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Commerical Vehicle Enforcement using License Plate Recognition Technology

Stephanie R. Hargrove
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Stephanie R. Hargrove entitled "Commerical Vehicle Enforcement using License Plate Recognition Technology." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

Lee D. Han, Major Professor

We have read this thesis and recommend its acceptance:

Thomas Urbanik II, Arun Chatterjee

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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Commercial Vehicle Enforcement using License Plate Recognition Technology

A Thesis Presented for
the Master of Science Degree
The University of Tennessee, Knoxville

Stephanie R. Hargrove
May 2007

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ABSTRACT

Speed limits for large trucks have been reduced at many locales for air quality and safety reasons. To realize an improvement in air quality and safety, however, diligent enforcement and fitting punishment have to be implemented. This may put a strain on already tight resources and manpower for state and local agencies. To this end, this paper presents a license plate recognition (LPR) technology based heavy vehicle speed enforcement system that requires relatively minimal initial investment and no increase in enforcement personnel, cruisers, or pursue/pull-over activities. The efficiency of the system is achieved by catching speeding trucks in the act and then enforcing the law at weigh stations, which all trucks, with few exceptions, are required to enter.

The configuration of the system for the Knoxville, TN study site is presented. Strategic placement of LPR units on I-40 and I-75 enables the speed tracking and enforcement process. Identified trucks are checked against the CVEIW national database for additional inspection, enforcement, and citation activities.

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CHAPTER I. INTRODUCTION

Background

The speed limit for large trucks (gross weight over 10,000 pounds) in the Knoxville, TN metropolitan area was lowered from 65 to 55 mph in April 2006. This was a measure that the Knoxville Regional Transportation Planning Organization put into effect to reduce harmful emissions and improve air quality. The subsequent challenge is effectively enforcing the policy with the State's constrained resources and manpower in Tennessee Department of Safety (TDOS).

In fact, Tennessee is not alone in concern. Across the country, urban areas are making an attempt to lower the emission levels due to large trucks. A Federal Highway Administration study found that reducing large truck speeds by ten mph could reduce emissions of NOx by eighteen percent per large truck[1]. But without diligent enforcement which requires resources and manpower, lowering the speed limit alone would not reduce emissions.

With I-40 and I-75 passing through Knoxville the weigh station (denoted as a star in Figure 1) results in one of the busiest locations in the country observing an average of 12 million trucks annually. The majority of the trucks are required to enter the station, operated by Tennessee Highway Patrol (THP), for weighing and inspection. Currently, all speeding trucks are not pulled over along I-40 and I-75 for traffic violations.

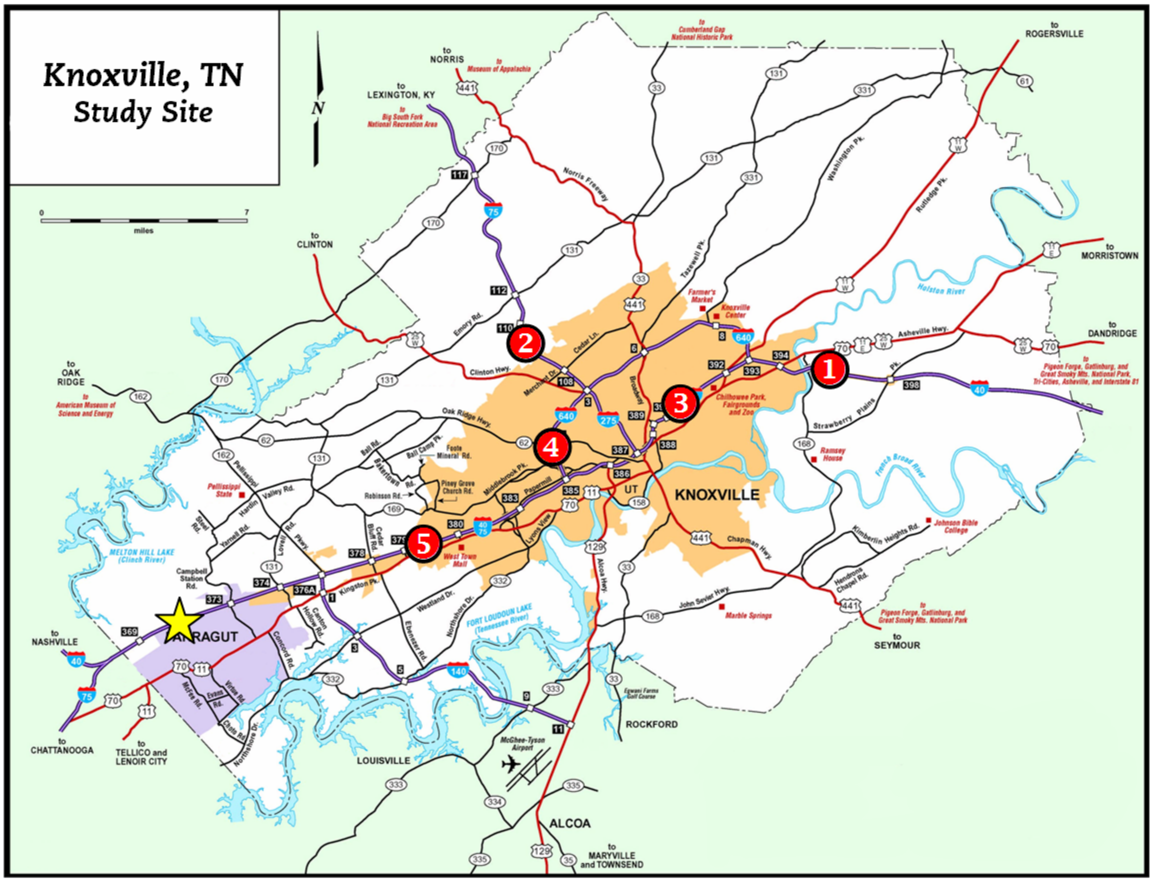

Figure 1. Weigh station and I-40/I-75 in Knoxville area.

According to Table 1, the number of citations given out by the THP is growing. Between the fiscal years 2003-2004 and 2004-2005, the number of speeding trucks cited increased by almost three thousand; total citations increased by over eighty seven thousand. If the THP received more resources citations would increase.

License Plate Recognition (LPR)

LPR is a fast-growing technology that enables the automation of toll way control, parking and access control, law enforcement, and origin and destination identification. The LPR technology utilized in this research was developed and manufactured by PIPS Technology. PIPS's LPR technology consists of Platefinder firmware, cameras, Triple Flash technology, an Optical Character Recognition (OCR) engine, processors and application software.

The Platefinder firmware continually searches the camera's field of view for the presence of a license plate. When the license plate is detected, the cameras capture color and infrared images of the vehicle and plate. There are three types of cameras: the infrared (IR) illuminator, the color overview, and the dual lens. The IR illuminator captures the actual license plate. Almost all license plates have a coating that is highly reflective to infrared, and therefore are easily identified by the camera. The IR illuminator camera tells the color overview camera to capture a color image of the vehicle at the moment a license plate is located. The color overview image is not used in the process of identifying a plate, but helps to create a solid evidentiary report and gives the

Table 1. Trooper Activity for FY 03-04 and FY 04-05

	FY 03-04	FY 04-05
DUI	4,033	4,094
SPEEDING TRUCKS	**4,145**	**7,085**
OTHER MOVING	186,889	205,466
CHILD RESTRAINT LAW	3,623	5,601
SEATBELT LAW	29,832	50,563
OTHER NON-MOVING	137,724	180,821
TOTAL CITATIONS	**366,246**	**453,630**
FELONY ARRESTS	1,914	2,176
WARNINGS ISSUED	10,117	11,934
PROPERTY DAMAGE CRASHES INVESTIGATED	18,312	21,311
INJURY CRASHES INVESTIGATED	12,280	12,962
FATAL CRASHES INVESTIGATED	489	607
TOTAL CRASHES INVESTIGATED	31,081	34,880
TOTAL TRUCKS WEIGHED	N/A	10,784,799
OVERWEIGHT ASSESSMENTS	N/A	6,675
SAFETY INSPECTIONS	N/A	71,644

Source: Trooper Activity for mentioned fiscal years.
***Note: Starting in 2002, seatbelt warnings and Tennessee Crash Reporting System-01/06/05 are counted in with total warnings. 2003 & 2004 crash data are preliminary*
http://www.nhtsa.dot.gov/safecommunities/ServiceCenter/scnews/features5.html

user immediate details of the vehicle as opposed to the black and white infrared image of the plate. The dual lens is the combination of the IR illuminator and the color overview camera. As a license plate is detected, the dual lens camera is triggered to capture both color and infrared images of the vehicle and plate.

The Triple Flash technology varies the flash, shutter, and gain settings on the camera to capture multiple images of each plate. This ensures the highest quality photo regardless of light and weather conditions. Only the highest quality image produced is used for processing.

The OCR provides the ability for a machine to recognize and convert printed characters into data. The OCR engine used in the study has been customized by PIPS and is unlike some others in the LPR community. PIPS does not use a generic OCR engine for all states and regions, but a customized OCR engine specific to the state or region of interest. The engine was helpgul in capturing the large range of license plates traveling I-40. More importantly, PIPS's OCR engines are very tolerant of skewed and off-axis plate reads, various plate sizes, syntax rules and designs.

The processors house the Platefinder firmware, triple flash technology and OCR engine. The application software allows the captured data to be used in a variety of ways through the processor.

The LPR process generally consists of two stages: image capturing and image processing. Image capturing involves electro-optics that produces a digitalized image. Depending on the technology employed (continuous firing strobes or triggered capture), images of each vehicle (containing the target license plate) are captured. Analysis begins by locating the license plate within the image. During this process, the entire image must be carefully analyzed due to bumper stickers, phone numbers and other miscellaneous numbers and letters near the license plate which could skew the task. After locating the license plate, the LPR isolates each character on the plate using the OCR engine. This process is tolerant of variation in character font, style, size, tilt and perspective. Depending on lighting, angle and other external conditions, LPR could potentially achieve high accuracy.

There were two different versions of LPR technology used during the collection of data. The ‘older’ version uses an IR illuminator camera (P366), a color overview camera (P359), and the P357 processor. The ‘newer’ version only uses a dual lens camera (P372). The P372 incorporates the IR illuminator camera, color overview camera and the processor within one single enclosure.

Objective

The objective is to implement a permanent speed tracking system in Knoxville, TN using License Plate Recognition (LPR) technology. This study has been conducted in order to provide first-hand information on the accuracy and the need for LPR technology. It is hoped that this study will result in two permanent LPR units strategically placed in the proximity of the weigh station. One location at the Campbell Station interchange just before the weigh station (the square in Figure 2) for identification of oncoming trucks and the second before the weigh station entrance ramp near the WIM unit (the triangle in Figure

2) for processing. A third LPR unit may prove beneficial at the on-ramp of the Watt Road interchange beyond the weigh station to capture vehicles that bypass the weigh station. It is important to note that it is not a crime to avoid a weigh station with an alternate route; however, this system captures data on non-violators and allows THP personnel to identify the trends of various carriers. This can lead to targeted inquiries as to why a motor carrier consistently bypasses the weigh station. In addition, mobile (permanent would be desirable) LPR units can be placed inconspicuously at one or more of the five sites identified in Figure 1. Applying the simple relationship of average speeds, distance divided by travel time, one can easily identify a speeding truck. The travel time is determined by the time difference between two LPR units spotting the same vehicle.

The critical part that makes this system work efficiently and economically is the fact that all trucks, with few exceptions, have to enter the weigh station. In effect, the THP officer on duty in the weigh house could pull over speeding trucks while weighing them. No extra trooper or cruiser is needed; nor the need for high-speed pursuits and pull-over maneuvers. Initially, warnings can be given. Citations could be issued after the warning period has expired.

In addition to speed enforcement, the system also checks for anomalies by comparing the license plate information against CVIEW and other national or local databases (Figure 3). A wireless Internet connection via cellular network was set up to provide real-time access to CVIEW for this study. The system successfully captured truck images, digitized license plates, obtained license plate numbers, compared the plate numbers against CVIEW database, and

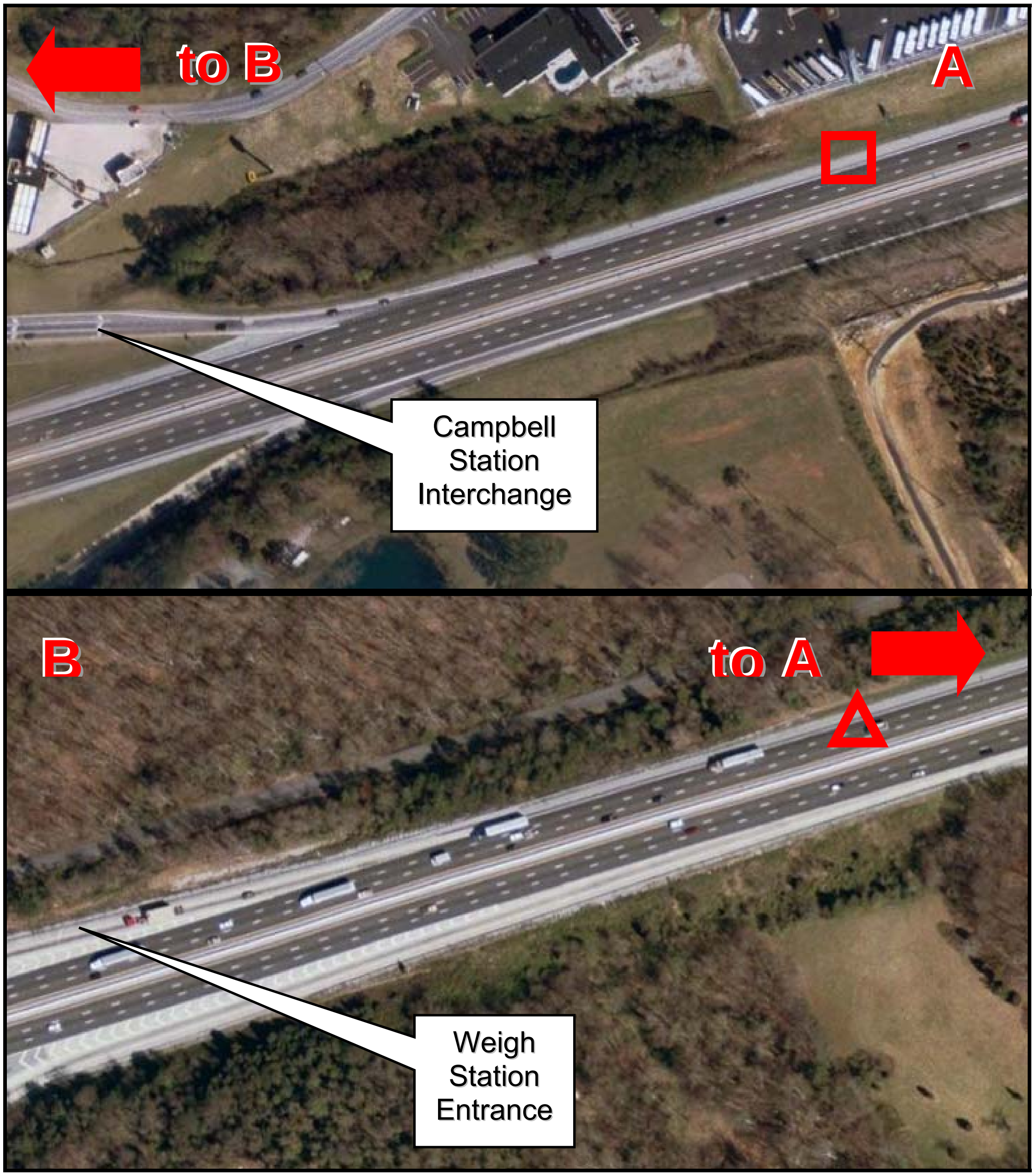

Figure 2. Placement of suggested permanent LPR units.

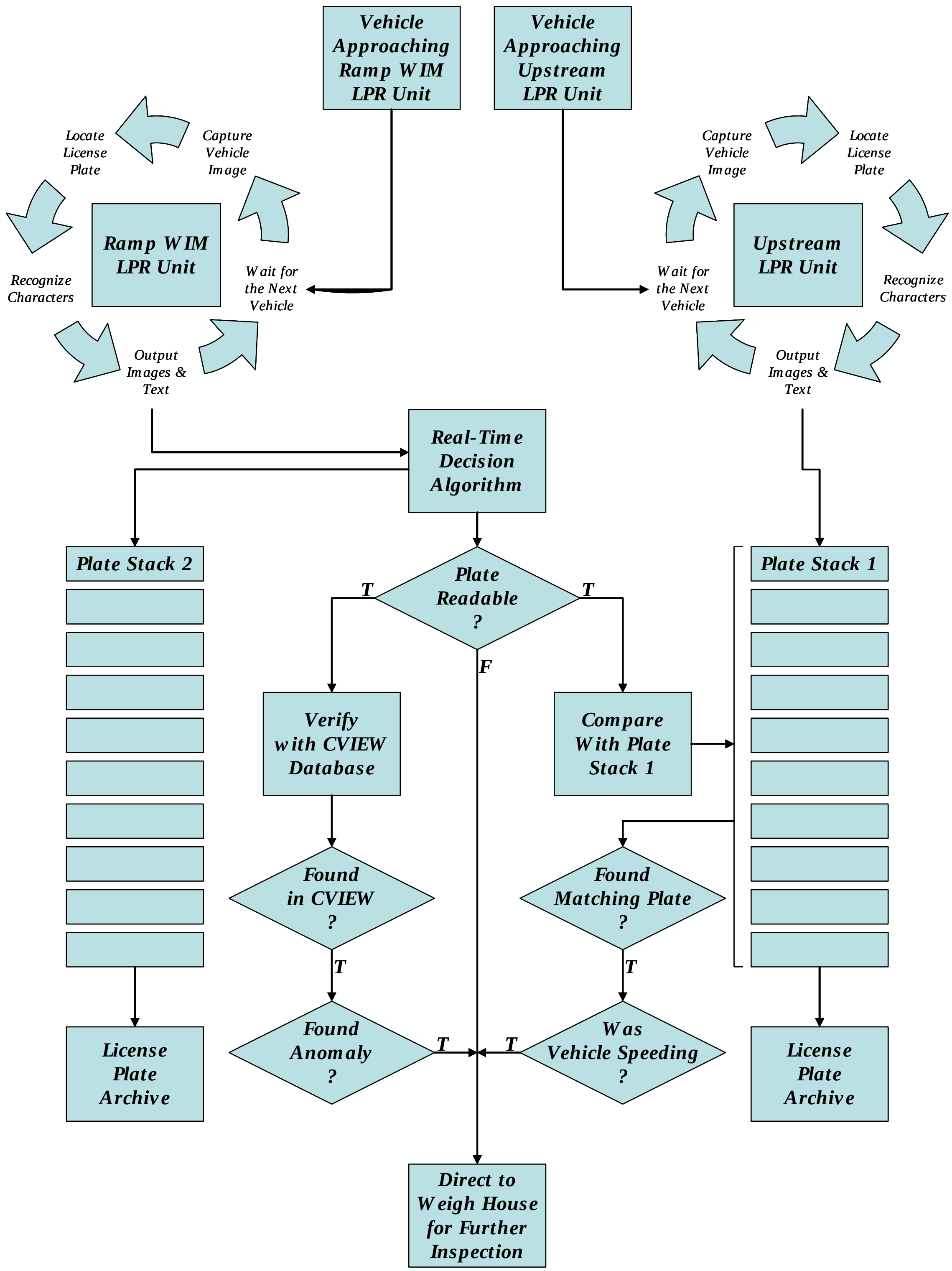

Figure 3. Simplified speed and anomaly enforcement algorithm.

reported information on these trucks in real-time, often with a lag time of less than 3 seconds. The system is capable of archiving license, weight, inspection, and citation information to facilitate future enforcement and operational activities.

CHAPTER II. LITERATURE REVIEW

Heavy Duty Vehicles

Heavy Duty vehicles and their operations in urban areas have contributed to congestion, air pollution, safety and even security concerns. A contributing factor to many of these concerns is speeding. Consider the following statistics:

- The Federal Motor Carrier Safety Administration (FMCSA) statistics for the year of 2001 states that speed was a factor in 21 percent of all large truck injury crashes and 30 percent of all fatal crashes [2].
- Near 30% of all large truck drivers involved in fatal truck accidents throughout the US had at least one prior speeding conviction compared to the rate of 20% for passenger vehicle drivers.
- A recent study conducted on the Interstate Highways in Knoxville area found that near 70% of large trucks were speeding during off-peak hours.
- The City of Philadelphia saw a 69% reduction of truck-involved accidents after imposing a controversial city law allowing impoundment of commercial vehicles and severe fines for speeding ticket and other violations [3].
- Speed limits for tractor-trailers on the interstate have been lowered from 65 mph to 55 mph in the areas of Chattanooga and Knoxville, TN to reduce nitrogen oxide (NOx) emission. Many counties and cities in

Tennessee as well as other states are considering similar measures to reduce air pollution.

As suggested by these items, reducing large truck speed is likely to, or at least perceived, to have positive effects on transportation safety and air quality.

Mobile6

With the encouragement from EPA and their MOBILE6 model, the city of Knoxville, TN has decided to lower the truck speed from 65 to 55 on I-40. MOBILE6 is the latest motor vehicle emission factor model released by the US Environmental Protection Agency (EPA) in January 2002. The model exhibits significant advancements in understanding vehicle performance when estimating emissions. State and local air quality and transportation agencies are required to use MOBILE6 in State Implementation Plan development and transportation conformity determinations. After the release of MOBILE6 a two year grace period was given before it was required for new transportation conformity determinations in most area. MOBILE6 uses 4 parameters to classify vehicles: model year, weight, fuel type and body type [4].

Applications of LPR

LPR technology is quickly growing as an effective tool to combat criminal activity, enhance productivity and improve officer safety. Local, state and federal agencies worldwide have adopted LPR systems to improve the efficiency and effectiveness of their enforcement efforts. Each PIPS Technology LPR system acts as a force multiplier. An aggressive officer could enter in a few hundred plates per day while the system is capable of logging thousands. With remarkable capture and read rates, even at vehicle speeds over 130 miles per hour, the system can check 3000 to 4000 plates per shift, freeing up the officer for other duties. By making officers aware of their surroundings and alerting them to potentially dangerous situations before they happen. LPR can help to avoid conflicts and save lives. With PIPS Technology LPR solutions, integration and accessing up-to-the-minute data is fast and seamless. Databases can be easily maintained and new information can be quickly uploaded across all deployed units for improved enforcement. The LPR technology has been used, but not limited to, in the following law enforcement applications:

- Identification of Felons or Wanted Individuals
- Monitoring School and Playground Areas for Sexual Predators
- Amber Alerts
- Identification of Delinquent Citations
- Crime Scene Intelligence and Surveillance
- Monitoring of Gang Activity and Locations
- Drug Enforcement
- Stolen Vehicle Recovery

Florida DOT Motor Carrier Compliance Office (MCCO) is currently using LPR to record license plates of large trucks at weigh stations to compare the plates against crime information databases [5]. MCCO uses LPR equipment along unattended weigh-in-motion (WIM) scales to record the license plate of overweight trucks entering and leaving Interstate highways. Routine activities of overweight trucks bypassing weigh stations are observed by officers for enforcement purposes [6]. Tennessee Department of Safety (TDOS) is currently working with the University of Tennessee to conduct a similar study at a broader level, [7, 8] of which the research presented here is a part of.

CHAPTER III. STUDY METHODOLOGY

In order to determine the accuracy and need of the LPR technology for speed enforcement, the following are examined in the study:

Component 1. The relationship of the license plate and LPR technology. Determining how effectively the LPR technology captures each state's commercial vehicle license plate.

Component 2. The capabilities and sensitivities of the LPR technology when used for speed enforcement.

Component 3. The actual speed of large trucks traveling the I-40 corridor.

The following section will present a plan developed to collect data for these components of the study.

Data Collection Plan

Data collection was divided into two phases: a single unit set-up and a dual unit set-up of the LPR technology. The single unit set-up of the LPR technology was used for component 1 and completed first. Once the single unit captured license plates at an efficient rate, the data was saved for processing.

The dual LPR unit set-up was used for component 2 and 3 of the study. A radar gun and Remote Traffic Microwave Sensor (RTMS) radar is also used to assist component 2 and 3. The data collected with the radar gun is compared against the data collected with the LPR technology for a present speed evaluation. The RTMS data supplies the study with vehicle speeds from 2005, before the speed limit change on I-40. The RTMS data will also be compared against speeds determined by LPR technology in 2007.

Data Collection for Single Unit Set-Up

Location

To analyze the LPR technology only one set-up is required. The weigh station is chosen for this set-up for the following reasons:

- All trucks, with few exceptions, have to go through the weigh station
- Safety. The sites need to have wide open areas for equipment positioning and workers. This would reduce the likelihood of accidents and provide safety for personnel and motorists.
- The site must be accessible to vehicles to transport equipment and workers.

The set-up is at the entrance ramp to the weigh station, monitoring all entering trucks.

Time Period

There were no time constraints on this data.

Procedure Equipment

The P366 camera, P359 camera, and the P357 processor were used to collect data. A video camera was also used to determine the number of license plates not captured by the LPR equipment.

Data Collection for Dual Unit Set-Up

Location

In order to determine the speed of the commercial vehicles the LPR equipment must be placed in two locations. The research is limited to data collection of only one lane of traffic, because of the temporary set-up on the side of I-40. A permanent set-up placed above traffic would allow the observation of multiple lanes. The equipment is sensitive to field locations. Overhead locations are desirable but not achievable, and unless the equipment's mobile location is excellent the camera's ability to capture may drop.

The collection of data was completed in the right lane of westbound I-40. The dual set-up locations are 1.4 miles from each. For February 28th the locations were 1 mile apart. If the distance is greater, the speed calculated would over a large period of time and the speeds would not be very tangible. If the speed is calculated over a very short distance, the LPR camera would have to know the exact distance the license plate was captured. This proves impossible because the camera has a parameter of 6-8 feet that the plate will be captured in. Since it is not possible to know the distance to the nearest foot, the distance must be large enough to be minimally effected by distances up to 6 feet. The study site on I-40 is a straight section of interstate with some changes in elevation (Table 2).

Table 2. Elevations along Knoxville Study Site of I-40.

Location	Elevation (ft)
Lovell Road	921
Campbell Station	967
Weigh Station	1085

Time Period

Data were collected on weekdays excluding holidays and days involving inclement weather, congestion, and vehicle crashes. These days are excluded to prevent any abnormal traffic patterns. Data are to be collected between 1:00 and 4:00 when congestion is minimal.

Procedure Equipment

Due to the availability of equipment, the license plates were captured using two different version of LPR technology. The 'older' version of technology (the P363 camera, P359 camera, and P357 processor) was placed prior to the Campbell Station interchange. The 'newer' version of technology (the P372 camera) was placed prior to the weigh station. The speed is derived from the time difference between two LPR units capturing the same license plate. A radar gun was used to collect data at the Campbell Station interchange. The radar gun was not in operation when the LPR technology was set-up. This was to prevent speed changes caused by radar detectors.

Data Processing

When deployed with high-speed internet connection for database verification and a fast computer for post-processing, LPR results, though not perfect, can be improved within a few seconds after LPR units initially analyze them. The results are improved by correcting misread characters. The LPR data used in this study is post-processed by hand to determine exact number of:

- plates captured
- plates accurately read
- correct matches before the plates are processed
- correct matches after the plates are processed
- errors in the data

Post-processing ten hours of LPR data can take over a hundred hours, but it is the only way to determine the sensitivities and errors of the LPR technology. The processing is completed in 6 stages:

1. The LPR data is examined to remove all 'false' plates.
2. The unprocessed plates are matched to determine the number of plates captured and accurately read at both locations.
3. The plates are processed to correct all the misread plates.
4. The processed plates are then matched to determine the total number of plates captures at both locations.
5. Once all the plates are matched the speed is determined with the time difference and distance between the locations.

6. The data is then analyzed for abnormal data, like duplicated plates and time gaps.

RTMS Data

A network of Remote Traffic Microwave Sensor (RTMS) radars was installed in November 2001 to monitor the formation of queues as traffic approached the Lovell Road exit on I-40. The sensors collected the data of eastbound vehicles west of Lovell Road and westbound vehicles east of Lovell Road. These sensors are side-fired radar units. In side-fired configurations, sensors are usually mounted on poles located on the interstate. They are fully programmable to support a variety of applications.

The aim of the network was to collect a vehicle count of large trucks and vehicles over small time intervals. The speed collection by RTMS was a secondary concern and because the units operated in a side-fired mode, the speed estimate returned by the system is sometimes unreliable. The RTMS radar measured the dwell-time of each vehicle passing. Speed was calculated by dividing the vehicle-length and zone-length coefficient by the dwell-time. One RTMS speed value is the average speed of vehicles traveling in the right lane of I-40 over a period of time (Table 3. shows a common time interval). [9]

The data collection location is just before the Lovell Road Interchange for the right lane (lane 3) on westbound I-40. A sample of the RTMS data used in the study can be found in Table 3. The RTMS units can distinguish "long vehicles" from passenger cars by assuming that all vehicles in a lane are traveling at roughly the same speed. The RTMS radar does not capture a true classification count, nor does it capture 100% of truck traffic. The RTMS data used for the study is from February 23, 25 and March 2, 4 of 2007. Data requirements for the RTMS data are as follows:

- Data are to be between 1:00 and 4:00
- Data are to be on weekdays excluding holidays and days involving inclement weather, congestion, and vehicle crashes. These days are excluded to prevent any abnormal traffic patterns.

RTMS is no longer a reliable resource for collecting speeds along I-40. The sensors have not been maintained and most are without power. Only a few are still collecting data. The data that is collected is full of many gaps, because of power outages and needs for repair.

Table 3. Sample Data from RTMS file.

TIME	DATE	Volume Long Vehicles 3	Volume Other Vehicles 3	Speed 3
13:35:18	23/02/2005	31	13	71
13:35:29	23/02/2005	31	13	71
13:35:48	23/02/2005	31	13	66
13:35:50	23/02/2005	31	13	71
13:40:16	23/02/2005	17	9	69

CHAPTER IV. LPR TECHNOLOGY EFFICIENCY

Two components of LPR technology are examined in this section:

- The relationship between the license plate and the LPR technology; this examines the success of each individual state's license plate.
- The ability to use the LPR technology for speed enforcement.

Accuracy of License Plate Recognition

Application of LPR in the field usually requires 24 hours a day, 7 days a week operation. Some LPR systems have fewer problems with inclement weather and night visibility than others. LPR experiences problems with dirty, broken, bent, and deliberately altered plates. A license plate is considered accurately read only if all characters are identified correctly. That is, a plate that says "ABC 123" is not considered correctly read if LPR reports "A8C 123," even though five out of six characters were read correctly. This could occur quite frequently as "0" (zero) may be misread as "O" (as in Omega); "1" may be misread as "I" (see Figure 4); "2" may be misread as "Z;" and such.

The probability a character may be misread by LPR as another character is dependent on various attributes of the plate including font, colors, reflectance, and external factors such as lighting, viewing angle, presence of hitch-ball or other obstacles, and so on. Table 4 shows a "Character Translation Matrix," resultant from past research where each character on the left has a probability (in percent) of been misread as one of the characters on top. This table provides some insight that can help improve LPR accuracy in post processing. In

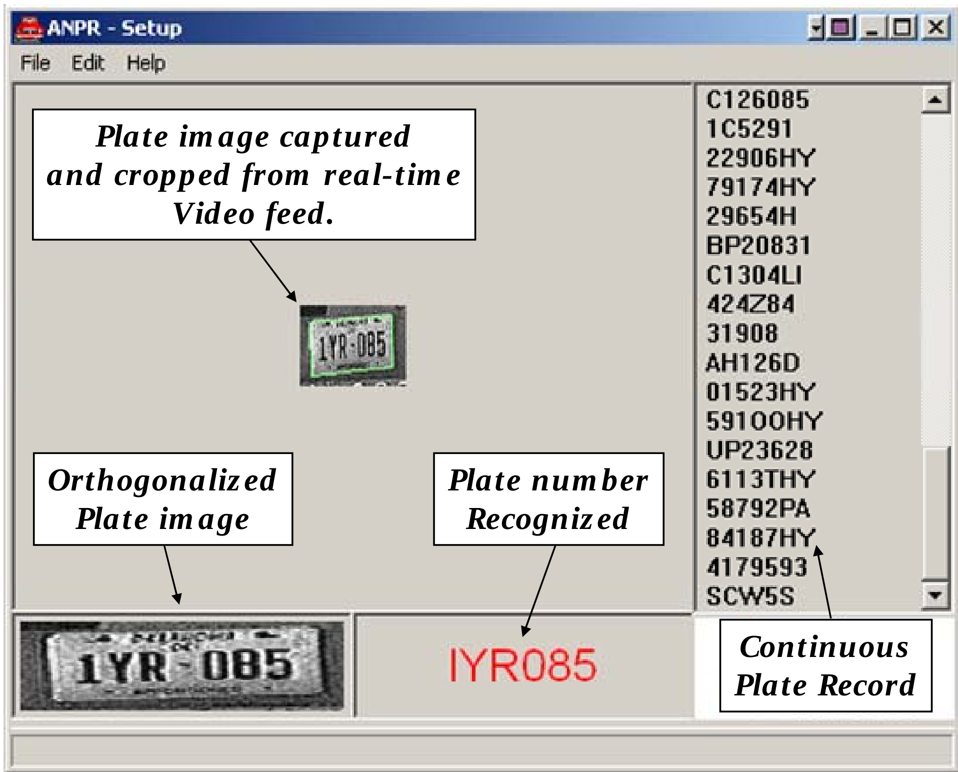

Figure 4. LPR process with a misread plate.

Table 4. Sample Character Translation Matrix

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
0	31				15				3				3	5			1								31		5				3					
1		56						5											26			5								2						5
2			58	1				5		1									1			5							2							27
3			1	56		1		5	5	2		2			1					27									1							
4	16				34					6	16											6			16				1					3		
5				1		63	2													2									30	1					1	
6	1					3	68		3			3			1		20								1				3							
7		4	4	4				47		1									4											22						14
8	4			4			2		51	1	4	24		1	1			1							1	2	1	2	1					2		
9			1	2	11			1	1	63		2		1											1	6	1		11						1	
A	1				28				5		60	1						1							1	1	1	2						1		
B	1			2			2		25	2	1	54		2	2	1		1			1				1	2		5								
C	6												71		3	1	6					3			6		3									
D	11								1	1		2		62			1								11	5	2	1			2	1				
E				1			1		1			2	2		60	28			5																	1
F												1	1		29	61										5				2						
G	2						18						5	1			61					5			2		5									
H					1				1		1	1						61			2		10	10				5					2	5		1
I		21						4							4				44	13		2								8						4
J				22		2													14	47									14		1					
K												1						2			56		5	5				10					5	16	1	
L		5	5		11								2				5		2			62														5
M																		10			5		61	10									10	2		
N																		11			6		11	64									6	2		
O	31				15								3	5			1								31		9				1					
P	1								2	6	1	2		6		6									1	64	1	11							1	
Q	10								1	1	1		2	2			5								17	1	59	1			1					
R									2		2	5		1				5			10				1	10	1	61						1		
S			2	1	2	23	2		1	8									1	14									48							
T		2				1		27								2			10											57					1	
U	6													3						1					3		1				71	12	1		3	
V	1													1																	13	75	3		7	
W																		3			6		12	6							1	3	69	1	1	
X					5				2		1							5			18		2	2				1					1	61	1	
Y					1	1				1											1					1				1	3	7	1	1	82	
Z		4	23					14							1			1	4			4														48

addition, based on the syntax of plates from various states, one could also better "guess" the correct plate number when one or more characters are misread.

LPR has been successfully deployed for passenger cars at many different locales. The use of LPR for large trucks is somewhat different as tractors usually have their license plates mounted in front, which is greater in dimension in comparison to passenger cars' plate mounting area in the back. After examining more than 1,600 tractors in the states of Tennessee, Georgia, and Florida, it was summarized that 92% of these heavy vehicles have their license plate mounted somewhere on the front bumper, see Figure 5. However, about 4% of the trucks do not have license plates mounted anywhere at all. This in effect caps LPR's accuracy at 92%, if everything else is perfect.

States' LPR Efficiency

Early in the study period, it became clear that truck license plates from certain states could be problematic due to their unique color, reflectance, font, and such. These states include Kentucky, Mississippi, Texas, Florida, and Alabama. Among the thousands of trucks traversing the stretch of I-40 near Knoxville each day, the majority of the trucks were registered with Tennessee (24.6%), Illinois (9.4%), Georgia (7.1%), Oklahoma (5.4%), and Indiana (5.2%), see Figure 6. The license plates from these and most other states are not problematic. However, about 20% of the trucks do have problematic plates. This presents a challenge to a LPR-based speed enforcement system and further reduces the

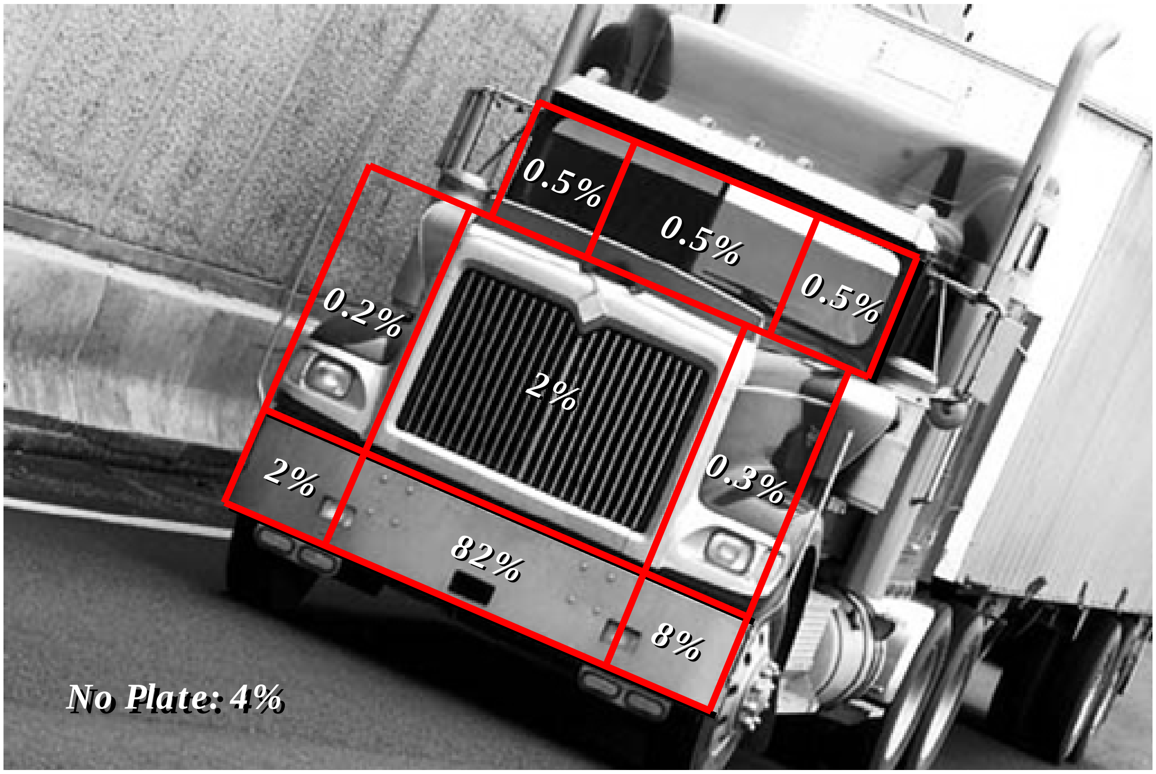

Figure 5. Placement of license plates on large trucks

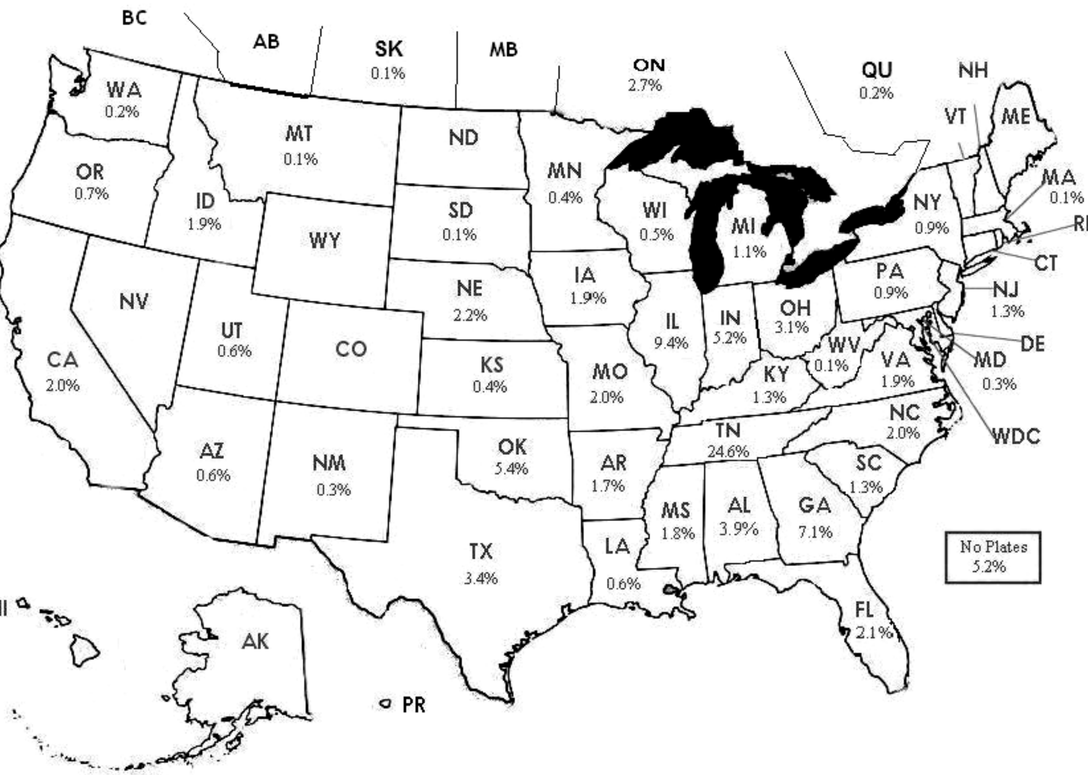

Figure 6. State of trucks' registration traversing I-40 in Knoxville study site.

maximum LPR accuracy to about 92% * (100% - 20%) =73.6%, if everything else were perfect.

A single LPR unit was set-up at the entrance of the weigh station to capture large truck license plates. With the LPR equipment, a video camera was used to record footage of truck license plates. The video was viewed later in slow motion to manually extract each license plate number to serve as ground truth for comparisons with results from the LPR data collected.

The LPR technology performed at slightly different levels in rainy, sunny, night, day, and other conditions. Overall, an accuracy of about 61% was achieved during this study. This is quite remarkable considering only 73.6% were actually readable. The LPR units accurately recognized 83% of all readable plates. Figure 7 presents the read accuracy of LPR units for plates of different states and Canadian provinces. Several states/provinces were able to enjoy 100% accuracy while others had lower rates. It should be noted that only states and provinces with plates present in this study have been plotted in Figure 7.

The accuracy statistics represented performance of mobile LPR units. That is, for the purpose of this study, LPR units were not permanently mounted at any location. Permanently mounted units will produce better accuracy as more desirable camera angle, height, and direction are less likely to be consistent with mobile configurations.

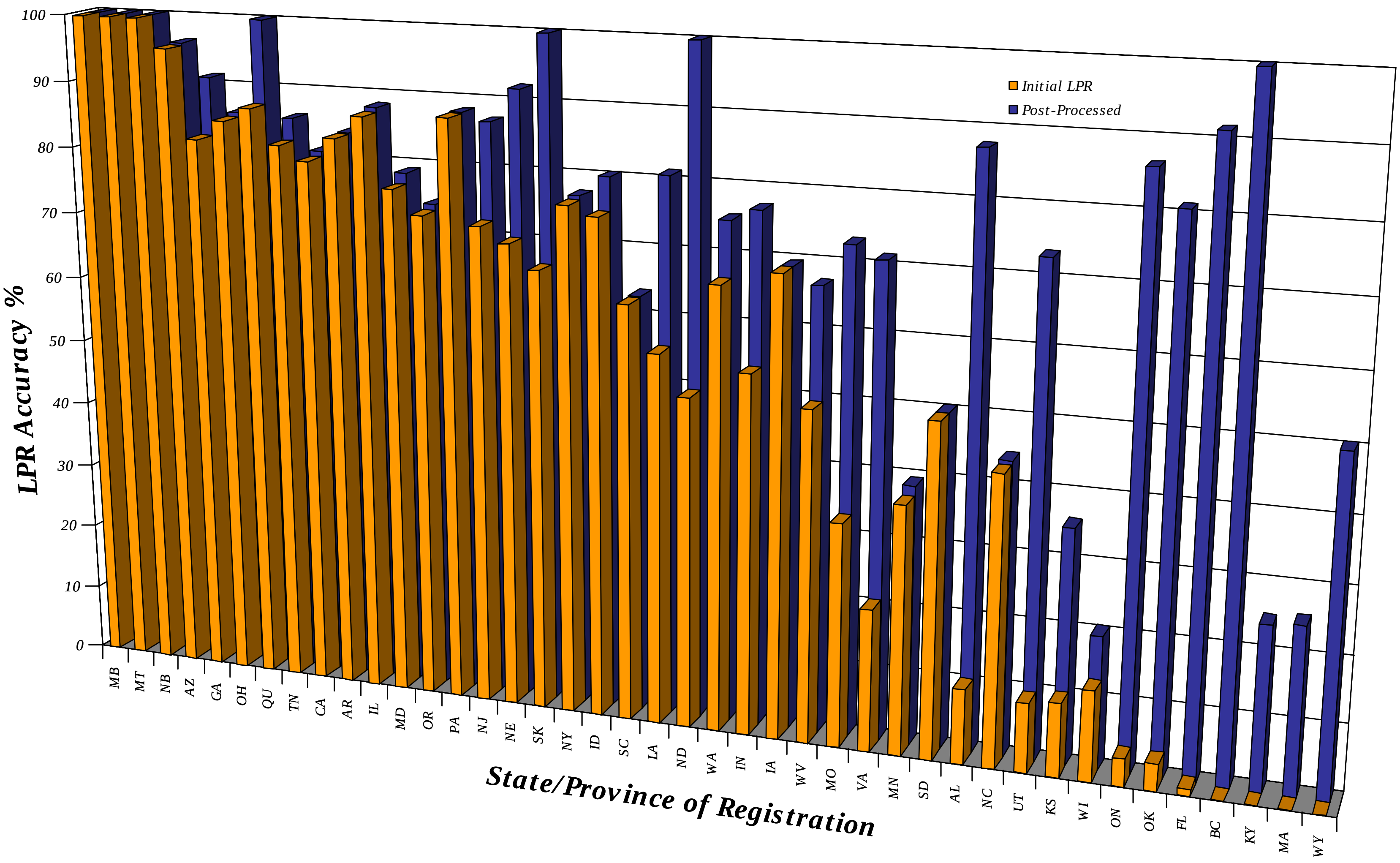

Figure 7. Initial LPR Accuracy and Results of Post-Processing.

License plate syntaxes from different states and provinces were derived from thousands of plates and literature, therefore, plate numbers not conforming to any syntax rules can be "corrected." With these correction mechanisms, post-processing the resultant license plates numbers, LPR accuracy can be improved for most states (see Figure 7).

LPR Efficiency for Speed Enforcement

The main goal of this study was to evaluate the potential implementation of a permanent LPR-based speed enforcement system at the weigh station on I-40. This section identifies the capabilities and sensitivities of the LPR technology when used for speed enforcement. The data studied was collected by the dual LPR unit set-up.

Plate Capturing Performance

Table 5 presents the read accuracy of the LPR units for the set-up at the Campbell Station Interchange and the weigh station. The overall number of images captured at the Campbell Station interchange for the collective days is 3144. The overall number of images captured at the weigh station was 1583 for the collective days. The overall number of plates captured at the Campbell Station interchange for the collective days is 2671. The overall number of plates captured changed to 1530 at the weigh station for the collective days. The 'older' version of LPR located at Campbell Station captured twice as many images as the 'newer' version of LPR at the weigh station. The images captured with the ‘older’ version contained 473 ‘false’ plates while the images captured with the ‘newer’ version only contained 33 ‘false’ plates. Examples of ‘false’ plates include: truck grills, road signs, oversized vehicle signs, trees, and UHAUL and taxi decals. These ‘false’ plates could prove troublesome when matching actual plates if not removed from the data. The OCR assigns characters to the ‘false’ plate and those characters could match an actual plate.

The reason the ‘older’ version has more ‘false’ plates is related to the sensitivity of the LPR equipment. The ‘newer’ version is not as sensitive and this is a downfall, because less ‘false’ and actual plates are captured. Overall, the ‘newer’ version at the Weigh Station captured 1141 fewer plates than the ‘older’ version at Campbell Station.

Table 5. LPR plate capturing performance.

Date	Location	Total Images Captured	Total Plates Captured	Total Plates Read Correct	LPR Read Accuracy
2/23/2007	Campbell Station	417	343	218	63.6%
	Weigh Station	251	233	138	59.2%
2/26/2007	Campbell Station	420	381	239	62.7%
	Weigh Station	401	388	245	63.1%
2/28/2007	Campbell Station	787	695	439	63.2%
	Weigh Station	365	358	223	62.3%
3/2/2007	Campbell Station	858	731	418	57.2%
	Weigh Station	290	281	176	62.6%
3/5/2007	Campbell Station	662	521	311	59.7%
	Weigh Station	276	270	174	64.4%
Overall	Campbell Station	3144	2671	1625	60.8%
	Weigh Station	1583	1530	956	62.5%

Overall, the Campbell Station and the weigh station location accurately read 60.8% and 62.5% of all plates, respectively (Table 5).

Plate Matching Performance

Before the speed of a large truck is determined the license plate must be correctly captured at both LPR locations and then matched. The LPR does not have to accurately read each plate before matching. Post processing is used to correct the misread plate and optimize the LPR technology. Table 6 shows LPR plate matching performance before and after processing. The number of before and after processed matched plates is 540 and 770, respectively. Before processing there were 230 plates captured at both locations but were not accurately read. Before and post processing matched an average of 44 and 76 plates per hour, respectively. Even after processing, 2956 captured plates where not matched.

Table 6. LPR plate matching performance.

			Before Processing		Post Processing	
Date	**Total Plates Captured**	**Plates Captured /Hour**	**Total Plates Matched**	**Plates Matched /Hour**	**Total Plates Matched**	**Plates Matched /Hour**
2/23/2007	385	227	53	32	93	55
2/26/2007	553	251	82	37	140	63
2/28/2007	822	374	133	59	231	103
3/2/2007	748	374	96	47	180	89
3/5/2007	597	314	86	46	126	68
Total	3726	-	540	-	770	-
Average	621	308	90	44	154	76

LPR Data Problems

A common problem is gaps in data. These gaps last from one to twenty minutes. The time gaps occur more frequently with mobile LPR set-ups because of truck vibrations and wind moving or knocking over the cameras. Other common causes of data gap for mobile LPR units are power outages and technical issues that come with constantly changing the settings.

The newest problem found while processing data is duplicated plates. The LPR technology is actually recording a plate twice with two separate times as the truck passes one location. Table 7 shows the time differences and amount of plates that experienced each. The largest time difference was 9 seconds. If speeds were being determined over a mile with times of 55 and 64 seconds the results, respectively, would be 56.4 and 65.6 mph. This is almost a 10 mph change for a 9 second time difference.

Table 7. Time differences for duplicated plates.

Time Difference (sec)	Number of Duplicated Plates
1	1
2	7
3	8
4	6
5	1
6	1
7	0
8	1
9	1

CHAPTER V. LPR SPEED DATA

The LPR data collection included fives days: February 23rd, February 26th, February 28th, March 3rd and March 5th of 2007. The data for February 28th was collected at a shorter distance, because of tree removal along I-40. The radar data was collected on March 6th of 2007. The RTMS data collection was completed on: February 23rd, February 25th, March 2nd and March 5th of 2005. In order to prevent any abnormal traffic patterns all data was collected between the hours of 1:00 and 4:00 pm on a weekday excluding holidays and days involving inclement weather, congestion and vehicle crashes.

During the time of the LPR data collection, the weigh station was closed for repair. This was an advantage for the study. Since the weigh station was closed the large trucks did not slow down to enter the station and the final LPR data is not affected by a decrease in speed. In order to prevent the decrease in speed for the proposed permanent units the location is before the weigh station road sign on I-40. For this study, the LPR equipment was set-up at the entrance of the closed weigh station for added safety.

Table 8 shows all the speed characteristics for the RTMS, LPR and radar data for each day. The overall radar and LPR data is 7 and 7.3 mph, respectively, greater than the overall time mean speed for the RTMS data. The overall LPR and radar speeds have a .3 mph difference.

Table 8. RTMS, LPR, and radar speed characteristics.

Data	Date	Space Mean Speed (mph)	Time Mean Speed (mph)	Median Speed (mph)	Mode Speed (mph)	Maximum Speed (mph)	Minimum Speed (mph)	Time (hr)	Total Vehicles
RTMS	2/23/2005	-	66.2	67	69	78	49	1.9	1365
	2/25/2005	-	68.8	69	69	78	64	1.8	748
	3/2/2005	-	65.8	66	62	74	57	1.9	1463
	3/5/2005	-	63.8	64	64	72	51	2	1286
	Overall	-	66.5	66	64	78	49	7.6	4862
LPR	2/23/2007	59.0	59.3	60	60	79	50	1.7	93
	2/26/2007	58.3	58.3	61	63	73	42	2.2	140
	2/28/2007	57.7	58.3	58	59	72	41	2.2	231
	3/2/2007	58.1	58.6	58	57	74	49	2	180
	3/5/2007	60.9	61.3	61	63	76	45	1.9	126
	Overall	58.8	59.2	59	59	79	41	10.0	770
Radar	3/3/2007	-	59.5	60	61	75	44	2.1	626

Table 9 contains the speed distribution for RTMS, LPR, and radar. The percent of large trucks going over the 55 mph speed limit for LPR and radar data is 81.64 and 86.74, respectively. The RTMS data has a percentage of 56.69 vehicles traveling over the 65 mph speed limit in 2005. In 2007, around 30 percent more vehicles are traveling over the speed limit than in 2005. There has been a large increase in vehicle traveling under 55 mph since 2005. The LPR and radar data show 14 and 11.02 percent of vehicles, respectively, traveling under the 55 mph speed limit. In 2005, the RTMS data only has 1.27 percent of all vehicles traveling under 55 mph.

Figure 8 shows the normal probability plot for LPR and radar speeds. The radar plot is located almost in the center of all the LPR plots, showing the similarities of the two data sets. The overall figure shows the corresponding trend of the LPR and radar data. Figure 9 shows the normal probability plot for the RTMS data. The RTMS data for 2/25/2005 has the smallest sample size and may be the reason for the slight skew in the plot.

Table 9. Mean speed distribution for RTMS, LPR, and radar.

	% RTMS	% LPR	% Radar
Less than 55 mph	1.27	14.00	11.02
55 mph	0.00	4.36	2.24
Greater than 55 mph	98.73	81.64	86.74
Greater than 60 mph	94.90	39.37	43.77
Greater than 65 mph	56.69	9.25	7.03
Greater than 70 mph	21.66	1.59	0.64
Greater than 75 mph	1.91	0.26	0

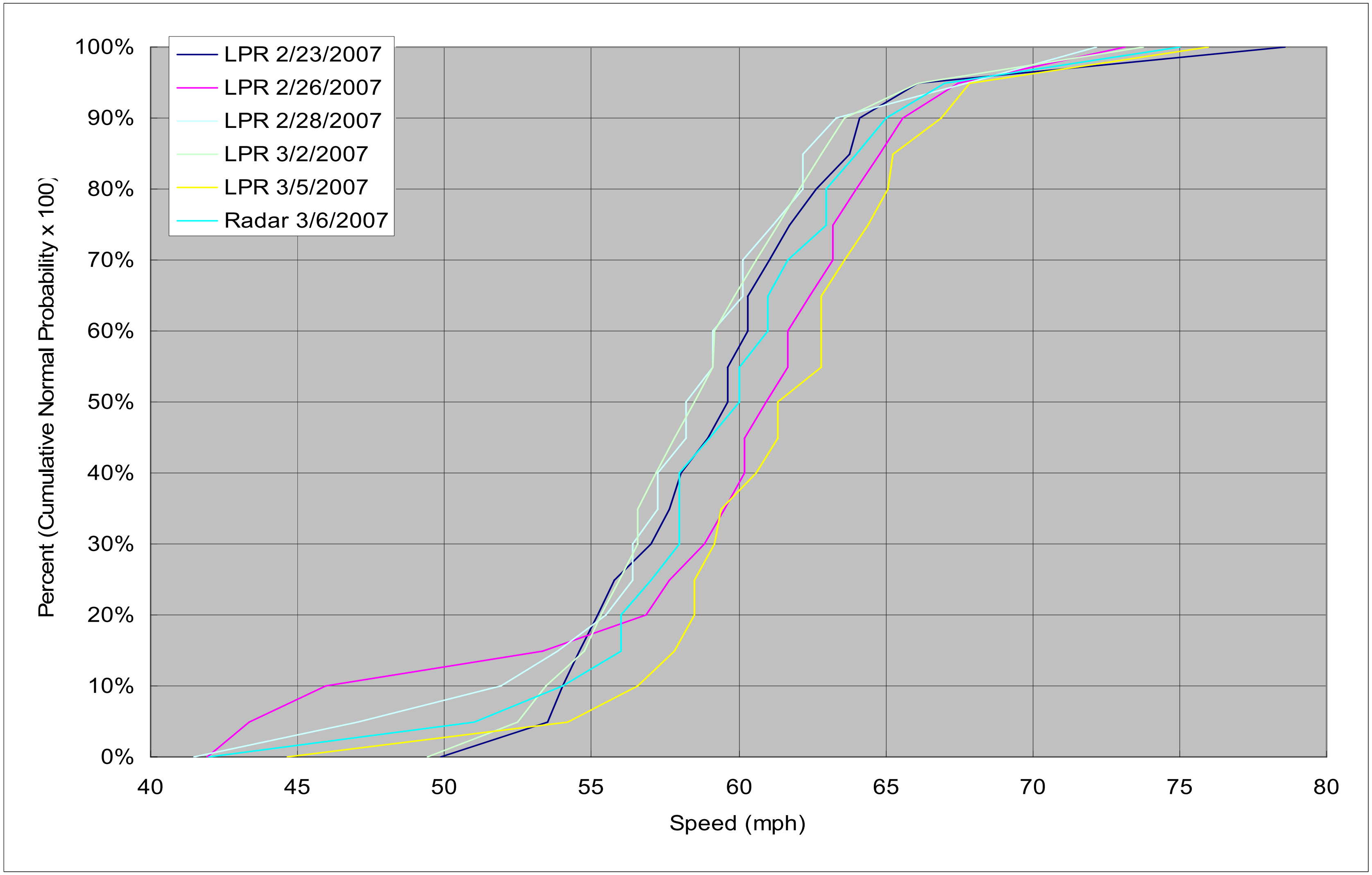

Figure 8. Normal probability plot for 2007 LPR and radar speeds on I-40.

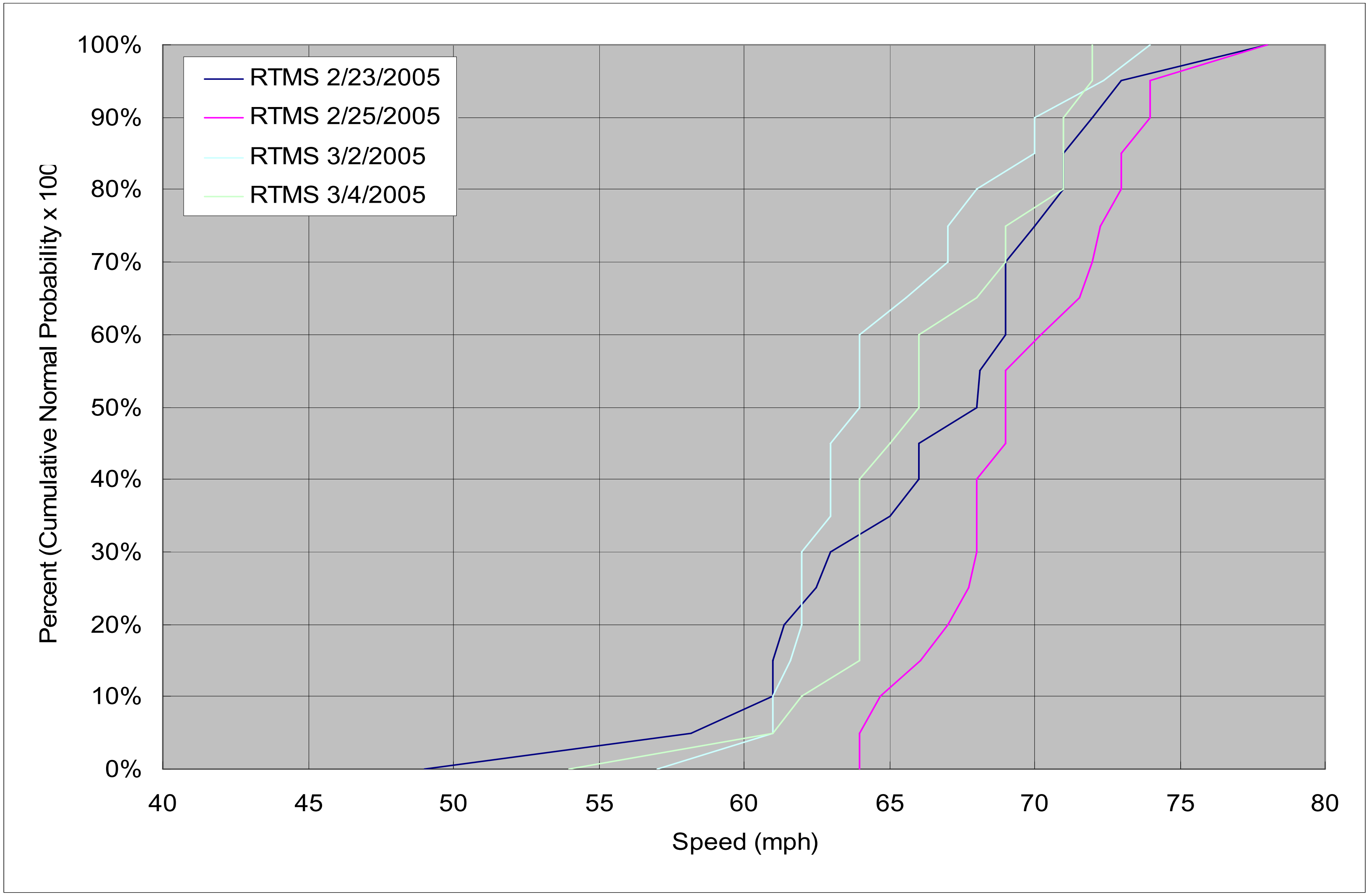

Figure 9. Normal probability plot for 2005 RTMS speeds on I-40.

CHAPTER VI. RESULTS AND DISCUSSION

Table 10 shows the change in speeds before and after the speed limit change. There was a 12.1% overall decrease in mean speed from 2005 to 2007. Overall, the maximum speed only decreased 1.4%. A large number of trucks have slowed down, but several are still going high-speeds on I-40.

The purpose of capturing large trucks with a radar gun was to determine the accuracy of the LPR data. Figure 10 shows the LPR data is similar to the radar data. In the plot, the cumulative LPR speeds are generally less than or equal to the cumulative radar speeds. For speed enforcement technology to work it must not capture speeds greater than the actual speed. The overall RTMS speed is around 7 mph greater than the LPR and radar speeds in Figure 10. Numerically the LPR data shows the speed since 2005 has decreased. In order to make a definite decision on the accuracy of the LPR technology when compared to RTMS and radar data a hypothesis test will be performed.

Table 10. Change in mean speeds before and after the speed limit change.

	RTMS-LPR Change in Speed (%)	RTMS-Radar Change in Speed (%)	Average (%)
Time Mean Speed (mph)	-12.4	-11.8	-12.1
Median Speed (mph)	-11.9	-10.0	-11.0
Mode Speed (mph)	-8.5	-4.9	-6.7
Maximum Speed (mph)	1.3	-4.0	-1.4
Minimum Speed (mph)	-19.5	-11.4	-15.5

Hypothesis Test

Hypothesis tests are performed on the RTMS, LPR and radar data to establish:

- LPR and Radar data in 2007 are relatively close. If LPR speed is lower than Radar speed, LPR can be used for enforcement purposes based on the conservative nature.
- A significant reduction in 2007 LPR and radar data from 2005 RTMS data. Concluding that the recent speed limit change has indeed lowered operational speed of trucks.

The RTMS, LPR and radar data hypothesis test were based on a t-test for independent samples. The test method was chosen according to the sample conditions that if both populations distribution are nominally distributed, but sample sizes and variances are unequal, a separate-variance t' method would be applied.[10] The data samples for RTMS, LPR and radar are a computation of all speeds collected by each form of technology.

For separate-variance t' method the population distribution is normal with unequal variances,

Null hypothesis, H_0: $\mu_1 = \mu_2$

Alternative hypothesis, H_a: $\mu_1 \neq \mu_2$

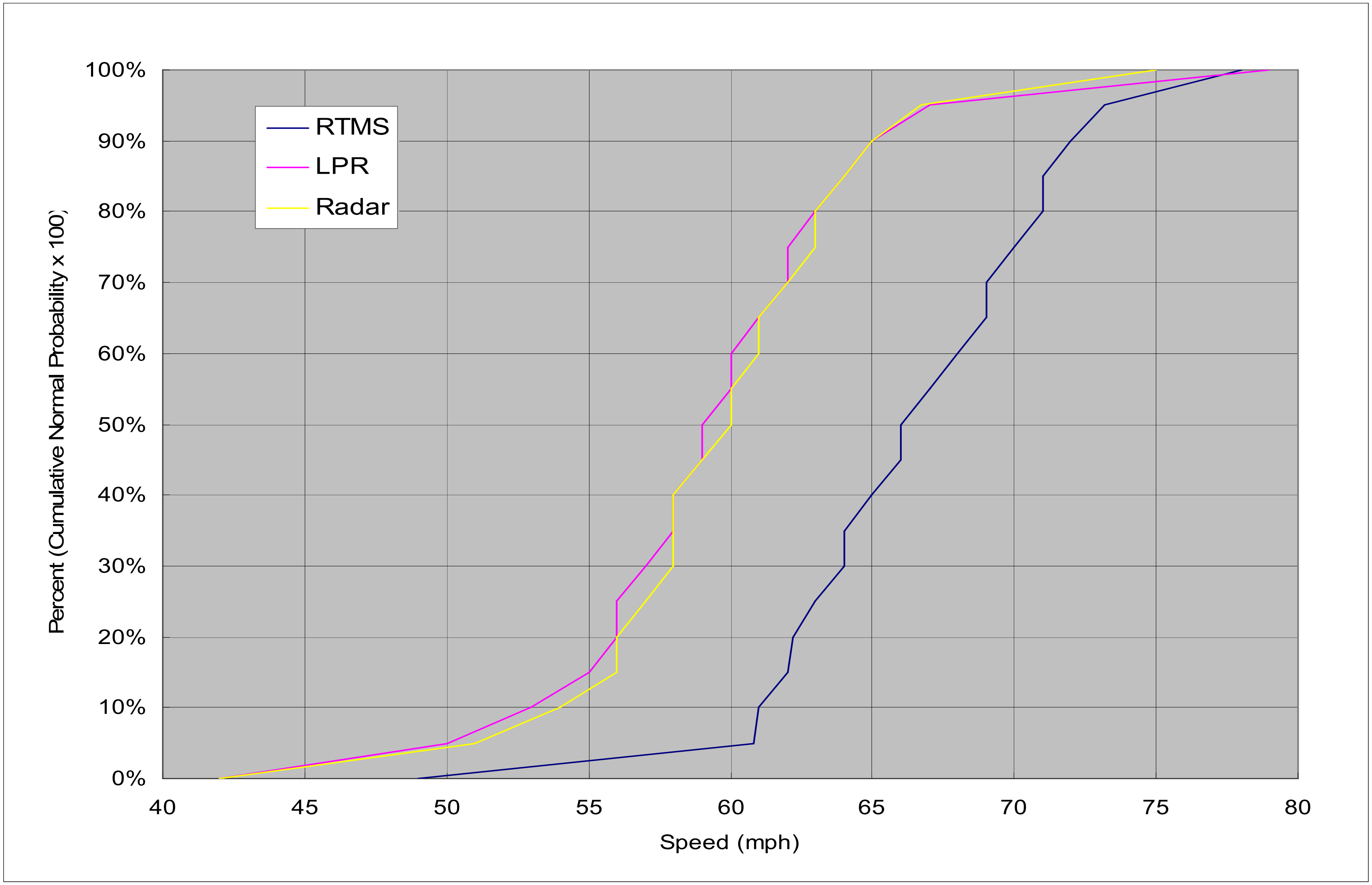

Figure 10. Normal probability plot determined by cumulative LPR, radar, and RMTS speeds on I-40.

Test statistic value, $t' = \dfrac{\bar{y}_1 - \bar{y}_2}{\sqrt{\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}}}$

$\bar{y}_1$ = mean of sample one

$\bar{y}_2$ = mean of sample two

s_1^2 = variance of sample one

s_2^2 = variance of sample two

n_1 = sample size of sample one

n_2 = sample size of sample two

Degree of freedom: $df = \dfrac{(n_1 - 1)(n_2 - 1)}{(1-c)^2(n_1 - 1) + c(n_2 - 1)}, \quad c = \dfrac{\dfrac{s_1^2}{n_1}}{\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}}$

Reject H_0 if $|t'| \geq t_{\alpha/2}$ or p-value < α (alpha value).

The statistical test for truck speed was completed in Microsoft Excel. A significance level of α = 0.05 is used in the tests. The significance level gives a confidence level of 100x (1-0.05) %= 95%.

The p-value is the probability of attaining an absolute value greater than or equal to the observed t statistics. If the p-value is greater than or equal to the alpha value, the null hypothesis is false and the alternative hypothesis is true. If the p-value is less than the alpha value the null hypothesis is true.

Table 11 gives the t-test results for the RTMS and LPR data. The mean LPR speed is 59.16 mph, still 4.16 mph over the speed limit. The mean RTMS speed is 66.48, only 1.48 over the old speed limit. The difference in mean speed of the RTMS and LPR data is 7.32 mph. The p-value for the one and two tail distribution for the RTMS and LPR data is less than the alpha; making the null hypothesis false and the RTMS and LPR data different. The LPR data tested against the RTMS data shows that the speed on I-40 in the Knoxville study site has decreased after the speed limit change.

The t-test results for the RTMS and radar data are given in Table 12. The mean radar speed is 59.48 mph, still 4.48 mph over the speed limit. The difference in mean speed of the RTMS and radar data is 7 mph. The p-value for the one and two tail distribution for the RTMS and radar data is less than the alpha; making the null hypothesis false and the RTMS and radar data different.

Table 11. T-Test Results for RTMS and LPR speeds

	RTMS	***LPR***
Mean, μ	66.48	59.16
Variance, s^2	21.46	27.51
Observations, n	157	770
Degree of Freedom, df	246	
alpha	.05	
t Statistic value	17.58750453	
P(T<=t) one-tail	1.08855E-45	
t Critical one-tail	1.651071345	
P(T<=t) two-tail	2.17709E-45	
t Critical two-tail	1.969654121	

The radar data tested against the RTMS data shows that the speed on I-40 in the Knoxville study site has decreased after the speed limit change.

Table 13 shows the t-test result for the LPR and radar data. The mean speed difference for the LPR and radar data is .32 mph. The p-value for the one and two tail distribution for the LPR and radar data is greater than alpha; making the null hypothesis true and the LPR and radar data equal.

Table 12. T-Test Results for RTMS and Radar speeds

	RTMS	***RADAR***
Mean, μ	66.48	59.48
Variance, s^2	21.46	23.82
Observations, n	157	626
Degree of Freedom, df	250	
alpha	.05	
t Statistic value	16.72373	
P(T<=t) one-tail	6.01E-43	
t Critical one-tail	1.650972	
P(T<=t) two-tail	1.2E-42	
t Critical two-tail	1.969497	

Table 13. T-Test Results for LPR and Radar speeds.

	LPR	***RADAR***
Mean, μ	59.16	59.48
Variance, s^2	27.51	23.82
Observations, n	770	626
Degree of Freedom, df	1362	
alpha	.05	
t Statistic value	-1.19058	
P(T<=t) one-tail	0.117012	
t Critical one-tail	1.645959356	
P(T<=t) two-tail	0.234024	
t Critical two-tail	1.961685706	

LPR Accuracy

A large number of license plates were not captured at both locations of the LPR units. Whether or not this is caused by having a mobile LPR set-up is not known. From experience of working with the equipment, it is assumed that a permanent set-up will improve, if not fix, this problem.

Errors Discussion

It was important for this study to examine the differences in the versions of the LPR technology. The sensitivity of the 'older' version of technology proves problematic with the large number of 'false' images captured, but it was able to capture twice as many plates as the 'newer' version (Table 4). If the difference in sensitivities in the 'older' and 'newer' versions of technology is eliminated, more of the same plates would be captured at both set-ups.

The reason for the difference in sensitivity may not only be the technology, but the actual set-up of the cameras. Each time data is collected the set-up is different and it is impossible to get the same set-up twice. During each set-up camera setting, distances and angles change. All of these changes can result in a decrease of technology performance. A solution would be using identical, permanent LPR units for all locations.

The cause of time gaps is simple to fix, but hard to avoid. Even permanent LPR units will experience gaps in data. There is no way to predict power outages or technical problems, and all technology, not just LPR, would be affected. A permanent LPR unit would experience less data gaps than the mobile units, but there is no way to prevent a data gap from happening.

Duplicated plates are a huge problem. These are caused by the view angle of a mobile LPR camera. The view of the camera observes an average width of eight feet and the plate is captured within that eight feet. When a duplicate plate appears it has been captured twice within this eight feet boundary. Because the mobile LPR unit captures plates from the side of the road the angle of the camera makes the observed field larger. A permanent LPR unit is located directly above the lane of traffic and has an observed field of four to five feet.

Unexplained, is the variance in times for the duplicated plates. The data contained duplicate plates with 8 and 9 second differences (Table 7). Obviously, it should not take a vehicle on the interstate 8 to 9 seconds to travel 8 feet. This is a serious problem that needs further examination. If the technology is not fast enough to capture the plate and time simultaneously, then it is obsolete for speed enforcement.

CHAPTER VII. CONCLUSION AND RECOMMENDATION

Reducing large truck speed violation will have positive effects on transportation safety and air quality. However, to attain compliance and enforce speed limit regulations, significant investment in the forms of manpower and other resources are needed. In addition, elevated enforcement activities on urban Interstate may lead to congestion (gawkers and rubbernecking) as well as crash concerns. To this end this paper presents a framework that would implement an automated license plate recognition system installed at strategic points along the Interstate system and capture violators at existing weigh-station locations. This would minimize the need for additional patrol officers and high-speed pursuit/pull-over maneuvers.

LPR is now a proven and affordable technology for most state and local jurisdictions. When deployed with high-speed Internet connection for database verification and fast computer for post-processing, LPR results, though not perfect, can be improved within a few seconds after LPR units initially analyze them. This study identifies some challenges with using LPR for heavy vehicle speed enforcement and offers some solutions. Compared with other vehicle identification technologies, often requiring user buy-ins, significant market penetration, and continued commitment from government agencies, the system described here appears to be readily deployable and maintainable over time.

The results show that since the speed limit change, speed has decrease by 7 mph. The speed decrease is a sign that drivers are acknowledging the change. The average speed is still 4 mph over the speed limit, when in 2005 it was only 1.5 mph. Much of the Knoxville community believes the speed limit change was a lone attempt to make nice with environmental agencies. It is important to enforce the lowered speed limit to show Knoxville that the change is a serious attempt to improve the environment and that the drivers should not disregard the change.

Some of the advantages and disadvantages of an LPR technology include:

- LPR performs well under inclement weather and lighting conditions, which allows for continuous speed enforcement.
- LPR does not require additional manpower to analyze the data after the field data collection activities. This study did use manpower for post processing, but software is available to process the data within seconds of collections.
- LPR can capture plates under heavy traffic conditions.
- LPR reads and stores detailed license plate data automatically, which makes the speed enforcement undeniable.
- A mobile LPR system requires long set-up times (some lasting 1-2 hours) before collecting data.
- In order to set-up the LPR equipment whether mobile or permanent trained technicians must be on-site.
- Due to the differences of the license plate placement between rear-mounting on cars and front-mounting on large trucks, it may become expensive to collect data on both cars and large trucks.

- Lane closures may be required when setting up a permanent LPR unit.

Continuing Research

The LPR technology's overall data proved to be accurate when compared to the overall radar data. This is not enough to verify the LPR technology accuracy for speed enforcement. The next step to verify the technology is testing individual vehicles. With the LPR units set-up at 2 locations a vehicle going a constant speed needs to travel between the units. If the speed determined by the LPR equipment is the same as the vehicle's speed the LPR equipment is ready for enforcement.

In this study, post processing was completed by hand. In the real world, post processing is completed by software. It is important to see the accuracy of this software for matching license plates for speed enforcement. Further research should be completed to compare data when it has been post processed by software and hand. If post processing does not match all plates captured at both locations, it does not make the technology unfeasible, but leaves room for improvement.

The collected data should be used to determine the changes in emissions. An emissions model can process the data to find the percent decrease in the amount of NOx and VOC emission. This is the information that the city of Knoxville needs to show the community to prove the benefits of decreased speed limits.

License plate characters and designs need to be uniform. LPR technology could be almost perfected if the software only had to focus on one type of character and design. The United Kingdom use of the LPR technology has had a great response mainly because of their use of a uniform license plate. The fraudulent misuse of license plates is another problem. Many commercial vehicles alter or remove their license plates to avoid from being caught for illegal actions. The most common alterations are spraying a film or placing a tinted cover on license plates. Departments of Transportation should be working to make sure plates are easy to read, and difficult to alter or make fraudulent.

Universal electronic vehicle identification (EVI) is another technology that must be considered. At present license plate are used for offender identification. There is a lot of work going on to produce a universal EVI system for vehicles. However even enthusiasts admit that all vehicles being equipped with EVI is 20 plus years away. In terms of looking at a vehicle, a missing or broken license plate is clearly visible to a passing police officer, but how about a missing or inoperative EVI tag? Future changes in vehicle identification must be continually examined to prevent development or implementations of obsolete technology.

LPR Research Recommendations

LPR research is not learned in a matter of days. The technology is best learned by experience. When mobile LPR units are employed, camera and software settings must be changed at each set-up. The LPR equipment requires considerable effort with mobile set-ups, monitoring, and adjustments. Training will barely cover the mishaps that will be experienced in the field.

In the process of this study six set-ups where abandoned due to technical issues. Months of time that could have been used for data collection have been lost due to technical issues. The largest reason for the delays is the age of the equipment and the abuse it has experienced over the years from being constantly moved and reset.

This technology requires patience and time to learn and become fluent in application. It is important to establish a relationship with the manufacturer of the equipment. The manufacture’s trained technician can assist you in repairs, questions, and concerns. This technology has a great amount of capabilities, but a committed must be made in the application or no benefits will be received.

Overall, the LPR technology has proven to be an outstanding tool for calculating speed. With the large number of large trucks traveling I-40 every day, the only way for THP to monitor all the vehicles is an unattended enforcement system. LPR is an immensely powerful tool in the fight against many types of crime from parking charge avoidance to terrorism. The technology is becoming more robust, user-friendly and discreet. In the future, not only will LPR be used to further develop traditional applications, but new applications will arise apparent over time.

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VITA

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