative to fuel taxes for funding transportation programs. A RUC is similar to tolling in that road users pay based on distance travelled, which is seen as advantageous over fuel taxes that are levied-on a per gallon basis and will therefore return less and less revenue per mile driven as vehicles become more fuel efficient. While there are many ways that a RUC can be levied, the most popular approach is to use in-vehicle devices that determine miles driven with GNSS signals or through a connection to the vehicular diagnostic report. Travel information is uploaded to a back office where rates are assigned, and an invoice is generated. RUC systems in the future will likely be heavily reliant on the private sector to provide devices and manage individual user accounts.

The tolling industry has often viewed RUC as potential competition to tolls. For example, if a national RUC were to be implemented, the national roadway system could be thought of as a national toll road network. In this event, policy makers and the public may desire that RUC systems cover toll roads in their assessment and transaction processing systems to improve convenience for drivers. A national RUC account could be thought of as an interoperable toll account that would allow for travel and assessment of fees across all roadways. This may be seen as a loss of control over operations and customer touch points for toll road operators. Furthermore, such a national approach would directly compete with tag/transponder providers and integrators that operate existing back office tolling systems.

However, toll road operators and their contractors have an opportunity to leverage their knowledge and skill sets to influence RUC system development, particularly in terms of back office operation and account management. Operators are experienced with managing accounts while processing trip transactions at a larger scale than any RUC pilot conducted to date. And there is still time for the tolling industry to get involved with RUC development. To date there have been several pilots of the concept but only one deployment: the Oregon OReGO system. It is voluntary and participation numbers are well below what was envisioned upon its implementation.