Best Practices Guide for Improving Automated License Plate Reader Effectiveness through Uniform License Plate Design and Manufacture

July, 2012

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In early 2011, Customs and Border Protection (CBP) asked the American Association of Motor Vehicle Administrators (AAMVA) if stacked letters are part of a state's official license plate number. AAMVA advised that a national standard does not exist. Subsequent discussions revealed a broader scope of issues that adversely impact Automated License Plate Reader (ALPR) effectiveness in accurately reading license plate numbers. Further complicating the issue is the fact that many of the business rules governing the creation of license plate numbers vary from state to state.

As a result, AAMVA formed the *ALPR Working Group* to address the non-standardization of license plate design and manufacture among the states as well as the provinces and territories of Canada (hereinafter referred to as jurisdictions).

The Working Group, funded by CBP, conducted its first meeting in June 2011. Working group members included representatives from state motor vehicle agencies, law enforcement, a toll authority and CBP. Several industry representatives served as technical advisors to the working group.

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Executive Summary

Since their inception more than a century ago, the license plate has primarily been used to display information for fast and accurate identification of a motor vehicle and to demonstrate compliance with motor vehicle registration laws.

Automated License Plate Readers (ALPRs) provide law enforcement with the ability to check license plates against various databases. Inconsistent business rules utilized by the entities who issue license plates result in "misreads", diminishing law enforcement's ability to identify and apprehend suspected criminals or terrorists, recover stolen vehicles, or assist people in need of assistance. In addition, these inconsistencies hamper Customs and Border Protection's (CBP) ability to correctly identify vehicles crossing international borders.

Tolling authorities that collect tolls using ALPR or similar technology are also harmed by inconsistencies between jurisdictions and government entities are losing revenue from uncollected tolls caused by inaccurate reads of license plates.

A recent study conducted by the Police Executive Research Forum (PERF)[1] and the Mesa, Arizona Police Department concluded that ALPRs increased license plate reads by a factor of more than eight . What the study did not, and could not reveal, is the number of hits "missed" because of license plate misreads. A study conducted by one tolling authority established a misread rate of 20%. Regardless of the misread rate in a particular jurisdiction, there is no refuting that misreads occur. And when they do, the potential exists to miss opportunities to arrest a suspected criminal or terrorist, to recover a stolen vehicle, or collect toll revenue.

The purpose of this guide is to identify best practices in license plate design, manufacture and issuance to aid jurisdictions in creating and issuing license plates best suited to vehicle identification. The lack of national standards regarding the design and manufacturing of license plates limits the effectiveness of ALPR technology meant to assist in improving highway and public safety. License plates serve a common purpose across jurisdictions. They should also share common characteristics that allow readability, usability, and connections to vehicle registration records.

The scope of these recommendations is limited to the physical characteristics of license plates, the information displayed on plates, and the placement of license plates on motor vehicles and trailers. Rules on issues peripheral to these concerns, such as plate assignment (plate with owner), personalization, or manufacturing sites are outside the scope of this document.

[1] Critical Issues in Policing Series: "How Are Innovations in Technology Transforming Policing?" Police Executive Research Forum, January 2012.

Section I
Problem Statement

A functional, accurate and cost effective system for reading license plates is critical to public safety and security. Automated License Plate Readers (ALPRs) provide law enforcement with the ability to check the license plate against various databases such as the National Crime Information Center (NCIC), Terrorist Watch Lists, and suspended driver records, to name just a few. The police agency using the technology may choose which databases to check against using ALPR technology.

Inconsistent business rules utilized by the entities who issue license plates result in "misreads", diminishing law enforcement's ability to identify and apprehend suspected criminals or terrorists, recover stolen vehicles, or assist people in need of assistance. In addition, these inconsistencies hamper Customs and Border Protection's (CBP) ability to correctly identify vehicles crossing international borders using ALPR technology.

These inconsistencies include, but are not limited to:

- use of stacked characters and whether they are part of the official license plate number
- use of non-alpha/numeric characters
- license plate design and manufacture
- license plate covers, frames and lighting
- one vs. two plate requirements

Federal, State, local and tribal public safety agencies rely on accurate and timely information to effectively and efficiently perform the multiple tasks required as part of their job. Information is available in multiple formats, including Be On the Look Out (BOLO), Attempt to Locate (ATL), officer safety information, missing persons, Amber Alerts for at risk children, Silver Alerts for at risk adults, and more. Information regarding homeland security, terrorism or extremist activity is also available. Much of this information can be, and often is, associated with a vehicle's license plate. The ability of license plate readers to quickly and accurately scan thousands of license plates is as critical to the men and women of law enforcement who contact hundreds of thousands of people throughout the United States and Canada every day, as it is to CBP officers and agents monitoring international ports of entry.

The tolling authorities that collect tolls using ALPR or similar technology are also harmed by inconsistencies between jurisdictions. Government entities are losing revenue from uncollected tolls caused by inaccurate reads of license plates.

The full potential of ALPR will not be realized without standardizing certain business rules for license plate design and manufacture across all North American jurisdictions. Currently, the disparity of license plate characters, the use of special logos, and plate visibility issues are significant challenges preventing

fully effective use of this technology. National standards for license plate formats are necessary to maximize the efficiency and effectiveness of ALPR technology and its role in improving officer, traffic, and public safety as well as to minimize lost revenue to governments that administer toll roads.

Section 2
License Plate History & Background

Introduction

Since their inception more than a century ago, the license plate has primarily been used to display information for fast and accurate identification of a motor vehicle and to demonstrate compliance with motor vehicle registration laws.

Specialty and vanity plates have since emerged and become a source of revenue for highway funding, toll authorities and sponsoring organizations. They also promote the issuing jurisdiction and many worthy causes.

Hand-Made, Horse-Drawn

The first record of a registration plate in the United States was in Philadelphia, Pennsylvania in the 1850s. Even then, legibility of plates was a concern and horse-drawn vehicles required registration to be identified with numbers "not less than four inches high". Among other things, these numbers provided a means of identification when reporting an incident involving inappropriate or reckless driving. Today, only the state of Indiana still requires a license plate on a horse-drawn carriage.

The construction of these early registration plates was left to the innovation of the vehicle owner; wood, brass or other metals affixed to leather backings were common means of construction. During the next 50 years many cities required registration, and frequently required payment of a modest registration fee.

Early Mass Production and Uniformity

In the early 1900s with the advent of motorized vehicles, jurisdictions took responsibility for registration and standardization of plate issuance.

In 1901, New York became the first state to require license numbers on motor vehicles. In 1903, Massachusetts was the first state to issue a standard statewide plate. Others soon followed, but issuance of plates remained inconsistent.

California also began requiring plates in 1903 but did not produce them; the Automobile Club of Southern California (an early AAA organization) issued license plates – called mouse ears – to members for $1.00. The state assumed this responsibility in 1910.

Starting in 1903, "mouse ear" plates were sold for $1 by the Automobile Club of Southern California.

By 1915, nearly all jurisdictions issued license plates on an annual basis and charged a registration fee that allowed a vehicle to be driven on public roads. It was recognized early on by government officials that a registration system provided a level of security and a source of transportation revenue. However, license plate design continued down an inconsistent, haphazard path. It wasn't until 1956 that a standard plate size (12" x 6") was introduced at the request of automobile manufacturers to make it easier to incorporate mounting devices for license plates.

Integrating Safety Concepts

With the rapid increase in the motor vehicle population in the 1920s and 30s, traffic crashes increased dramatically, leading to the need to improve not only vehicle identification, but also vehicle safety. The license plate became one means to improve safety by providing a device that improved the night

visibility of motor vehicles. The first retro-reflective license plates in the U.S. were issued by New Mexico in 1936 and used glass beads embedded in paint.

As retro-reflective technology advanced, fully retro-reflective plates became possible and the first was issued by Connecticut in 1947, followed by Maine in 1949. Delaware followed suit in 1950, followed by Rhode Island and Oregon in 1951.

During the 1950s, relatively new sheeting utilized enclosed lens technology and gave retro-reflective plates their biggest boost. Minnesota had the distinction of being the first state to use the sheeting on automobile license plates.

The effect that retro-reflective plates had on nighttime motor vehicle crashes was dramatic, and it did not go unnoticed. In 1956 - the first year of use in Minnesota - deaths due to automobile crashes in rural areas dropped from 24 to nine percent. Urban area fatalities involving parked vehicles decreased from 28 to 7 percent. Over the first 14 years that the State of Maine had retro-reflective plates on its vehicles, highway officials estimated that there was a 58 percent reduction in after-dark, vehicle-related fatalities.

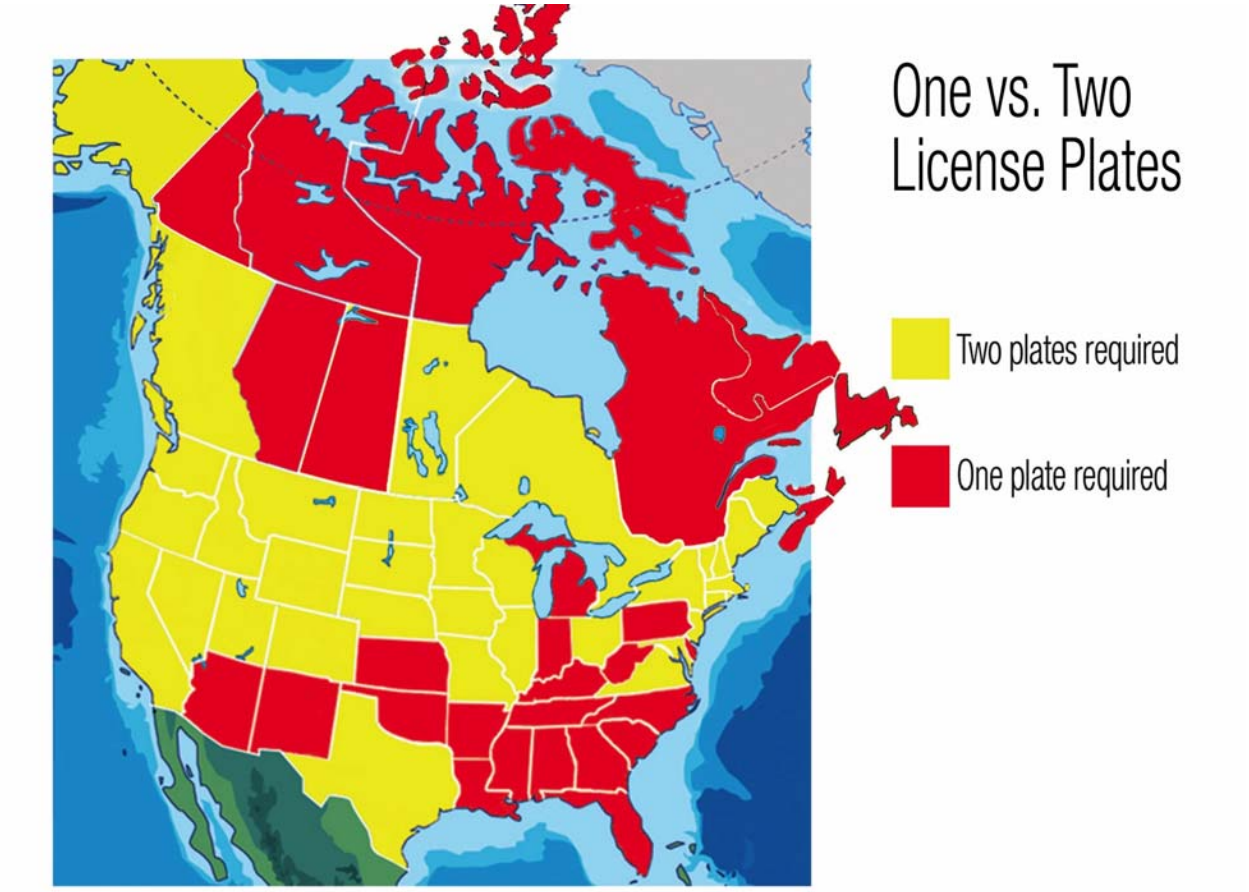
Standards Materialize

Tiny San Marino – the smallest republic in Europe, with an area of only 24 square miles – had the distinction of being the first country on that continent to make reflective license plates mandatory; on all 2,500 of its automobiles. In another hemisphere, the South and Central American countries of Peru and Costa Rica also became pioneers in retro-reflective license plates. In Canada, the provinces of Newfoundland and Alberta led the way. Today, all 50 U.S. states and a majority of other countries in the world use retro-reflective plates.

With the advent of retro-reflective license plates, law enforcement realized a benefit in improved legibility. While one of the original intents of a vehicle registration number was to aid law enforcement, the reality was that non-reflective plates could only be easily read during daylight hours. Retro-reflection provided greatly improved legibility at night, and even today fully retro-reflective plates continue to have strong endorsement from U.S. law enforcement officials, who advocate fully retro-reflective plates on both the front and rear of the vehicle for improved safety and law enforcement efficiency.

While early license plates were often homemade or devised of porcelain, steel became the predominant base material for plates during the first half of the 20th century. However, during the period that covered the Second World War, there was a high demand for steel. In order to conserve steel for the war effort, most states issued only one plate per vehicle. Today, aluminum dominates as the material used in license plate manufacture.

After 1945, most states returned to the pre-war practice of requiring two plates per vehicle. Since then a number of states have moved from two plates to one or vice versa. States typically move to one plate with the intent to save on the cost of the second plate. During the late 1980s, Connecticut was the last state to move from one plate to two plates. Law enforcement effectiveness was cited as the primary reason for the change. The U.S. and Canada are two of a small number of countries that allow one plate. The following chart identifies the North American jurisdictions that require either one or two license plates.



In the U.S. and Canada, 38 jurisdictions require two plates, while 28 require only one.

Within the U.S. and Canada, each jurisdiction is responsible for issuing license plates for vehicles registered in their jurisdiction. In order to create a plate unique and easily recognizable to that jurisdiction, combinations of colors were originally used. Plate background color and colors of the alphanumeric were varied, along with the characters, to create the necessary combinations needed for vehicle classifications and to differentiate plates among the jurisdictions. With increases in vehicle populations and registration classifications, color alone was not enough. Graphic technology became available in the early 1970s that allowed another level of differentiation of license plates. In 1973, Illinois was the first state to use graphics preprinted on the reflective sheeting, for a special plate for disabled veterans. South Dakota quickly followed with the first general issue graphic of Mount Rushmore National Monument. Today, all jurisdictions use graphic plate design. When first introduced, graphic design plates were viewed as attractive and as a mechanism to enhance the image of the jurisdiction. However, since the proliferation of graphic plate designs, law enforcement is no longer able

to easily recognize the issuing jurisdiction. The wide spread use of graphics and colors frequently makes legibility of the plate characters a challenge for law enforcement.

Modern Features and Security

Until the 1990s, all of the U.S. and Canada, and the majority of the rest of the world, produced license plates with raised (embossed) alpha/numeric characters. In the late 1990s, digital printing technology was introduced resulting in flat, digitally printed license plates. Today, almost half the states are using flat plates.

As a result of increasing concern with the use of counterfeit license plates used to perpetrate crimes, security features were added to the license plate. These security features allow for easy recognition of fraudulent plates and provides one more obstacle for criminals to overcome.

The following functions of a license plate have been, and continue to be, the most important over the past century:

- Display of information necessary for fast and accurate identification of a motor vehicle in actual traffic conditions
- Display of information (including the validation sticker) necessary to show compliance with motor vehicle registration laws by the owner of the vehicle
- Provide an added margin of visibility and safety by making vehicles more visible through use of a bright reflective surface of the plate

More recently, additional functions of license plates have emerged to:

- Provide revenue for highway funds, toll authorities and sponsoring organizations (specialty and vanity plates)
- Provide a way for individuals to express their pride, or to promote conservation, education and other causes
- Provide access control to parking, facilities, and gated communities.

In the U.S., the majority of states produce plates in a state correctional facility where labor is cheap, while the rest of the world produces plates through private commercial manufacturers.

The Future of License Plates

Today's license plate sheeting uses glass bead technology that is decades old and limits product performance improvement initiatives. Glass beaded sheeting capabilities are based on specifications that are related to how we view highway and roadway signs. In recent decades, highway and roadway reflective sheeting technology has evolved to meet the needs of motorists. Meanwhile, license plate sheeting has remained unchanged. With an understanding that license plates are viewed differently (especially at shorter distances), there is an opportunity to develop a product that offers better visibility, legibility and aesthetics.

In addition to sheeting improvements, there are new printing processes and materials that can increase the readability of the license plate. New inks for printing background graphics and alphanumerics can

increase the contrast between them and provide improved readability of the license plate. New machine readable features, such as two-dimensional bar codes, can provide a higher confidence than alphanumeric reading only in an automated read environment. The combination of the new materials, along with machine readable features, will add another level of improved license plate readability, both human and automated in the future.

Section 3
Fundamentals of Automated License Plate Readers

Introduction

This section provides an overview of automated license plate readers (ALPR), the license plate reading process, and key challenges in license plate reader systems as they relate to license plate design.

Automated license plate reader systems are increasingly being used throughout the world. The terms are interchangeable, but the technology is generally known as LPR (license plate readers), ALPR (automated license plate reader) or ANPR (automated number plate reader).

Growth of the technology in the United States has been significant in the last five years and is projected to grow exponentially over the next five to ten years. Typical applications for license plate reader technology by law enforcement, motor vehicle administrations and other entities, include, but are not limited to:

- Recovery of stolen vehicles
- Amber Alerts
- Open road tolling (pay by plate)
- Congestion charging
- Parking enforcement
- Access control
- Traffic studies
- Electronic vehicle registration
- Automatic speed enforcement
- Asset recovery
- Insurance fraud
- On-street parking enforcement
- Travel or journey time calculations
- Security monitoring

As the demand for ALPR systems expands in both law enforcement and commercial applications, ALPR technology continues to evolve. It provides cost efficient approaches in varied environments that include both environmental challenges (e.g., mobile-based platforms, high speed traffic) and license plate challenges (e.g., introduction of new designs, fonts, etc. across multiple states).

The reads from ALPR systems, namely the license plate number and in some applications the license plate jurisdiction, are primarily used as input into downstream systems to support the intended application. For example, in open road tolling systems, the license plate number/jurisdiction are used to support the collection of toll revenues, while in federal and state law enforcement systems, the license plate number/jurisdiction are used to support law enforcement queries against both large-scale (e.g., National Crime Information Center) and local data sources. More frequently, ALPR system results, generated from a variety of applications, are used as evidence in court cases.

In the majority of applications, manual verification and/or certification of ALPR results is required at some point in the process. To the extent ALPR systems can improve and retain a high degree of accuracy, operational costs can be reduced. In some applications, ALPR system service level objectives call for a 95 percent accuracy rate in correctly identifying both the license plate number and jurisdiction when the license plate is completely visible in the license plate image. The most significant challenge to maximizing license plate read rate accuracy is the ability of license plate reader system vendors to quickly adapt to the introduction of jurisdictional license plate designs with varying fonts, graphical designs, stacked letters, etc.

Automated License Plate Reader Systems

ALPR systems include deployment of fixed, portable, mobile, and handheld platforms.

Fixed Platforms

Fixed license plate reader systems are defined as any ALPR system that is permanently mounted on a fixed infrastructure such as overhead gantries, roadside bollards and/or poles, roadside buildings, etc. ALPR fixed platforms are commonly used in open road tolling, security, and in some federal and local law enforcement applications.

Fixed ALPR in Open Road Tolling

Fixed ALPR in CBP Inbound

Portable Platforms

Portable ALPR systems are defined as any ALPR system that can be transported between locations, assembled, operated and then disassembled. Once deployed, they operate as a fixed platform. Examples include portable trailers, traffic barrels or other platforms configured with, or containing ALPR equipment.

Portable Speed Trailer with LPR

Border Patrol Tactical Trailer

Mobile Platforms

Mobile license plate reader systems are defined as any ALPR system that is mounted on a vehicle, whether a police car, tow truck, street sweeper, parking enforcement vehicle, etc. These systems can include one to four camera configurations and are typically mounted on the roof or trunk, or they are custom manufactured.

Typical components of mobile systems include cameras that obtain images of the plate and vehicle which in turn are passed to a processor mounted in the trunk. The processor locates the license plate in the image and extracts the license plate number. It then compares the textual license plate read against selected data sources and sends the output in the form of an alert to a mobile data terminal (screen) and an operator in the cab. The alert typically contains the name of the data source to which the image was compared such as an expired license or registration system, an infrared image of the license plate and color overview image of the vehicle in question. Data generated from mobile ALPR systems can also be stored or transmitted via a back office software application.

Roof Mounted ALPR

Trunk Mounted ALPR

Handheld Platforms

Handheld license plate reader platforms are defined as ALPR systems that are held and operated by individuals using devices such as barcode readers, ruggedized PDA, and/or smart phones that provide other capabilities (e.g., communications, internet access). These technologies provide mobile ALPR capabilities and rely on the user to point the imager towards the location of the license plate.

Use of these devices is limited to no or low speed applications and are subject to unique challenges such as shadows, low ambient light, distance/angle to the license plate surface, and non-reflective surfaces. These limits can be overcome using techniques to suppress shadows and enhance low light situations by managing white light or infrared illuminators resident in the device. Since infrared imagers are not typically available on commercial general purpose handheld devices, overcoming readability of non-reflective surfaces using a color imager generally requires special Optical Character Recognition (OCR) techniques.

Hand held platforms are useful because they are easily deployed and can be used in parking lots, parking enforcement, covert applications, portable checkpoints, etc. Benefits include portability, relatively low cost and tactical use. One major drawback is that they are battery operated and their use in ALPR activity drains batteries much faster than normal usage.

ALPR Camera Technology

Two primary approaches are used to capture images from which the license plate information can be extracted. One approach is to capture a single still image of the license plate at an "optimal" distance from the camera, where the illumination, lens settings and field of view can all be controlled to yield the best possible images under any ambient lighting and weather conditions. Another approach is to capture multiple images as the vehicle travels through the field of view of the camera. In this approach, near instantaneous adjustments to the flash, shutter and gain settings are performed to optimize the license plate image for different environmental conditions.

Monochrome (black and white), color, and infrared cameras are employed in various solutions. Monochrome cameras tend to yield the best resolution, can work with most types of visible light illumination, and are generally less costly. Color cameras are useful when the color information can be used to improve the separation between characters and background, and for identification of the jurisdiction. Color cameras require white light in order to produce accurate color information and are of very limited value at night without the use of additional illumination.

Infrared cameras are tuned to respond to infrared (IR) illumination. Infrared cameras tend to be most sensitive at night and tend to be fitted with a band-pass filter designed to block visible light (to limit the effect of headlights and sunlight). This tuned IR illumination is effective at reflecting off the reflective background finish of the plate, and not reflecting off the non-reflective characters (or vice versa).

Additional cameras are often employed as part of the solution so that both a plate image and a vehicle image can be simultaneously captured to provide context and for investigative purposes.

License Plate Recognition Process

The license plate recognition process begins when a vehicle is detected by an ALPR system and ends when ALPR system information has been collected, analyzed, and handed off to backend systems for further processing.

The key steps of the ALPR process are to:

- Detect the vehicle and/or license plate
- Locate the license plate in the image(s)
- Extract license plate characters from the background
- Identify the license plate number
- Determine the license plate jurisdiction *(optional)*
- Hand-off ALPR results to backend systems

The following paragraphs describe each of the ALPR steps in detail.

Detecting the Vehicle and/or License Plate

External triggers such as through-beam infrared sensors, retro-reflective license plate sensors, ground-based induction loops, laser range sensors, etc., can be used to detect the presence of a vehicle in the field of view of the ALPR system. These types of triggers are primarily used in fixed platform ALPR systems. Alternatively, the ALPR system detects the presence of a license plate by analyzing the camera's video signal (which may capture up to 30 images per second) and looking for potential license plate candidates. This type of detection is primarily used in mobile platform ALPR systems and can support vehicle speeds up to 140 mph.

Once the vehicle is detected, the ALPR captures one or more images containing the license plate that will be used to support the subsequent license plate number and jurisdiction determination. In addition, vehicle and/or license plate detection is used to correlate other information gathered by the license plate system such as scene images, driver images, time stamps, or other vehicle-related information that can be determined by the ALPR system.

Locating the License Plate in the Image

Once one or more images containing a license plate are captured, a "license plate finder" algorithm is used to determine the exact location of the license plate in the image. This may be accomplished by searching for license plate characteristics (e.g., high-contrast objects) and/or character strings in the image that indicate the presence of a license plate. This process is one of the most difficult steps of the ALPR process as the license plate must be located in potentially 'noisy' images that contain other information that may appear as license plates (e.g., bumper stickers, other writing, contrasting graphic designs). In addition, the type and condition of the license plate (e.g., retro-reflective, non-reflective, license plate frames and covers, license plate orientation) may require the use of special lighting and camera technologies to both locate and present the optimal license plate image to the character recognition algorithms.

Camera Arrangement	Resulting Image with Unchanged Ambient Conditions
Flash Duration = 130 µs Shutter Duration: = 200 µs Gain = 2	
Flash Duration = 390 µs Shutter Duration: = 500 µs Gain = 2	
Flash Duration = 780 µs Shutter Duration: = 1000 µs Gain = 2	

As shown in the picture to the left, ALPR cameras can vary flash, shutter, and gain settings to capture multiple images per vehicle over a wide range of ambient and environmental conditions.

By varying camera settings and controlling illumination, the ability to locate a license plate within an image can be greatly improved. In addition, the 'best' image can also be used to improve the accuracy of the subsequent character extraction and license plate number determination.

An example of a license plate that has been located in the larger vehicle image captured by an ALPR camera.

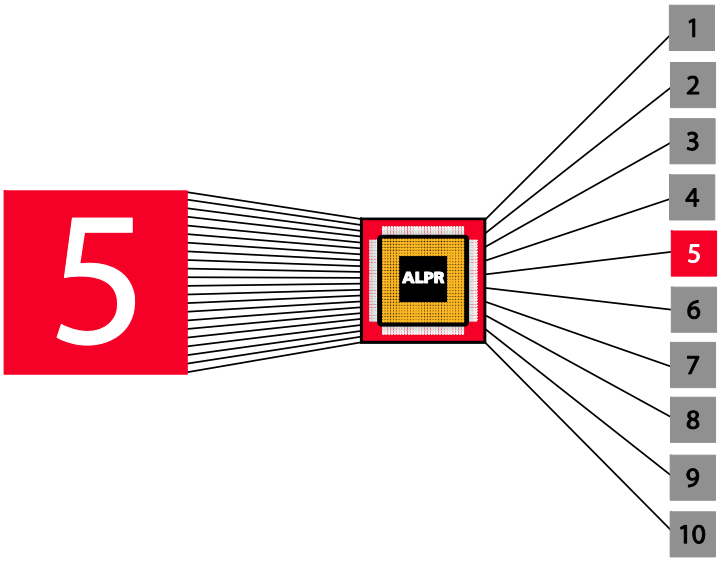
Extracting the Characters from the Background (Segmentation)

Once the license plate is identified in the images(s), the region around the license plate may be further analyzed to extract the characters from the background. In the following example, pixels comprising the candidate region are separated into foreground and background pixels to provide a more suitable candidate image used by the OCR algorithms to translate a character string image into an alphanumeric value that constitutes the license plate number. This is made more difficult when there is little contrast between the license plate number and the plate background.

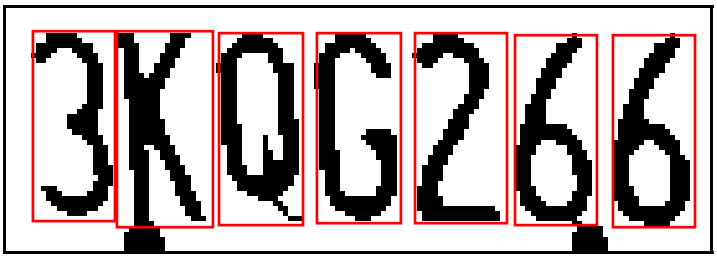
The segmented or pre-processed license plate image is then passed off to OCR software where the images are converted to individual alpha-numeric characters.

Determining the License Plate Number

The OCR engine converts pre-processed and segmented images containing the license plate number into an alphanumeric value that can be used by backend processing systems.



During the process, each alphanumeric character is extracted and fed through a recognition engine whose job is to identify each character on the license plate.



Result: **3KQG266**

The OCR software can be further tuned and augmented to address regional and jurisdictional license plate variances such as stacked characters and differing fonts. In the following license plate examples, the ascender and descender of the letter 'Q' takes on different characteristics that may require specifically tuned OCR engines depending on the region or jurisdiction in which the ALPR system is deployed. The number '4' in the first two license plates below provides another example. Note that the image processing and segmentation steps described above must discern the actual license plate number from other alphanumeric information such as vehicle registration tabs and jurisdiction names and logos.

Determining the License Plate Jurisdiction

Some ALPR systems are capable of identifying the jurisdiction of origin of the license plate by recognizing key features on the plate such as the jurisdiction logo, background graphics, special symbols, unique character font features, etc. Other techniques include applying syntax rules and other regionalization rules to provide additional clues to determine the license plate jurisdiction.

Handing Off LPR Results to Backend System

Once the license plate number and, in some cases, the jurisdiction, is determined, the information is handed off to backend systems in support of the intended ALPR system application. These systems may compare the license plates to watch lists or other law enforcement systems to allow interdiction or other actions to occur in near real-time. Sometimes these actions are not for interdiction purposes but merely to allow vehicles to gain access to secure locations, parking garages, etc.

In some cases, the ALPR data - along with supplemental data such as scene and driver images, vehicle location, and date and time stamps - are stored in highly-scalable and searchable data sources to support intelligence analysis, bill generation, or other processes that may occur at a later date.

ALPR systems are often configured to automatically communicate or transmit all of the collected data to a backend data archive or server. Communication methods can include any conventional networking protocols including cellular, WIFI, hardwire, thumb-drive; all with a variety of security protocols. In many cases, this communication process occurs in the background without any effort from the system user.

Once the data is inserted into the backend data management software, it is immediately available for review and search. These systems are generally web-based and can support numerous workstations simultaneously. Often the software solutions used to manage data sources allows information to be queried in a multitude of ways; by location, time, plate number, etc.

In addition, the image captured and the results generated by the ALPR system can be digitally signed and encrypted to enable a third party to verify that the data was collected at a specific time and location

and that no one has tampered with it. This approach also provides for a chain of custody for legal evidence purposes.

Key Challenges of License Plate Reading

Certain steps of the ALPR process present unique challenges that require continuous innovations in hardware and software technologies. A key challenge is the constant introduction of new and varied license plate designs that greatly expands the types of license plates that ALPR systems are required to process. Some of those challenges and the current techniques being applied to address those challenges include the following.

Detecting the Vehicle and/or License Plate

Challenge: ALPR systems operate in outdoor environments subject to constantly changing conditions including lighting, weather, varying vehicle speed and acquisition angles, and varying distances from cameras.

Techniques: ALPR camera locations, focal points, illumination controls, and vehicle detection sensors are carefully controlled to help ensure the capture of optimal images used for subsequent license plate location and optical character recognition. Often ALPR cameras are sequencing illumination levels or acquisition parameters to counteract the constantly changing conditions in which they are operating.

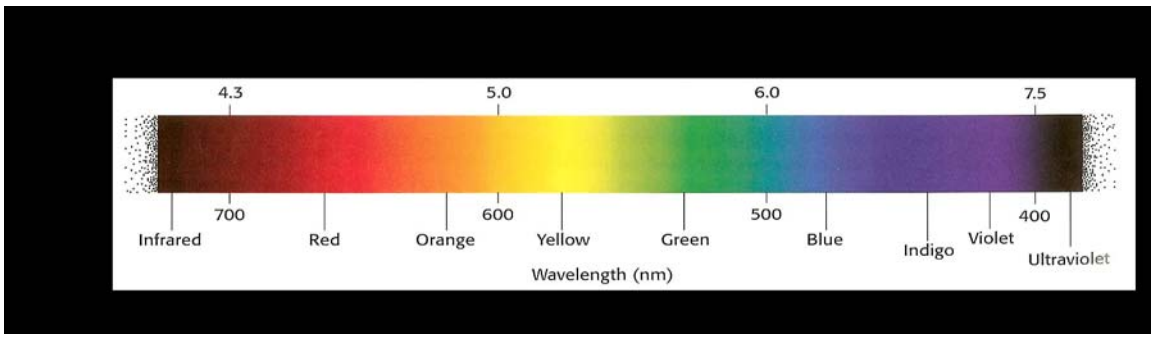
Locating the License Plate in the Image(s)

Challenge: Low contrast license plates, license plate frames and covers, other noise in the image (e.g., bumper stickers) all impact the ability of license plate detection algorithms to locate the license plate in the larger image captured by the ALPR system.

Low contrast license plate

The effect of a license plate cover

Techniques: Commercial license plate reader systems typically use a narrow band of infrared illumination to light the plate for detection purposes in nearly all weather and lighting conditions. This band ranges from 750 nanometer (nm) which has a visible bright red glow, 810nm, 850nm, 940nm, and 950nm. A 950nm infrared illumination is completely invisible to the naked eye.



The purpose in using several bands of infrared light is to filter out the effects of background graphics and/or to highlight the alphanumeric characters for OCR software systems. To help overcome graphic heavy backgrounds, a spectral analysis can be performed automatically on a plate-by-plate basis to determine which IR illumination is best suited for each plate, at the time it is read by the ALPR. In general, lower IR bands such as 750nm handle heavier graphics and higher IR bands of light are more effective with lower density graphic backgrounds.

Extracting License Plate Characters

Challenge: License plates with noisy backgrounds and symbols, and graphics that encroach on the character fields present conditions that make it difficult to recognize specific license plate characters.

These busy plate backgrounds make the plate number difficult to read

These plate designs contain symbols and graphics which encroach the license plate numbers

Technique: To address these challenges, ALPR systems can use different illumination techniques to improve the contrast between characters and background. Also, specialized segmentation algorithms are used to segment the characters from the background.

Determining the License Plate Number

Challenge: Poorly designed fonts and variations in fonts themselves, additional symbols, half-height characters, location of registration stickers, license plate frames and covers, and holograms on characters, increase the complexity of OCR algorithms used to determine the alphanumeric characters of a license plate.

In this example, the R could be read as an A; and the Q as an O

In this example, the J is too tight and the A is too narrow

In the ALPR image above, the B could be read as an 8 and the Q as an O.

These plates display symbols that cannot be queried and are considered part of the official license plate number.

These plates contain half-height stacked characters which in some cases are considered part of the plate number, while in other cases, they are not.

These two plates, from the same state, are inconsistent in the placement of registration stickers. In the example on the right, the stickers could be read as a character by an ALPR.

When characters are located too close to the plate's edge, license plate frames can easily prevent the plate number from being read by an ALPR.

While no U.S. or Canadian jurisdiction currently utilizes enscripted foil, these plates present a challenge for ALPRs.

Techniques: In addition to illumination and filtering techniques described above, neural network character identification and hand-written OCR software techniques are applied. Hand written OCR software is a bit-by-bit development effort to build an OCR software "engine" to match the uniqueness of a jurisdiction's alphanumeric character set, whereas neural network character identification self learns plate characters through pattern analysis.

Determining the License Plate State or Province

Challenge: Lack of standardization for logos and their location on the plate, as well as inconsistent and multiple alphanumeric template/patterns.

Examples of inconsistent placement of the state name.

Techniques: For recognition purposes, each unique jurisdictional logo is treated as its own style of plate or template. Recognition software then compares all of the different templates in its memory and determines which "style" of license plate best matches the license plate in question. To be successful, the matching algorithm has to account for changes in size, rotation and illumination.

Section 4
Law Enforcement and Public Safety Benefits

Introduction

Prior to the introduction of ALPR technology, a law enforcement officer could run a minimal number of plates per shift. ALPR technology allows an officer to "read" more than eight times the license plates than officers conducting only manual checks. Moreover, by eliminating the manual check process, not only is officer efficiency increased, but it allows officers to focus more on their surroundings, which improves both officer and public safety.

A recent study was conducted by the Police Executive Research Forum (PERF)[2] and the Mesa, Arizona Police Department. This study, funded by the National Institute of Justice, spanned a 48-week period. In addition to concluding that license plate reads increased in number by a factor of more than eight, the study further concluded that hits increased by a factor of more than four and arrests and stolen vehicle recoveries doubled.

What the study did not, and could not reveal, is the number of hits "missed" because of license plate misreads. A study conducted by one tolling authority established a misread rate of 20%. Regardless of the misread rate in a particular jurisdiction, there is no refuting that misreads occur. And when they do, the potential for missing an opportunity to arrest a suspected criminal or terrorist or to recover a stolen vehicle exists.

ALPR is one of the most significant advancements in technology and has proven beneficial to law enforcement and public safety. ALPR technology has transformed the way law enforcement is able to address public and traffic safety concerns, and it has substantially improved officer safety.

[2] Critical Issues in Policing Series: "How Are Innovations in Technology Transforming Policing?" Police Executive Research Forum, January 2012.

Challenges to Law Enforcement

In the past, a law enforcement officer could be familiar with all fifty states' license plates. Today, with the proliferation of license plate designs, specialty, and vanity plates - reaching into the hundreds in some states - the number of plates has increased from 50 to more than 5,000 in the United States, making it virtually impossible for instant visual recognition for today's police officer. The issue is exacerbated by the introduction of new license plate designs each year. In addition, novelty plates that closely resemble official license plates have added to the difficulty law enforcement contends with in determining plate validity.

Jurisdiction	2009	2012
Arizona	52	64
Louisiana	164	197
Maryland	800	935
Missouri	172	200
Montana	152	177
Pennsylvania	245	310
South Carolina	385	417
Texas	225	376
8 state total	**2,195**	**2,676**
% Increase from 2009 to 2012		**22%**

A sampling of eight states illustrates the significant growth in the number of license plates in the United States in recent years

The one versus two license plate debate continues

The International Association of Chiefs of Police estimates that 70 percent of all crimes involve the use of a motor vehicle. Requiring a vehicle to have both a front and rear license plate doubles the opportunity for an officer or witness to capture license plate information.

The absence of a front plate on a vehicle is also an issue for school bus drivers who report drivers who fail to stop for the buses while loading or unloading students. These drivers often rely on the presence of a front license plate to be able to report the violation.

Officer Safety Benefits

Safety is of paramount concern for any law enforcement officer initiating a "routine" traffic stop. Officers in patrol vehicles that are not equipped with ALPR technology are not as informed about the vehicle and its occupants as those who have the technology.

ALPR technology provides the ability to automatically and rapidly check the vehicle plate number against selected databases. License plates are often "flagged" when the owner is associated with certain information (wanted party, attempt to locate, be on the lookout for, amber alert, stolen car, etc.) With ALPR technology, officers stopping drivers for sometimes minor traffic offenses can be made aware of

this type of information, which allows them to use the appropriate officer safety tactics given the information they have, instead of unknowingly walking into a dangerous encounter.

Traffic Safety Benefits

One significant example of a traffic safety benefit involves suspended drivers. These drivers pose a significant threat to highway safety. The New York Department of Motor Vehicles reports that in 2011, there were more than 1 million suspended drivers operating motor vehicles in New York State.

Research shows that suspended drivers are more likely to be involved in a traffic crash. Suspended drivers tend to drive more aggressively and commit more types of other traffic infractions than drivers whose licenses are not suspended. ALPR technology has the capability to quickly identify vehicles whose registered owner has a suspended or revoked license and/or registration, making it much faster and easier for law enforcement officers to detect and apprehend illegal operators, mitigating the public safety threat on the roadways.

Benefits to Law Enforcement – Beyond Traffic Safety

ALPR's are at the forefront of discussions about the impact of technology impact on improving traffic and public safety. There is no arguing the value of automated license plate reader technology in the field of auto theft recovery and investigation. The ALPR is a force multiplier for officers in the field, reading and checking the status of thousands of license plates in a single shift, all while the investigator is able to watch his/her surroundings for activity, malevolent or benign. The ALPR is a tireless partner, constantly on the watch for stolen vehicles and wanted subjects, or amber alerts and missing persons. This technology is all the more effective when there is a front and rear license plate for the ALPR to read.

What follows are just a few of the documented examples of how ALPR technology has benefited law enforcement in the performance of their public safety mission:

- In an October 2010 case, an ALPR helped recover a vehicle that was stolen in connection with a homicide committed in Montgomery County, Maryland.
- In 2011 in Washington D.C., the only lead in a series of robberies was the partial license number of a silver vehicle believed to be involved. The ALPR system revealed several hits on that vehicle in a specific area. Thanks to ALPR technology suspects were arrested for five robberies.

> *"Thanks to this technology, we were able to catch suspects for five robberies" – Assistant Chief Alfred Durham, Washington, D.C. Police Department*

- In a 2011 kidnapping case in Minneapolis, the Metro Transit Police and the FBI were looking for a tan Suburban with "078" as part of the license plate. According to Minneapolis Police Department Assistant Chief Harteau, a search on an ALPR database identified a suspect vehicle.

- In an April 2, 2011 story published in the New York Post, a heroin addicted bank robber was apprehended with the use of ALPR.

> *The New York Post*
> *by Jamie Schram*
> *NEW YORK — The heroin-addict bank robber who became one of the most-wanted men in New York had grenades inside his Queens home, sources revealed yesterday.*
> *Marat Mikhaylich was captured after the NYPD's high-tech license-plate readers, along with some old-fashioned detective work led cops to his stolen getaway car, the sources said.*

Investigative Uses of ALPR Data

Police are increasingly finding value in ALPR data for investigations of major crimes. Many agencies began using ALPR's to locate stolen vehicles, identify expired registrations, and other routine operations. However, as agencies collect more records and use the database to assist in investigations, Amber Alerts, and even cold cases, it is becoming more apparent how powerful a tool ALPR can be. While the technology can't identify the driver of a vehicle, ALPR data can place a suspect's car in the vicinity of a crime, or be used to challenge an alibi. Since the ALPR captures the date, time, and location of each plate it detects, investigators can learn a great deal of information about a specific vehicle of interest in an investigation.

For instance, during a homicide investigation in Louisiana detectives performed a search of the victim's license plate against the sheriff's department ALPR records. The search yielded several instances of the vehicle passing ALPR cameras mounted throughout the parish. Witnesses had provided a partial description of a suspect vehicle, so detectives retrieved images of the victim's vehicle and looked at the cars that were captured after the victim passed the ALPR cameras. They soon found photos of a car matching the suspect vehicle close behind the victim on several occasions. Investigators were then able to identify the entire plate number, and the subsequent investigation led to additional evidence and the arrest of a suspect.

Public Safety Benefit

The nationwide AMBER Alert program was greatly enhanced with the emergence of ALPR technology. ALPR equipped vehicles have the ability to scan thousands plates an hour thus increasing the chances of finding a particular vehicle associated with a child abduction more rapidly.

Many police agencies use ALPR equipped vehicles to collect plate information as they respond to bank robberies and other major crimes to capture plate numbers of vehicles leaving the area as police respond to the scene of the crime.

Homeland Security Enhancements

ALPR technology has also become an important national security tool. ALPR technology is utilized to query the license plate numbers of vehicles entering and departing the United States to identify potential threats to national security. ALPR units are set-up in locations in proximity to critical infrastructure to identify potential threats. In two recent counter-terrorism cases, ALPR technology was used to identify vehicles being used by individuals suspected of plotting terrorist attacks against the United States.

Section 5
Mobility and Revenue Loss

Introduction

This section discusses how Automated License Plate Reader (ALPR) systems benefit public mobility in ways that continue to expand as ALPR technology is deployed in support of wide-ranging public and private projects. For example, ALPR systems benefit toll collection on roads and bridges, mitigate the impact toll collection has on transportation efficiency and the environment, and help provide revenue assurance for highway lane management, maintenance and improvement.

ALPR systems are deployed by Customs and Border Protection along the U.S. borders with Canada and Mexico to improve law enforcement capabilities and enhance traveler mobility across those borders. In addition, ALPR systems are being used in applications that include commercial vehicle enforcement, parking enforcement, time measurement systems, and high-occupancy toll lanes, to name a few.

Mobility and Toll Collection

Collection of user fees, or tolls, has served as a primary means of funding key transportation projects for as long as roads have existed. Tolls provide a direct approach to funding highways and bridges without increasing local or state taxes, and they ensure that those who benefit the most for projects pay for them directly.

For toll roads to be effective however, tolls must actually be collected. Traditionally this has involved staff at a gate or in a booth collecting cash and making change at strategic points along the roadway. This process stops each vehicle in the traffic lane for a brief period. The collection site often becomes a choke point – especially during high usage periods - slowing traffic and reducing the efficiency of the corridor where collection takes place.

Some jurisdictions have replaced toll collectors with technology that allows for self-payment, e.g., transponders. This can still slow the approaching vehicle. It also results in the loss of the gatekeeper who restricts access to only those paying the toll. Violators not only reduce the travel time benefits for qualified carpoolers and toll-paying travelers, but they also erode public support and negatively impact toll revenues.

When toll collection slows traffic, the reduced efficiency is felt in several ways, most notably slowing traffic, increasing congestion, adding emissions into the environment, and increasing the time required to move people and commercial goods.

Public agencies respond to bottlenecks and inefficiencies by engineering changes to roadways to improve traffic flow. These changes traditionally involve added lanes for capacity as well as an increase in the number of toll collectors. They are expensive and increase the overhead associated with toll collection and road construction. The increased roadway demand and additional infrastructure often results in increased tolls, sometimes with discounts during off-peak periods.

Businesses respond to the bottleneck by adjusting the number of deliveries per trip, changing inventory systems, and moving work to off-peak hours. Individual drivers are often forced to reduce time associated with work and family. As driving takes up a larger portion of their day, drivers may develop dangerous multi-tasking habits involving cell phone use, texting, eating, etc., that endangers not only themselves, but other road users. Idling in traffic is an expensive for businesses and drivers. A report by the Hinckle Charitable Foundation estimates that a five minute reduction in daily idling would save up to $83 per year in annual fuel costs for a vehicle.

Slower, inefficient traffic is also more polluting. Toxic emissions from idling vehicles are associated with local violations of clean air rules that require additional offsetting of public and private expenses. Canada's Office of Energy Efficiency estimates that saving just three minutes of idling time per vehicle in that country would reduce CO2 emissions by 1.4 million tons annually; the equivalent of removing 320,000 cars from the road each year.

Today, as motor vehicle transportation solutions orient their designs toward improved mobility, reduced congestion and more reliable levels of service, the use of vehicle license plates and ALPR technologies has increased substantially. The conundrum in this development is that as ALPR technologies improve to more efficiently automate the identification of vehicles and their owners, license plates take on increasingly complex designs as do the data sources which support the owner identification models used by jurisdictions, which works at cross-purposes against the goal of accurate plate reading.

By 2011, ALPR technologies of various designs were in use on the vast majority of toll roads and managed lane facilities. They also provide a component of many safety programs. With toll roads, ALPR technologies and license plate identification is used for License Plate Tolling (LPT) and toll evasion enforcement. Managed lane facilities – High Occupancy Vehicle (HOV) and High Occupancy/Toll (HOT) -use ALPR technologies for the same reasons. But in some cases it is also used to enforce HOV violations automatically, without the need of a law enforcement officer to visually detect violations.

These automated toll and lane management programs are intended to improve mobility and to enhance safe travel throughout North America. The toll industry advocates for user-based transportation funding in general. There are several facilities that employ ALPR technologies that rely on license plate information and the associated registered owner information for the collection of tolls and toll evasion enforcement. The North Texas Turnpike Authority in Dallas, Texas; Florida's Turnpike Enterprise in Orlando, Florida; the Miami-Dade Expressway Authority in Miami, Florida; the E-470 Public Highway Authority in Denver, Colorado, and the Washington State Department of Transportation's State Route 520 Bridge are agencies that rely entirely on license plate information and ALPR technologies to augment automatic vehicle identification systems to conduct their All-Electronic toll collection and toll evasion enforcement operations.

Managed lanes, commonly called HOT or HOV lanes - are intended to lessen congestion and provide greater mobility in the adjacent general purpose lanes of state highways or interstate highways located in urban areas. Just a few examples of managed lane facilities that employ license plate information and ALPR technologies for their operations include the Houston Texas Metro HOT Lane Corridors; the Colorado Department of Transportation's (CDOT) High Performance Transportation Enterprise's I-25 Express lanes; and the Georgia State Toll Road Authority's (SRTA) I-85 HOT lanes; and the nation's newest and most prominent HOT lane project on the Washington, DC Capital Beltway - the I-495 Express lanes.

Revenue Loss

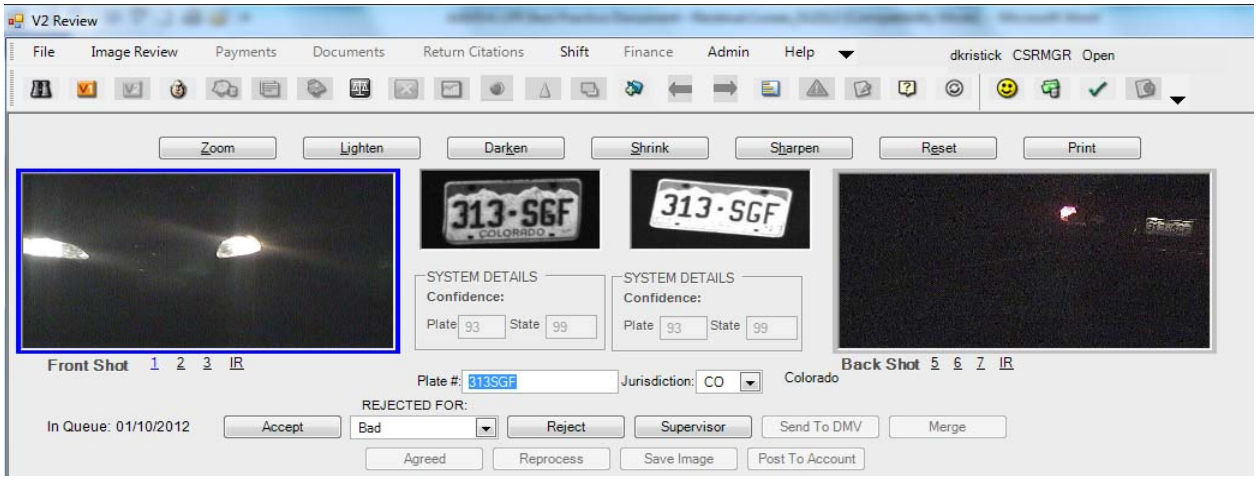
Poorly designed license plates, environmental conditions and purposeful avoidance to register and title vehicles are the most significant contributors to revenue losses within departments of motor vehicles, toll authorities, and parking facilities using ALPR systems. Better license plate design and manufacture should improve the effectiveness of ALPRs and subsequently increase toll collections.

Poorly designed license plates, environmental conditions and purposeful avoidance to register and title vehicles are significant contributors to revenue loss within departments of motor vehicles, toll authorities, and parking facilities using ALPR technologies.

Lost revenue at the E-470 Public Highway Authority in Colorado during the years 2009-2011 is used here as an example. E-470 used newly designed digital cameras operating in the visible and infrared light spectrums during all ambient light conditions. Captured vehicle and license plate images were also evaluated with an optical character recognition (OCR) engine manually set at a 70 percent confidence level. Image review processes involved a second review by a human to confirm automated efforts of the OCR engine to accurately identify the plate number.

Lost toll revenues amounted to $2.9 million in 2009; $3.9 million in 2010; and $3.7 million in 2011

An example of image quality follows.



Once the data is read, it is then compared to DMV recordss for registered owner information. When the plate and vehicle information do not match an existing RFID account, a toll statement requesting payment is sent to the registered owner.

The following table provides examples of image reject reasons. Each reject represents lost revenue. In the example that follows, over a three year period, an average of 7.52% of collectable revenue was lost.

	2009		2010		2011	
Total Image Transactions	**14,595,550**		**21,316,784**		**21,698,673**	
Reject Reason	**Total**	**%**	**Total**	**%**	**Total**	**%**
Plate obstructed	77,781	.53%	69,664	.33%	69,627	.32%
No plate	237,694	1.63%	312,908	1.47%	343,483	1.58%
Tampered plate (bent, covered w/plastic)	10,168	.07%	16,122	.08%	17,549	.08%
No DMV record	51,301	.35%	182,168	.85%	182,926	.84%
No matching record found in DMV lookup	94,618	.65%	169,681	.80%	121,611	.56%
State not idenfiable	64,902	.44%	26,346	.12%	16,965	.08%
Visible temp or car dealer plate	341,339	2.34%	771,257	3.62%	735,464	3.39%
Out of state DMV reject	289,732	1.99%	9,582	.04%	194	.00%
Unenforceable totals	1,189,456	8.15%	1,581,720	7.45%	1,511,441	6.97%

The lost toll revenue estimate was found by using an average toll rate of $2.50 per transaction was $2.9 million in 2009, $3.9 million in 2010, and $3.7 million in 2011. Easily identifiable license plates can mitigate lost revenue in the transportation industry as well as other businesses and enforcement models that utilize imagery and license plate information as the core of their revenue enforcement efforts.

Potential Revenue Gain (Vehicle Miles Traveled (VMT) Calculating)

As vehicles are engineered to provide greater efficiencies and with the growth of popularity of hybrid or electric vehicles, the use of gasoline and the associated gas tax revenues from the use of gasoline will continue to decline. As traditional transportation funding through gasoline tax revenues dwindle, other forms of funding are being evaluated through pilot programs and studies.

While the decision to enact VMT will be the subject of state and national policy discussions over the next several years, the engineering of the systems and technologies used to implement this user-based funding mechanism is already well underway.

Benefits of ALPRs for General Mobility

License plate recognition, advanced electronic toll readers and transponders, and vehicle occupancy detection are all being used as a means to enforce tolls and vehicle occupancy restrictions. They also help to eliminate the bottleneck created by traditional enforcement methods.

Improved traffic flow reduces the load on roadways, increases lane throughput, and simplifies engineering. This makes roadway development and maintenance less expensive. Businesses can focus less on overcoming the adversity created by inefficient traffic movement, and more on investing in improvement. Individual drivers can focus on the singular task of operating a vehicle safely. Both groups benefit enormously from the cost savings associated with reduced idling and higher speeds. Reduced pollution benefits all of society in numerous ways, from improved health to reduced cost in mitigation strategies that counteract pollution.

Agencies utilizing ALPR systems must recognize and plan for the fact that it is difficult for ALPRs to accurately read 100% of license plates. ALPR's do however, offer tremendous benefits in efficiencies and cost savings. In order to play an enforcement role while allowing traffic to flow with no bottleneck, ALPR systems must ideally contain the optics and computing power to read license plates and deal with a variety of challenges, including:

- broken, bent or dirty plates
- headlight glare
- retro-reflectivity variances
- varied license plate design and color
- poor ambient lighting
- license plate frames and/or covers or otherwise obscured plates

Mobility at United States Borders with Canada & Mexico

All vehicles and persons entering the United States are subject to inspection. Customs & Border Protection (CBP) takes this mandate seriously. Every vehicle and every person entering at a land border port must be queried through various law enforcement databases before they are allowed to enter the U.S. Although the inspection process encompasses more than just queries, each query takes time to perform and time is a factor in vehicle wait times, which at some major ports have in the past, been an hour or more. CBP, through the Western Hemisphere Travel Initiative (WHTI), has installed technology at most ports of entry which automate many functions previously done manually. This automation has resulted in reduced vehicle inspection times while maintaining the integrity of the inspection process.

CBP balances traveler facilitation and enforcement, and strives to require travelers spend as little time as possible waiting at the border. They do so while maintaining high levels of enforcement against terrorists, weapons, illegal aliens, narcotics and other contraband. Radio Frequency Identification (RFID) technology, improved ALPRs and the

Vehicle Primary Client application remain key in facilitating travel. These tools allow traveler information to be pre-positioned for officers and automatically queried through law enforcement databases as the vehicle approaches the primary inspection point. WHTI increases the security of U.S. land borders by requiring travelers to present one of a limited number of designated securely-issued travel documents, which can be verified electronically in real-time, to establish identity and citizenship.

Benefits of ALPRs to CBP

Approximately 130 million vehicles enter the U.S. at land borders annually. Conservatively, it takes an officer at least 10 seconds to query a vehicle license plate manually. To avoid overstatement of time savings 10 seconds is used as the average time saved for each successful automated license plate query. If all plate queries were completed manually, officers would spend more than 361,110 hours per year performing this task.

CBP has used ALPRs at the land borders since 1998. Beginning in 2008, WHTI has replaced all original inbound ALPRs with improved versions that achieve at least 5% improved readability over the older versions, which read all plates (readable and unreadable) at no better than 85%. The old ALPRs saved officers about 305,000 hours per year by automating plate queries. The new WHTI ALPRs save about 325,000 hours per year. This means that nationally travelers spend 20,000 fewer hours waiting in line as a result of improvements brought about by the WHTI ALPRs.

CBP constantly strives to incrementally improve ALPR performance through a strong maintenance program and on-going ALPR performance reviews. The reviews verify that the readers are 95% accurate and identify issues or patterns that can be corrected to improve performance. The time savings from ALPRs translates into less wasted time – and greater mobility – for travelers entering the U.S. at land ports of entry. Building on the success of WHTI, CBP is optimizing inbound operations and leveraging WHTI technologies, especially ALPRs, and process improvements for outbound traffic and Border Patrol checkpoint operations.

Key accomplishments that, along with ALPRs, have increased CBP's ability to expedite the legitimate flow of traffic across U.S. borders include:

- **Reduced inspection process time**: Today, the overall throughput improvement is 20 percent at all Ready Lane locations.
- **Technology infusion**: Today, ALPR technology is being deployed to selected vehicle outbound lanes on the Southwest border to assist in limiting the flow of cash and weapons into Mexico.

CBP continues to deploy the necessary resources and innovative solutions to secure, protect, and facilitate our borders.

Other ALPR Applications that Benefit Mobility

Commercial Vehicle Enforcement (CVE)

Commercial Vehicle Enforcement entities have used license plate recognition in the United States and Canada for the last 10 years. Several specialized companies have emerged that utilize ALPR's to read license plates and compare the plate number to Federal safety data sources to ensure trucks are in compliance with federal and state motor carrier safety programs. In addition, ALPR's can be integrated with thermal imaging technology to identify brake wear issues, and they can be integrated with Weigh-in-Motion (WIM) scales to identify unsafe loading and stability issues. The Washington Department of Transportation, through a federal grant and in cooperation with enforcement by the Washington State Patrol, implemented a highly successful installation of this technology, which is currently being expanded for state-wide use.

ALPR camera in use at a roadside truck scale

Municipal Parking Enforcement

On-street parking enforcement through the use of ALPR technology has been used effectively for over 10 years as well. With these systems, parking scofflaws who fail to pay their parking citations and/or fines are placed in a data source that is downloaded to an ALPR-equipped vehicle. The ALPR quickly identifies those who have failed to pay which allow municipalities to boot vehicles ensuring parking revenues are recaptured.

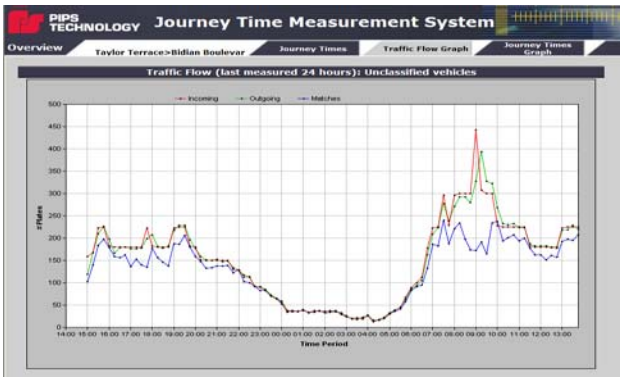
In a 30-day trial using one ALPR-equipped vehicle, the Long Beach Police Department in southern California identified nearly 300 scofflaws who had five or more unpaid parking citations. They captured nearly $200,000 in unpaid fines. In addition, seven arrests were made that were not associated with a parking citation.

ALPR technology is quickly emerging as a beneficial tool in the maintenance of streets. Mounted to a street sweeper, an ALPR can aid in the detection of vehicles parked in zones that prohibit parking during sweeping operations. The technology can speed up and augment the citation process during such operations.

ALPR cameras mounted on top of a street sweeper aid in street maintenance.

Travel Time/Journey Time Measurement Systems

Travel Time Measurement Systems (TTMS / JTMS) that use license plate recognition technology have emerged in the United States within the last five years. TTMS measures license plates observed at entrance points on roadways where ALPR cameras are mounted and then at exit points to determine the average travel time and speed of that road segment. The generated data can be uploaded to state or local websites or variable message signs for the benefit of the traveling public. In addition, this data can provide vehicle counts based on time of day along with speed data for internal or external use at Departments of Transportation.



Sample data from a TTMS/JTMS system

A variable message sign indicating travel times

Bus Lane Enforcement

ALPR is emerging as key technology for the enforcement of designated municipal bus lanes in metropolitan areas all over the world. ALPR cameras monitor passenger or commercial vehicles that unlawfully access or transition through bus lanes during peak traffic times or when designated by special signage. Violations are manually reviewed and submitted for citation by a law enforcement agency responsible for that particular jurisdiction. New York City is currently in the process of procuring and implementing this technology to ensure reliable and unobstructed public transportation.

High Occupancy Toll (HOT) Lanes

High Occupancy Toll Lanes are also a recent application in the use of ALPR Technology. This application allows for motorist to pay for the right to use car pool lanes by registering their plates, for a fee, with local jurisdictions. ALPR cameras monitor the lanes and provide alert notification to law enforcement if a plate not a registered toll user is identified in the HOT lane.

Section 6
Best Practices for License Plate Design & Manufacture

Introduction

The purpose of this section is to identify best practices in license plate design, manufacture and issuance to aid jurisdictions in creating and issuing license plates best suited to vehicle identification. The lack of national standards regarding the design and manufacturing of license plates limits the effectiveness of ALPR technology meant to assist in improving highway and public safety.

License plates serve a common purpose across jurisdictions. They should also share common characteristics that allow readability, usability, and connections to vehicle registration records.

The scope of these recommendations is limited to the physical characteristics of license plates, the information displayed on plates, and the placement of license plates on motor vehicles and trailers. Rules on issues peripheral to these concerns, such as plate assignment (plate with owner), personalization, or manufacturing sites are outside the scope of this document.

Background

Vehicles routinely move across jurisdictions. As a result, license plates are commonly viewed by both civilians and law enforcement who must quickly sift through unfamiliar elements to identify the number and originating jurisdiction. In addition, ALPRs must be configured to capture information from license plates issued all over the continent.

The ultimate objective of issuing these guidelines is to recommend uniformity in the design and manufacture of license plates that better enables government officials and other entities with an operational need to read license plates.

Scope

License plates serve a common purpose across jurisdictions. They should also share common characteristics that allow readability, usability, and connections to vehicle registration records. Registration programs must adhere to basic uniform guidelines recognizing that their products will be displayed in multiple jurisdictions.

License Plate Display

License plates must appear in consistently predictable locations on vehicles to ensure that people and systems can quickly locate the license plate and capture the information contained on the plate. Therefore, the number of plates issued to a vehicle and the placement of plates on the vehicle should be as similar as possible across jurisdictions.

Number of License Plates

It is recommended that two license plates be issued for all passenger type vehicles and single unit trucks. Larger trucks that commonly serve as power units and motorcycles should be issued a single license plate. Trailers should be issued a single license plate.

Both front and back plates are common means for reporting vehicles in motion or approached from the front or rear while parked. In addition, studies have consistently demonstrated that front license plates improve identification of vehicles in critical situations either through eyewitnesses, electronic readers, or cameras. Systems designed to capture front and rear license plates also deliver higher levels of accuracy. It is recommended that front and rear license plates be present on all vehicles to the extent practical. It is understood that some jurisdictions may not immediately have the funding to issue two plates if they currently issue only one plate.

Placement of License Plates

When a single license plate is issued, it is recommended that it be displayed on the rear of the vehicle in the location designated for that purpose by the vehicle manufacturer, except that power unit plates should be required to be displayed on the front of the vehicle. Single plates for motorcycles and trailers should be required to be displayed on the rear of the vehicle in the location designated.

When two license plates are issued, it is recommended they be displayed on the front and rear of the vehicle in the locations designated for that purpose by the vehicle manufacturer.

All license plates should be required to be displayed horizontally so that they are easily read from left to right.

It is recommended that license plate frames and/or covers be prohibited from interfering with readability of the license plate number, the name of the issuing jurisdiction, and/or registration sticker(s).

Observable Plate Characteristics

While license plates are unique to each jurisdiction and vehicle, it is recommended they also be sufficiently similar to each other that they can be instantly recognizable as license plates. Without such an expectation, it would be difficult to recognize a plate as an official government-issued identifier and not simply a sign, advertisement, or private reference number. As a result, all license plates must share certain observable characteristics.

If a jurisdiction allows individuals to place novelty or decorative plates on the front of the vehicle, the plate should not contain designs, numbers or letters in a format similar to an official plate issued by any jurisdiction.

Retro-reflective Surfaces for Visibility

To provide a measure of acceptable identification, it is recommended that license plates contain a retro reflective surface and be readable in both daylight and darkness from distances of 75 feet. A retro-reflective surface reflects light back to its source with a minimum scattering of light. This provides illumination without distortion when viewed under headlights. Since license plates commonly lose over 50% of their initial reflectivity within 10 years, they should be replaced periodically in order to maintain acceptable levels of retro-reflectivity.

License Plate Dimensions

Placing license plates in consistent locations on a vehicle is easier if the plates are consistent in size. Motor vehicle manufacturers provide mounting surfaces for license plates that meet existing Society of Automotive Engineers (SAE) and AAMVA standards.

License plates for passenger vehicles, trucks, and trailers should be approximately 12 inches in horizontal length and six (6) inches in vertical height.

License plates for motorcycles should be approximately seven (7) inches in horizontal length and four (4) inches in vertical height.

Additional or multiple size license plates should be discouraged.

Character Sizing

It is recommended that license plate characters be readable at average trailing distances and not so crowded that they cannot be differentiated from each other when read. Characters at least 2.5 inches in height and proportionally wide, spaced .25 inches apart will provide sufficient readability at 75 feet.

Alphanumeric Characters

License plate configurations are used to query registration systems. It is recommended that the configuration of a license plate be limited to alpha numeric characters. Non-alphanumeric characters that appear on a license plate should not be part of the configuration, nor should graphic designs.

It is recommended that jurisdictions select ink pigments for alphanumeric characters that allow for high-contrast recognition for infrared and visible light illumination to the human eye. Ink pigments should be tested in both daylight and nighttime conditions. Inks should be opaque. Some states use translucent inks that allow light to reflect off the background retro-reflective material, rendering the characters nearly invisible to ALPR systems. This allows for better and more accurate character capture relative to background graphics. It lowers acquisition costs to end-users by allowing ALPR vendors to use a consistent illumination standard.

Special Characters

It is recommended that non alphanumeric characters such as hearts, ampersands, dashes, etc. not be part of the license plate number, even when such characters are available on standard keyboards.

Stacked Characters

Where stacked and half-height characters are used, it is recommended they be part of the official plate number. Where one character appears above another, the top character should be entered first, immediately followed by the bottom character, in sequence, with the other characters on the plate.

Stacked characters should be vertical – not staggered or slanted – and no less than half size of regular plate characters to ensure readability. No more than two (2) characters should be stacked.

Fonts

It is recommended that the size of the alphanumeric on the plate be maximized to provide the best legibility. The font and spacing should present each alphanumeric as a distinct and identifiable character. Standardized fonts and font sizes that clearly distinguish alphas and numerics should be used. For example, similar characters like A and R, 8 and B, and 0 (zero), O and Q should be easily distinguishable from each other. Standardized fonts and font sizes allows for better OCR accuracy among vendors and lowers ALPR acquisition costs to end users. It also provides improved readability and greater confidence.

Unique License Plate Numbers

It is recommended that license plate numbers be unique to each vehicle and not be repeated unless first invalidated or purged from the jurisdiction's registration system (e.g., plate number ABC 123 should not be used on multiple plates regardless of the plate type or special characters). This allows accurate retrieval of vehicle registration information without having to input additional data elements or review multiple records to determine the appropriate record.

Alphanumeric images should be more centered within the plate and away from bolt holes and where license plate frames might encroach. This keeps characters away from plate frames and bolt holes which can cause ALPR systems to misread.

Jurisdiction/Country of Origin

It is recommended that the state or province of origin be readable and appear in the top center location of the license plate so it is quickly discernible. The full state name should appear to avoid confusion between states with similar postal abbreviations. Missouri has taken the lead in passing legislation that says only Missouri schools may be featured on Missouri license plates.

Only the issuing jurisdiction's name should appear on license plates. This includes designs and logos for out-of-jurisdiction universities or organizations.

Graphics and Logos

Placement and use of state/province logos and graphics should be uniform to provide improved jurisdiction identification.

Embossed vs. Flat Plates

Both embossed and flat license plate designs are easily ready by ALPR technology.

Expiration of Registration

It is recommended that the date of registration expiration be displayed by means of a retro-reflective validating sticker on the rear license plate. Secondary decals do not need to be retro-reflective and may be placed on the windshield for jurisdictions that have multiple uses for the stickers.

The jurisdiction should require registration stickers be placed in a consistent area while ensuring they do not obscure any part of the license plate number.

Jurisdictions are urged to color code annual registration stickers allowing law enforcement to easily determine the expiration year without actually reading the expiration year or month.

Security Features

Security features make license plates difficult to counterfeit and should be employed. These features should be difficult to duplicate, be an integral part of the license plate, be visible from a distance and not interfere with plate message legibility. Features such as bar codes and embedded identifiers that are visible use infrared and/or visible light could assist in counterfeit detection. Holograms and 'invisible' images seen only through infrared light may be used by ALPRs in the future to assist in license plate recognition.

Law Enforcement and Other Stakeholder Consultation

It is recommended that motor vehicle agencies consult with the jurisdictional, and if applicable local law enforcement representatives, prior to adopting a new license plate standard or design. This ensures that standards for readability and image capture are maintained with an eye on public safety and crime prevention. Other stakeholders should be consulted as appropriate. Jurisdictions located on international borders should consider consulting with Customs and Border Protection and/or the Canada Border Services Agency.

Appendix A
ALPR Working Group Member List

Working Group Chair

Lieutenant Colonel Thomas M. Fresenius
New York State Police
Office of Counter Terrorism
T: 518-457-9579
tfreseni@troopers.state.ny.us

DMV Representatives

Christina Flores
Public Information Officer
Texas Department of Transportation
4000 Jackson Drive Austin, TX 78731
T: 512-302-2076
cflore2@dot.state.tx.us

Kristina Hargis
Director, Office of Vehicle and Motor Carrier Services
Iowa Department of Transportation
PO Box 9278
Des Moines, IA 50306-9278
T: 515-237-3040
tina.hargis@dot.iowa.gov

Andrew Conway
Chief, Registration Policy & Automation
2415 First Avenue
MS D303
Sacramento, CA 95818
T: 916-657-6259
aconway@dmv.ca.gov

IACP Representative

Mike Fergus
Program Manager
International Association of Chiefs of Police
515 North Washington Street
Alexandria, VA 22314-2357
T: 703-836-6767, Ext 811
Fergus@theiacp.org

Law Enforcement Representatives

Lieutenant Paul O'Keefe
Aurora Police Department
Investigative Support Section
T: 303-739-1702
pokeefe@auroragov.org

Captain Dale Stockton, retired
Carlsbad Police Department
LPR Project Manager - ARJIS
T: 760-685-0292 cell
dstockton@arjis.org

Toll Authorities Representative

Dave Kristick
Director of Operations, E-470 Public Highway Authority
22470 E 6th Parkway, Aurora, CO 80018
T: 303.537.3702
C: 303.210.5033
dkristi@e-470.com

Customs and Border Protection Representatives

George St. Clair
Program Support/LBI
Office of Field Operations
T: 267-324-5377
george.f.stclair@cbp.dhs.gov

Colleen Manaher
Director, Land Border Integration
US-VISIT Transition
DHS/CBP/OFO
T: 202-344-3003
Colleen.m.manaher@dhs.gov

Technical Advisors

Ivan Blackman
Manager
National Information Crime Bureau (NICB)
Vehicle Information and identification Programs
T: 1-800-447-6282, Ext 7042
iblackman@nicb.org

Technical Advisors, *continued*

Bernard Howe
ELSAG North America
205H Creek Ridge Road
Greensboro, NC 27406
T: 336-379-7135
bernard.howe@elsag.com

Greg Florin
Business Development Manager
3M Traffic Safety Systems Division
3M Center, Building 235-3A-09
St. Paul, MN 55144
T: 651-733-5233
C: 651-338-0079
gjflorin2@mmm.com

Juan A. Herrera, Ph.D.
Perceptics
9737 Cogdill Road, Suite 200N
Knoxville, TN 37932-3350
T: 865-671-9243
juan.herrera@perceptics.com

Anoop Gupta
Marketing Manager
3M Traffic Safety Systems Division
3M Center, Building 235-3A-09
St. Paul, MN 55144
T: 651-733-7540
C: 651-238-1200
akgupta@mmm.com

Greg Lary
PIPS Technology, Inc.
804 Innovation Drive
Knoxville, TN 37932
T: 865-392-5540
glary@fstech.com

Craig McIntire
Unisys
22960 Shaw Rd, Suite 700,
Sterling VA 20166
T: 703.787.2080
craig.McIntire@unisys.com

AAMVA Staff Liaison

Brian Ursino
Director – Law Enforcement
4301 Wilson Blvd., #400
Arlington, VA 22203
T: 703.350.5103
bursino@aamva.org

AAMVA Representatives

Cathie Curtis
Director, Vehicle Programs
98 Wedgewood Drive
Winthrop, ME 04364
T: 207.395.4100
ccurtis@aamva.org

Sheila Prior
Director, Region III & IV Member Support '
10800 North 101st Street
Scottsdale, AZ 85260
T: 480-275-4584
sprior@aamva.org

Appendix B
AAMVA Recommendations for Uniform License Plates

AAMVA endorses the concept of a uniform motor vehicle registration license plate system. In addition, AAMVA recommends that member jurisdictions adopt the following minimum standards:

1. Two registration license plates should be issued for all passenger type vehicles and single unit trucks. One plate can be issued for tractors, motorcycles, and all types of trailers.

2. The name of the issuing jurisdiction should be prominently displayed on the top center of the plate. Alpha-numeric characters commonly referred to as the registration number or plate number should be displayed in the center of the plate.

3. The registration expiration should be displayed on the vehicle by means of a retro-reflective validating sticker on the rear license plate, except on vehicles that are required or permitted to have only one license plate, or those plates manufactured with an expiration date and for which a sticker is not required. Secondary decals should be placed on the windshield for jurisdictions that have multiple uses for the stickers. New validating stickers may be issued upon renewal of registration in lieu of issuing new plates for the vehicle.

4. License plates should be manufactured in two sizes, depending on their use. Passenger type vehicles, tractors, trucks, trailers, etc., should be issued standard 6" x 12" plates. Smaller plates measuring 4" x 7" may be used on motorcycles or other small vehicles.

5. License plates can be issued for multi-year periods and should be reissued or replaced on a regular basis to ensure that they remain retro-reflective and the information they display remains legible.

6. Fully retro-reflective license plates should be adopted and used.

7. Motor vehicle agencies should consult with jurisdictional law enforcement, and if applicable local law enforcement representatives, prior to adopting new license plate standards or designs. Other stakeholders should be consulted as appropriate.

8. Jurisdictions should standardize license plates, including specialty plates, e.g., placement of graphics, font and font size, alpha-numerics, plate numbers, use of stacked characters, etc.

9. License plates must be readable in daylight and night using low beam headlights, under optimal conditions at a distance of no less than 75 feet.

10. Duplication of license plate numbers, including look-alikes, e.g., ABC OOO vs. ABC 000, is discouraged to allow accurate retrieval of vehicle registration information.

11. Retro-reflective decals should be color-coded with durable printing. Motor vehicle agencies should consult with jurisdictional law enforcement, and if applicable local law enforcement representatives, prior to adopting new color schemes for registration stickers.

12. A license plate is considered to be fully retro-reflective if the base retro-reflective sheeting used for its' manufacture meets the following initial retro-reflective specifications (see table below):

Color	Entrance Angle	
	4°	40°
White	50	16
Yellow	25	10
Orange	25	10
Lemon-Yellow	25	10
Gold	25	10
Green	18	7
Blue	18	7
Red	9	3

13. "Decorative plate" means a license plate or other similar device that is not issued for registration purposes by a jurisdiction or agency responsible for the registration of the vehicle. A decorative plate may contain alpha or numeric characters but the alpha or numeric characters are not recorded in the jurisdictional records and are not a part of the registration records maintained by the jurisdiction. The use of decorative plates that resemble official license plates issued by a jurisdiction should be prohibited.

14. "Specialty plate" means an official license plate issued for recognition or fund raising.

15. Graphics on license plates should not distort or interfere with the readability of the alphanumeric characters or with any other identifying information on the plate by either human eye or machine readable technology such as Automated License Plate Readers (ALPR).

16. Plate type identifiers displayed on license plates should be standardized and placed in a uniform location on the license plate within a jurisdiction, e.g., commercial, dealer, etc.

Jurisdictions should design and manufacture license plates in accordance with AAMVA's Best Practices Guide for Improving Automated License Plate Reader Effectiveness through Uniform License Plate Design and Manufacture.

Appendix C
ALPR Case Law

462 F.3d 557: United States of America, Plaintiff-appellant, v. Curtis Ellison, Defendant-appellee

United States Court of Appeals, Sixth Circuit. - 462 F.3d 557
Argued: October 5, 2005 Decided and Filed: September 5, 2006

Excerpted relevant sections:

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No argument can be made that a motorist seeks to keep the information on his license plate private. The very purpose of a license plate number, like that of a Vehicle Identification Number, is to provide identifying information to law enforcement officials and others. The reasoning in *Class* vis-a-vis Vehicle Identification Numbers applies with equal force to license plates: "[B]ecause of the important role played by the [license plate] in the pervasive governmental regulation of the automobile and the efforts by the Federal Government to ensure that the [license plate] is placed in plain view," a motorist can have no reasonable expectation of privacy in the information contained on it. 475 U.S. at 114, 106 S.Ct. 960 (discussing Vehicle Identification Numbers).

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The dissent implies that even if an individual has no expectation of privacy in a license plate number, a privacy interest is somehow created by the entry of this information into a law-enforcement computer database. This argument flies in the face of established Fourth Amendment doctrine. First, despite the dissent's concerns over the information available in a LEIN search, Ellison had no privacy interest in the information retrieved by Officer Keely. The obvious purpose of maintaining law enforcement databases is to make information, such as the existence of outstanding warrants, readily available to officers carrying out legitimate law enforcement duties. The dissent fails to state how using a license plate number — in which there is no expectation of privacy — to retrieve other non-private information somehow creates a "search" for the purposes of the Fourth Amendment.[3] Moreover, the computer investigation utilized in this case was far less invasive than other government actions that fall outside the protections of the Fourth Amendment.
See, e.g., Oliver v. United States, 466 U.S. 170, 177, 104 S.Ct. 1735, 80 L.Ed.2d 214 (1984) (entering private property with "No Trespassing" signs to observe marijuana plants in an "open field" not visible from outside the property); *Dow Chemical Co. v. United States,* 476 U.S. 227, 239, 106 S.Ct. 1819, 90 L.Ed.2d 226 (1986) (photographing an industrial complex with a precision aerial mapping camera); *California v. Ciraolo,* 476 U.S. 207, 213-14, 106 S.Ct. 1809, 90 L.Ed.2d 210 (1986) (using aerial surveillance in public airspace to observe the curtilage of a private residence); *Smith v. Maryland,* 442 U.S. 735, 745-46, 99 S.Ct. 2577, 61 L.Ed.2d 220 (1979) (placing a pen register on a phone line to record the numbers dialed from a private residence). This is not a case where the police used a technology not available to the public to discover evidence that could not otherwise be obtained without "intrusion into a constitutionally-protected area." *Kyllo v. United States,* 533 U.S. 27, 34-35, 121 S.Ct. 2038, 150 L.Ed.2d 94 (2001) (holding that the use of thermal-imaging technology to detect heat inside

a private home violates the Fourth Amendment). The technology used in this case does not allow officers to access any previously-unobtainable information; it simply allows them to access information more quickly. As the information was obtained without intruding upon a constitutionally-protected area, there was no "search" for Fourth Amendment purposes.

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Every court that has addressed this issue has reached the same conclusion. The Tenth Circuit has held on two occasions that license plates are "in plain view on the outside of the car" and thus, are "subject to seizure" because there is no reasonable expectation of privacy. *United States v. Matthews,* 615 F.2d 1279, 1285 (10th Cir. 1980); *see also United States v. Walraven,* 892 F.2d 972, 974 (10th Cir.1989). The Fifth Circuit has also held that "[a] motorist has no privacy interest in her license plate number." *Olabisiomotosho v. City of Houston,* 185 F.3d 521, 529 (5th Cir.1999); *accord United States v. Sparks,* 37 Fed. Appx. 826, 829 (8th Cir.2002); *Hallstein v. City of Hermosa Beach,* 87 Fed.Appx. 17, 19 (9th Cir.2003). The only two panels of this court to address the question have reached the same result. *United States v. $14,000.00 in U.S. Currency,* No. 98-4380, 2000 WL 222587, at *3 (6th Cir. Feb.14, 2000) (finding no Fourth Amendment violation in a computer check of a license plate); *United States v. Batten,* 73 Fed. Appx. 831, 832 (6th Cir.2003) (same). As one panel wrote, "[T]here is no case law indicating that there can be any reasonable expectation of privacy in license plates which are required by law to be displayed in public on the front and rear of any vehicle on a public street." *Batten,* 73 Fed.Appx. at 832; *see also* Wayne R. LaFave, 1 Search & Seizure § 2.5(b) (4th ed. 2004) ("[I]t is apparent that when a vehicle is parked on the street or in a lot or at some other location where it is readily subject to observation by members of the public, it is no search for the police to look at the exterior of the vehicle.") (citing *Katz* and *Olabisiomotosho*).

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Thus, so long as the officer had a right to be in a position **to observe** the defendant's license plate, any such observation and corresponding use of the information on the plate does not violate the Fourth Amendment. In this case, Officer Keeley had a right to be in the parking lot observing the van — he was in a public place conducting a routine patrol. The district court's finding that the van was not parked illegally is thus irrelevant — such a finding goes only to probable cause, which is not necessary absent a Fourth Amendment privacy interest.[4] Once Officer Keeley conducted the check and discovered the outstanding warrant, he then had probable cause to pull over the vehicle and arrest the man identified as Ellison. The arrest and resulting search during which the handguns were found in no way violated the Fourth Amendment, and the district court's order granting the motion to suppress was in error.

Appendix D
International Association of Chiefs of Police Resolution

INTERNATIONAL ASSOCIATION OF CHIEFS OF POLICE

RESOLUTION

Adopted at the 119th Annual Conference
San Diego, CA
October 3, 2012

Validating the Public Safety and Homeland Security Needs for Retro-Reflective Front and Rear License Plates

Submitted by: Highway Safety Committee
HSC.022.a12

WHEREAS, heightened homeland security concerns and procedures emphasize the need for fast and reliable identification of vehicles by law enforcement officers and citizens alike, which is extremely important for law enforcement officers who steadfastly patrol the approximately four million miles of highways and roads within the United States; and

WHEREAS, traffic enforcement activities have proven to be invaluable in the detection and apprehension of individuals involved in terrorist and/or criminal activities; all means of initial identification, including retro-reflective front and rear license plates, are essential; and

WHEREAS, motor vehicles are used in the majority of all serious crimes committed in the United States and the quick discovery of such vehicles can help solve these crimes; and

WHEREAS, retro-reflective front and rear license plates are essential in the quick and accurate identification of motor vehicles even at highway speeds; and

WHEREAS, retro-reflective front and rear license plates serve as a significant safety device, warning motorists of the presence of vehicles that are disabled or that otherwise lack sufficient headlights or taillights and allowing those vehicles to be observed at a safe distance and in a timely manner; and

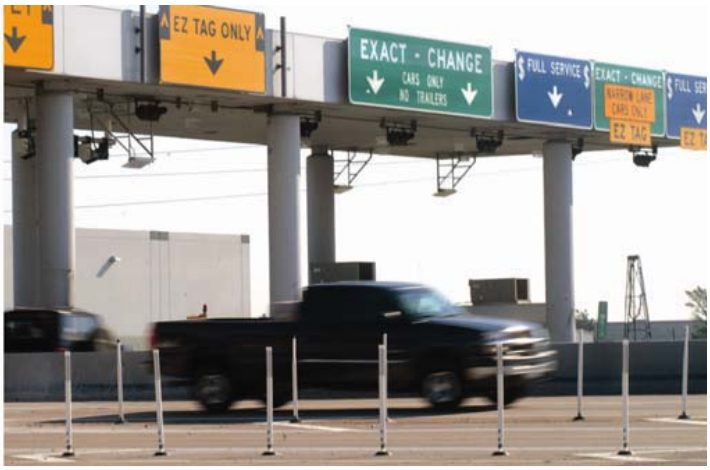
WHEREAS, it is important to keep license plates legible and to maintain their retro-reflectivity because they are relied upon by law enforcement and citizens alike for public and traffic safety; now, therefore, be it

RESOLVED, that the International Association of Chiefs of Police (IACP), duly assembled at its 119th Annual Conference in San Diego, California, recognizes that the efficient and reliable identification of vehicles is a critical element of national, state and local safety and security, supports the issuance of retro-reflective front and rear license plates with clearly identifiable registration numbers and states of registration, and urges that States issue new plates as required to maintain effective vehicle identification and to protect the security and integrity of the vehicle registration process; and , be it

FURTHER RESOLVED, that the IACP supports the use of the *Best Practice Guide for Improving Automated License Plate Reader Effectiveness through Uniform License Plate Design and Manufacture* published by the American Association of Motor Vehicle Administrators.

Appendix E
Texas Traffic Institute Front License Plate Research

Front License Plate Market Research: Comparison of Single Versus Dual License Plates



Texas A&M Transportation Institute

Front License Plate Market Research:

Comparison of Single Versus Dual License Plates

by

Melissa Walden, Ph.D, P.E.
Senior Research Scientist

Laura Higgins, M.S.
Associate Research Scientist

Troy Walden, Ph.D.
Associate Research Scientist

Sarah Hammond, M.S.
Assistant Research Specialist

August 2012

TEXAS A&M TRANSPORTATION INSTITITE
The Texas A&M University System
College Station, Texas 77843-3135

EXECUTIVE SUMMARY

License plates are a critical element of the transportation system in regards to enforcement and tolling. Additionally, the plates contribute to the effectiveness of parking and homeland security applications. License plates identify vehicles, provide retro reflective characteristics for readability and safety in nighttime conditions, register vehicles for tax purposes as well as indicate the vehicle's origin (state and county in some cases) based on where it is registered. There are 31 states that require two plates (front and rear) on vehicles while the remaining 19 only require a rear plate.

Policy makers as well as individual drivers have strong opinions related to the one versus two plate debate. Law enforcement believes that two plates aide in vehicle identification and the benefits associated with the retro reflectivity is a distinct advantage. With the integration of more automatic license plate reader (ALPR) technology into enforcement, two plates increase the opportunities to identify vehicles (speed detection, stolen vehicles, red-light running, etc.). On the other side of the debate, those who support single plates site the possibility of vehicle fraud, the expense of issuing two plates, and the negative effect on the aesthetics on the front of the vehicle. Interestingly, these discussions are unique to North America since other countries require two plates and it is accepted much like the cultural expectation that individuals do not drive after drinking.

The conclusions drawn in this study were based on the literature review and field studies. The research team collected license plate data in four states: Pennsylvania and Arizona were the one plate states and Maryland and Texas were the two plate states. These states were selected based on geography, proximity to other states or the international border, use of ALPR technology, and presence of tolling. The study results are summarized below:

- Front plates were easier to read in the daytime environment due to the effects of sun glare [1].
- Lack of front plates has significant impact on the generation of photographic evidence related to fining toll violators. With respect to Virginia's toll violations, 23% could not be pursued due to the lack of license plate data (rear plates were unreadable) [2; 3].
- Without front license plates, the E-470 corridor in Colorado would lose at least $23.1M in toll revenue or 34.5% of their tolls on an annual basis [4].
- The United States Customs and Border Protection (CBP) reports that the number of plates not read (excluded) on vehicle without two plates made a significant impact in their border processing. At the northern border 6% of the plates could not be read and 3.4% across the southern border [5]. The major difference between the international borders is the presence of dual plate states between the US and Mexico. With the volume of vehicles processed everyday along with the homeland security concerns, the front plate allows CBP to operate more effectively.
- Pennsylvania is a one plate state with a 360 mile turnpike that crosses the state east to west. Law enforcement would like to see two plates to improve their ability to read plates, especially large

commercial trucks, using ALPR technology. Sixteen percent of the plates through the tolling facilities are not able to be read which impacts the state's ability to pursue toll violators.

- Phoenix's Sky Harbor Airport reports that 10,000 parking transactions per year, an average of $30/transaction, rely on ALPR plate reads to determine accurate charging. Fifteen percent of those transactions had to be processed manually since the rear plates could not be read due primarily to sun glare.

- Field studies showed a 97% read rate for parked vehicles in two plate states and 76% in one plate states. For moving vehicles, the read rate in Maryland and Texas was 89%, Pennsylvania and Arizona it was 22% and 58% on the roadways connecting Maryland and Pennsylvania. These read rates are based on the opportunity to read a front plate; a vehicle had a license plate mounted on the front bumper.

- For those states with more than 100 miles of toll roads, one plate states account for 55% of the total toll way miles [6]. As fiscal pressures mount, efficiency in the collection of tolls and the pursuit of violators becomes critical. Front plates increase the likelihood of collecting that revenue.

As early as 1925, experts in the transportation field recognized the benefits of standardized placement of license plates and proposed front and rear plate positioning. They believed that this standardization "would help all concerned with their (license plates) observance" [7]. Identification of vehicles is a critical issue for enforcement, tolling, parking, and homeland security. The use of two plates maximizes the opportunity for this identification to be completed efficiently and effectively whether by an individual or through ALPR technology. With the increase in the use of ALPR technology across all of the applications, it is clear that the presence of two plates provides better observation opportunities related to all the applications.

BACKGROUND

License plates are a critical part of the transportation system for many reasons. Although vehicles can be described according to make, model, color, and/or other distinguishing factors, these general attributes can be subjective and even common. A vehicle's license plate provides a unique identifier that connects the vehicle to its owner and status. License plates provide:

- identity of vehicles for law enforcement, tolling, parking and other public applications,
- retro reflective elements for readability and as a safety benefit in nighttime conditions,
- a means of registering vehicles for tax and other purposes, and
- designation of the vehicle's origin (state and sometimes county) based on where it is registered

License plates have been used on vehicles in the United States since the early days of the twentieth century. Today, each state has multiple versions of license plates that are available to the citizens, although all have a standard size of 12×6 inches. In addition to the differences in appearance, there is another key difference between some of the states – those that use a rear-only (single) license plate and those that use both front and rear (dual) license plates.

Table 1 provides a list of states in each category. There are nineteen states that require one license plate while the remaining thirty one are primarily two plate states.

Table 1. Summary of License Plate Use.

States with Rear-Only License Plates		States with Front and Rear License Plates		
Alabama	Michigan	Alaska	Maryland	Oregon
Arizona	Mississippi	California	Montana	Rhode Island
Arkansas	Oklahoma	Colorado	Nebraska	South Dakota
Delaware	Pennsylvania	Connecticut	New	Texas
Florida	New Mexico	Hawaii	Hampshire	Utah
Georgia	North Carolina	Idaho	New Jersey	Vermont
Indiana	South Carolina	Illinois	New York	Virginia
Kansas	Tennessee	Iowa	Nevada	Washington
Kentucky	West Virginia	Maine	North Dakota	Wisconsin
Louisiana		Minnesota	Ohio	Wyoming
		Missouri		

Note: Massachusetts and Nevada require two license plates, but there are exceptions to that requirement based on model and/or year[8].

According to the National Conference of State Legislatures (September 1999), eight jurisdictions responding to a questionnaire were considering changing their license plate requirement (with a majority of these wanting to cut back from two to one) [9]. Indiana has attempted to move from one plate to two, but the legislation was defeated citing a lack of evidence that benefits outweighed costs. In contrast, Utah introduced legislation in 2006 to change their requirements from two plates to one. This revision did not pass.

Many factors impact the advantages of using two versus one license plate. Discussions have focused primarily on the law enforcement aspect of vehicle identification; however over the course of this project, it was determined that enforcement is only one aspect of the debate. Although law enforcement is one of the main proponents of the two plate requirement, they acknowledge that their job could be accomplished if only given one plate per vehicle, albeit a slightly more laborious and less efficient method. A few of the key issues related to single versus dual license plate use from general enforcement and visibility perspectives are summarized in Table 2.

Table 2. Issues Related to License Plate Use.

Advantages of Two License Plates	Disadvantages of Two License Plates
Assists law enforcement officials • Vehicle can be identified from either front or rear (by the officer alone or in conjunction with an automatic license plate reader or ALPR) • Could potentially assist in hit and run identification Increases safety in general • Retro reflective material on front of car increases visibility at all times • Provides some type of reflection for drunk/inattentive drivers who neglect to turn on their headlights during dark hours [1] Assists with photo and laser radar enforcement • Provides two opportunities for photographic evidence • Provides a retro reflective target for laser speed detection	Increase of possibility of vehicular fraud • Relatively lax enforcement of law allows one to take one pair of license plates and distribute it between two cars Expense of adding twice as many plates • Some states believe that is significantly more expensive to issue two plates, but interviews indicate that in most states the cost is minimal and passed on to the consumer • Argued that money would be better spent on finding cheaper solutions that would provide equal levels of retro reflectivity / visibility Damage to particular models • Even though all models have a location for a front license plate bracket, the equipment is frequently left off of the car when delivered to the dealerships • Owners believe that this may lead to unprofessional alterations that affect the value or appearance of the vehicle • US advertising typically does not include front license plates where as European publications almost always include a front license plate

The early appreciation of having two license plates on a vehicle is evidenced in a 1925 publication of in the Journal of Automotive Engineers [7]. The Division of Simplified Practice, one of the austerity efforts within the federal government, recommended that license plates have standard locations: front and rear. It was thought that front and rear plates can be obscured or damaged, so requiring specific locations on the vehicle for license plates would help all concerned with their observance and improve proper identification.

Currently, the requirements regarding license plates in the United States are largely a political issue, with very little scientific evidence to support the use of one verses two plates. Strong arguments exist on both sides of the

issue, but neither has the sufficient amount of quantitative data supporting its premise to reach a definitive conclusion, as can be seen by the United States' distinct split on the issue amongst the states.

When examining the arguments, it generally appears that those in favor of requiring two license plates have a mindset of safety and identification, whereas those in favor of one are coming from a fiscal and aesthetic perspective. The cost of a license plate and the number of license plates issued will vary from state to state, hence making the argument of cost versus safety analysis for each state's scenario different. Interestingly, the fiscal argument appears to be present whether people advocate for one or two license plates. With the increased use of automated license plate recognition (ALPR) technology (enforcement, tolling, parking, etc.), the presence of both front and back plates increases the opportunity to capture revenue especially with respect to securing payment for violations related to tolling and the effective processing of parking fees. It is reasonable to assume that the usage of ALPR technology will continue to expand in terms of the number of units deployed, but also in the diversity of applications. ALPR is only a tool to assist in the reading of license plates; the plates have to be available to read in order for ALPR to work just as when an individual manually reads the plate. When we consider this expectation, the need for front mounted plates seems to be a logical conclusion.

In order to address the lack of quantitative evidence related to one versus two license plate requirements, this project examined vehicle identification based on enforcement/traffic safety, homeland security, tolling, and parking perspectives. In order to address possible geographic issues the data collection was completed in two regions of the country: Mid-Atlantic and Southwest.

This research effort proposed to utilize the scientific approach to identifying critical information and trying to determine quantitative data that can be used as part of an analytical process in assessing the issues related to using one versus two license plates. The following section details the methodology employed to meet the objectives of this project.

STUDY OBJECTIVES

The primary goal of this research project was to evaluate the benefits and challenges associated with the use of dual license plates (front and rear) as opposed to a single license plate (rearonly). The project objectives focused on two areas where license plates are critical: law enforcement and general vehicle identification.

Law Enforcement

- Identify law enforcement practices involving license plates and vehicle identification, including the use of ALPR systems.
- Determine if rear or front plate placement (or both versus rear only) provides higher identification rates when using ALPR systems.
    - Identify the impacts from time of day, direction, lighting, and flash to vehicle identification when using ALPR systems.
- Identify situations and the likelihood of those situations, in which the lack of a front license plate could impede vehicle identification, and whether that identification is attempted by a person visually scanning vehicles or by an ALPR system.

- Assess the probability of vehicle identification by law enforcement officers by sight alone considering the availability of one or two plates.

General Vehicle Identification

- Compare the identification rates related to tolling, parking, and enforcement technology prominent in speed and red light cameras in regards to one or two license plates.
- Identify practices of vehicle identification using one or two plate placement related to homeland security and access entry.
- Determine the impact of the use of licenses plates for identification of vehicles by witnesses during the investigation of crimes or other incidents.
- Examine the fiscal implications of one verses two plates as they relate to multiple applications.

In addition to the identification aspects of single verses dual license plates, TTI examined the fiscal implications as they relate to multiple applications (enforcement, tolling, parking, etc.).

METHODOLOGY

This project involves diverse stakeholders who may serve as the consumers of the results of this report. In order to illustrate the impact of one verses two license plates, the project team included quantitative as well as qualitative approaches to data collection and analysis. From the quantitative perspective, the research team observed both stationary vehicles and those in motion to determine the rate which the vehicles could be identified according to their license plate. These types of observations could be replicated in different areas by any number of researchers.

The research team was also interested in studying how human behavior affects vehicle identification by law enforcement officers and other transportation professionals. The quantitative data addressed how many vehicles could be identified using front and/or rear plates, but the qualitative data informed the researchers as to how an individual or agency uses this data and articulates challenges associated with vehicle identification using license plates. Although this type of data collection is often considered subjective it is important to interpret the data from a practical perspective. The combination of quantitative and qualitative methodology provides for a comprehensive analysis that serves the diverse consumers of this type of market study research.

The focus of this project was to assess how vehicle identification using two license plates compares to rear only plates. The intent of the methodology was to examine the identification with respect to all applications not just law enforcement. Based on this approach, the researchers could not ignore the impact that ALPR technology has on the identification process and, subsequently, whether states should consider using two plates on all vehicles registered in their state.

In an effort to represent perspectives from different parts of the country, TTI identified four states in which to collect data. By utilizing four states (two dual plate states and two single plate states); TTI was able to produce a study that was more representative of the identification needs of enforcement and other identification activities. Two regions were identified, Mid-Atlantic and Southwest, as data collection areas for this project. TTI selected states to provide opportunity for observation in diverse environments. Maryland, Pennsylvania, Texas

and Arizona were the primary states, but due to their proximity to other states, the observation process included, at a minimum, the selected states as well as the adjacent states. All states had at least minimal deployment of ALPR systems as a means of identification and enforcement.

Based on the preliminary review of publications, TTI determined that it needed to work in states where the ALPR systems were already integrated into enforcement activities. TTI also wanted to ensure that it could readily identify enforcement agencies that would be willing to participate in this project and planned on utilizing existing relationships/partnerships with ALPR providers to enlist that participation. Maryland (two plates) and Pennsylvania (one plate) are geographically located in proximity to New Jersey (two plates), Virginia (two plates), West Virginia (one plate), Delaware (one plate), and the District of Columbia (two plates), therefore observations in these states not only included plates from the selected states, but also a number of plates from the adjoining states. Travel related to conducting the observations in these states was minimized since large population centers as well as rural areas were located close to each other and readily accessible in southeastern Pennsylvania and Maryland (especially in the Baltimore metro area).

The second set of states, Texas (two plates) and Arizona (one plate); represent a significantly different type of area as compared to the mid-Atlantic states. TTI conducted the majority of the observations in these states in the El Paso (TX)/Las Cruces (NM) area, College Station, and Houston. In Arizona, observations focused on Phoenix and Tucson in addition to the rural areas between these metro centers. These locations present unique issues with license plate identification. There is a great deal of interstate transit between Arizona, New Mexico and Texas in this area along with a large military population that included residents from a diverse set of states who are in Texas temporarily for military assignments. There are also significant issues related to border crossings for work (personal and commercial vehicles) as well as recreation.

It was important to attend to issues of diversity in the observation of the license plates (two vs. one plate, design of plates, states, etc.) in order to provide the best data set for analysis. By using states that are adjacent to each other and selecting states that present as many different licenses plate observations as possible, the analysis was more representative of the issues of license plate recognition. Since data collection represented a significant portion of the project cost, it was critical that this task was performed in such a manner to maximize the amount of data collected.

The work plan was structured to provide useful, practical, and reliable information that can be used to determine whether two license plates are more effective than only a rear plate. It was important to consider perspectives that not only included law enforcement, but also tolling, parking, and homeland security. The following section details the activities used to examine the effectiveness of one verses two license plates on vehicles.

VEHICLE INDENTIFICATION

Intuitively, it makes sense that individuals and/or ALPR technology will be more effective when provided with an increased number of chances to look at a license plate. In order to understand the difference that the use of one plate versus two plates make to the vehicle identification, it is important to understand that recognition process for individuals with and without the assistance of technology.

The ability to recognize a vehicle is critical to a number of applications [10]. Typical vehicle characteristics include body color, make and model, license plates and/or other distinguishing factors such as body damage, window tint, or stickers. A vehicle's make or model has distinct features that are key to human perception. Vehicle type (e.g. truck, sedan, or van) can be recognized even from a significant distance.

In the case of law enforcement, officers may use license plates to identify vehicles for homeland security, auto theft, traffic violations, and other criminal activities. Traffic law enforcement benefits frequently go beyond the traffic stop since many of these stops lead to the identification and/or apprehension of individuals involved in more serious crimes. The National Highway Transportation Safety Administration (NHTSA) and the International Association of Chiefs of Police (IACP) have focused on this opportunity by deploying a training course called Conducting Complete Traffic Stops [11]. The inclusion of license plate information in this process is not only important to identifying criminals, but also to officer safety.

Even though the officers may be searching for a specific license plate number, they often use other factors as a means of identification to reduce the number of options prior to focusing on the plate. These characteristics are easier to see and mentally process, they allow officers to eliminate the vehicles that do not fit the general description, and require minimal interaction with their dispatch [10]. It is difficult for a law enforcement officer to only use the license plate as the primary identifier without the use of ALPR technology since the officer must type in the plate number to their on-board computing system and/or contact dispatch for confirmation. This process can be time consuming and cause delays.

Human Recognition Verses ALPR Technology

When ALPR technology is employed in the enforcement environment, the technology performs the visual identification by reading and processing the plate in order to alert the officer to a potential offender or stolen property. The technology allows an officer to assess hundreds of plates per hour and automatically alerts the officer to those plates that are known to be stolen or belong to individuals involved with other criminal activity [12]. The ALPR process is very efficient, but, like a police officer, it cannot read what it cannot see. If license plates are affixed to the front and rear of vehicles, the technology, as well as identification solely by a law enforcement officer, can work more efficiently whether the vehicle in question is moving or in a stationary position. Dual plates allow an officer to specifically identify a vehicle from the safety of their police car regardless of whether the vehicle is in motion or stationary.

Vehicles require identification in other applications in addition to enforcement. Government and private entities are looking for ways to make processes more efficient/cost effective and less dependent on human interaction especially in regards to repetitive activities related to tolling, parking, and automated enforcement such as red light violations and speeding. License plates serve as unique identifiers in all of these applications and directly affect accurate identification of the vehicle involved in the violation and, in some cases, revenue generation.

Although the concept of identifying a motor vehicle seems simple, it can be complex and time consuming. Once the vehicle itself is identified, the vehicle has to be connected to the driver or the owner in order to pursue an enforcement issue of seeking payment for a traffic (red-light cameras and speeding) tolling or parking violation.

The ability to identify the vehicle from the front as well as the rear increases the opportunity to recognize and compare the plate to a known database of vehicle information. Even without the benefit of quantitative data related to license plate identification, it is reasonable to conclude that the use of front and rear license plates increase the probability to accurately identifying a motor vehicle in multiple and diverse situations. Clearly, with the advent of ALPR technology and its relevance to various applications, there is or will be a significant benefit to government, private entities, as well as enforcement.

The following section of this report provides data and case studies from the literature as well as the field studies conducted specifically as part of this project.

APPLICATIONS IN LICENSE PLATE IDENTIFICATION

In order to address the objectives of this project, the research team reviewed existing literature and collected data from specific states to determine the impact of utilizing dual license plates (front and rear placement) verses only using a single rear plate. Initially, the research team was focused on enforcement, but found that the enforcement community has little incentive to collect data related to the identification of vehicle via the license plate. Most of the existing data is anecdotal. The enforcement related data included in this report was collected by the research team in each of the four states with moving vehicles and those that were stationary.

Although the enforcement data demonstrates a difference in the recognition of vehicles with dual plate, the researchers found an even more profound impact when they examined the fiscal impact in tolling as well as an improvement in recognition in security applications. The impact of ALPR technology cannot be ignored as a critical factor in regards to the current and potential benefits of requiring a front license plate. As the use of ALPR technology increases across a diverse set of applications, front plates will become even more beneficial. This section details the cases studies found in the literature as well as the data analysis based on the field studies that were conducted as part of this project.

Case Studies from the Literature

As part of the literature review, the research team selected examples related to the identification of vehicles either manually or by using ALPR technology. These examples have been summarized in the form of case studies related to enforcement and tolling. The intention was to highlight practical insights gleaned from the existing literature as a means of informing the methodology, data collection, and the formation of conclusions related to the debate of one versus two plates.

California: Automated Photo Enforcement Countermeasures

A study was conducted in California to examine the effect of two countermeasures: photo spray and license plate shields [1]. Field tests examined the impact of plate treatments on the readability of the front and rear license plates in different directions (east and west) in both daylight and darkness. The study also provides some insight on the recognition of the plate placement. In the darkness setting, there was not a noticeable difference between the readability of either the front or rear plates. Observations made during in daylight environment did produce a difference between the readability of the front verses rear plates. The presence of sun glare had a noticeable effect on the readability of the rear plates, but not those placed on the front of the car. These results are consistent with observations made by the staff at Phoenix's Sky Harbor Airport parking facilities.

Although this study was conducted exclusively using ALPR technology, it is reasonable to assume that the sun glare would also affect an individual's ability to recognize and read the plates regardless of the treatment.

Virginia: Report of the Tolling Legislation Working Group

Virginia has a number of toll roads including those that are part of the general roadway that serve as HOT lanes. These roadways are a critical part of the state's transportation infrastructure and serve as a critical element to address mobility issues in Virginia's most congested areas.

> "The HOV lanes move more people in carpools, vanpools, buses, motorcycles, clean fuel vehicles, and trucks from Virginia to the core areas of Arlington and Washington DC than the regular highway lanes, Metrorail, and the Virginia Railway Express. Our transportation network could not function without HOV lanes [2, p2]."

Electronic toll collection technology has improved the transportation environment so that high-occupancy and tolling facilities can be expanded. The challenge associated with electronically monitoring these facilities is the enforcement of the occupancy and toll violations with minimal impact to those facilities [2; 3]. Manual enforcement, individual officers alone or as part of saturation patrols, is expensive, frequently inefficient, and diverts resources [2; 3; 13].

Additionally, this type of enforcement only results in short term impact on violation rates and disrupts traffic flow on roadways that are intended to improve mobility. Along with the growing demand for efficient travel, tolling authorities and government entities need to recoup the revenue that is used to justify the construction of such facilities. With that in mind, it is important to maximize the opportunity to identify vehicles via license plates. Although Virginia is a two plate state, not all of their tolling facilities are equipped with ALRP cameras that read the front plate which significantly contributes to the 539,000 violations (23% of total violations) which are not pursued due to the lack of photographic evidence. It is easy to imagine the financial impact that this has on the revenue generation in Virginia [3].

Table 3. Virginia Toll Transactions and Violation Disposition [3]. (Year Ending 6/30/2011)

	Total toll transactions	200,000,000
	Toll violations	1,914,000
	Violations not resulting in a court summons	1,871,000
Paid Violations	Violations processed through V-tolling	647,000
Paid Violations	Violations pursued through notices	445,000
Paid Violations	Violation paid after 1st notice	164,000
Unpaid Violations	Violation not paid, but disregarded since a third violation did not occur during the calendar year	173,000
Unpaid Violations	Returned to sender	65,000
Unpaid Violations	Violations not processed due to lack of photo	539,000
Unpaid Violations	Violator (1st time violator) with no additional violations during the calendar year (no fine)	283,000
	Violations resulting in court summons (6,750 individual violators)	43,000

From these statistics, it is evident that improving the capability to identify and photograph license plates could significantly improve reclamation of fees for violations. Adding cameras positioned to capture front plates in addition to the rear-plate cameras currently in service could significantly increase the number of vehicles that are successfully photographed.

Georgia: Enforcement Strategies for High-Occupancy Toll (HOT) Lanes in Atlanta

The metro Atlanta area is well known for its congestion. With three major interstates (I-20, I-75, and I-85) converging in its downtown area along with the population growth in its suburbs, the city is seeking ways to improve their transportation infrastructure while relieving its congestion challenges. Atlanta is currently utilizing HOT lane corridors without complete barrier separation as a means of addressing the significant congestion challenges along its most travelled roadways [13]. Effective enforcement presents several issues when addressing toll violations, lane integrity, and occupancy restrictions. In order to augment traditional enforcement by individual officers, the HOT lanes are equipped with enforcement cameras that capture the license plates of violators. The ALPR equipment is directed only at the rear plate. This application is not solely due to the fact that Georgia is a one plate state, but rather because the violation has to occur (i.e. vehicle must pass the gantry/reader without a valid transponder) before the camera needs to capture the image of the plate. If reading front plates was an option, there may be other available approaches to enforcement (occupancy and other tolling violations).

Denver, Colorado: E-470 and How Front License Plates Impact Tollway Efficiency

The E-470 roadway in the Denver-Aurora Metropolitan Area serves an excellent example of how much front license plates can impact the efficiency of our transportation infrastructure in the tolling application. E-470 is a 47-milelong, controlled-access road with fully electronic tolling. The toll way intersects significant highways (I-25, I-70, and I-76) and serves as an outer beltway for the Denver-Aurora Metropolitan Area [14]. E-470 is not a state road and is managed by the E-470 Public Highway Authority; therefore it is critical that the system generate the expected revenue since tolling authority receives no state or federal funding or local taxes.

Over a twelve month period, E-470 Public Highway Authority tracked the number of transactions and tolls due based on which license plate was used to generate the toll. There were a total of 23,798,636 transactions resulting in more than $67.2 million in revenue [4]. Front plates accounted for 8,007,895 toll transactions and $23.1 million in revenue. Based on feedback directly from E-470 staff, the ability to capture front plates is critical to the success of the toll way. Thirty-four percent (34%) of the tolling revenue would have been lost without the ability to read a front license plate.

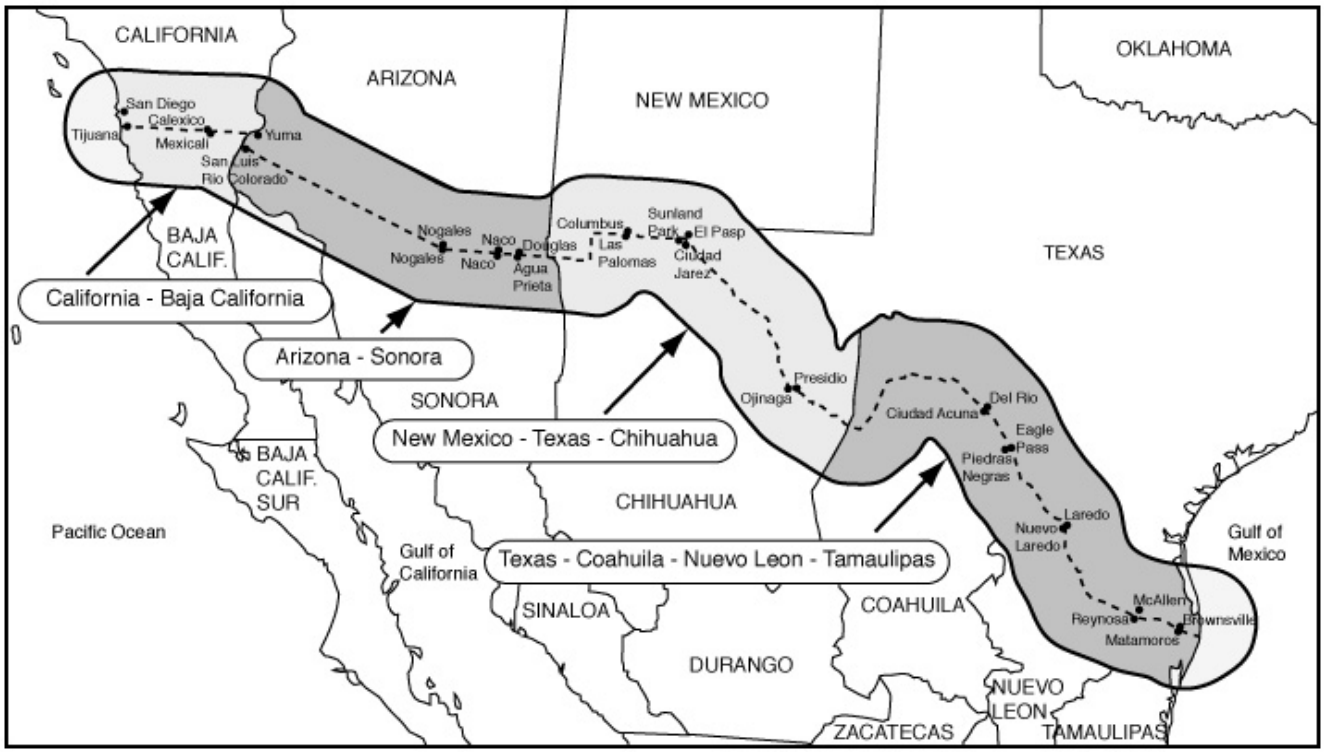
Table 4. E-470 Transactions for 12-Month Period [4].

Plate Side	Transaction Count	Toll Due	% of TOT
FRONT	8,007,695	$ 23,062,441	34.3%
REAR	5,389,926	$ 14,577,152	21.7%
UNKNOWN	10,401,015	$ 29,589,750	44.0%
TOTAL	23,798,636	$ 67,229,342	

According to Dave Kristick of the E-470 Public Highway Authority, front plates are even more important in the capture of large, long-haul truck revenue [4]. Due to the prevalent use of apportioned plates with the trailers, the ability to capture the front plates of large trucks is crucial. The operation of the E-470 toll way provides a strong case for why front plates will be a critical element of tolling as either a means of generating the toll and/or pursuing violations.

U.S. Customs and Border Protection: Effects of License Plate Placement on ALPR at Border Crossings

The U.S. Customs and Border Protection (CBP) utilize ALPR technology on both the northern and southern borders of the United States [15]. The border facilities process a significant number of vehicles each day, so efficiency of the identification process is paramount. U.S Customs and Border Protection in conjunction with RTR technologies studied the effectiveness of ALPR applications on at northern and southern border crossings and the results of that investigation are summarized in this case study.



Authorities at the international borders relied on ALPR technology for this investigation. The agency defined a valid read as one that is read (correctly or erroneously) and excluded several instances since the issue was beyond the capabilities of the ALPR system due to limitations in the field of view. In order to be included, the plate's number and state must be visible. Those vehicles with obstructions such as a trailer hitch, part of the plate being out of the field of view, temporary plates, towed vehicles, motorcycles, as well as commercial vehicles with more than one specific plate were excluded.

The Canadian and Mexican states that border the United States have the following requirements for license plates:

Table 5. International States Bordering the United States [8].

	Dual Plates	Rear Plate Only
Canada	British Columbia Saskatchewan Manitoba Ontario New Brunswick	Yukon Territory Alberta Quebec Nova Scotia
Mexico	Baja California Baja California Sur Chihuahua* Cuahuila* Sonora* Tamaulipas*	Norte Nuevo Leon

Note: In Mexico, the front plate requirement only applies to privately owned vehicles. The (*) indicates that in these Mexican states, a front plate is only required on vehicles that are registered to owners who live within 20 miles of the U.S. border.

At the northern border crossings, vehicles with rear-only plates had significantly more exclusions (e.g. the rear plate was obscured by something and there was no front plate to read) than those with dual plates and the read rates were lower [5]. The general traffic lanes had approximately 6% of their vehicles excluded and the commuter lanes had a 4% exclusion rate.

Seventy-five percent of the read rates for rear-only plates were below the average of the dual plate reads. The southern border exclusions were better with only 3.4% of the general lane traffic excluded and 1.3% of the commuter lanes vehicles were excluded. This is likely due to the fact that most of the traffic across the southern crossings have two plates since the two most populous states in the U.S., Texas and California, are dual plate states and have significant cross traffic on a daily basis.

Additionally, the Mexican states adjacent to these borders require two plates for those most likely to cross into the U.S. on a frequent basis. Finally, at the southern border, the read rates for those plates with license plates mounted only on the rear of the vehicle were all lower than those with dual plates.
The ability to efficiently process vehicles at border crossings is not only an issue of congestion, but also homeland security. It would be impossible to process all of the crossings effectively without the use of ALPR technology. Additionally, the technology allows the U.S. Customs and Border Protection to load license plates that are known to be connected to security risks as well as criminal activity [16]. In July 2012, the federal government issued a request for information (ALPR technology) in support of the Drug Enforcement Administration (DEA), along with CBP, National License Plate Reader (LPR) Initiative [17]. This provides further proof that ALPR technology is the wave of the future in terms of vehicle identification. Checking each plate manually would not be possible without long lines and additional personnel. Since ALPR technology is a critical tool in border security, it stands to reason that states should give the federal enforcement officers any practical

tool that can improve the efficiency and effectiveness of their operations. Dual plates seem to be a low cost tool to address these issues.

Revenue Collection: Tolling and Parking

Although there were not specific examples in the literature related to vehicle identification from the revenue generation perspective, it is important to note that license plates do serve a critical need in the tolling and parking industries. ALPR can be used by tolling agencies to track violators and to automatically collect tolls, though regular toll collection is more commonly accomplished using toll tags/transponders. ALPR systems are generally positioned to the side of or above roadway lanes just past tolling plazas/checkpoints to photograph vehicle plates. Similarly, parking facilities that charge by the hour or day can use ALPR to verify when vehicles enter and leave a facility.

Case Studies and Data Analysis from the Field Studies

The research team travelled to the Mid-Atlantic and Southwestern states to interview stakeholders related to law enforcement, tolling, and homeland security. Given the close proximity of the states in that region, the research team was able to visit other areas adjacent to the target states. The research team surveyed multiple parking lots, garages, and other locations in several jurisdictions in Arizona, Maryland, Pennsylvania, and Texas. The team tabulated the number of cars in those facilities and the percentage of those cars with visible license plates. There were more than 9000 vehicles observed during this task verses the 2500 originally projected at the beginning of this study.

The research team tested the ability of ALPR systems to identify vehicles based on front and rear license plates under various conditions. The observations utilized ALPR systems currently deployed by the law enforcement agencies that participated in the project - researchers rode-along with selected officers to conduct some of the observations. Care was taken to include officers who primarily deal with traffic related enforcement (e. g. state patrol) as well as those officers who engage in more general patrol activities (municipal and county). As part of this task, the researcher recorded how vehicles were identified (front license plate, rear license plate or both) during the officer's shift. During this process qualitative data was gathered from the officers and other stakeholders to augment the quantitative data.

The following section provides data from specific states and jurisdictions. The research team collected data and interviewed individuals related to enforcement, tolling, parking and homeland security. These observations serve as practical examples of those applications that were found in the literature.

General Enforcement

The law enforcement agencies interviewed in this study that use ALPR systems did not use the technology on all patrol vehicles at the time of this report due to the expense of the systems, though several indicated that they would be in favor of expanding their agency's ALPR capabilities, based on the benefits that have been realized from the units they have. The purchase and maintenance of ALPR units are often funded through competitive grants that are specifically focused on reducing certain types of crimes, such as stolen vehicles. Other funding sources that were mentioned by law enforcement agencies include homeland security funding, especially for agencies close to Washington, D.C., and a local community grant that was repaid via the increased collection of

parking fines. The specific funding source for a law enforcement operated ALPR unit often dictates the units primary use/assignment within that agency – e.g., an ALPR system purchased with a stolen-vehicles grant will be installed on a patrol vehicle within the agency's stolen-vehicle unit, and ALPR units purchased with Homeland Security funds are likely to be positioned at locations where vehicles will be crossing a defined borders or perimeters.

However, in nearly all cases, ALPR units are to alert officers and agencies to license plates associated with other outstanding crimes as well. The interviewed agencies have made use of ALPR systems, individually or networked across regions or states, to track Amber and Silver alerts, to find vehicles and people connected with crimes that have been reported locally or listed in the National Crime Information Center (NCIC), and for enforcement of suspended vehicle registrations, insurance violations, and outstanding traffic and parking warrants. As ALPR becomes more widespread and technology costs decrease, it is likely that agencies will adopt the units more widely across their patrol and roadway surveillance operations.

Maryland State Police: Dual Plates and ALPR Creates an Effective Enforcement Partnership

Maryland is a two plate state that is bordered by three single plate states, Pennsylvania, West Virginia, and Delaware, and two dual plate states, Virginia and the District of Columbia. This geographic location makes for some challenges for enforcement and security concerns.

Maryland is a small state with many challenges including the proximity of the state to the District of Columbia (critical homeland security issues), areas of high crime rates, and a diverse set of vehicles that utilize their roadways. There is a great deal of interstate traffic between Maryland, Virginia and the District of Columbia so the state depends on both front and rear plates to address these challenges.

The Maryland State Police (MSP) department currently operates 20 vehicles equipped with ALPR units, and will be adding more units to its fleet soon, with the goal of having at least one ALPR mobile unit per barrack/district. In addition, several fixed ALPR units are mounted to scan traffic lanes at selected high-traffic locations in the state. The state police use ALPR to assist in locating stolen vehicles, stolen license plates, Silver and Amber alerts, Gold alerts (adults who are vulnerable due to mental illness or other impairment), other missing people, and people wanted in connection with a crime. Several local jurisdictions in Maryland also use ALPR to look for suspended registrations, insurance violations, and outstanding traffic warrants.

The MSP's mobile (vehicle-mounted) units include two forward-facing cameras, one each on the right and left sides on top of the vehicle. The left-hand camera reads two lanes to the left of the police vehicle to read plates of oncoming traffic; the right-hand camera reads one lane to the right, to widen the camera's detection field and maximize the ability to identify parked vehicles on the right side of the road.

The state police mobile units, the fixed units, and any ALPR units being operated by municipal and county police jurisdictions in Maryland are all centrally networked. Mobile units can monitor fixed ALPR units in real time. Each unit downloads an updated list of plate numbers twice daily from the National Crime Information Center (NCIC) and the state Motor Vehicle Administration; in addition, emergency notifications (such as Amber, Silver,

or Gold alerts) can be manually entered and pushed by the networking center to all ALPR units in real time rather than waiting for the next NCIC download.

Beyond the immediate alerts to officers in the ALPR-equipped vehicles, the collected license plate data has been of enormous benefit to criminal investigations. Suspects and witnesses to crimes can be found much more quickly, based on previous reads of their vehicles during routine patrols. Vehicles that may be connected with Homeland Security alerts can be tracked as they cross highways monitored by the fixed ALPR units. The ability to push emergency alerts out to all ALPR units is valuable as well; a vehicle associated with a recent Amber alert was tracked within 40 minutes of the alert being posted.

Lancaster, Pennsylvania: A Small Town with Many Tourists

Pennsylvania is a single plate state with a major turnpike running east to west. There are a number of cities in Pennsylvania, but there are also a considerable number of rural roadways in the state. The South Central town of Lancaster has approximately 60,000 people with several major tourist destinations in the immediate area so there is a great deal of traffic created beyond the local community. Although the enforcement resources in Pennsylvania have adapted to only having one license plate for the majority of the vehicles they encounter, it is still a challenge to identify oncoming traffic and many of the vehicles parked in the local area.

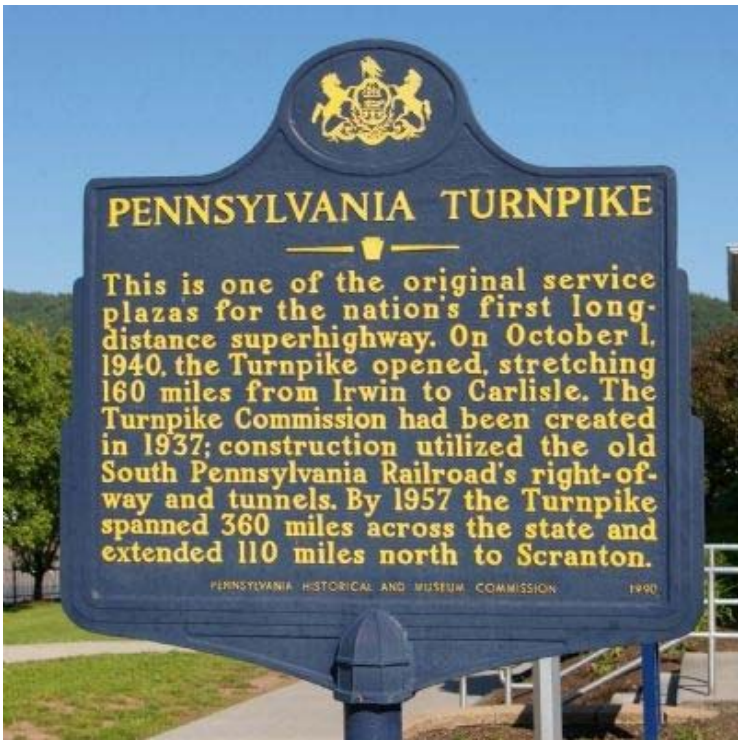
The local police department has two vehicles that are equipped with ALPR cameras: one unmarked car that is used by Community Service Aids who patrol for parking-violation scofflaws, and one car that is used by the auto theft unit (regular patrol car as seen on the right). Each of the two ALPR-equipped cars has two cameras mounted on the left and right; the cameras lock into place at a 45- degree angle forward or a 45-degree angle backward, but can also be positioned, unlocked, to a 90-degree angle to more easily read plates in a parking lot. The two cameras have slightly different fields of view – the left (driver) side camera has a narrower field but a longer range that is useful for scanning the farther-away left side of a road, and the right (passenger) side camera has a wider field but a shorter range. The cameras are also fairly effective at scanning multiple lanes of traffic.

Each day an updated list of license plate numbers associated with stolen cars and parking violation scofflaws is received from the Commonwealth Law Enforcement Assistance Network (CLEAN) and uploaded to the ALPR system. Between January 1, 2012 and late April 2012, over 300,000 plates were read by the two ALPR-equipped vehicles; the Lancaster Bureau of Police has a total of 1.3 million images stored (those read since October 2011).

It is difficult to pinpoint differences in the number of vehicle thefts before and after the introduction of the ALPR systems in Lancaster; this is in part due to other crime-prevention cameras implemented throughout the city in

recent years by the Lancaster Community Safety Coalition. These combined efforts have greatly decreased the overall crime rates in the city. However, the theft of license plates has decreased sharply since the ALPR systems began operation. The ALPR system used for parking enforcement paid for itself in three months because of increased collection of outstanding parking fines.

Pennsylvania Turnpike Commission: How Front Plates Could Assist in Tracking Violations



The Pennsylvania Turnpike uses ALPR systems for revenue collection and to track tolling violations. Vehicles that have traveled the Turnpike without paying the toll are tracked and their owners contacted for payment, though the Turnpike currently has no real authority to enforce payment. The Turnpike's ALPR cameras are positioned so that pictures can be taken of the front and rear of a violating vehicle (approximately vehicle width) from a distance of 17 feet. Typically, when a vehicle crosses detection points on the Turnpike without an EZ Pass transponder, or without paying a toll at one of the tollbooths, the cameras are triggered. Several images are taken of a single plate so that the system has multiple opportunities to scan and interpret the plate's number; the system usually captures at least two pictures of the vehicle's front (for trucks) and four to five pictures of the rear plate, and may take 16 or more images of a given plate.

For passenger vehicles, the Turnpike Commission tries to obtain a readable picture of the rear plate (to avoid including the driver in the photograph); for trucks the practice is to obtain a readable picture of the front of the vehicle, since the plate of concern is on the tractor rather than the trailer. The clearest picture is then selected to copy and include with the violation notice that is sent to the vehicle owner.

Even with the multiple images, it is not always possible to see or read a given vehicle's plate. The position of the plate, especially on trucks, may be out of the camera's capture window (often due to deliberate placement by truck drivers to circumvent toll collections), and the plate itself may be difficult to read because its surface condition or because the image is too dark, particularly at night.

The ALPR system confidence level is configured at 85%. In all, an average of 16% of plates captured by the cameras as potential violations are voided during the identification process, and another 3% are voided during the appeals process. This level of accuracy is achieved using both plates when available.

International and Multi-State Influence: El Paso and Horizon City Police

The second most populous state, Texas requires two license plates. The state is home to five of the twenty largest cities in the United States and also has the longest international border of any state. One of the areas the project wanted to focus on was the El Paso region which is unique based on its significant international, military, and bi-city relationship with Las Cruces, New Mexico. Texas is a major transportation hub with several sections of interstate roadways connecting the east and west coasts as well as I-35 which runs north and south directly through the center of the country connecting from Canada to Mexico.

The El Paso Police Department has used ALPR since 2006, and currently operates 23 mobile units with ALPR. Besides the mobile units, the El Paso Police also own six ALPR-equipped trailers that can be parked alongside a roadway. The trailers include a radar system and "your speed is" display that faces approaching traffic, while the ALPR camera is positioned on the opposite side to read rear license plates as vehicles pass it. While the license plate reads from the trailer-mounted cameras do not provide instant feedback to patrol officers as do the vehicle-mounted ALPRs, they provide additional data to the department's analysts.

Nearby Horizon City has one ALPR-equipped patrol car in its 20-vehicle police fleet. Information from NCIC and the Texas Crime Information Center (TCIC) are downloaded daily, and can also be refreshed wirelessly on demand while the vehicle is patrolling. License plate reads from Horizon City are uploaded to the El Paso Police database for storage and analysis.

The ALPR technology used by both of these agencies is equipped with one camera per unit; the camera can be mounted anywhere and facing any direction, but the most common orientation for a vehicle-mounted camera is to the forward right of the patrol vehicle, for reading plates on parked cars. The orientation of Horizon City's ALPR unit can only be changed manually from outside the car; the units in El Paso can be panned and tilted electronically from inside the vehicle. Future ALPR systems for the El Paso Police department are going to include two cameras per unit to be able to read forward and backward simultaneously.

Both departments use ALPR to track stolen vehicles, vehicles associated with other crimes, and vehicles belonging to sex offenders. The units can also help track uninsured vehicles or vehicles with expired registrations.

Phoenix Metro Area, Arizona: Local Police Agencies and the Impact of Vehicle Identification

Arizona is a single plate state with two major metropolitan areas, Phoenix and Tucson. Like Texas, Arizona has a significant international presence based on its border with Mexico. It is also boarded by New Mexico, California, Nevada, Utah, and shares its northeast corner with Colorado. The state has several international crossings as well as major interstate thoroughfares running east and west.

The Phoenix Police Department has been using ALPR since 2004 and currently has a total of four ALPR units; one is assigned to the Auto Theft unit, one to parking enforcement, and two to general patrol. The Phoenix ALPR units each include three vehicle-mounted cameras, two facing forward to the left and right, and a third facing to the right of the patrol vehicle for reading plates in a parking lot. The two forward-facing cameras can read up to

two lanes on either side of the patrol vehicle (three lanes are possible, but accuracy diminishes). The sidefacing camera scans approximately six to nine feet, or a little less than one lane width, to the right of the patrol vehicle.

Glendale's department originally acquired ALPR units in 2006, specifically to track stolen vehicles; the department is now using its second generation of four ALPR units, and their use has expanded to general patrol activities as well as continuing to track stolen vehicles and stolen license plates. Glendale's mobile units each have two forward-facing and two backward-facing cameras. The cameras can be placed in different configurations, but are usually set up to read plates on parked vehicles to the side of the patrol vehicle.

In both cities, anywhere between a few dozen and a few thousand plates may be read by an ALPR unit on a given day, depending on the vehicle's patrol pattern. In April 2012, the four ALPR-equipped vehicles in Phoenix read a total of 62,833 license plates, averaging 523 plates read per unit per day. The Phoenix PD currently has about two million plates in its database; Glendale purged its old data in 2010 after getting new software for its ALPR system which could not read the previously collected data, and currently has approximately 280,000 plates in its database.

Phoenix Sky Harbor Airport: Reading License Plates Translates to Revenue

Parking revenues are the second highest revenue source for Sky Harbor, following only airline revenues. Before the economic downturn in 2008, Sky Harbor reached $80 million per year in parking revenues, and revenues are beginning to climb back toward that level again as of 2012. Each of the 65 entry and exit lanes for airport parking at Sky Harbor are monitored with an ALPR camera, positioned to photograph the vehicle's rear plate. The objective is to provide a visual record of every vehicle entering and leaving the parking facilities in order to prevent fraud and ensure that correct parking revenues are collected from each customer.

On average, 10,000 parking transactions per year (at an average value of $30 per transaction) rely on the ALPR reads to determine accurate charges; most of these are due to lost tickets, and with the record provided by the ALPR read of a given vehicle upon entry, the correct charge can be determined. Less commonly, attempted fraud, falsely lost tickets and swapped tickets, can be detected and prevented. Also because of the ALPR system, the number of vehicles stolen from Sky Harbor parking facilities has decreased significantly in recent years.

The system accuracy on plates that are read is 85% (rear plates only in the current configuration). Typically, 10-15% of license plates entering or exiting the facilities cannot be read by the system, most often because of sun glare. To remedy the problem, canopies are placed over the reader location to minimize early-morning and late-afternoon glare off of rear plates as vehicles enter the facility. Currently, because so few vehicles entering the parking facility display a front license plate, it is not cost-effective to add a second camera to each entrance/exit lane.

To back up the information provided by the entry/exit ALPR reads, a manual license plate inventory (LPI) is conducted of one of the airport's four parking facilities each week. On an average night 14,000 vehicles are parked in the airport's four parking facilities. In a typical LPI, approximately 200 plates can be inventoried per man-hour. Depending on the size and vehicle occupancy of the facility being inventoried, an LPI can take between two and 15 man-hours. Typically, one out of every eight vehicles (12.5%) is parked tail-in, generally requiring the person conducting the LPI to walk around to the rear of the vehicle to read the rear plate because most vehicles in the area do not have a front plate. Because of the significant percentage of vehicles without visible plates due to tail-in parking, the parking facility staff cannot perform their audit using the mobile ALPR unit to double-check inventories.

VEHICLE IDENTIFICATION: ESTIMATING THE EFFECTS OF FRONT PLATES

As can be seen in the case studies, agencies will adjust their vehicle identification procedures and their use of ALPR (where applicable) to accommodate existing conditions as much as possible. In states where a majority of vehicles do not have front plates, ALPR systems are more likely to be set up to capture rear plates. Furthermore, the law enforcement agencies interviewed in both one- and one plate states do not tend to track the number of front plates versus rear plates that are captured during patrols. For these reasons, the exact benefit of front plates in improving vehicle identification is difficult to calculate. However, two vehicle identification scenarios that are common to most of the interviewed agencies were simulated by the research team's counts of license plates on parked and moving vehicles in each of the four case study states.

Identifying Parked Vehicles

The first scenario is the identification of vehicles that are parked perpendicular to a driving lane in a parking lot. Because some percentage of vehicles are likely to be parked tail-in, the presence or absence of front plates will help to determine the percentage of vehicles that can be identified using a mobile ALPR unit. For the parking lot vehicle counts in this study, the research team counted the total number of vehicles as well as the total number of license plates that faced the driving lanes between the rows of parking spaces (rear or front plates, depending on whether each vehicle was parked tail-out or tail-in), simulating the ALPR camera configurations and ranges used by most of the law enforcement agencies to read plates on parked cars.

Based on the parking lot plate counts (See Table 6), ALPR-assisted patrols of the parking lots sampled in Maryland and Texas would have the opportunity to read license plates on 97% of the vehicles parked there. In contrast, similar patrols of the sampled lots in Pennsylvania and Arizona would be able to capture the plates of (on average) only 76 % of the parked vehicles.

Table 6. Parked Vehicle Counts. (Mixed front and rear plates)

State	City/Location	Date/Time	Total Vehicles	Vehicles with Visible Plates	% with Visible Plates
MD	Jessup	Wednesday, 4/11/12, 10:34 a.m.	211	205	97%
MD	Hanover Lot #1	Wednesday, 4/11/12, 2:43 p.m.	198	196	99%
MD	Hanover Lot #2	Wednesday, 4/11/12, 2:53 p.m.	1855	1794	96%
TX	El Paso	Tuesday, 4/24/12, 4:15 – 4:40 p.m.	1129	1049	93%
TX	College Station Lot #1	Saturday, 6/23/12, 12:15 p.m.	167	165	99%
TX	College Station Lot #2	Saturday, 6/23/12, 12:40 p.m.	271	268	99%
TX	College Station Lot #3	Saturday, 6/23/12, 1:15 p.m.	261	258	99%
TX	College Station Lot #4	Saturday, 6/23/12, 1:45 p.m.	1298	1276	98%
Total for Maryland and Texas (2-plate states)			**5390**	**5210**	**97%**
PA	Lancaster Lot #1	Thursday, 4/12/12, 11:30 a.m.-12:15	332	259	78%
PA	Lancaster Lot #2	Thursday, 4/12/12, 1:30 p.m.-2:30 p.m.	1812	1288	71%
AZ	Tempe	Tuesday, 5/22/12, 1:25-2:30 p.m.	1607	1317	82%
Total for Pennsylvania and Arizona (1-plate states)			**3751**	**2864**	**76%**

When law enforcement or parking personnel assess a parking lot for stolen vehicles, parking violations, etc., they can either use staff resources to personally conduct the audit or ALPR technology. Regardless of the methods, the license plate must be visible in order to be read. It is evident that the use of front plates increases the opportunity for these individuals to perform their work tasks and, in some cases, increase their revenue.

Identifying Moving Vehicles

The second scenario is identification of vehicles that are in motion– on a roadway, crossing through a toll plaza, crossing over a border, or entering or leaving a parking facility. ALPR cameras may be mounted on patrol vehicles, to portable trailers, or to stationary structures.

The moving-vehicle license plate counts conducted by the research team were of oncoming traffic, comparing the total number of vehicles to the number of front license plates (with the assumption that virtually all vehicles in all four states would be equipped with rear plates). As can be seen in Table 7, the highest percentages of vehicles with front plates were seen on roadways that began and ended within the one plate states of Maryland and Texas. This high percentage of front plates is seen even at the border crossing bridge between Texas and Mexico. The highways spanning the one plate state of Maryland and the one plate state of Pennsylvania, not surprisingly, carried a mixture of vehicles from both states, as well as several other neighboring states. This mixture resulted in varying percentages of vehicles with front plates (39% up to 66%), with an average of 58% of observed vehicles across the three highways displaying a front plate. Researchers observed that these percentages tended to shift up and down on these highways depending on the location relative to the Maryland-Pennsylvania state line. The roadways that were contained within Pennsylvania and Arizona carried the lowest percentage of vehicles with front plates, averaging 22%.

Among the agencies interviewed for the case studies, the overall accuracy of the ALPR systems (i.e., the percentage of accurate reads of plates that are captured by the cameras) ranges from 85 to 92 percent. The law enforcement agencies that were interviewed in the case study states do not generally track the numbers of vehicles that are photographed from the rear versus the front or the percentage of vehicles that are not captured at all by ALPR systems due to a lack of a front plate.

Phoenix Sky Harbor Airport is, however, able to compare the total number of vehicles that enter its four parking facilities to the number of plates that are successfully read. The ALPR cameras at each entrance are set up to capture rear plates only, and approximately 10 to 15 percent of those plates are not captured by the cameras. Since the ALPR system achieves approximately 85% accuracy on plates that are captured, this missing percentage of captured plates lowers the actual accuracy of the plate reads to between 72 and 77 percent. The vast majority of these unread plates are due to the limitations of the single camera arrangement dictated by the absence of front plates on most local vehicles. If all vehicles entering Sky Harbor's facility had front plates as well as rear plates, a second camera placed to capture front plates would help to achieve nearly 100% capture and thus raise the overall accuracy of the system to the desired level.

Even if a majority of vehicles entering Sky Harbor's parking facilities had a front plate (such as the 85 to 94 percent of vehicles observed on roadways in Texas and Maryland), the added reads from a two-camera configuration could significantly improve the capture rate for vehicle identification. It is likely that the ability to capture both front and back plates would similarly improve the capture rate in other moving-vehicle environments such as law enforcement patrols.

Table 7. Moving Vehicle Counts. (Front plates only)

State	City/Roadway	Date/Time	Total Vehicles	Front Plates	% with Front Plates
MD	City of Elkridge, W. Nursery Rd @ Winterson Rd	Monday, 4/9/12, 9:50-10:55 a.m.	652	578	89%
MD	I-97, Baltimore to Annapolis to Baltimore	Monday, 4/9/12, 9:30-11:00 a.m.	2123	1822	85%
TX	Horizon City, Horizon Road	Monday, 4/23/12, 9:57 – 10:15 a.m.	250	229	92%
TX	El Paso, San Paulo St.	Monday, 4/23/12, 2:20-2:50 p.m.	718	634	88%
TX	El Paso, Stanton St. International Bridge	Tuesday, 4/24/12, 11:50 a.m. -12:20	180	161	89%
TX	College Station, Texas Ave.	Saturday, 6/23/12, 6:30-7:30 p.m.	1009	952	94%
Total for Texas and Maryland (2 plates)			**4932**	**4376**	**89%**
MD/PA	Highway 97, Gettysburg to Baltimore	Monday, 4/9/12, 6:07-6:29 p.m.	615	407	66%
MD/PA	I-83, Baltimore, MD to York, PA	Tuesday, 4/10/12, 11:25-11:45 a.m.	241	127	53%
MD/PA	Highway 272, Lancaster to Baltimore	Tuesday, 4/10/12, 5:08-6:10 p.m.	220	86	39%
Total for Roads Spanning Maryland and Pennsylvania			**1076**	**620**	**58%**
PA	I-30, York to Lancaster	Tuesday, 4/10/12, 11:55-12:10	584	188	32%
AZ	I-10 Phoenix to Tucson	Monday, 5/21/12, 9:30- 10:30 a.m.	2285	662	29%
AZ	Phoenix, 7th Ave @ Washington St.	Tuesday, 5/22/12, 8:30-8:50 a.m.	683	22	3%
AZ	Glendale, 57th Ave @Glendale Rd.	Tuesday, 5/22/12, 10:30 – 11:00 a.m.	488	18	4%
Total for Pennsylvania and Arizona (1 plate)			**4040**	**890**	**22%**

Law enforcement, tolling and homeland security applications process data from moving vehicles. Based on the data from the field studies it is evident that the lack of a front plate has an adverse affect on the ability to identify vehicles that are moving.

STATE LICENSE PLATE POLICIES – RESULTS OF DMV INTERVIEWS

Departments of Motor Vehicles (DMVs) in each state were contacted by telephone and/or email. Responses were obtained from 33 states – 21 states that mandate two license plates per vehicle and 12 states that mandate only a rear plate. Table 8 lists the states represented by the interview responses.

Table 8. States Requiring One vs. Two Plates.

States Requiring Two Plates	State Requiring Rear Plate Only
Alaska	Alabama
California	Arkansas
Colorado	Delaware
Hawaii	Georgia
Idaho	Indiana
Maine	Kansas
Maryland	Louisiana
Minnesota	New Mexico
Missouri	North Carolina
Nebraska	Oklahoma
New Hampshire	Pennsylvania
Nevada*	Tennessee
Oregon	
South Dakota	
Texas	
Utah	
Vermont	
Virginia	
Washington	
Wisconsin	
Wyoming	

Note: The (*) indicates that although two plates are issued in Nevada, vehicles without a designated space for a front plate do not have to display the front plate.

Reasons for License Plate Policies (One plate and One plate)

Of the DMV respondents from the 21 states that currently require two plates, 16 (76%) indicated that a primary reason for the establishment and/or retention of the one plate requirement was greater ease of vehicle identification by law enforcement. In 2006-2007, Utah considered changing from a two plates to a one plate, but this change was not approved by the legislature. Of the 12 DMV respondents from one plate states, five attributed the policy to cost considerations. In New Mexico, the difficulty of enforcing two plates per car (at one point labeling plates with front and rear to prevent vehicle owners from splitting one set of plates between two cars) also factored into the decision to begin requiring only one plate.

License Plate and Vehicle Registration Costs

Stated production costs per plate ranged from $0.50 to $5.65. These costs are passed on the vehicle owner, usually as part of the vehicle registration fees. Registration fees and the basis for them varied widely from state to state, from a low of $21.05 in Indiana to a high of $202 in California. Several states charge a base registration fee, with additional fees levied by individual counties.

States considering a change in license plate requirements

Of the 21 respondents from states currently requiring two plates, only Maine indicated that legislative proposals are currently under consideration to change the requirement to one plate. Another ten of the responding one plate states have had similar legislation introduced in past years. The objective of the proposed legislation in all of these cases is to reduce production costs to the state. In most of these states, the cost issue has been overridden by the needs and preferences of law enforcement. Two states, Nevada and Wyoming, have passed or are considering a different modification to the one plate requirement for vehicle models that do not have a designated space for a front plate. Nevada still issues two plates to every vehicle owner, but exempts owners of these types of vehicles from displaying the front plate. Wyoming is considering legislation which would allow owners of qualifying vehicle models to apply for a similar exemption, replacing the front plate with a front windshield sticker.

Of the 12 respondents from one plate states, only one has recently had a bill introduced to require two plates. A bill was introduced in North Carolina's state legislature in the 2006-2007 session but was unsuccessful. Law enforcement in New Mexico has requested that similar legislation be introduced in that state's legislative sessions, but no such bill has ever made it to the floor for a vote.

CONCLUSIONS

Based on the literature and the project field studies, the identification of a vehicle is a critical need for law enforcement as well as tolling authorities, parking applications, and homeland security. The manual identification process is dependent on the license plate, but the individual, especially law enforcement officers, must use other means to reduce the pool of potential vehicles. This is accomplished by using the color, make, and/or model to reduce the number of cars that will have to be assessed before identifying a particular license plate. It helps to have two licenses plates in the manual process; it is not the primary means of identification. With the advent of the ALPR technology, the license plate becomes a primary and highly efficient means of vehicle identification. ALPR eliminates some of the manual steps involved with indentifying and verifying vehicles that may be involved with traffic and tolling violations, Amber or other similar alerts, homeland security concerns and/or stolen vehicles. By utilizing front and rear plates, the opportunity for correct identification increases. This is the reasoning that law enforcement uses to support issuance of two plates versus one. A large part of policy making depends on its fiscal aspects. This study examined multiple applications: enforcement, tolling, and parking related to the location of the license plates on vehicles. In order to understand the financial impact that license plates have on enforcement, the research team developed a scenario to illustrate how the use of front plates can help to support the implementations of the ALPR. If a state requires front plates and law enforcement can utilize ALPR technology, the officers can observe more vehicles than they can without the cameras.

In Chicago, over 25K vehicles stolen every year and an average of thirty are recovered each month [18]. The ALPR technology can read up to 10,000 license plates during an eight hour shift compared to an officer being able to run between 10-40 vehicle plates after designating a vehicle as suspicious.

Table 9. Chicago: Recovery of Stolen Vehicles with and without ALPR Technology.

		Recovery of Stolen Vehicles/Year	
Details		**Without ALRP**	**With ALPR**
Labor costs/year		$ 40,000	$ 40,000
Cost of ALPR equipment/car	3 camera unit		$16,550
10-40 plates/8 hr shift	# of plates read/year	10,400	
	10,000 plates/8 hr shift		2,600,000
# of stolen cars/year		25,000	25,000
# of stolen cars recovered	30 vehicles/month	360	90,000
% of stolen cars recovered		1.44%	

The data included in the table above is based on information available from ALPR vendors and jurisdictions. There are approximately 25,000 vehicles stolen in Chicago (Illinois is a two-plate state) each year with an average of 30 recovered each month. It is estimated that an individual officer can read and identify 10-40 during an 8 hour shift while a patrol car equipped with ALPR technology can identify approximately 10,000 vehicle plates during that same shift. If we assume that these estimates are reasonable, then ALPR technology can increase the number of plate reads exponentially annually which will give officers the potential to identify and recover significantly more stolen vehicles. This scenario is not intended to promote the use of ALPR technology, although it does assist in identification in a number of different applications, but rather illustrate that front license plates provide more opportunities to identify vehicles. These opportunities are not limited to enforcement, but also include tolling and parking revenue.

Half of the fifty states have at least one mile of toll road. Those states are evenly split between those that require one or two plates [6]. Of those states with at least 100 miles of toll roads, the one plate states represent 55% of the total toll miles. As fiscal pressures mount, automating the tolling process with ALPR technology will soon become the only efficient method of collecting tolls and identifying violators. The toll collection focuses on a transponder interaction between the facility and the vehicle. In contrast, the identification of violators and the pursuit of lost revenue depend on the ability to capture the license plate information. Based on the literature, interviews and field studies, it can be concluded that two plates offer significant fiscal and process benefits to enforcement and tolling in terms of revenue. These benefits outweigh the cost associated with issuing additional license plates due to assuming the cost of plates is passed on to the owner of the vehicle. One of the concerns related to the use of front plates is the placement of vehicles that are not manufactured with a place to attach a front plate.

Individual states could deal with this issue based on the vehicle type. The number of miles of toll roads has increased across the United States on interstate and non-interstate highways. General toll roads and high-occupancy tolling facilities are becoming popular means of improving mobility and helping to pay for

construction of new roads or upgrading of existing roadways (See Figure 1) [6]. With the advent of this approach to transportation infrastructure, it seems that states should reconsider their plate policies in order to ensure the efficiencies of the improvements of our highway infrastructure.

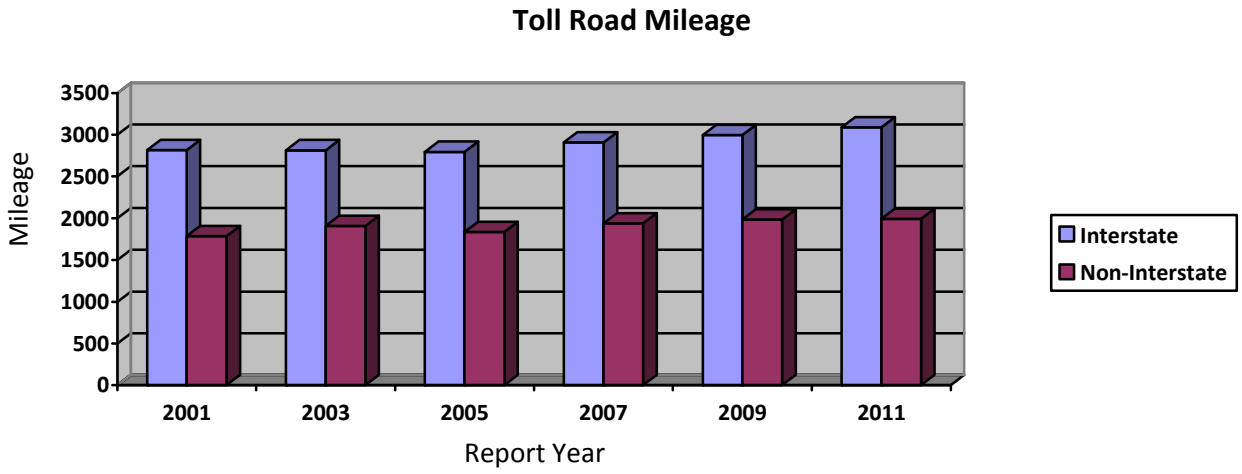


Figure 1. Toll Road Miles in the United States [6].

In addition to the ramifications of one versus two plates in regards to toll roads, efficiency related to homeland security should also be considered. In a two week period, the border patrol assessed the read rates on the northern border between the United States and Canada. In this application the read rates, using ALPR, across seventeen lanes were between 86.9% and 94.3%. The lanes where only the rear plates were read had a range of 86.9%-90.8% while the lanes where both plates were read resulted in a range of 90.8%-94.7%. Clearly the use of the front and rear APLR cameras, made a significant difference in the read rate. Considering how many cars are processed through the border, it is important for this process to be as efficient as possible.

The criticality of front plates in the tolling process was echoed by Dave Kristick who is the Director of Operations for E-470 Public Highway Authority in Colorado. In an interview as part of this study, he indicated:

> "Colorado is a two plate state and it makes a huge difference. The two plate environment is crucial for public safety and revenue purposes. You cannot accomplish mileage based funding without a two plate vehicle since you must be able to identify the vehicle when other vehicle identification technologies fail. Cashless, all electronic toll systems rely completely on ALPR systems- at that point; you can't just say it is about deterrence anymore, it is about how you will best assure your toll revenue [4]."

Initially the premise of this project focused on vehicle identification in general as it relates to one versus two license plates. As the research team progressed through the literature review and field work, the augmentation of the ALPR technology became a central consideration. The team understands that not all states have tolling to consider and many parking facilities still rely exclusively on people to manage the business aspects. Most law enforcement resources (officers and vehicles) are not equipped with ALPR technology. That being said, as

budgets (private and public) are reduced and/or come under increased scrutiny, all of these applications will have to consider alternate means of enforcing traffic, pursuing violations, maintaining homeland security, addressing stolen vehicles, and using automation as a means of deterrence to preserve safety and ensure fiscal responsibility. Using two license plates seems to be a small issue when you examine it in a vacuum, but in reality the specific identification of a vehicle is a critical part of how the United States will address their transportation infrastructure in the near future through enforcement and tolling applications.

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Appendix F
North Carolina State University Study on Effects of License Plate Attributes on ALPR

This Appendix presents findings from a study funded by the North Carolina Department of Transportation's Division of Motor Vehicles and conducted by researchers at the Institute for Transportation Research and Education at North Carolina State University. An experiment designed to develop a comprehensive understanding of the readability of North Carolina's license plates with an Automatic License Plate Recognition system was conducted. This effort utilized two infrared camera systems for data collection in a controlled environment involving over 900 license plates with 25 mph test vehicle speeds during a nighttime evaluation on a closed test track. Standard-issue and specialty plate types were included in the study, containing standard and personalized syntax with varying license plate ages and conditions. The key finding of this research was that the current, standard issue, standard syntax license plate had the highest capture and read rates among plates tested in this study. Factors which substantially decreased the capture and read rates were personalized syntax, specialty license plates, and the presence of stacked characters on a specialty license plate.

Effects of License Plate Attributes on Automatic License Plate Recognition

Daniel J. Findley, PhD, PE
Senior Research Associate
Daniel_Findley@ncsu.edu
(919) 515-8564

Christopher M. Cunningham, PE
Senior Research Associate
cmcunnin@ncsu.edu
(919) 515-8562

Jeffrey C. Chang, EI
Research Assistant
jcchang3@ncsu.edu

Kyle A. Hovey
Research Assistant
kahovey@ncsu.edu

Michael A. Corwin
Research Assistant
macorwin@ncsu.edu

Institute for Transportation Research and Education
North Carolina State University
Centennial Campus Box 8601
Raleigh, NC 27695-8601

Revised Version for AAMVA Automated License Plate Reader Working Group
Based on Final Report Developed For

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EXECUTIVE SUMMARY

This technical assistance project report describes the methodology of an experiment designed to develop a comprehensive and thorough understanding of the readability of North Carolina's license plates with an Automatic License Plate Recognition system. This research focused on law enforcement applications and utilized two infrared camera systems for data collection in a controlled environment. Age, reflectivity, and condition will be considered during the analysis of the readability of over 900 license plates. The following list summarizes the settings and conditions of the effort:

- 25 mph test vehicle
- Nighttime evaluation
- Test track
- 40' spacing of license plates
- 9' lateral offset between license plates and camera
- Standard-issue and specialty plate types
- Standard syntax and personalized plates
- Varying license plate age and condition

The key finding of this research project is that the current, standard issue, blue ink license plate has the highest capture and read rates of all the plates tested in this study. Factors which decreased the capture and read rates were personalized syntax, specialty license plates, and the presence of stacked characters on a specialty license plate.

INTRODUCTION

Automatic license plate recognition (ALPR) – also known as automatic number plate recognition, automatic vehicle identification, car plate recognition, and license-plate recognition - is a valuable tool for law enforcement agencies to identify vehicles. A typical, contemporary ALPR system uses cameras and infrared lighting to capture images of license plates and optical character recognition to translate the images into text. This automation allows a law enforcement agency to automatically scan thousands of license plates a day and compare the plates to agency databases with minimal effort for officers. For ALPR systems to be effective and efficient, license plates must be readable by this technology. However, due to variations of license plates across jurisdictions and the variety of possible designs within a jurisdiction, law enforcement agencies face some difficulties with complete and accurate matches of license plates.

In North Carolina, the standard issue plate includes three letters and four numbers embossed on the plate, separated by a dash mark with "First in Flight" along the top border and "NORTH CAROLINA" along the bottom border. The current design, featuring blue ink, has been in use since 1983, except for a period of time between early 2007 and late 2009, in which red ink was applied to the embossed characters (Exhibit 1). In addition to personalized standard issue plates, many specialty plates are also available, which may also be customized by the vehicle's owner. The standard issue license plates have consistent, expected syntax (three letters and four numbers), while personalized plates introduce tremendous variability from a vehicle owner's choice of letters, numbers, and symbols. Additionally, the full backgrounds available on some specialty plates decrease the contrast between the background and characters, further exacerbating the task of character recognition on license plates.

Exhibit 1. Standard Issue NC License Plates [Current Issue (left) and 2007 to 2009 Issue (right)]

RESEARCH OBJECTIVE AND SCOPE

The primary objective of this research was to develop a comprehensive and thorough understanding of the readability of North Carolina's license plates with an ALPR system. This research focused on law enforcement applications and utilized the City of Raleigh Police Department's infrared ALPR system and a Federal Signal / PIPS Research and Development's ALPR system for data collection in a controlled environment. Age, reflectivity, contrast ratio, and condition of the license plates were considered during the analysis of the readability of the license plates.

LITERATURE REVIEW

The deployment of an ALPR system for identifying, reading, and comparing to relevant databases numerous vehicles in the vicinity of the equipment offers promising efficiencies and effectiveness for law enforcement agencies. This literature review summarizes the technology and techniques employed by ALPR systems, as well as, applications of ALPR systems.

AUTOMATIC DETECTION AND RECOGNITION

The development of image processing tools and algorithms for recognizing and reading license plates has been critical for the refinement and improvement of ALPR systems. In broad terms, there are three essential steps in the process of identifying a specific license plate alphanumeric sequence: 1) identifying the license plate (as opposed to other parts of the vehicle or road signs), 2) identifying and separating license plate characters, and 3) recognizing each character. Kim et al. (1996), Chang et al. (2004), Duan et al (2005), Ozbay and Ercelebi (2005), and Daramola et al. (2011) each developed methods that address one or more of the fundamental steps of identifying license plate characters.

In experimental testing, systems designed to automatically detect license plates and recognize characters have produced reliable results in the majority of the test samples. Kim et al. (1996) applied a genetic algorithm to 70 license plates in Korea with a 93% extraction rate. Chang et al. (2004) obtained a 94% success rate applying ALPR algorithms to over 1,000 license plates in Taiwan. Ozbay and Ercelebi (2005) achieved a 93% recognition rate on a sample of 340 license plates in Turkey. Duan et al. (2005) evaluated an automated system with 805 license plates in Vietnam and found a system accuracy of 93%. Daramola et al. (2011) tested 100 license plate images from 50 vehicles with a resulting 98% recognition rate.

The syntax, or the expected order of letters and numbers, of the characters on the license plate is a critical aspect influencing the readability of a license plate. Errors in the predicted characters can arise due to the similarities of some characters, particularly between numbers and letters. These errors are most prevalent in the case of personalized license plates or when syntax rules allow for letters and numbers in the same position on a license plate. Previous research from Chang et al. (2004) and Ozbay and Ercelebi (2005) support this conclusion with the most likely errors occurring between the following characters: B and 8, E and F, D and O, D and 0, O and 0, 1 and 7, S and 5, Z and 2 (Ozbay and Ercelebi 2005). Five of the eight combinations are matches between letters and numbers, supporting a need for syntax to read plates consistently.

ALPR IMPLEMENTATION AND APPLICATIONS

Plotnikov and Shuldiner (2002) identified three key factors influencing an ALPR's ability to accurately read a license plate: ambient light, video recording settings, and ALPR settings. Data were collected by using video of moving vehicles with variations of lighting and exposure settings of the video recording. The analysis settings of the ALPR system were structured to achieve the highest accuracy possible, with particular focus on the syntax of the license plates. The study found that the highest read rates in

various lighting conditions occurred when the sun was in front of the vehicle such that the license plate was completely shaded. Video recording settings and ALPR settings each influenced the read rate, indicating the importance of proficient operators.

Oliveira-Neto et al. (2009) studied the applicability of an ALPR system with two units for large-truck speed monitoring and enforcement in Knoxville, Tennessee. The output from the ALPR systems were compared to the raw images of the license plates which resulted in an accuracy of 61% and 63% from the units. The initial results were then constrained by a travel time criteria and a text-mining technique which significantly improved the resulting license plate matches. After refining the data, the authors were able to achieve a 97% positive detection rate between two ALPR units with only 2% false positive matches.

A variety of uses of ALPR system data exist outside of law enforcement applications. License plate identification through automated means can provide transportation agencies and highway users with valuable information about travel times along a route (Shuldiner, et al. 1996, French et al. 1998, Clark et al. 2002, Buisson 2006, Findley 2010a). Matched license plate data can also supply necessary information for transportation planning processes, including origin-destination studies and cordon studies (Shuldiner, et al. 1996, French et al. 1998, Gupta et al. 2002, Foyle 2010). Other transportation engineering studies including parking studies (Findley 2010b) and path-based traffic volume studies (Schroeder 2010) can benefit from matched license plate data.

SUMMARY

Previous literature focuses on technology to read license plates, techniques for data cleaning and reduction, or uses for the data captured by ALPR systems. However, the authors of this research found no previous studies which have focused on the impact of the license plate attributes on the readability by an ALPR. This study will focus on license plate attributes as a means to improve readability.

METHODOLOGY

The purpose of this research effort was to test the readability of North Carolina license plates through automated, infrared camera systems. Therefore, only the physical features of the license plate were of interest during the experiment, other conditions that could influence the accuracy of the ALPR were controlled to the fullest extent possible. Recently returned license plates were tested in this study to evaluate the readability of plates that are currently displayed on vehicles across the state. This data provides a baseline assessment to compare future changes in license plate design. The license plates included in the study were collected from the manufacturer of North Carolina licenses plates, Correction Enterprises, a division of the North Carolina Department of Correction. The licenses plates were selected from the existing stock of returned license plates. Critical features collected on each license plate included the production year, retroreflectivity, and condition (rating of physical condition). A total of 905 license plates were collected for testing with the quantities by license plate type shown in Exhibit 2.

Among the types of plates were:

- Standard issue plates
  - Standard issue plates (pre-2007 and current) with blue characters (Exhibit I)
  - Standard issue plates (2007 to 2009) with red characters (Exhibit I)
- Specialized and personalized plates
  - Specialized plates in the standard issue format with special artwork on the left and a stacked suffix (Exhibit 3)
  - Existing specialty plates with the previous full-background design (New specialty plates with the new full-background standard template format (Exhibit 3)

Exhibit 2. License Plates Tested by Plate Type

Plate Type	Number of Plates
Standard Issue – Blue Ink	240
Standard Issue – Red Ink	274
Specialty – No Stacked Character	47
Specialty – Stacked Character	95
Specialty – Full Background (With White Box)	240
Specialty – Full Background (Without White Box)	6

Exhibit 3. Example Specialized Plate in Standard Issue Format with Artwork and Stacked Suffix

Exhibit 4. Example Full Background Plate without White Block (left) and with White Block (Right)

LICENSE PLATE ATTRIBUTE CHARACTERIZATION

Each license plate was cataloged and characterized to compare to the output of the field testing. The license plates were cataloged in a spreadsheet and characterized by their age (by production date), contrast ratio between the license plate background and alphanumeric values, retroreflectivity value, and condition assessment rating. The contrast ratio is a measure of the difference in contrast between

the background and characters of a license plate. The contrast ratio is calculated by dividing the background grayscale value by the character grayscale value and was generated automatically by the ALPR system. The retroreflectivity of each license plate was measured with a retroreflectometer. The retroreflectivity of each plate was measured in a consistent location that could be easily replicated across all similar plate types.

The following condition assessments were used by Correction Enterprises in evaluating each license plate:

- Functional (functioning as designed in terms of overall condition – does not include any of the following damage conditions)
- Faded
- Bent
- Cracked surface
- Peeling sheeting

FIELD TESTING

The North Carolina State Highway Patrol Training Academy in Raleigh was utilized for the experiment. This limited-access facility features several road courses for officer training, including an oval with straight segments of approximately one quarter of a mile which were used for this study (Exhibit 6). These facilities are surrounded by natural areas which offer little background lighting and reflectivity interference with the ALPR system. The experiments were conducted during nighttime conditions to minimize the impact of lighting on the tests. The experiment was conducted on March 7, 2012.

Exhibit 5. Field Testing Location

Two ALPR systems were utilized for the testing: the City of Raleigh Police Department's infrared ALPR system and a Federal Signal / PIPS Research and Development's ALPR system. Both systems were Federal Signal / PIPS Technology infrared camera systems and were mounted under the vehicle's light bar. Immediately prior to field testing, a PIPS technician ensured that the equipment was properly calibrated for the field conditions.

Exhibit 6. ALPR Cameras Turned Off (top) and in Operation (bottom)

Many environmental issues can affect the readability of license plates, including: sunshine, darkness, direction of sun / shadows, presence of clouds, precipitation, fog, etc. Additionally, vehicle mounting factors can impact readability, including: occlusions created by trailer hitches, poorly designed frames, bike racks, trailers, height of the license plate off the ground, etc. The field testing scenario was developed to control for the potential environmental and vehicle mounting factors through specifications of the environmental conditions, ALPR operation, and license plate placement. This test scenario mimics the reading of parked car's license plates as shown in Exhibit 7. The testing began at 7:00 PM, which was 45 minutes after sunset (with sunset time defined by United States Naval Observatory (USNO 2012)).

Multiple runs on the test course were required to test the full sample of license plates. During each run, thirty license plates were placed perpendicular to the ALPR-equipped vehicle's direction of travel and spaced at an interval of forty feet. Among the 30 license plates examined during each run, 25 were replaced for successive runs and 5 remained constant throughout the testing to serve as a calibration of the ALPR systems. The lateral offset, or perpendicular distance from the test vehicle to the license plates, was set as 9 feet to imitate parked vehicles alongside the roadway. During the testing, the license plates were stationary. The license plates were supported by wooden posts and mounted onto a piece of black poster board with a matte finish at a height of 24" above the ground (Exhibit 7). The test vehicle equipped with the ALPR was moving at a consistent speed of 25 mph while passing each plate. The license plates were placed in a pre-specified order for comparison to the ALPR system data.

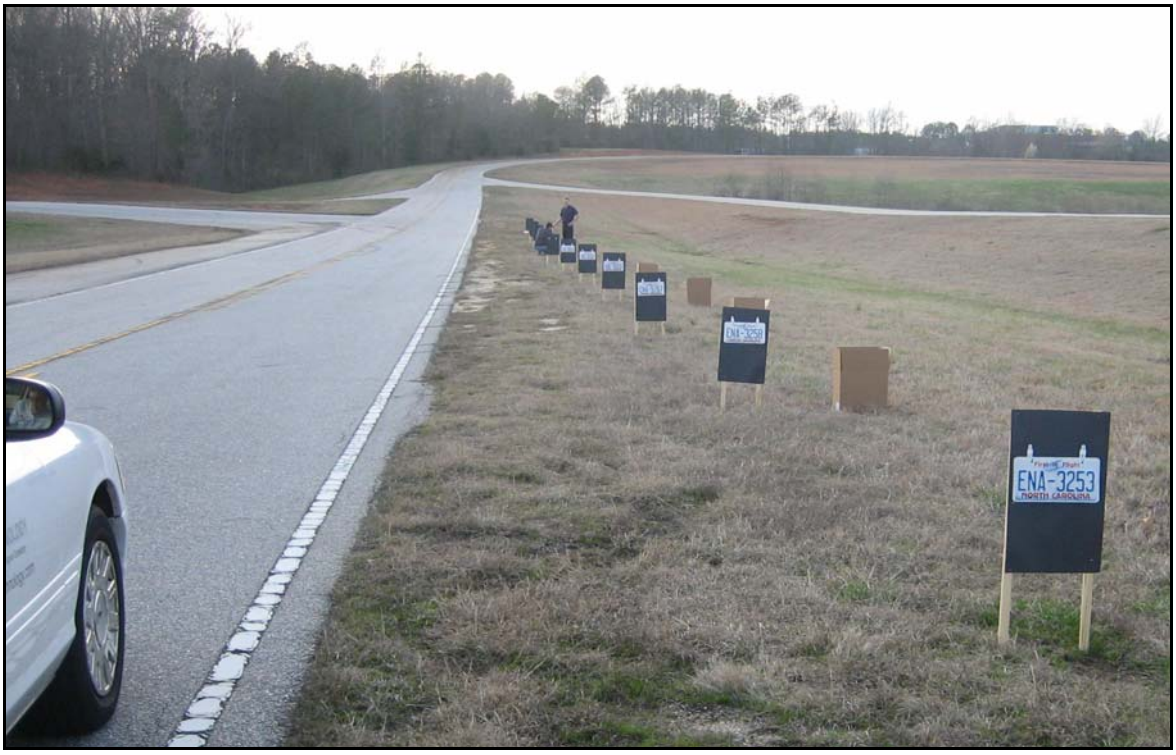

Exhibit 7. Field Testing Layout

MEASURES OF EFFECTIVENESS

The following measures of effectiveness serve as the basis for evaluating the readability of NCDMV's current license plates. These measures facilitate the evaluation of license plates based on the type of plate, age, contrast (between lettering and background), retroreflectivity, and condition.

- Capture Rate – The capture rate quantifies the percentage of license plates that are correctly identified as license plates to be analyzed by the ALPR system and is defined by the following equation:
    - Capture Rate = Number of License Plates Recognized As License Plates / Total Number of License Plates Studied

- Read Rate – The read rate quantifies the percentage of license plates that are accurately read among the plates that were captured by the ALPR system and is defined by the following equation:
    - Read Rate = Number of License Plates Accurately Read / Number of License Plates Recognized As License Plates
- Character Read Rate – The character read rate quantifies the percentage of a specific letter, number, or symbol that is accurately read by the ALPR system.

RESULTS

The 902 license plates included in this study were evaluated with two ALPR systems: the City of Raleigh Police Department's infrared ALPR system (Raleigh PD) and a Federal Signal / PIPS Research and Development's ALPR system (PIPS R&D). Both systems were Federal Signal / PIPS Technology infrared camera systems and were mounted under the vehicle's light bar. The PIPS R&D system most likely represents the ideal testing equipment with a new camera and optimized algorithms for finding and evaluating the license plates included in the study, while the Raleigh PD system represents a system currently in operation in the field. A license plate is referred to as captured if that plate is correctly identified as a license plate to be analyzed by the ALPR system, while a license plate is referred to as accurately read if all of the characters on the license plate have been correctly reported and matched to the actual characters. Exhibit 8 presents the license plate matching outcomes for the Raleigh PD system and PIPS R&D system. The PIPS R&D system captured and accurately read 367 license plates (shown in the bottom row) and the Raleigh PD system captured and accurately read 293 license plates (shown in the far right column). Among the license plates studied, 77% resulted in the same outcome for each of the systems: 271 were correctly identified as a license plate by both ALPR systems and accurately read; 297 license plates were correctly identified as license plates, but not accurately read; and 123 license plates were not captured by both systems.

Exhibit 8. License Plate Match Outcome Raleigh PD & PIPS R&D

		PIPS R&D ALPR Match Type and Quantity			***Raleigh PD ALPR Total***
		Capture and Read	Capture Only	No Capture	
Raleigh PD ALPR Match Type and Quantity	Capture and Read	271	16	6	***293***
	Capture Only	81	297	23	***401***
	No Capture	15	70	123	***208***
PIPS R&D ALPR Total		***367***	***383***	***152***	***902***

Exhibit 9 displays the capture and read rate of the Raleigh PD system and the PIPS R&D system. As an example of the information provided in the Exhibit, Exhibit 9 shows that 154 standard issue, blue ink license plates were included in the study. Among the 154 license plates, 149 (96%) were appropriately identified as license plates by the Raleigh PD system. Among the set of 148 plates captured by the Raleigh PD ALPR system, 142 (96%) plates were accurately read by the system. Exhibit 10 and Exhibit 11 present the read rate and number of correctly read characters for each of the 36 alphanumeric

characters, for the Raleigh PD system and PIPS R&D system, respectively. As an example of the information provided in the exhibits, Exhibit 10 shows that the letter "B" was accurately read 14 times on personalized standard issue, blue ink license plates, for a read rate of the letter of 78%.

Similar to the alphanumeric read rate exhibits, Exhibit 12 shows the read rate for stacked characters, as well as the capture rate. A total of 341 stacked characters appeared on the 902 plates included in the study. The Raleigh PD and PIPS R&D systems were able to capture 75% and 84% of those plates, respectively. The Raleigh PD and PIPS R&D systems were able to accurately read 60% and 65% of the captured plates, respectively.

Exhibit 9. License Plate Capture and Read Rate – Raleigh PD & PIPS R&D

Plate Type	Syntax Type	Number of Plates	Raleigh PD		PIPS R&D	
			Capture Rate % (Number)	Read Rate % (Number)	Capture Rate % (Number)	Read Rate % (Number)
Standard Issue - Blue Ink	Std	154	96% (148)	96% (142)	95% (147)	95% (140)
	Person	86	84% (72)	40% (29)	83% (71)	48% (34)
Standard Issue - Red Ink	Std	249	66% (164)	45% (74)	75% (186)	60% (111)
	Person	25	56% (14)	7% (1)	72% (18)	11% (2)
Specialty FIF - No Stacked Character	Std	43	86% (37)	57% (21)	88% (38)	68% (26)
	Person	4	50% (2)	50% (1)	50% (2)	50% (1)
Specialty FIF - Stacked Character	Std	83	80% (66)	20% (13)	87% (72)	28% (20)
	Person	12	33% (4)	0% (0)	50% (6)	0% (0)
Specialty Non-FIF - New Style	Std	213	80% (171)	7% (12)	89% (189)	17% (33)
	Person	27	52% (14)	0% (0)	67% (18)	0% (0)
Specialty Non-FIF - Old Style	Std	5	20% (1)	0% (0)	40% (2)	0% (0)
	Person	1	100% (1)	0% (0)	100% (1)	0% (0)
	Total	***902***	***77% (694)***	***42% (293)***	***83% (750)***	***49% (367)***

Note: Std = Standard, Person = Personalized

Exhibit 10. Alphanumeric License Plate Character Appearances and Read Rate – Raleigh PD

Values	Read Rate % (Number of Correct Readings)																	
	Blue Ink				Red Ink				Specialty Plates				All Plate Types				All Plates	
	Personalized		Standard		Personalized		Standard		Personalized		Standard		Personalized		Standard			
A	100%	(35)	100%	(43)	100%	(7)	100%	(2)	100%	(6)	29%	(2)	100%	(48)	90%	(47)	95%	(95)
B	78%	(14)	100%	(9)	100%	(4)	50%	(1)	100%	(2)	13%	(1)	83%	(20)	58%	(11)	72%	(31)
C	100%	(18)	100%	(21)	90%	(9)	100%	(13)	100%	(6)	38%	(3)	97%	(33)	88%	(37)	92%	(70)
D	80%	(12)	93%	(13)	50%	(1)	67%	(6)	100%	(1)	44%	(4)	78%	(14)	72%	(23)	74%	(37)
E	100%	(33)	100%	(20)	100%	(10)	N/A	(0)	100%	(4)	50%	(3)	100%	(47)	88%	(23)	96%	(70)
F	100%	(11)	100%	(17)	100%	(1)	100%	(1)	50%	(2)	44%	(4)	88%	(14)	81%	(22)	84%	(36)
G	100%	(7)	N/A	(0)	50%	(1)	N/A	(0)	50%	(2)	0%	0	77%	(10)	N/A	(0)	77%	(10)
H	78%	(7)	100%	(7)	100%	(5)	90%	(18)	100%	(5)	60%	(3)	89%	(17)	88%	(28)	88%	(45)
I	100%	(28)	N/A	(0)	100%	(6)	N/A	(0)	100%	(4)	0%	0	100%	(38)	N/A	(0)	100%	(38)
J	100%	(11)	100%	(5)	100%	(5)	100%	(21)	67%	(2)	50%	(4)	95%	(18)	88%	(30)	91%	(48)
K	100%	(9)	100%	(4)	N/A	(0)	80%	(4)	100%	(3)	0%	(0)	100%	(12)	50%	(8)	71%	(20)
L	97%	(34)	100%	(5)	100%	(5)	100%	(4)	100%	(1)	0%	(0)	98%	(40)	50%	(9)	83%	(49)
M	92%	(24)	100%	(1)	100%	(2)	50%	(2)	100%	(6)	40%	(4)	94%	(32)	47%	(7)	80%	(39)
N	96%	(22)	100%	(26)	N/A	(0)	78%	(21)	50%	(1)	43%	(3)	92%	(23)	83%	(50)	86%	(73)
O	93%	(25)	N/A	(0)	75%	(3)	N/A	(0)	80%	(4)	100%	(1)	89%	(32)	100%	(1)	89%	(33)
P	94%	(16)	100%	(33)	100%	(3)	97%	(30)	100%	(3)	0%	(0)	96%	(22)	91%	(63)	92%	(85)
Q	N/A	(0)	N/A	(0)	N/A	(0)	N/A	(0)	0%	0	0%	0	N/A	(0)	N/A	(0)	N/A	(0)
R	100%	(35)	93%	(28)	100%	(7)	100%	(15)	100%	(2)	25%	(2)	100%	(44)	85%	(45)	92%	(89)
S	97%	(32)	100%	(27)	80%	(4)	100%	(11)	80%	(4)	50%	(7)	93%	(40)	87%	(45)	89%	(85)
T	92%	(22)	100%	(27)	80%	(4)	95%	(40)	80%	(4)	0%	(0)	88%	(30)	88%	(67)	88%	(97)
U	100%	(14)	N/A	(0)	100%	(2)	N/A	(0)	100%	(1)	45%	(5)	100%	(17)	45%	(5)	79%	(22)
V	100%	(4)	100%	(33)	100%	(2)	93%	(27)	100%	(1)	0%	(0)	100%	(7)	90%	(60)	91%	(67)
W	100%	(9)	100%	(28)	N/A	(0)	65%	(15)	100%	(2)	14%	(1)	100%	(11)	76%	(44)	80%	(55)
X	100%	(6)	100%	(15)	N/A	(0)	97%	(95)	0%	0	14%	(1)	100%	(6)	93%	(111)	93%	(117)
Y	100%	(12)	100%	(30)	50%	(2)	92%	(85)	0%	(0)	0%	(0)	82%	(14)	91%	(115)	90%	(129)
Z	100%	(5)	100%	(52)	100%	(1)	95%	(41)	0%	0	0%	(0)	100%	(6)	92%	(93)	93%	(99)
0	100%	(3)	96%	(49)	N/A	(0)	78%	(39)	100%	(1)	95%	(103)	100%	(4)	91%	(191)	92%	(195)
1	79%	(11)	100%	(70)	N/A	(0)	94%	(66)	100%	(1)	97%	(94)	80%	(12)	97%	(230)	96%	(242)
2	100%	(3)	100%	(57)	100%	(2)	97%	(62)	100%	(2)	100%	(127)	100%	(7)	99%	(246)	99%	(253)
3	75%	(3)	100%	(60)	N/A	(0)	97%	(72)	100%	(2)	96%	(95)	83%	(5)	97%	(227)	97%	(232)
4	83%	(5)	98%	(63)	100%	(1)	93%	(74)	0%	0	93%	(101)	86%	(6)	94%	(238)	94%	(244)
5	100%	(3)	100%	(57)	N/A	(0)	90%	(53)	0%	(0)	98%	(111)	75%	(3)	97%	(221)	96%	(224)
6	100%	(3)	100%	(60)	N/A	(0)	87%	(67)	0%	0	100%	(94)	100%	(3)	96%	(221)	96%	(224)
7	N/A	(0)	100%	(60)	N/A	(0)	100%	(70)	100%	(1)	97%	(69)	100%	(1)	99%	(199)	99%	(200)
8	33%	(1)	100%	(58)	100%	(2)	89%	(54)	0%	0	94%	(92)	60%	(3)	94%	(204)	93%	(207)
9	100%	(1)	98%	(58)	N/A	(0)	88%	(45)	100%	(1)	99%	(77)	100%	(2)	96%	(180)	96%	(182)
Total	***95%***	***(504)***	***99%***	***(1,043)***	***92%***	***(97)***	***92%***	***(1,148)***	***87%***	***(85)***	***87%***	***(1,163)***	***93%***	***(686)***	***92%***	***(3,354)***	***93%***	***(4,040)***

Exhibit 11. Alphanumeric License Plate Character Appearances and Read Rate – PIPS R&D

Values	Number of Character Appearances (Read Rate, %)																			
	Blue Ink				Red Ink				Specialty Plates				All Plate Types				All Plates			
	Personalized		Standard		Personalized		Standard		Personalized		Standard		Personalized		Standard					
A	100%	(35)	98%	(44)	90%	(9)	100%	(2)	100%	(8)	29%	(2)	98%	(52)	89%	(48)	93%	(100)		
B	89%	(16)	100%	(10)	100%	(4)	100%	(2)	100%	(5)	40%	(4)	93%	(25)	73%	(16)	84%	(41)		
C	100%	(18)	100%	(20)	100%	(10)	100%	(15)	80%	(4)	56%	(5)	97%	(32)	91%	(40)	94%	(72)		
D	100%	(15)	100%	(14)	83%	(5)	89%	(8)	0%	(0)	63%	(5)	95%	(20)	87%	(27)	90%	(47)		
E	100%	(32)	100%	(19)	100%	(13)	100%	(1)	100%	(5)	33%	(2)	100%	(50)	85%	(22)	95%	(72)		
F	100%	(11)	100%	(14)	100%	(1)	100%	(1)	100%	(3)	70%	(7)	100%	(15)	88%	(22)	93%	(37)		
G	100%	(7)	N/A	(0)	75%	(3)	N/A	(0)	100%	(4)	0%	(0)	93%	(14)	N/A	(0)	93%	(14)		
H	78%	(7)	100%	(7)	100%	(4)	90%	(26)	75%	(3)	50%	(3)	82%	(14)	86%	(36)	85%	(50)		
I	100%	(28)	N/A	(0)	86%	(6)	N/A	(0)	100%	(3)	0%	(0)	97%	(37)	N/A	(0)	97%	(37)		
J	91%	(10)	100%	(5)	100%	(4)	100%	(19)	67%	(4)	18%	(2)	86%	(18)	74%	(26)	79%	(44)		
K	100%	(9)	100%	(4)	0%	(0)	80%	(4)	83%	(5)	14%	(1)	88%	(14)	56%	(9)	72%	(23)		
L	100%	(35)	100%	(5)	100%	(6)	67%	(2)	100%	(3)	0%	(0)	100%	(44)	44%	(7)	85%	(51)		
M	96%	(25)	100%	(1)	60%	(3)	80%	(4)	100%	(7)	60%	(6)	92%	(35)	69%	(11)	85%	(46)		
N	87%	(20)	100%	(26)	67%	(2)	79%	(26)	67%	(2)	43%	(3)	83%	(24)	83%	(55)	83%	(79)		
O	88%	(23)	N/A	(0)	75%	(3)	N/A	(0)	80%	(4)	100%	(1)	86%	(30)	100%	(1)	86%	(31)		
P	94%	(15)	97%	(32)	100%	(4)	97%	(33)	100%	(4)	0%	(0)	96%	(23)	90%	(65)	92%	(88)		
Q	N/A	(0)	N/A	(0)	N/A	(0)	N/A	(0)	0%	(0)	0%	(0)	N/A	(0)	N/A	(0)	N/A	(0)		
R	100%	(35)	97%	(29)	90%	(9)	100%	(17)	100%	(4)	18%	(2)	98%	(48)	83%	(48)	90%	(96)		
S	100%	(33)	100%	(24)	75%	(3)	100%	(12)	71%	(5)	47%	(7)	93%	(41)	84%	(43)	88%	(84)		
T	96%	(22)	100%	(27)	80%	(4)	98%	(44)	100%	(5)	25%	(2)	94%	(31)	91%	(73)	92%	(104)		
U	100%	(14)	N/A	(0)	67%	(2)	N/A	(0)	100%	(1)	73%	(8)	94%	(17)	73%	(8)	86%	(25)		
V	100%	(4)	100%	(33)	75%	(3)	100%	(31)	100%	(2)	20%	(1)	90%	(9)	94%	(65)	94%	(74)		
W	100%	(9)	96%	(27)	50%	(1)	57%	(16)	100%	(2)	17%	(1)	92%	(12)	71%	(44)	75%	(56)		
X	100%	(6)	100%	(14)	N/A	(0)	97%	(112)	100%	(2)	33%	(2)	100%	(8)	94%	(128)	94%	(136)		
Y	100%	(12)	100%	(30)	60%	(3)	95%	(97)	100%	(1)	0%	(0)	89%	(16)	93%	(127)	93%	(143)		
Z	100%	(5)	100%	(52)	100%	(1)	98%	(48)	0%	(0)	0%	(0)	100%	(6)	93%	(100)	94%	(106)		
0	100%	(3)	98%	(51)	N/A	(0)	78%	(40)	100%	(1)	91%	(113)	100%	(4)	90%	(204)	90%	(208)		
1	69%	(9)	100%	(68)	0%	(0)	97%	(70)	100%	(3)	98%	(103)	71%	(12)	98%	(241)	97%	(253)		
2	100%	(3)	100%	(56)	100%	(2)	100%	(75)	100%	(3)	99%	(136)	100%	(8)	100%	(267)	100%	(275)		
3	100%	(4)	100%	(60)	100%	(1)	99%	(79)	100%	(2)	97%	(112)	100%	(7)	98%	(251)	98%	(258)		
4	100%	(5)	95%	(57)	33%	(1)	89%	(77)	0%	(0)	94%	(113)	75%	(6)	93%	(247)	92%	(253)		
5	67%	(2)	100%	(57)	N/A	(0)	88%	(68)	0%	(0)	96%	(111)	50%	(2)	94%	(236)	94%	(238)		
6	100%	(2)	100%	(60)	N/A	(0)	90%	(83)	0%	(0)	99%	(100)	100%	(2)	96%	(243)	96%	(245)		
7	N/A	(0)	100%	(59)	N/A	(0)	99%	(80)	100%	(1)	100%	(78)	100%	(1)	100%	(217)	100%	(218)		
8	67%	(2)	100%	(58)	100%	(2)	93%	(62)	0%	(0)	95%	(104)	80%	(4)	96%	(224)	95%	(228)		
9	N/A	(0)	100%	(58)	N/A	(0)	85%	(53)	100%	(1)	98%	(84)	100%	(1)	95%	(195)	95%	(196)		
Total	***96%***	***(496)***	***99%***	***(1,029)***	***84%***	***(129)***	***93%***	***(1,302)***	***91%***	***(107)***	***88%***	***(1,268)***	***93%***	***(732)***	***93%***	***(3,599)***	***93%***	***(4,331)***		

Exhibit 12. License Plate Stacked Character Read Rate – Raleigh PD & PIPS R&D

Stacked Character	Number of Plates	Raleigh PD		PIPS R&D	
		Capture Rate % (Number)	Read Rate % (Number)	Capture Rate % (Number)	Read Rate % (Number)
AA	1	100% (1)	100% (1)	100% (1)	100% (1)
AI	6	50% (3)	33% (1)	50% (3)	0% (0)
AT	23	52% (12)	67% (8)	78% (18)	78% (14)
BC	3	100% (3)	67% (2)	100% (3)	100% (3)
BP	97	86% (83)	58% (48)	93% (90)	72% (65)
CF	22	73% (16)	31% (5)	91% (20)	45% (9)
CH	2	0% (0)	N/A (0)	50% (1)	0% (0)
CP	3	100% (3)	33% (1)	100% (3)	100% (3)
CV	3	100% (3)	100% (3)	100% (3)	100% (3)
DI	1	100% (1)	100% (1)	100% (1)	100% (1)
DU	11	45% (5)	60% (3)	45% (5)	100% (5)
DV	2	50% (1)	0% (0)	100% (2)	50% (1)
EF	10	40% (4)	100% (4)	90% (9)	89% (8)
FF	2	50% (1)	0% (0)	50% (1)	100% (1)
GT	1	0% (0)	N/A (0)	100% (1)	0% (0)
HD	28	93% (26)	23% (6)	96% (27)	7% (2)
HG	1	100% (1)	100% (1)	100% (1)	100% (1)
IC	5	100% (5)	100% (5)	100% (5)	100% (5)
KA	1	100% (1)	100% (1)	100% (1)	100% (1)
KF	4	75% (3)	67% (2)	100% (4)	50% (2)
KV	1	100% (1)	100% (1)	100% (1)	100% (1)
LP	1	0% (0)	N/A (0)	0% (0)	N/A (0)
NG	3	0% (0)	N/A (0)	0% (0)	N/A (0)
PH	1	100% (1)	0% (0)	100% (1)	0% (0)
RE	1	0% (0)	N/A (0)	0% (0)	N/A (0)
RF	2	0% (0)	N/A (0)	50% (1)	0% (0)
SA	1	0% (0)	N/A (0)	100% (1)	0% (0)
SF	3	100% (3)	0% (0)	100% (3)	0% (0)
SM	66	83% (55)	87% (48)	83% (55)	84% (46)
SP	9	89% (8)	25% (2)	78% (7)	0% (0)
SR	6	67% (4)	75% (3)	50% (3)	100% (3)
ST	6	50% (3)	67% (2)	83% (5)	80% (4)
TF	4	0% (0)	N/A (0)	25% (1)	0% (0)
TH	2	100% (2)	0% (0)	50% (1)	100% (1)
VV	4	100% (4)	25% (1)	100% (4)	50% (2)
WC	4	75% (3)	100% (3)	100% (4)	100% (4)
WM	1	100% (1)	100% (1)	100% (1)	100% (1)
Total	***341***	***75% (257)***	***60% (154)***	***84% (287)***	***65% (187)***

MODELING READABILITY

A logistic regression model was developed to model the probability of capture and read for standard issue license plates, as shown in Exhibit 13. The models were based on the ink color (blue or red), contrast ratio between the characters and background, and syntax type (standard or personalized), while utilizing data from the Raleigh PD ALPR system. Each of the terms were statistically significant (at the 0.05 level). The model predicting the capture rate has a pseudo R-squared value of 0.4464 and the read rate model has a pseudo R-squared value of 0.3046. Exhibit 14 presents a plot of the probability of capture among the ink color and syntax type at various levels of contrast. Exhibit 15 presents a plot of the probability of read among the ink color and syntax type at various levels of contrast. Blue ink and standard syntax produce higher probabilities of read than red ink and personalized syntax combinations with significant differences at all levels of contrast.

Exhibit 13. Logistic Regression Model of Standard Issue License Plates

Capture Rate			
Variable	***B***	**Standard Error**	**z**
Red Ink	-1.321*	0.389	-3.40
Contrast	0.026*	0.002	10.96
Personalized	-0.841*	0.407	-2.07
(Constant)	0.053	0.393	0.13

Read Rate			
Variable	***B***	**Standard Error**	**z**
Red Ink	-2.105*	0.370	-5.69
Contrast	0.014*	0.415	-7.51
Personalized	-3.114*	0.003	5.59
(Constant)	0.401	0.470	0.85

* Significant at < 0.05

Where:
Red Ink = Presence of Red Ink on License Plate (0 = Blue Ink, 1 = Red Ink)
Contrast = Contrast Ratio of License Plate Characters and Background
Personalized = Presence of Personalized Syntax (0 = Standard Syntax, 1 = Personalized Syntax)

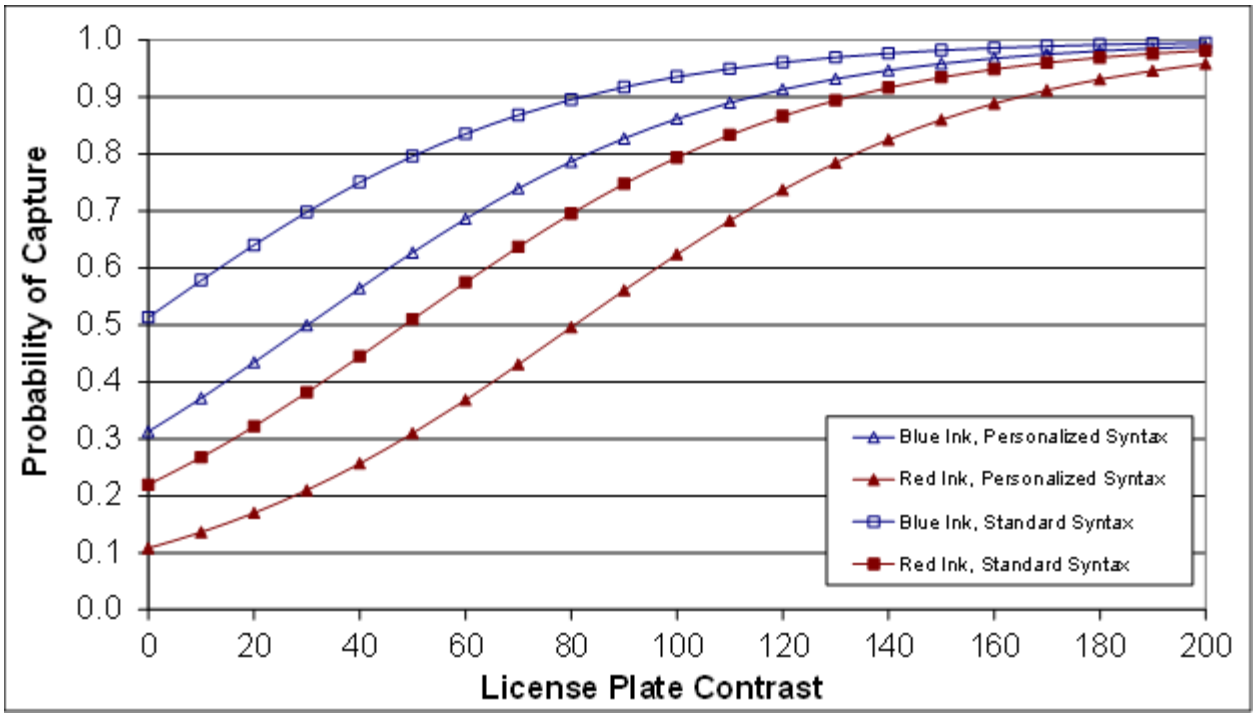

Exhibit 14 - Probability of Capture for Standard Issue License Plates

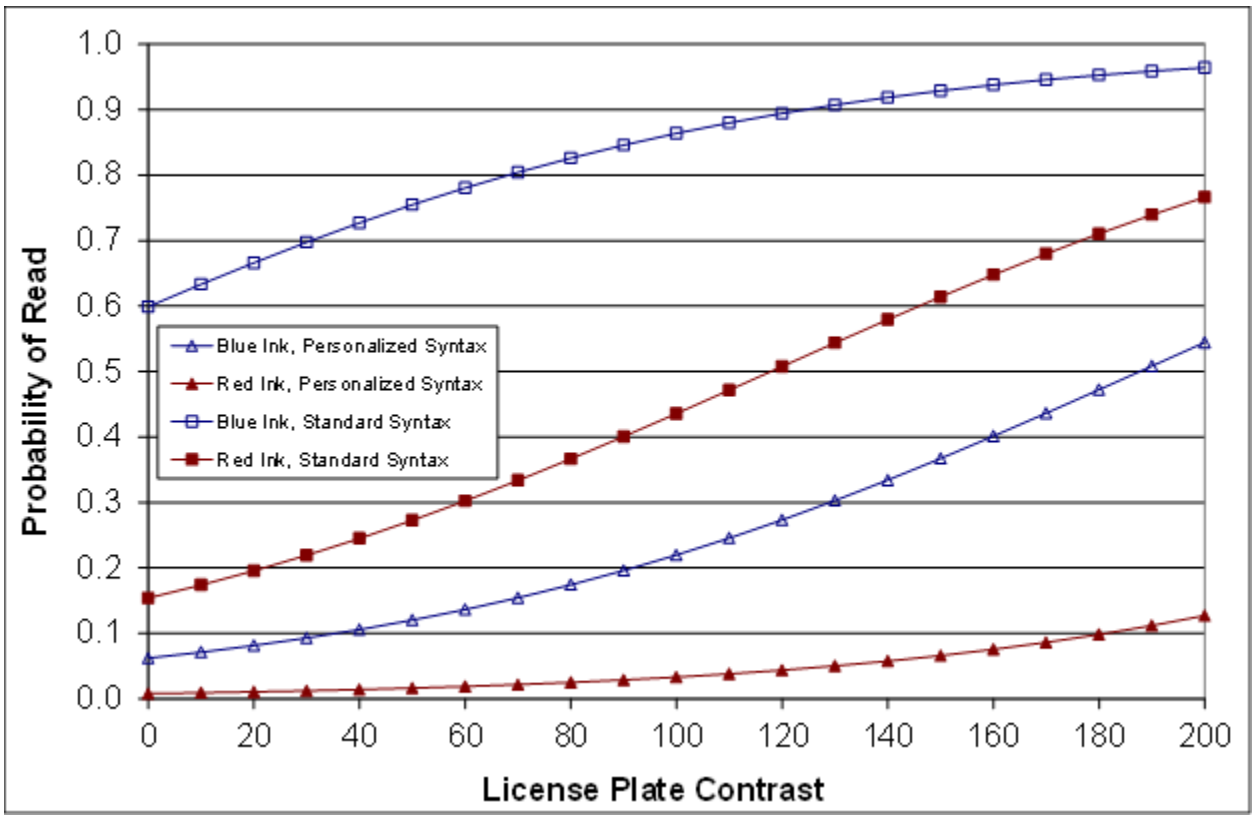

Exhibit 15. Probability of Read for Standard Issue License Plates

FINDINGS

The key findings of this research project include the following observations about North Carolina license plate readability by an ALPR system:

- The current, standard issue, blue ink license plate has the highest capture and read rates of all the plates tested in this study. These plates were the type most accurately recognized as license plates and accurately read by the ALPR system. The personalization of the blue ink license plate resulted in a read rate approximately half of the read rate of the standard issue syntax.
- The red ink which was used on plates from 2007 to 2009 performed significantly worse than blue ink in terms of both capture rate and read rate.
- Among the specialty license plates with the First in Flight background, the plates without the stacked character were more easily captured and read than the plates with the stacked character.
- Among the specialty license plates with the full background, the ALPR system was generally able to appropriately recognize the plates as license plates, but had difficulty accurately reading the plates for both the standard syntax and personalized syntax (none of the 27 personalized plates were read correctly by either system).

CONCLUSIONS AND RECOMMENDATIONS

The inherent purpose of a license plate – to identify a specific vehicle – should be considered when designing, approving, or instituting a new license plate. ALPR systems are a tool to efficiently identify thousands of vehicles per hour, if license plates are readable. Therefore, to maximize the effectiveness of ALPR systems, license plate issuing agencies should consider the implications of the data presented in this paper of license plate attributes and readability. Ink color, syntax type, and contrast (through color choice, background choice, and specific ink characteristics), which are determined by the license plate issuing agency, have a significant impact on the ability of a law enforcement agency's ability to recognize and accurately read a license plate using an ALPR system. Therefore, readability should be a criteria for consideration when decisions are made regarding ink color and syntax type. Consistent with previous research (Ozbay and Ercelebi 2005), this research found that many incorrect matching combinations are matches between letters and numbers, supporting a need for syntax to read plates consistently. Availability and design of specialty plates should also be thoroughly considered by license plate issuing agencies, particularly with regard to stacked characters, background colors, and consistent location of symbols.

This research effort found significant difficulty with accurate readings of various specialty and personalized license plates. Although it might be possible to adjust and modify an ALPR to capture some of the more difficult to read license plate types presented in this paper, these modifications would likely impact a system's ability to accurately read other license plate types. Therefore, law enforcement agencies should consider the likelihood of encountering each license plate type when optimizing an ALPR system to maximize the overall likely capture and read rate among the population of license plates common in the agency's jurisdiction.

Future research efforts could involve various tests to evaluate the effectiveness of various enhancements to license plates or test conditions. High contrast inks could be implemented on existing license plate designs for potential improvements in capture rate and read rate for various plate types. Similarly, digitally printed license plates and digitally printed license plates with bar codes could be tested for impacts on readability using an ALPR system. In addition to the controlled field testing presented in this paper, alternative scenarios consisting of a variety of conditions (on-street parking, weather, daytime, etc.) could be executed to examine other environmental variables of interest to law enforcement agencies.

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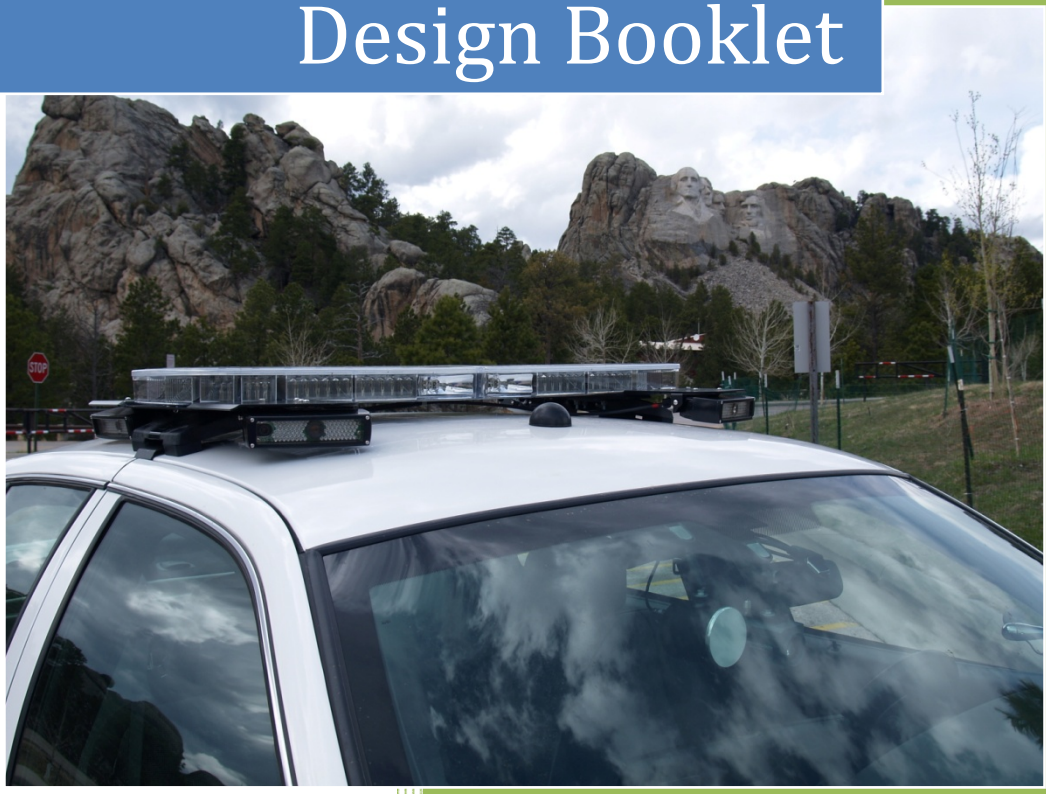
Appendix G
License Plate Configuration and Design Booklet

License Plate Configuration Design Booklet



American Association of
Motor Vehicle Administrators

Revised 4/12/12

Part I. License Plate Length, Repeats & Record Retrieval

Jurisdiction	Maximum number of alpha-numeric characters allowed	Plate numbers repeated for different types of plates		Information besides plate number, needed to ensure correct record is retrieved
		Yes/No	Notes	
Alabama	7 includes spaces, dashes, and stacked characters	No		N/A
Alaska	6	No		N/A
Alberta	7	No		N/A
Arizona	7 5 or 6 - specialty plates	No		N/A
Arkansas	7	No		Over the years, some numbers have been inadvertently repeated. When an inquiry is made on repeated numbers, each plate is listed with the license plate type. Any type listed may then be selected to proceed with the inquiry
British Columbia	6	No		N/A
California	7 5 or 6 - if stacked letters or symbols	No	Look alikes, e.g., 1 for an I, or zero for an O on personalized plates are not allowed.	N/A
Colorado	7 6 – motorcycle plates	No		N/A
Connecticut	6 – current plates 8 – with system redesign *However, since Connecticut's plates are embossed, certain space restrictions apply due to sizing limitations on the license plates.*	Yes	In the past, approximately 23 generic class codes have been repeated. Duplicate vanity and low number plates can be repeated as long as they are in different classes.	Current system has class codes and sub codes used to differentiate between types of plates issued. In modernized systems, plates will be distinguished by type and usage.
Delaware	7	No		N/A
District of Columbia	7	Yes	Standard and personalized plate numbers can be repeated on various plate types.	The individual running the record must determine which record is appropriate, VIN# based on the vehicle make, model and color.

Jurisdiction	Maximum number of alpha-numeric characters allowed	Plate numbers repeated for different types of plates		Information besides plate number, needed to ensure correct record is retrieved
		Yes/No	Notes	
Florida	7 - center design plates 5 - left design plates	No		N/A
Georgia	7	Yes	Standard plate numbers, as well as collegiate or personalized plates can be repeated on various plate types.	System will return records for all vehicles with entered plate number. The individual running the record must determine which record is appropriate, based on the vehicle make, model and color or the category of the plate.
Hawaii	6	Yes	Only on military specialty license plates, disabled persons, and electric vehicle.	The individual identifying the license plate must also remember the words or symbol located on the left side of the license plate. If only the letter/number is provided, the individual running the record must try all the alpha prefixes of these plates to determine which record may be appropriate, based on the vehicle make, and color.
Idaho	7 *does not include stacked alpha/numerics*	Yes	There are instances of this, although working to clean them up. Possible for a passenger car/truck and a motorcycle to have the same plate number.	The individual requesting the information needs to select the appropriate record based on the vehicle type.
Illinois	7 *does not include stacked characters*	Yes	Specialty plate may display the same characters as a standard plate.	The additional information should include the 2 letter stacked suffix on the right hand side of the plate.
Indiana	6 – passenger, specialty, RV and motorcycle plates 7 - truck plates 8 - trailer plates	No	Numbers were repeated in the past, but due to problems, the practice was discontinued	N/A
Iowa	7	No		N/A
Kentucky	6 *includes stacked characters*	No		N/A

Jurisdiction	Maximum number of alpha-numeric characters allowed	Plate numbers repeated for different types of plates		Information besides plate number, needed to ensure correct record is retrieved
		Yes/No	Notes	
Louisiana	7 *not including stacked characters*	Yes	The numerical series repeats for all special plates. Each plate type would have an alpha prefix specific to the plate type.	Special plates are indexed by the numerical series in conjunction with an alpha prefix. Most special plates include the prefix as stacked characters to the left of the numerical series.
Maine	7	Yes	Standard and personalized plate numbers can be repeated on various older plate types. Since 2007, new plate classes cannot duplicate older classes. For the three or four plates with stacked class codes, the class code is not part of the number.	System will return records for all plates with repeated numbers. Individual running the record must determine which record is appropriate, based on the vehicle make, model and color.
Manitoba	6 *(3 alpha / 3 numeric)*	No		N/A
Maryland	7	No	Exception: Expired personalized plates could be re-issued to a new applicant upon request.	vehicle class
Michigan	7	No		N/A
Minnesota	8	No		N/A
Mississippi	7	Yes	Specialty plates can have the same number, but not the same double stack characters	the type of specialty plate
Missouri	4 to 6	No		N/A
Montana	7 ½ *half is a space*	Yes	Plate number can be repeated as long as plate design is different.	type of plate design
Nebraska	7 *does not include dash*	Yes		plate type
Nevada	7	Yes		plate prefix
New Brunswick	6	No		
New Hampshire	7 *includes numbers and symbols*	Yes	Not applicable for all plate types. For example, you cannot have the same regular passenger digits on a state park plate	When a plate number that contains a repeated number is run, the system will return records for all vehicles with that plate number. The individual running the record must determine which record is appropriate, based on the vehicle make, model and color.

Jurisdiction	Maximum number of alpha-numeric characters allowed	Plate numbers repeated for different types of plates		Information besides plate number, needed to ensure correct record is retrieved
		Yes/No	Notes	
New Jersey	7 5 - dedicated, sports and organizational plates	No		
New Mexico	7 6 - motorcycle plates	No		
New York	8 - car and truck plates 6 - motorcycle plates	Yes		Plate class distinguishes one from the other.
North Carolina	7 – standard plates 8 - personalized plates 4 - specialty plates	Yes	For specialty plates. However, the prefix or suffix will make it a different plate number when running the plate.	Prefix or suffix for specialty plates. Same number will not be repeated twice in unless it has a prefix or suffix.
North Dakota	7 – standard plate 5 – stacked letter and logo plates	Yes	Stacked letter plates can repeat alphas/numerics. All other plates cannot repeat alphas/numerics.	
Northwest Territories	6 *includes spaces*	Yes	Motorcycle and regular passenger plates may have duplicate numbers, however the MVIS system differentiates them by type.	All plates that contain that sequence would be pulled.
Nova Scotia	7 *does not include symbols*	Yes / No	Usually plate numbers are not repeated. However, in some situations, numbers may be repeated.	System will return records for all vehicles with the plate number. The individual running the record must determine which record is appropriate, based on the vehicle serial number, make, model and color.
Ohio	7 - standard plates 6 - logo plates *does not include stacked characters used for dealers*	No		N/A
Oklahoma	7 - with stacked letters 6 -without stacked letters *standard plates only*	No		N/A
Ontario	8	No		N/A
Oregon	7 In some cases, the first two characters are stacked to the left-side.	No	Exception: a vanity plate number for a different vehicle type than the regular plate configuration issued to before. Happens very rarely.	For exceptions, enter an asterisk at the beginning of the entry. The asterisk identifies the configuration as being a custom plate.

Jurisdiction	Maximum number of alpha-numeric characters allowed	Plate numbers repeated for different types of plates		Information besides plate number, needed to ensure correct record is retrieved
		Yes/No	Notes	
Pennsylvania	7 *does include stacked characters*	No		N/A
Quebec	7	No		N/A
Rhode Island	6	Yes		When a plate number that contains a repeated number is run, the system will return records for all vehicles with that plate number. The individual running the record must put in Plate Type (01-Passenger, 02-Commercial, etc.)
Saskatchewan	6	No		N/A
South Carolina	7	No		N/A
South Dakota	6 - standard 7 - personalized, exempt entity, and trailer ID	No		N/A
Texas	7	No	*Exceptions:* • "Old plates" can be displayed on vehicles 25 years or older w/ Antique or Classic registration. • Radio Operator plates may be featured on numerous owned by the radio operator.	System will return records for all vehicles with the plate number. Record 1 of 2, 1 of 3, etc. will display. The individual running the record must determine which record is appropriate, based on the vehicle make, model and color.
Utah	7	No		N/A
Vermont	7 *does not include stacked characters*	Yes	Standard and personalized plates can be repeated on various plate types.	System will return records for all vehicles with the plate number. Plate number also followed by a letter. Each letter that follows a plate number is a "vehicle type". The vehicle type represents the type of vehicle for the plate being run. A – Car B Truck C – Trailer D – Agriculture G – Motorcycle I – Bus J – Municipal K – State

Jurisdiction	Maximum number of alpha-numeric characters allowed	Plate numbers repeated for different types of plates		Information besides plate number, needed to ensure correct record is retrieved
		Yes/No	Notes	
Virginia	7 8 – if stacked	Yes	Numeric only plate numbers are sometimes issued on a different plate type.	plate type
Washington	7 includes stacked	No	The plate identifier is different for each plate, and because of this no two plates are the same.	Plate number must include the stacked alpha identifiers to access the record.
West Virginia	8	No / Yes	99% of plates are unique a few of the oldest series of plates may repeat a limited number of segments of numbers below 2000. However, each of these old style plates have very distinctive plates, e.g., Prisoner of War, handicapped and low numbered passenger vehicle plates numbered under 2000.	subclass Class A are all passenger vehicle cars, SUVs, pickup trucks under 8000 pounds
Wisconsin	7	Yes, historically. No, currently.	In the past, yes, but the practice is being eliminated.	System will return records for all vehicles with the plate number. The individual running the record determines which record is appropriate based on the vehicle and plate type.
Wyoming	7	Yes	The numbers, as well as personalized plates are repeated on a passenger, truck, collegiate, motorcycle, light trailer, trailer, commercial, handicapped, house trailer, and multi-purpose vehicle. In addition, some of the numbers on specialty plates (Fire Fighter, EMT, etc) are repeated on other specialty plates.	Plate number and the type of plate must be run together. The individual running the record must determine which record is appropriate based on the vehicle make and color.
Yukon	6	No		N/A

Part II. Stacked Characters

Jurisdiction	Plates contain stacked characters	# of Stacked Characters	Location of Stacked Letters	Stacked characters are part of official license plate number	Position of stacked characters same when printed or inquired	Stacked characters printed on registration
Alabama	Yes	2	left side - National Guard plate left side, after the 1 or 2-digit county indicator – other plates	Yes	In sequence	Yes
Alaska	No	N/A	N/A	N/A	N/A	N/A
Alberta	No Only the Lt. Governor's plate is stacked		left side	Yes The plate number on system would be **LTG0V** (zero not the letter O)	In sequence	Shows as LTG0V
Arizona	No	N/A	N/A	N/A	N/A	N/A
Arkansas	Yes	2	either left or right side	Yes	In sequence	Yes
British Columbia	No			N/A	N/A	N/A
California	Yes	2 or 3	either left or right side	In some instances, yes. For example, disabled person and disabled veteran license plates, the "DP" and the "DV" are part of the plate number on the database.	In sequence	Yes
Colorado	Yes	2 or 3	left, right or both	No	N/A	No
Connecticut	Yes	up to 4	position varies	No, but in some cases stacking is used for identification purposes. e.g., . "comb" stacked indicates a combination plate.	N/A	N/A
Delaware	Yes	2	left side	Yes	In sequence	Yes
District of Columbia	Yes DC gov't vehicles only	2	left side	Yes	In sequence	Yes

Jurisdiction	Plates contain stacked characters	# of Stacked Characters	Location of Stacked Letters	Stacked characters are part of official license plate number	Position of stacked characters same when printed or inquired	Stacked characters printed on registration
Florida	No	N/A	N/A	N/A	N/A	N/A
Georgia	No	N/A	N/A	N/A	N/A	N/A
Hawaii	No	N/A	N/A	N/A	N/A	N/A
Idaho	Yes	up to 4	left side	No	N/A	No
Illinois	Yes	2	right side, w/ 1 or 2 exceptions	Yes	In sequence	Yes
Indiana	No	N/A	N/A	N/A	N/A	N/A
Iowa	No	N/A	N/A	N/A	N/A	N/A
Kentucky	Yes *specialty plates only*	2	right side	Yes	In sequence	Yes
Louisiana	Yes	2	Left side	Yes	In sequence	Yes
Maine	No *However, a few older plates have stacked #s*	N/A	left side	No	In sequence	No
Manitoba	No	N/A	N/A	N/A	N/A	N/A
Maryland	Yes	2, 3 or 4	right or left side	Yes	In sequence	Yes
Michigan	No	N/A	N/A	N/A	N/A	N/A
Minnesota	No *However, some old permanent plates have stacked letters*	N/A	left side	Yes	In sequence	Yes
Mississippi	Yes	2	Right side	Yes	In sequence	Yes
Missouri	No	N/A	N/A	N/A	N/A	N/A
Montana	Yes *two plates only*	2	left side – disabled vet left side second position – purple heart disabled vet	No	In sequence	No

Jurisdiction	Plates contain stacked characters	# of Stacked Characters	Location of Stacked Letters	Stacked characters are part of official license plate number	Position of stacked characters same when printed or inquired	Stacked characters printed on registration
Nebraska	No	N/A	N/A	N/A	N/A	N/A
Nevada	Yes	3	left side	Yes	In sequence	Yes
New Brunswick	No	N/A	N/A	N/A	N/A	N/A
New Hampshire	Yes	2	left side	No for conservation plate which uses CH, but for construction equipment the "CE" is part of the plate	In sequence	Yes
New Jersey	Yes	2	left or right side	Yes	In sequence	Yes
New Mexico	Yes	2, 3 or 4	left or right side	Yes	In sequence	Yes
New York	Yes	2, or more	left or right side	Some are, some aren't.	In sequence	Yes
North Carolina	Yes	2	left or right side	Yes	In sequence	Yes
North Dakota	Yes	2	left	Yes	The plates are listed under a particular series in the system *(e.g., Lewis and Clark is LC stacked; Gold Star is GS stacked)*	Yes
Northwest Territories	No	N/A	N/A	N/A	N/A	N/A
Nova Scotia	Yes	2 or 3	left or right side	Yes	In sequence	Yes
Ohio	Yes	2 or 3	left side	No	In sequence	Yes
Oklahoma	Yes	2 and 3	left side or middle	Yes	In sequence	Yes
Ontario	No	N/A	N/A *Note: Some plate types print on the left side*	No	N/A	N/A
Oregon	No	N/A	N/A	N/A	N/A	N/A
Pennsylvania	Yes	2	left or right side	Yes	In sequence	Yes
Quebec	No	N/A	N/A	N/A	N/A	N/A
Rhode Island	No	N/A	N/A	N/A	N/A	N/A

Jurisdiction	Plates contain stacked characters	# of Stacked Characters	Location of Stacked Letters	Stacked characters are part of official license plate number	Position of stacked characters same when printed or inquired	Stacked characters printed on registration
Saskatchewan	No	N/A	N/A	N/A	N/A	N/A
South Carolina	Yes	2	left side or both sides	Yes	In sequence	No
South Dakota	Yes	2 or 3	left side	Yes	In sequence	Yes
Texas	No	N/A	N/A	N/A	N/A	N/A
Utah	No	N/A	N/A	N/A	N/A	N/A
Vermont	Yes	3	left side	No	N/A	No
Virginia	Yes	2	left or right side	Yes 99% of the time; but there are exceptions	In sequence	Yes
Washington	Yes	2 or 3	left or right side	Yes	In sequence	Yes
West Virginia	Yes	2	left or right side	Yes	In sequence	Yes
Wisconsin	Yes	2	right or left sides	Yes. Except for moped plates.	In sequence	Yes
Wyoming	Yes	2 and 3	left side	No. Stacked characters are used to identify plate type.	No	No
Yukon	No		N/A	N/A	N/A	N/A

Part III – Use of Non-Alphanumeric Characters

Jurisdiction	Plates contain non-alpha or numeric characters	Symbols or characters used [1]	Non-alpha or numeric symbols or characters considered part of official plate number	Non-alphanumeric characters printed on registration card as they appear on the license plate
Alabama	Yes	dash	Historically, no, but we recently requested that county licensing officials send license plate numbers exactly as they are printed on the plate (with spaces and dashes). The license plate number should appear in an inquiry whether or not the spaces or dashes were entered.	Not in the past, but we are now encouraging county licensing officials to include spaces and dashes on the registration receipt.
Alaska	No	N/A	N/A	N/A
Alberta	Yes	dash only	No	No
Arizona	No	N/A	N/A	N/A
Arkansas	No	N/A	N/A	N/A
British Columbia	Yes	dash	No	No
California	Yes	plus sign	No However, the database will denote it's a KIDS plate and position of the symbol will appear after the symbol type chosen for the plate number. For example, 3/Plus Sign means the plus sign appears as the 3rd character in the plate number.	No
Colorado	Yes	dash, periods, slashed zero	No	No
Connecticut	Yes	dots	No	No
Delaware	Yes	hyphens, spaces, and ampersands	No	No
District of Columbia	No	N/A	N/A	N/A
Florida	Yes	dash	No	No
Georgia	No	N/A	N/A	N/A
Hawaii	Yes	dash	No	No
Idaho	No	Dash	No. Typically part of the special plate design, and not part of the plate number.	No
Illinois	No	N/A	N/A	N/A

Jurisdiction	Plates contain non-alpha or numeric characters	Symbols or characters used [1]	Non-alpha or numeric symbols or characters considered part of official plate number	Non-alphanumeric characters printed on registration card as they appear on the license plate
Indiana	No	NA	N/A	N/A
Iowa	No	N/A	N/A	N/A
Kentucky	Yes	spaces and dashes	Yes	Yes
Louisiana	Yes *personalized plates only*	dash, period, space	No	No
Maine	Yes *for vanity plates*	dash, ampersand	No	Yes
Manitoba	Yes *personalized plates only*	dashes and spaces	Yes	Yes
Maryland	No	N/A	N/A	N/A
Michigan	No	N/A	N/A	N/A
Minnesota	Yes	hyphen *(personalized plates only)*	No	No
Mississippi	No	N/A	N/A	N/A
Missouri	Yes	dashes, spaces, and hyphens	No	No
Montana	Yes	ampersands, dash or dot zero with slash for amateur radio plate	Yes - amateur radio	No
Nebraska	Yes	dash	No	No
Nevada	No	N/A	N/A	N/A
New Brunswick	No	N/A	N/A	N/A
New Hampshire	Yes	dash, plus sign, ampersand	Yes	Yes
New Jersey	Yes	dash	Yes	Yes
New Mexico	Yes	zia symbol (+), apostrophe ('), dash (-), and Spanish Ñ	Yes	Yes
New York	No	N/A	N/A	N/A
North Carolina	Yes	period, apostrophe, exclamation point, colon, dash, comma, ampersand, question mark, dollar sign, equal sign, number	No	No

Jurisdiction	Plates contain non-alpha or numeric characters	Symbols or characters used [1]	Non-alpha or numeric symbols or characters considered part of official plate number	Non-alphanumeric characters printed on registration card as they appear on the license plate
North Carolina, *continued*		sign, single quote, plus sign, slant line, asterisk, at (@) and double quotes		
North Dakota	No	N/A	N/A	N/A
Northwest Territories	No	N/A	N/A	N/A
Nova Scotia	Yes	dash, DOT and other symbols/graphics	No	No
Ohio	No	N/A	N/A	N/A
Oklahoma	No	N/A	N/A	N/A
Ontario	No	N/A	N/A	N/A
Oregon	No	N/A	N/A	N/A
Pennsylvania	No	N/A	N/A	N/A
Quebec	No	N/A	N/A	N/A
Rhode Island	Yes	dash	No	No
Saskatchewan	Yes	dash	No	No
South Carolina	Yes	ampersand	Yes	Yes
South Dakota	No	N/A	N/A	N/A
Texas	Yes	spaces, hyphens, periods *Texas has a unique, "T for Texas" specialty license plate in several colors which features a stylized "T" in the design area on the left side of the plate. The "T" IS part of the alphanumeric plate number.*	No	No
Utah	No	N/A	N/A	N/A

Jurisdiction	Plates contain non-alpha or numeric characters	Symbols or characters used [1]	Non-alpha or numeric symbols or characters considered part of official plate number	Non-alphanumeric characters printed on registration card as they appear on the license plate
Vermont	No	N/A	N/A	N/A
Virginia	Yes	dash, ampersand	No	No
Washington	No	N/A	N/A	N/A
West Virginia	No	N/A	N/A	N/A
Wisconsin	Yes	dash *(only used for plate readability)*	No	No
Wyoming	No	N/A	N/A	N/A
Yukon	No	N/A	N/A	N/A

[1] *graphics such as a hand, heart, wheelchair, logos, and/or other non-alpha/numeric graphics are not part of any jurisdiction's plate number*

Part IV – Images of License Plates Containing Stacked Graphics

Alabama

Alberta

Arkansas

California

Colorado

Connecticut

Delaware

District of Columbia

Idaho

Illinois

Kentucky

Louisiana

Maine

Maryland

Minnesota

Mississippi

Montana

Nevada

New Hampshire

New Jersey

New Mexico

New York

North Carolina

North Dakota

Nova Scotia

Oklahoma

Pennsylvania

South Carolina

South Dakota

Vermont

Virginia

Washington

West Virginia

Wisconsin

Wyoming