U.S. Department of
Transportation

**Federal Railroad
Administration**

Evaluation of LED Sign Technology at a Passive Highway-Rail Grade Crossing

Office of Research,
Development,
and Technology
Washington, DC 20590

DOT/FRA/ORD-16/01

Final Report
February 2016

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE February 2016	3. REPORT TYPE AND DATES COVERED Technical Report April 2011–January 2014

4. TITLE AND SUBTITLE
Evaluation of LED Sign Technology at a Passive Highway-Rail Grade Crossing

5. FUNDING NUMBERS
RR97A5/JLA47
RR97A5/KLA47
RR97A5/MLA47
RR97A6/MJ573

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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55 Broadway
Cambridge, MA 02142

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-FRA-14-05

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Railroad Administration
Office of Railroad Policy and Development
Office of Research and Development
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FRA/ORD-16/01

11. SUPPLEMENTARY NOTES
Safety of Highway-Rail Grade Crossing series

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the FRA Web site at http://www.fra.dot.gov.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The U.S. Department of Transportation's (DOT) John A. Volpe National Transportation Systems Center (Volpe Center), under the direction of DOT's Federal Railroad Administration (FRA) Office of Research, Development, and Technology (ORD), conducted a research study that evaluated the effectiveness of light-emitting diode (LED) regulatory signs at a passive highway-rail grade crossing. In this study, a grade crossing in Swanton, Vermont had its existing Grade Crossing Crossbuck (R15-1) signs and Advance Warning signs (AWSs) (W10-1) replaced with flashing LED-equipped signs. Vehicle speed profiles were measured at four locations on the northbound approach lane of the crossing in three phases: with the original signs prior to any changes at the crossing, after the LED enhanced Crossbuck signs were installed, and after the LED enhanced AWSs were installed. Daytime and night-time data samples were analyzed separately. After the LED enhanced Crossbuck signs were installed, test results showed: 1) a statistically significant decrease of 2.9-3.3 mph in mean vehicle speed at night at the four measurement locations and 2) improvements of 1.5%-2.5% in the rate of mean vehicle speed decrease for both the daytime and nighttime data sets.

14. SUBJECT TERMS
Light-emitting diode, Crossbuck, Advance Warning, highway-rail, grade crossing, passive warning devices, motor vehicle speed profiles

15. NUMBER OF PAGES
65

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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1 pint (pt) = 0.47 liter (l)	
1 quart (qt) = 0.96 liter (l)	
1 gallon (gal) = 3.8 liters (l)	
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1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)	1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)
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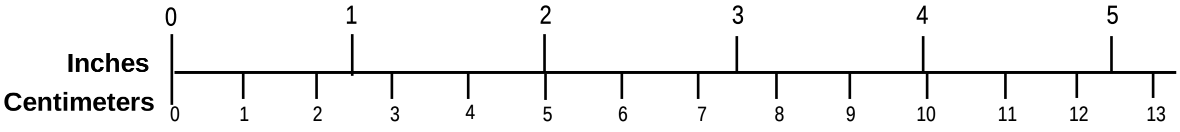

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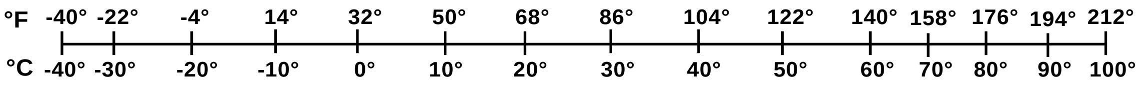

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

Acknowledgements

The U.S. Department of Transportation (U.S. DOT) Federal Railroad Administration (FRA) Office of Research, Development, and Technology sponsored the work leading to this report. The authors would like to thank Sam Alibrahim, Chief of the Office of Research and Development's Train Control and Communications Division, FRA, and Tarek Omar, Program Manager, Train Control and Communications Division, FRA, for their guidance during the project and in developing this report. The authors would also like to thank Frank Frey, Office of Railroad Safety, Highway-Rail Crossing and Trespasser Programs Division, FRA.

The authors would like to thank Leonard Allen, Chief, Systems Safety and Engineering Division, U.S. DOT John A. Volpe National Transportation Systems (Volpe Center) and Marco daSilva, Volpe Center Program Manager for Highway Rail Grade Crossing Safety and Trespass Research, as well as Ryan Brown, Frank Foderaro and Bernard Kennedy of the Volpe Center for their support. The authors would also like to acknowledge Scott Gabree, Ph.D. and Gina Melnik, Ph.D., Volpe Center Surface Transportation Human Factors Division, for their insightfulness. Additional thanks to Alan Kauffman of Computer Science Corporation, Volpe Center onsite contractor, for his technical support in data collection system development, installation, and maintenance.

The authors would also like to thank Ronald Bocash, Chief Engineer of Signal and Communication, Genesee & Wyoming Inc. and David Jescavage, Town Administrator, Town of Swanton, Vermont. Additionally, the authors wish to acknowledge Lou Frangella, FRA Office of Railroad Safety Region I Grade Crossing Manager, for his contributions.

Lastly, the authors would like to thank Mark Pfenning of Swanton, Vermont for his generosity in allowing the FRA Mobile Driver Feedback Device to be deployed on his property.

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Executive Summary

Passive highway-rail grade crossings (grade crossings) present unique risks to motorists. Many of these intersections are only equipped with a Grade Crossing Crossbuck (R15-1) sign and a STOP or YIELD sign, which leaves some confusion as to how drivers should react. Despite the low volume of vehicles that utilize these crossings, incidents at passive grade crossings accounted for approximately 36.5% of all public grade crossing incidents in 2012. While active warning devices such as gates and flashing lights are still the most effective method of warning drivers about oncoming trains, the benefit-cost ratio of active warning systems often does not justify the investment. For this reason, many years of research has been devoted to creating passive warning systems that are inexpensive yet effective. Devices, ranging from augmented signs and flashing lights to pavement markings, have been studied to determine how they alter driver behavior. In recent years, light-emitting diode (LED) enhanced traffic signs have emerged as a potentially useful safety technology. These signs are designed to capture the attention of drivers and direct their attention toward the regulatory information being displayed (e.g. STOP, YIELD, and Railroad Crossing).

The use of LED-enhanced warning devices is now permitted in the United States and they are included in the Manual on Uniform Traffic Control Devices (MUTCD). The need for such technology stems from the substantial cost of upgrading from a passive to an active warning system, as well as the high relative frequency of incidents that occur at grade crossings equipped with passive warning devices.

This research determined if the speed profiles of motor vehicles that approached a passive grade crossing were influenced by enhancing the visibility of regulatory signage. In this study, the research team replaced existing Crossbuck and Advance Warning signs (AWSs) (W10-1) at a rural grade crossing in Swanton, Vermont with LED-equipped signs. The vehicle speed profiles were measured at four discrete locations on the northbound approach lane of the crossing during three distinct phases: baseline, or prior to any changes at the crossing, after the installation of LED enhanced Crossbuck signs, and after the installation of LED enhanced AWSs. Daytime and nighttime data samples were analyzed separately.

After the LED-enhanced Crossbuck signs were installed: 1) a statistically significant decrease of 2.9-3.3 mph in mean vehicle speed at night at the four measurement locations and 2) improvements of 1.5%-2.5% in the rate of mean vehicle speed decrease for both the daytime and nighttime data sets, as shown in Figures E-1 and E-2.

While the results of this research appear promising, the measurement of any long-term trends attributed to the LED-enhanced AWS technology was prevented by the unplanned addition of a double yellow centerline by the local public works department. Also, the centerline treatment prevented the team from comparing the tandem LED sign configuration with the baseline configuration on Lakewood Drive. Further research under controlled test conditions as well as a human factors analysis of the LED sign technology is recommended.

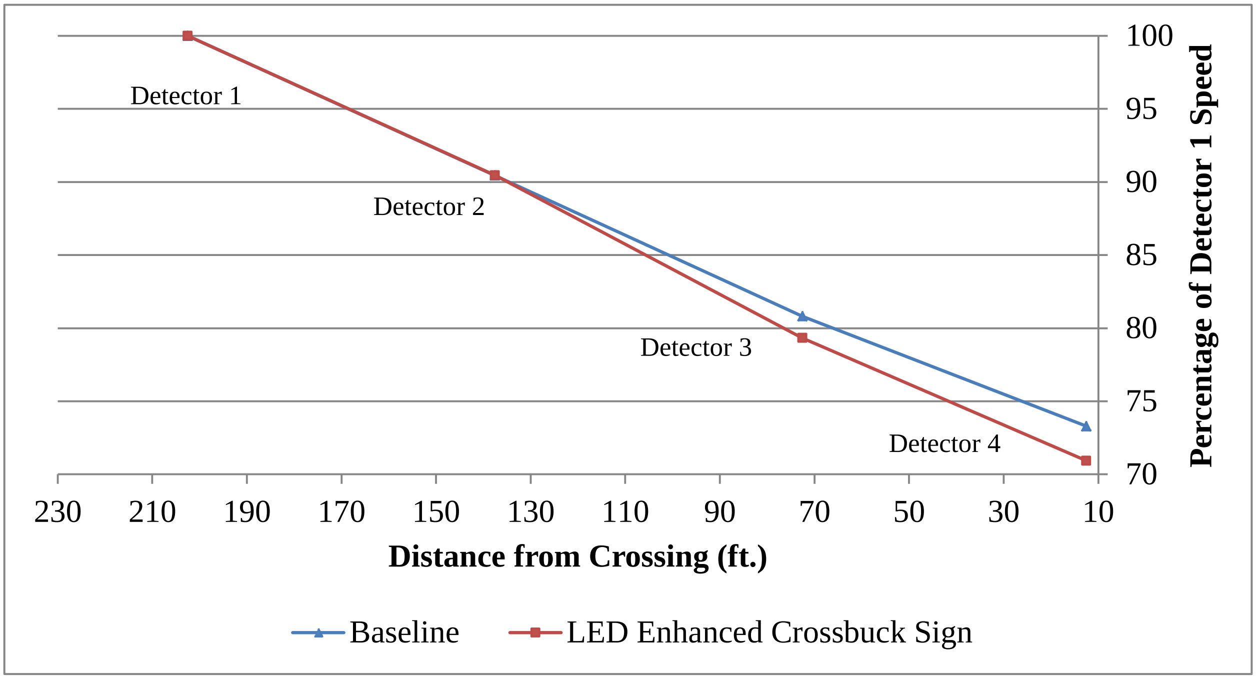

Figure E-1. Rate of Mean Speed Decrease over the Detection Zone as a Percentage of the Detector 1 Mean Speed for Daytime Data

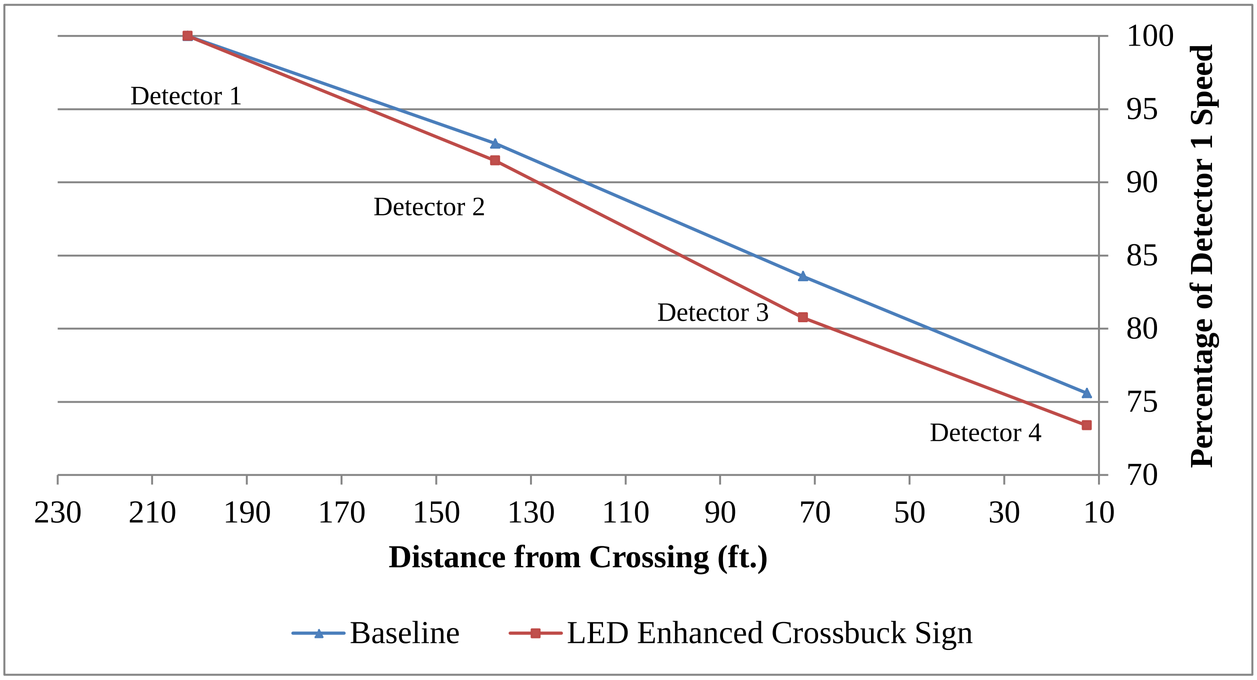

Figure E-2. Rate of Mean Speed Decrease over the Detection Zone as a Percentage of the Detector 1 Mean Speed for Nighttime Data

1. Introduction

Passive grade crossings present unique risks to motorists. Many of these intersections are equipped with only a Grade Crossing (Crossbuck) (R15-1)[1] sign in tandem with either a STOP or YIELD sign, leaving some confusion as to how drivers should react. Despite the low volume of vehicles that utilize these crossings, incidents at passive grade crossings accounted for approximately 36.5% of all public grade crossing incidents in 2012 (FRA, 2014). While active warning devices such as gates and flashing lights remain the most effective method of warning drivers to the presence of oncoming trains, the benefit-cost ratio of these systems often does not justify the investment. For this reason, research has been conducted over many years to create passive warning systems that are inexpensive yet effective.

Devices ranging from augmented signs and flashing lights to pavement markings have been studied to determine how they alter driver behavior. In recent years, light emitting diode (LED) enhanced traffic signs have emerged as a potentially useful safety technology. The purpose of these signs is to capture the attention of drivers, thereby directing driver attention toward the regulatory information being displayed (e.g. STOP, YIELD, Railroad Crossing).

The use of LED enhanced warning devices is now permitted in the United States and they are now included in the Manual on Uniform Traffic Control Devices (MUTCD). The need for such technologies stem from the substantial cost of upgrading from a passive to an active warning system, as well as the high relative frequency of incidents that occur at grade crossings equipped with passive warning devices. In 2011, Ngamdung and Carroll calculated the traffic moment (TM) for active and passive crossings in the United States. TM is a value which represents rail and highway traffic exposure. Their findings showed that the incident rate, relative to TM, was nearly nine times greater for passive crossings than active crossings in 2008 (Ngamdung and Carroll, 2011).

In the past five years, LED enhanced warning devices have been implemented on a limited basis at grade crossings throughout the country. While studies have evaluated the effects of LED enhanced traffic signs at highway intersections, no studies thus far have been published on their use in railroad crossing applications (Gates, Carlson, & Hawkins, 2004).

1.1 Background

While there is no published research that documents the effectiveness of LED enhanced signs at grade crossings, these signs have already been deployed on multiple railroads (Hartley & Campbell, 2009) (Campbell, 2010) (Bowen, 2013). As the number of installed signs continues to rise, there is an increasing need to characterize the benefit provided by this technology.

1.2 Objectives

This research assessed the impact of two LED-enhanced passive warning device configurations on the speed profiles of motor vehicles as they approached a grade crossing. In the first configuration, the standard Grade Crossing (Crossbuck) (R15-1) [1] signs at the grade crossing were replaced by LED enhanced Crossbuck signs. In the second configuration, the LED

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[1] The Grade Crossing (R15-1) and Advance Warning (W10-1) are defined in the Manual of Uniform Traffic Control Devices 2009 Edition, Chapter 8B, *Signs and Markings*. http://mutcd.fhwa.dot.gov/htm/2009/part8/part8b.htm .

enhanced Crossbuck signs remained in operation and the Grade Crossing Advance Warning signs (AWS) (W10-1)[1] on the crossing approaches were replaced by LED enhanced versions. It was postulated that using the two signs in tandem on each approach would yield a greater reduction in motor vehicle speeds than either sign would individually.

1.3 Overall Approach

Since grade crossing incidents are rare events, a long-term analysis would be needed to determine the ability of a new technology to reduce incident frequency at many crossings with a high degree of confidence. A significant investment in time and funding is required to evaluate a technology that may offer minimal or no benefits at all. Alternative metrics, such as motor vehicle speed and user compliance, are frequently employed as proxies. Typically, a "before/after" study is performed to determine how these proxy measures respond to the introduction of new technology. During the "before" phase, data is collected and analyzed to establish a baseline level for the metric being tested. After the new technology is introduced, users are allowed to acclimate to the technology during a "novelty" period. This is followed by the "after" phase, in which data is collected and evaluated about the new technology. A critical requirement of this approach is that the "users", motorists in this case, are unaware that the data collection is occurring.

For this study, motor vehicle speed profiles were measured before and after the installation of the LED enhanced signs. This scenario was slightly more complex than described above since two sign configurations were being evaluated. First, the Crossbuck signs were deployed and the impact was measured. Next, the AWSs were installed. Since the Crossbuck signs remained deployed, it was not possible to directly measure the impact of the AWSs on motor vehicle speed. Daytime and nighttime data samples were analyzed separately.

1.4 Organization of the Report

- Chapter 2 presents the methodology for this research
- Chapter 3 describes the data analysis
- Chapters 4 and 5 contain the results and discussion of the data analysis
- Chapter 6 presents the conclusions

2. Methodology

2.1 Sign Selection

The signs selected for the study, shown in Figure 1, were Tapco® BlinkerSigns®, purchased from CTC, Inc. The R15-1 Crossbuck signs measure 48" long by 9" wide, and the W10-1 AWSs each have a diameter of 36". The signs satisfy the guidelines in MUTCD section 2A.07 for reflectivity and LED placement, and the LED color matches the background color of the warning sign. The LED lights flash at a frequency of one Hertz (1Hz).

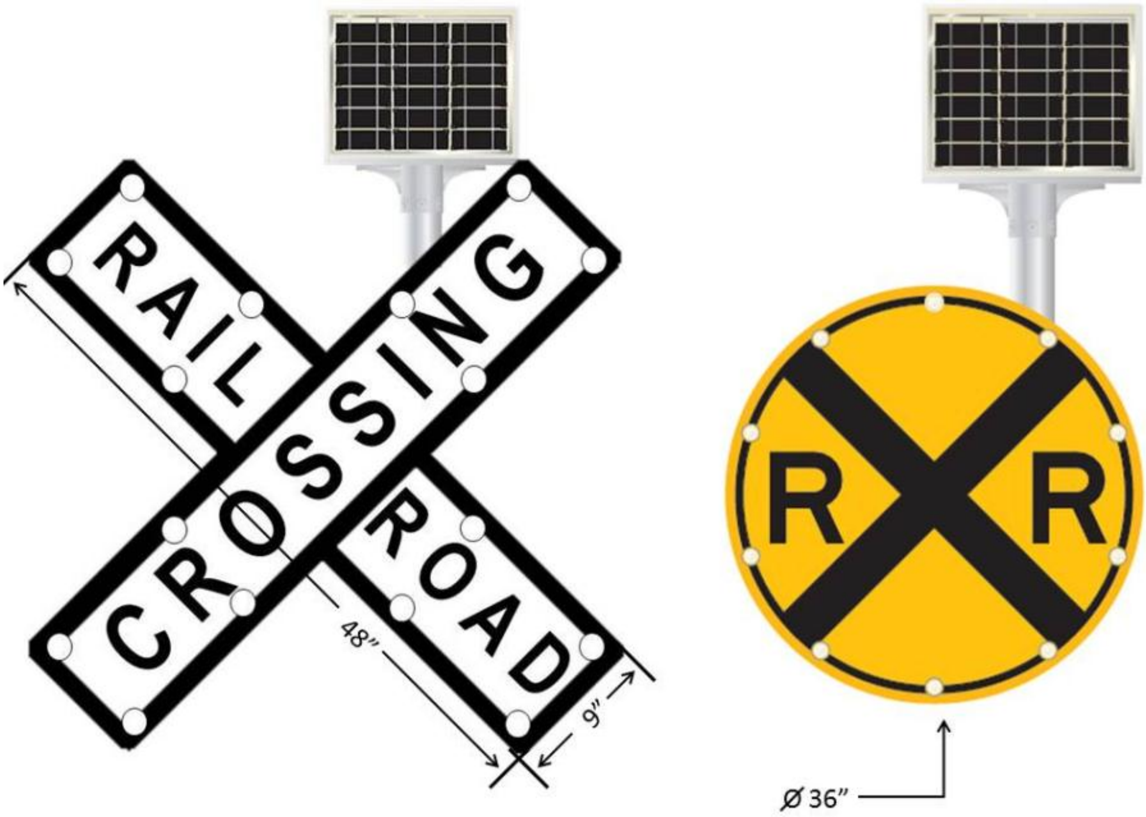

Figure 1. A Diagram of Both LED Signs with Dimensions. (Left) LED Crossbuck (R15-1). (Right) LED Advance Warning Sign (W10-1)

The signs are powered by nickel-metal hydride batteries and have solar panels affixed to their poles for charging. The batteries are designed to operate continuously, without charging, for a minimum of 14 days and have a lifespan of up to five years. Each LED light consumes one watt of power and is designed with a life expectancy in excess of 100,000 hours. The Crossbuck signs are configured with 16 LED lights and the AWSs are equipped with 10 lights.

2.2 Data Collection System

The FRA Mobile Driver Feedback Device (MDFD) was developed by Westat Corporation of Rockville, Maryland. The device was delivered to FRA as part of a Transportation Research Board (TRB) Innovations Deserving Exploratory Analysis (IDEA) safety project. The MDFD is a trailer-mounted equipment platform with a 32-foot extendable mast. The device includes the following components:

- A Pan-Tilt-Zoom (PTZ) camera system mounted on top of the mast
- A ruggedized, panel-mounted computer
- A machine vision processing (MVP) system capable of performing video-based vehicle detection, speed measurement, and vehicle classification
- A wireless cellular modem for remote access and control of certain MDFD features

The core of the MDFD is the Autoscope Pro Terra® MVP system, manufactured by Econolite Group, Inc. The system is autonomously powered by a bank of a dozen 6-volt direct current (VDC) deep-cycle lead-acid batteries that are charged by four adjustable, 115-watt solar panels. The MDFD is shown in Figure 2.

One of the original objectives of the project was to evaluate the capability of the FRA MDFD. Initial testing was performed at the Volpe Center during the winter and spring of 2013. These tests had two objectives:

- Determine if the performance and functional characteristics of the Autoscope MVP system were suited to the Lakewood Drive environment
- Characterize the operational limits of the Autoscope MVP system

The results showed that the MVP technology is sensitive to the height of the video camera, the angle between the camera and the road surface, wind conditions, and shadowing. The testing also revealed that the accuracy of the Autoscope MVP system decreases as a function of distance from the camera.

After the MDFD was deployed at the field test site, a series of tests were performed to determine the accuracy of the Autoscope speed measurement function. A factory-calibrated radar was employed as a reference standard to perform these tests. The radar, manufactured by Stalker Applied Concepts, Inc., operates in the Ka band at a frequency of 34.7 Gigahertz (GHz) with an accuracy of +/- 0.3% from 12 – 200 miles per hour (mph). As verification, the radar was tested with a set of tuning forks, as detailed later in the report.

The Autoscope® speed measurement function was compared to the Stalker radar® from speeds of 15 mph to 45 mph in five mph increments. The results of this testing showed that the Autoscope measured speeds varied from the radar speeds in a range of 8-12%. Since the speed limit on Lakewood Drive is 30 mph, this equated to a resolution of approximately three mph; this was a concern, since previous testing of strobe and flashing beacon-equipped signage at passive grade crossings yielded changes in speed profiles on the order of one mph or less (Parham, Carroll, and Fambro, 2000). Therefore, a hybrid system suitable to the testing environment was implemented, which employed the Autoscope® video acquisition function to detect motor vehicles at specific locations. These events were paired with correlating speeds from the Stalker radar by means of computer generated timestamps.

Figure 2. The FRA Mobile Driver Feedback Device Deployed at the Lakewood Drive Grade Crossing in Swanton, Vermont

2.3 Site Selection and Description

The requirements for this type of study are as follows:

- The candidate grade crossing is equipped with passive warning devices only.
- The crossing is not stop-sign controlled. Since motor vehicles reduce speed to zero at a stop-sign equipped crossing regardless of the presence of a train, it would be difficult to attribute changes in vehicle speed profiles to LED signs.

- The highway intersection in closest proximity to the grade crossing has no impact on vehicle speed profiles at the crossing.
- The grade crossing is located on a railroad main line with daily train movements.

These requirements limited the total number of candidate grade crossings, especially those that could be reached with a one-day roundtrip by automobile from the Volpe Center.   This was crucial since frequent visits to the test site were necessary to download data files and maintain the trailer-based data collection system.

The town of Swanton is a rural community in Franklin County, Vermont about 260 miles north of Cambridge, Massachusetts. It is located in the Champlain Valley of northwest Vermont, about 65 miles south of Montreal, Canada and 35 miles north of Burlington. Refer to Figure 3, below. According to the 2010 census, the town has a population of 6,427 people living in an area of 62 square miles. There is also a Village of Swanton, which is the commercial and population center of the town, with almost 2,400 people residing in an area of 0.8 square miles. The primary private employers in Swanton are in the machine tool, pharmaceutical, and grain industries.

Figure 3. Swanton, Vermont and the Surrounding Area

St. Albans City, the Franklin County seat of government, is located approximately 8.5 miles south of Swanton. It is the regional economic hub and serves as the northern terminus of the Amtrak Vermonter train. St. Albans is also the headquarters of the New England Central Railroad (NECR), a short line railroad owned by the Genesee & Wyoming Corporation. The railroad operates 394 miles of track between the Vermont border with Quebec, Canada and the Port of New London, Connecticut. The NECR ships a variety of goods, including lumber, newsprint, chemicals, fuel oils, finished vehicles, feed mill ingredients, machinery and equipment, recyclables and non-metallic minerals.

The Swanton subdivision of the NECR, shown in Figure 4, is an 18.7 mile route between St. Albans and the Canadian border. An interchange with the Canadian National railroad (CN) is located at milepost 15.6 in East Alburgh, Vermont. Through a joint operations agreement with the NECR, CN operates one daily roundtrip train between St. Albans and Montreal via Swanton. The CN/NECR trains have two customers in Swanton; Cargill Corporation and Poulin Grain. Cargill, a large international feed producer, has a warehouse in Swanton and is among the NECR's largest customers. Poulin Grain is a Newport, Vermont based grain producer.

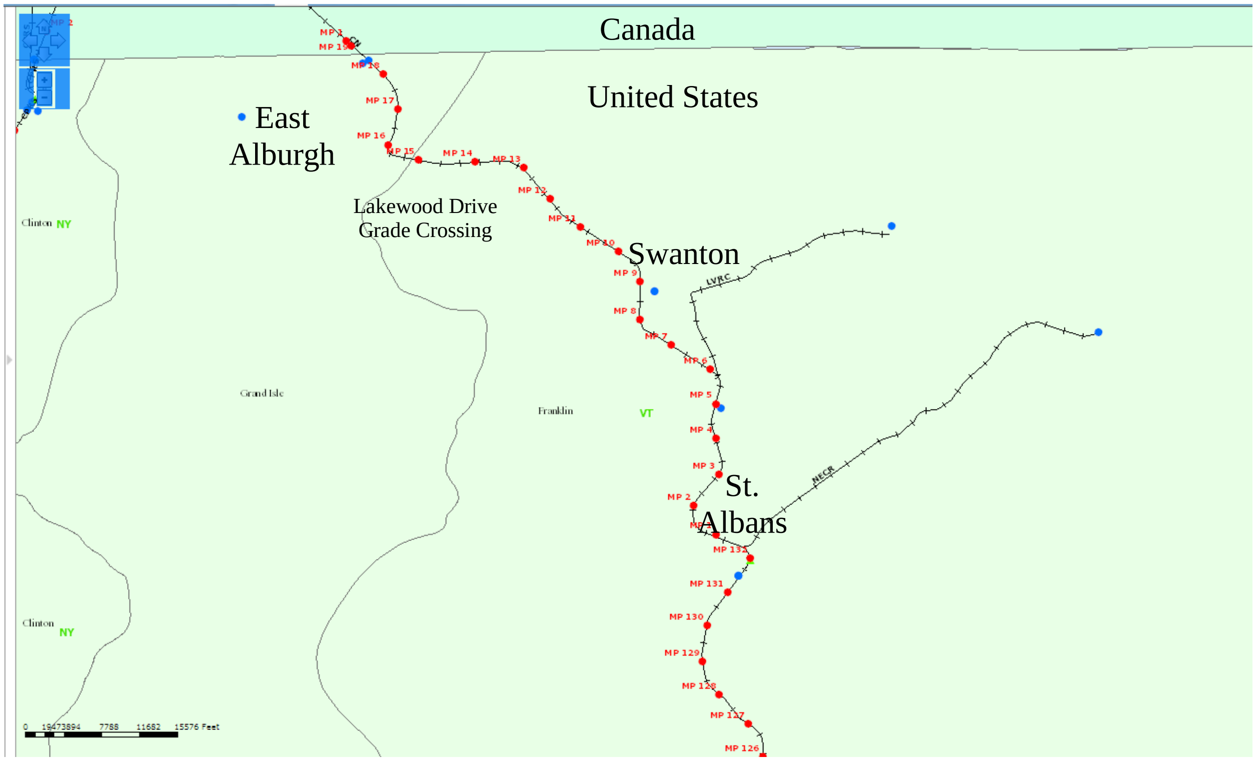

Figure 4. The Swanton Subdivision of the NECR

The Lakewood Drive grade crossing, USDOT crossing inventory number 247636V, is located at milepost 14.79 of the Swanton subdivision. The crossing is located on the western edge of Swanton, one-half mile east of the Missisquoi Bay Drawbridge that connects Swanton to East Alburgh via Lake Champlain. Lakewood Drive intersects Vermont Route 78 approximately 300 feet north of the grade crossing. Track speed on the Swanton subdivision is 25 mph. There is a permanent 5 mph speed restriction on the drawbridge and its approaches between mileposts 14.9 and 15.6. Each approach is STOP sign protected at mileposts 14.8 and 15.5, respectively. The drawbridge is closed to navigation from October 1st through May 14th.

Much of the land area between Lakewood Drive and the Village of Swanton is occupied by the 6,729 acre Missisquoi National Wildlife Refuge shown in Figure 6. The refuge visitor center is located on Tabor Road, one-half mile to the east of Lakewood Drive. The Lakewood Campground, a 217 campsite facility, is located 3.5 miles from the Lakewood Drive intersection with Route 78. It is open from May 1-October 11 and contributes to increased seasonal vehicle traffic on both Lakewood Drive and Tabor Road.

Figure 5. The Lakewood Drive Crossing Environment Prior to the LED Sign Study

Figure 6. Map of the Lakewood Drive Crossing in Relation to the Surrounding Area

Lakewood Drive is a two-lane rural local road with a posted speed limit of 30 mph. As of 2008, the average annual daily traffic (AADT) was 396 motor vehicles and approximately three percent were commercial vehicles. However, this number is subject to seasonal variation. The crossing, shown in Figure 7, is protected by a pair of regulatory Crossbuck signs installed 15-20 feet from either side of the crossing centerline. These are complemented by YIELD (R1-2) signs installed on separate posts 50-90 feet from the crossing. An AWS is installed 238 feet north of the crossing centerline and another is installed 564 feet south of the crossing centerline. There is a highway STOP sign at the intersection with Route 78, 300 feet north of the crossing. Route 78 is the northernmost Lake Champlain highway crossing between Vermont and New York State and serves a significant amount of commercial vehicle traffic.

In general, there are two daily train movements through the grade crossing, both of which are freight. One is a departure from St Albans in the morning that travels northbound toward Canada and the other is the return trip to St. Albans in the evening.

No accidents have occurred at the Lakewood Drive grade crossing dating back to 1975, which is the extent of the of the FRA grade crossing accident database. However, one accident occurred at a neighboring passive crossing on Tabor Road in 1987. The incident involved a motor vehicle collision with an Amtrak Montrealer train. Service for this train was discontinued in 1995.

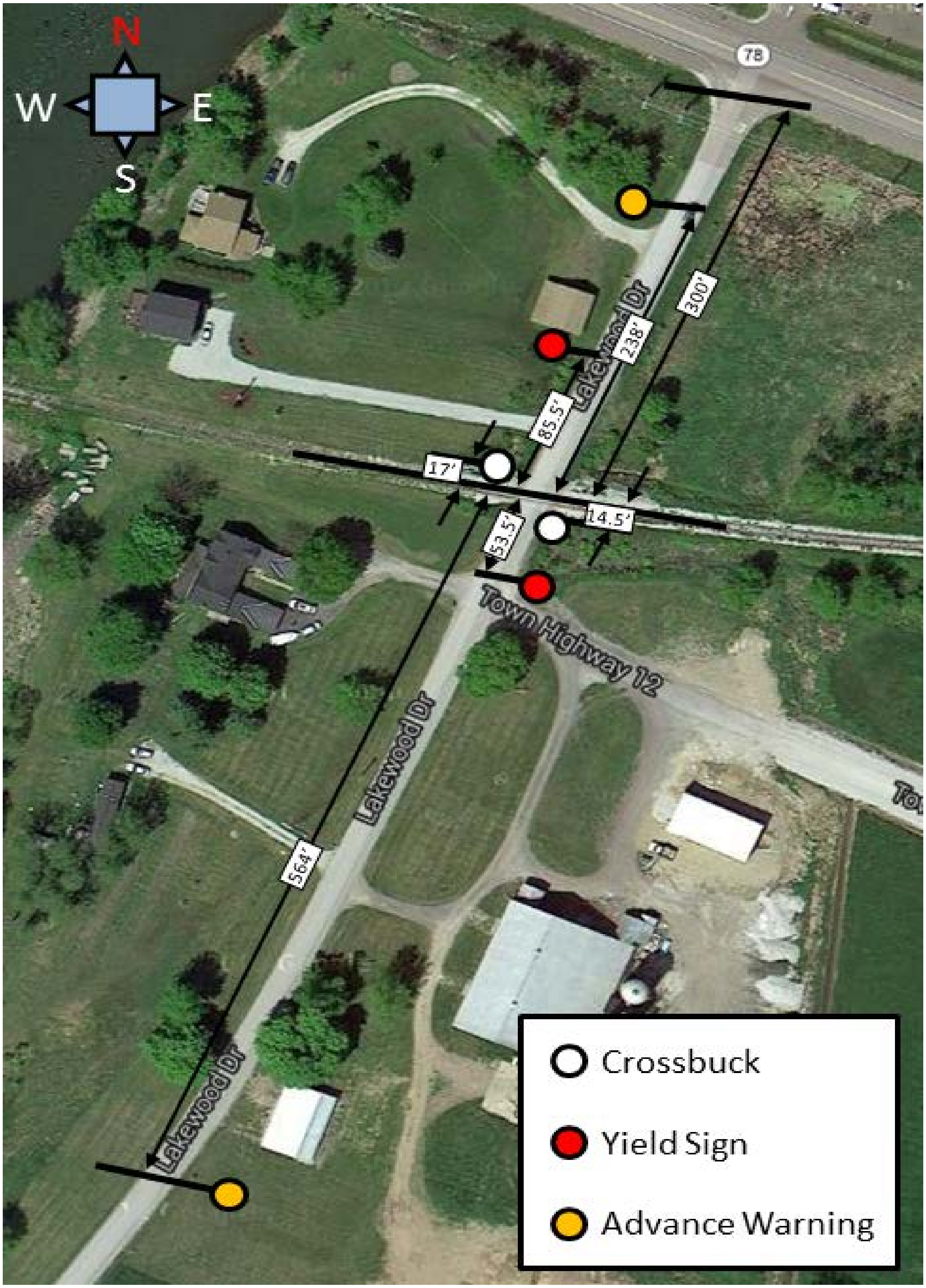

Figure 7. Diagram of the Lakewood Drive Crossing with Distances to the Track Center-Line

2.4 Test Schedule

As shown in Table 1, the test consisted of three phases. Each phase was designed to include a four week novelty period that would correspond to the installation of new hardware. Following each novelty period, two weeks of motor vehicle speed profiles were recorded. Phase 1, the baseline phase, began when the FRA MDFD was deployed on June 24th, 2013. The Phase 1 novelty period lasted over four weeks, through July 26th. This was immediately followed by the Phase 1 data collection period, which lasted approximately five weeks, through August 28th. Most of the Phase 1 data in the analysis was obtained between August 15th and 28th. Phase 2 began when the LED Crossbuck signs were installed at the crossing on the August 29th. After the Crossbuck installation, the Phase 2 novelty period ensued, which lasted four weeks, until September 25th. Phase 2 data collection began on September 26th, and continued until the October 9th, when the AWSs were installed at the crossing approaches. For Phase 3, the Crossbuck and AWSs were evaluated in tandem. The Phase 3 novelty period was originally intended to comprise four weeks, but was shortened to just one week, lasting through October 15th. Phase 3 data was collected until the FRA MDFD experienced a power failure on October 28th.

Table 1. The Project Schedule

Project Phase Schedule			
Phase 1			
	Start Date	End Date	Total Days
Novelty Period	6/24/2013	7/26/2013	33
Data Collection	7/27/2013	8/28/2013	33
Phase 2			
	Start Date	End Date	Total Days
Novelty Period	8/29/2013	9/25/2013	28
Data Collection	9/26/2013	10/8/2013	13
Phase 3			
	Start Date	End Date	Total Days
Novelty Period	10/9/2013	10/15/2013	7
Data Collection	10/16/2013	10/28/2013	13

Figure 8 shows the southbound approach to the crossing with the standard Crossbuck sign and the LED enhanced Crossbuck sign which replaced it. The northbound approach to the crossing with the standard AWS and after installation of the LED enhanced AWS is pictured in Figure 9.

Figure 8. Lakewood Drive Southbound Approach Crossbuck Sign Before (Left) and After (Right) LED Sign Installation

Figure 9. Lakewood Drive Northbound Approach Advance Warning Sign Before (Left) and After (Right) LED Sign Installation

2.5 System Setup

The MDFD, shown in Figure 10, was positioned 82.5 feet north of the railroad centerline and 15 feet from the edge of Lakewood Drive. The mast of the MDFD was raised to its maximum height in order to achieve the greatest possible detection distance. Since the site on which the MDFD was located was below the roadway grade, measurements were taken in reference to the roadway surface rather than ground level. The fully extended mast measured 25 feet from the surface of the roadway. The Autoscope® camera was mounted on top of the mast, at a height of 26.5 feet above the roadway surface, and aimed at the northbound traffic. A photograph of the MDFD as seen from the northbound approach to the crossing is shown Figure 11.

The Stalker® radar was mounted to the mast at a height of 11 feet from the surface of the roadway. The height and alignment of the radar were selected to optimize line-of-sight and situate the radar as low and parallel to the roadway as possible.

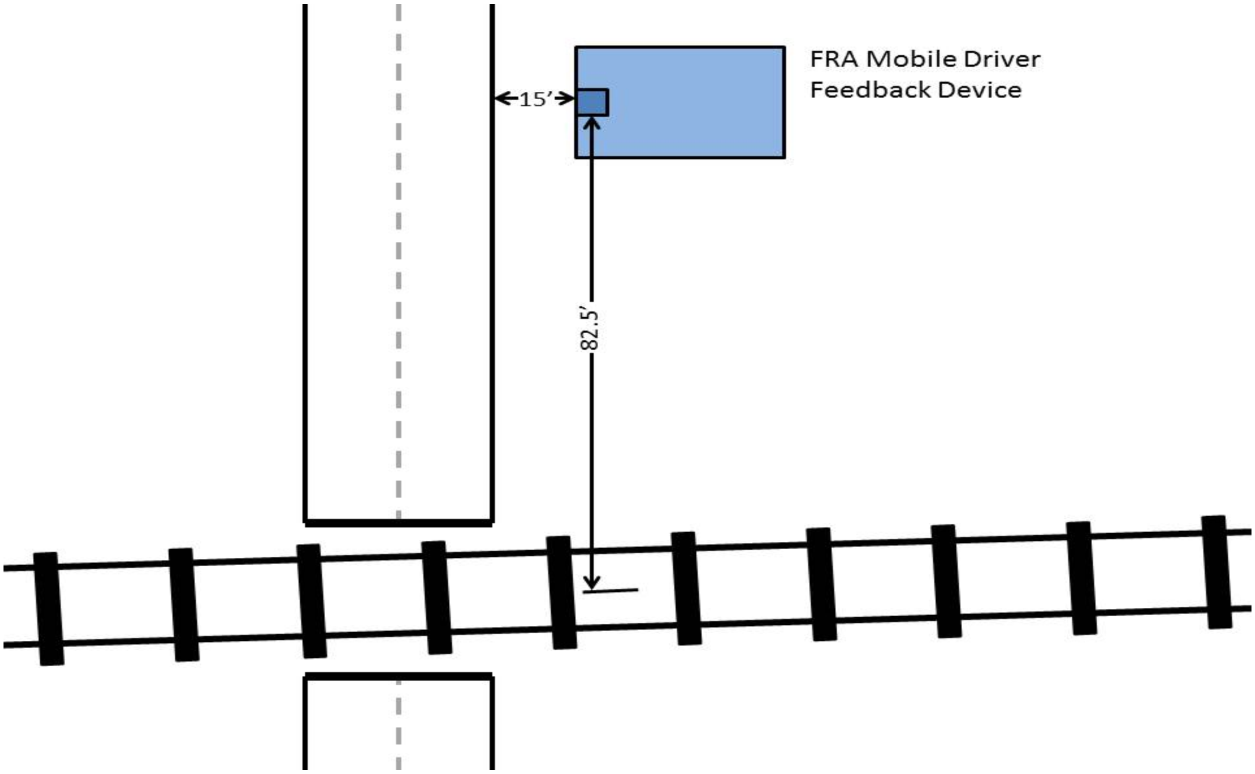

Figure 10. Diagram of the FRA Mobile Driver Feedback Device Location in Reference to the Lakewood Drive Crossing

Figure 11. View of Northbound Approach to Crossing. The Mobile Driver Feedback Device is in the Background

The Autoscope® MVP system requires calibration in order to establish distances. The calibration for Lakewood Drive is shown in Figure 12. The calibration process takes place in the following order:

1. Traffic cones are placed in a rectangle along the test area
2. The distances between the cones is measured and recorded
3. A still image of the scene is taken with the system camera
4. On the still image, calibration lines are overlaid on top of the cones
5. The lines are set to the physical distances recorded in step 2
6. The calibration file is uploaded to the camera

Once the Autoscope system was calibrated, a configuration file was created by adding virtual vehicle detectors to the scene, as shown in Figure 13.

The Autoscope® software monitored the state of each vehicle detector. The detectors, which were initialized in the "OFF" state, remained OFF until activated by a passing vehicle. The detectors returned to the OFF state after vehicles passed through them. Each state change, as well as the corresponding date and time of the state change, was written to a text file. These files, along with radar speed measurements, were later used in the data analysis.

Figure 12. The Lakewood Drive Grade Crossing During Autoscope® Calibration

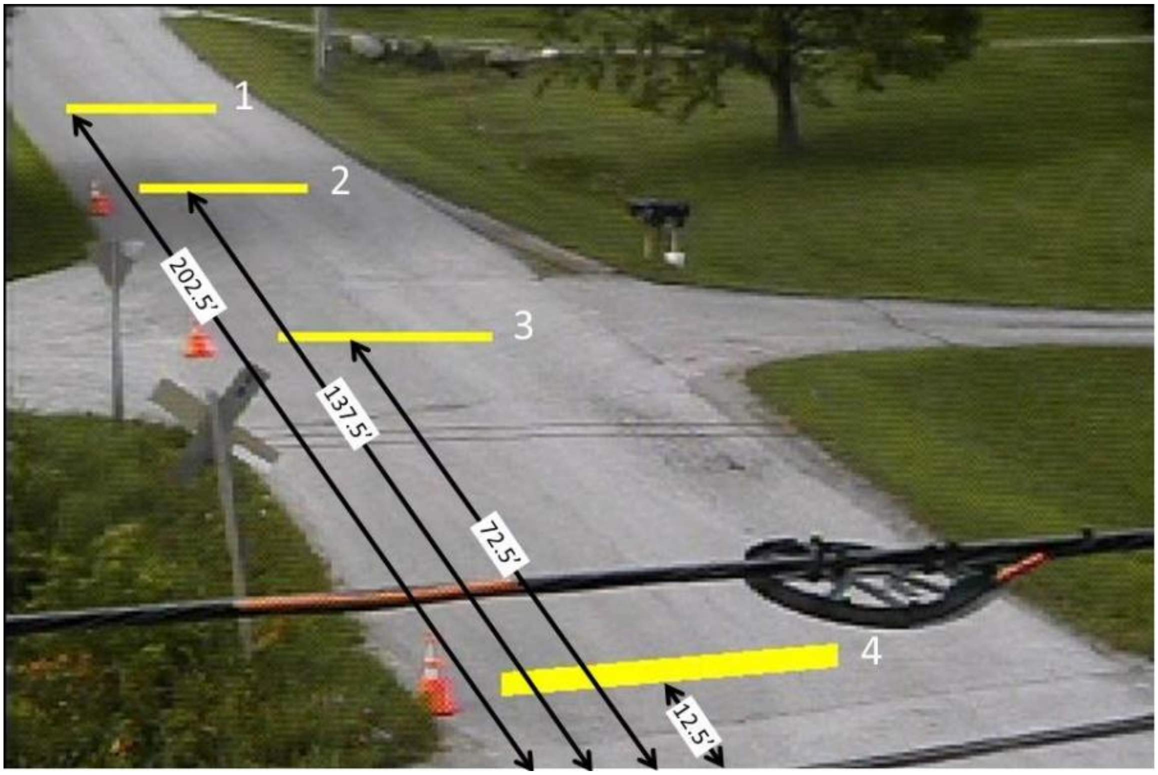

Figure 13. The Autoscope Configuration File Showing Detector Placement with Corresponding Detector Numbers, and Distances to the Crossing Center-Line (Crossing Not Shown)

Although the Stalker® radar was factory-calibrated, it was tested for accuracy before it was used in the field. The radar was tested using two tuning forks supplied by Stalker. The tuning forks, shown in Figure 14, were designed to emulate vehicle speeds of 25.25 mph and 40.25 mph, respectively.

Figure 14. The Tuning Forks Used in the Radar Calibration.
(Top) 40.25 mph Fork. (Bottom) 25.25 mph Fork

For each fork, 10 measurements were recorded by the radar in fork-test mode. The radar returned the same speed for all 10 trials with each fork. The radar was not set to record speeds in fractions of a mile per hour; thus, it returned speeds of 25 mph and 40 mph, rather than 25.25 mph and 40.25 mph. The measurements were performed at the Lakewood Drive test location, with the radar mounted on the FRA MDFD.

2.6 Data Collection

As shown in Figure 13, vehicles approaching the crossing from the south were detected at four locations. These locations corresponded to Autoscope virtual vehicle detectors positioned at distances of 12.5, 72.5, 137.5, and 202.5 feet from the centerline of the railroad track. The placement of the virtual detectors corresponded to the 180 foot sign legibility distance specified by the MUTCD[2]. Detector 1 was placed beyond the legibility distance, at a distance of 202.5 feet from the crossing (over 187.5 feet from the Crossbuck sign), with the intention of capturing vehicle speed before any speed reduction was elicited by the sign. Detectors 2, 3, and 4 recorded the remainder of the vehicle speed profile on the crossing approach.

Each detector recorded the following data: detector number, date, timestamp, and the state of the detector, which was either ON or OFF. These recordings were written to a text file on the system hard drive, with a separate file recorded each day (a day being defined as the hours between 00:00 and 24:00).

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[2] Manual of Uniform Traffic Control Devices 2009 Edition, Section 2C.05, *Placement of Warning Signs*. http://mutcd.fhwa.dot.gov/htm/2009r1r2/part2/part2c.htm.

Vehicle speeds were recorded by the Stalker® radar, which was also mounted to the FRA MDFD mast. The radar was configured to record all vehicles traveling northbound through the crossing at speeds in excess of 12 mph. The radar was programmed to acquire targets with the strongest reflected signal. This prevented the radar from providing erroneous measurements when two vehicles occupied the detector region simultaneously.

In most instances, the radar was able to capture speeds for all vehicle classes, including motorcycles, large trucks, vehicles with trailers, and passenger class vehicles. In some instances the radar captured bicycles. These events were manually identified and removed from the data. In other cases, the radar recorded speeds for vehicles traveling in the southbound direction. These vehicles did not trigger the vehicle detectors, and were excluded from the data. Vehicles which followed closely behind other vehicles could not be excluded automatically during the data collection process, but were manually removed during data analysis.

3. Data Analysis

Data sets were compiled by matching timestamps from vehicle detector events to radar speeds. Both events and speeds were recorded in text files on the FRA MDFD hard drive. The Autoscope® and Stalker® radar were both synchronized to the MDFD computer clock. Daytime and nighttime events were evaluated separately.

3.1 Programming

In order to match the timestamps of such a large number of events, a script was written in MATLAB® to search through radar speed data for dates and times corresponding to vehicle detector events. Since the timestamps from vehicle detector events did not include fractions of a second, there were typically 8-10 radar speeds for every second-long detector event. These radar events were all recorded into a second text file.

A second script was written to filter the matched radar data. The script filtered out any event that did not have at least six corresponding radar speed measurements, which helped remove instances of vehicles traveling in the southbound direction and noise caused by other objects moving through the crossing. The last line of speed measurements from each significant event was stored in a MATLAB® cell array. These final lines were sorted by detector number and written to four separate text files, one for each detector. This approach was found to provide the highest likelihood of correlation between vehicle speed measurements and detection zone location.

3.2 Manual Sorting

Three Microsoft Excel® files, corresponding to each of the three test phases (Baseline, Crossbuck, AWS), were created. Each file was populated with event data generated by the MATLAB® script. The data was separated into columns by detector number to produce a complete speed profile for each vehicle event.

As shown in Table 2, the data representing each detector was comprised of four data fields; Detector Number, Date, Time, and Speed. Events were removed from the spreadsheet if their existence was not substantiated by at least two vehicle detectors. These events were usually caused by vehicles traveling in the southbound lane.

During the manual sorting process, gaps often appeared in the speed profiles. These gaps were typically caused by cars moving at speeds less than 12 mph – the lower speed detection limit of the radar. These events were reviewed using video recordings to ensure that vehicles traveled through the entire crossing

Table 2. A Sample of Data Compiled from the Radar and Video Detection System

Detector Number	Date	Time	Speed (mph)	Detector Number	Date	Time	Speed (mph)	Detector Number	Date	Time	Speed (mph)	Detector Number	Date	Time	Speed (mph)
1	8/11/2013	0:05:33	35	2	8/11/2013	0:05:34	34	3	8/11/2013	0:05:35	32	4	8/11/2013	0:05:36	30
1	8/11/2013	4:05:19	32	2	8/11/2013	4:05:20	31	3	8/11/2013	4:05:21	29	4	8/11/2013	4:05:22	28
1	8/11/2013	4:23:51	43	2	8/11/2013	4:23:51	40	3	8/11/2013	4:23:52	37	4	8/11/2013	4:23:53	36
1	8/11/2013	20:41:47	24	2	8/11/2013	20:41:48	21	3	8/11/2013	20:41:50	19	4	8/11/2013	20:41:51	17
1	8/11/2013	20:47:00	27	2	8/11/2013	20:47:01	25	3	8/11/2013	20:47:02	22	4	8/11/2013	20:47:03	19
1	8/11/2013	21:00:08	33	2	8/11/2013	21:00:09	31	3	8/11/2013	21:00:10	27	4	8/11/2013	21:00:12	32
1	8/11/2013	21:01:49	35	2	8/11/2013	21:01:49	33	3	8/11/2013	21:01:51	31	4	8/11/2013	21:01:52	28
1	8/11/2013	21:06:16	25	2	8/11/2013	21:06:17	23	3	8/11/2013	21:06:18	20	4	8/11/2013	21:06:20	17
1	8/11/2013	21:10:07	37	2	8/11/2013	21:10:07	36	3	8/11/2013	21:10:08	35	4	8/11/2013	21:10:09	33
1	8/11/2013	21:11:59	36	2	8/11/2013	21:12:00	33	3	8/11/2013	21:12:00	30	4	8/11/2013	21:12:01	29
1	8/11/2013	21:18:49	34	2	8/11/2013	21:18:50	32	3	8/11/2013	21:18:50	30	4	8/11/2013	21:18:51	28
1	8/11/2013	21:33:20	29	2	8/11/2013	21:33:21	26	3	8/11/2013	21:33:22	21	4	8/11/2013	21:33:24	15
1	8/11/2013	22:46:04	28	2	8/11/2013	22:46:05	23	3	8/11/2013	22:46:06	18	4	8/11/2013	22:46:08	12
1	8/11/2013	22:53:29	37	2	8/11/2013	22:53:30	32	3	8/11/2013	22:53:30	29	4	8/11/2013	22:53:31	27

3.3 Filtering

Specific events were removed from the data pool to prevent them from skewing the study results. The most common of these events were vehicles that did not travel through all four detectors. A residential side street and a private driveway were located between detectors 2 and 3, which led to vehicles entering and exiting Lakewood Drive in the middle of the test area. The speed profiles of these vehicles were incomplete, so they were excluded from the data.

Vehicles that were following other vehicles were also excluded from the data due to their reliance on the speed of the lead vehicle, as well as the radar's inability to record the speed of both vehicles at the same time. All vehicles traveling less than six seconds behind the previous vehicle were removed from the data.

3.4 Weather and Lighting

Weather reports from the National Weather Service and Accuweather, Inc. were reviewed to identify days with measureable precipitation. For these days, video analysis was performed to remove vehicle events that occurred during inclement time periods.

Study data was categorized as daytime or nighttime based upon the information found in the sunrise/sunset table for Swanton, VT (which was provided by the United States Naval Observatory). Any event that occurred between the sunrise and sunset time was classified as daytime data. Nighttime data consisted of events that occurred 30 minutes after sunset and 30 minutes before sunrise.

3.5 Nighttime Data Collection

During daytime conditions, the virtual vehicle detectors were activated by the front end of vehicles passing through the detection zone. At night, the leading edge of a motor vehicle headlight beam was found to induce false activation of the vehicle detectors (shown in Figure 15). This phenomenon, known as headlight bloom, is magnified by the absence of street lighting, as was the case on Lakewood Drive. In other instances, the Autoscope® system failed to detect entire vehicle events because of poor functionality in low light conditions. The combination of timestamp discrepancies, resulting from headlight bloom, and incomplete detection data prevented the use of the MATLAB® scripts in matching vehicle events to appropriate corresponding radar events.

Nighttime data was processed manually by a video analyst. As vehicles traversed the virtual detectors, the analyst would pause the recording and transcribe the video timestamp. The video timestamps were matched to timestamps in the radar data text file.

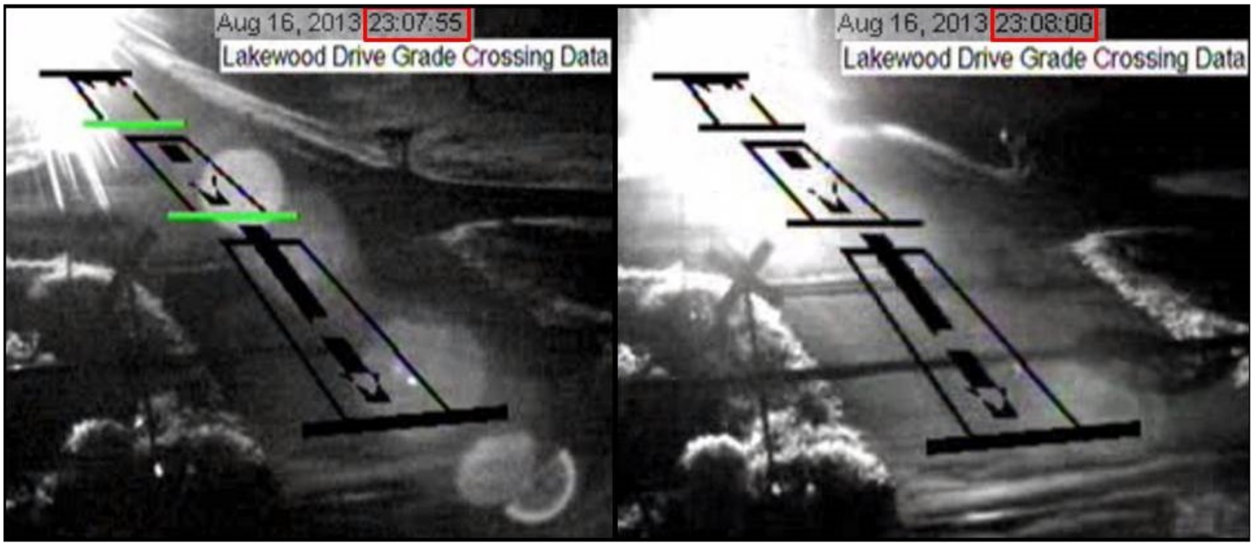

Figure 15. Side-By-Side Images Display a Vehicle Traveling through the Crossing at Nighttime. The Vehicle Headlights Activate the Virtual Detectors (Left) Five Seconds before the Vehicle Passes through the First Detector (Right)

3.6 External Factors

During the course of the Phase 2 and 3 data analyses, it was observed that a double solid yellow centerline was painted on the center of Lakewood Drive on October 1st 2013, during the middle of Phase 2 data collection. A follow-up analysis of the Phase 2 data showed significant differences in mean vehicle speeds before and after the addition of the centerline. For the remainder of this report, the Phase 2 data collected before and after the addition of the centerline will be known as Phases 2A and 2B, respectively. The Phase 2A and 2B schedules are shown in Table 3. This marked a significant change in the test environment from the Phase 1 baseline conditions and precluded the use of Phase 3 data in formulating any substantial conclusions related to the tandem sign configuration.

Table 3. Phase 2A and 2B schedules

Phase 2 Revised Schedule			
Phase Name	Start Date	End Date	Number of Days
Phase 2A	09/26/2013	09/30/2013	5
Phase 2B	10/02/2013	10/08/2013	7

3.7 Statistical Analysis

The objective of the analysis was to compare mean vehicle speeds from Phases 2 and 3 to those from Phase 1. For each phase, the vehicle speed profiles from each detector were found to closely resemble a normal probability distribution. The results of the Phase 1 analysis are shown in Figures 16 - 19, respectively.

The statistical analysis method was chosen from among the tests used to compare the means of two samples obtained from a normally distributed population. Since the population means and population standard deviations of the vehicle speed profiles were unknown, the t-test was employed to determine the significance of the data. In addition, the samples were independent of each other (unpaired) and the sample sizes were unequal. The Welch's corrected unpaired t-test, which accounts for differing sample sizes and unequal variances (σ^2), was selected. The robust nature of the Welch's corrected unpaired t-test was well suited to the samples, which were not entirely equal in size, and which had slightly differing variances (Ruxton, 2006)[3].

The null hypothesis (H_o) used in the analysis was:

$$(1)\ H_o: \mu_1 - \mu_i = 0$$

In order to prevent a Type I error, by testing solely for a decrease in vehicle speed, a two-tail analysis was employed, with the alternative hypothesis (H_1):

$$(2)\ H_1: \mu_1 - \mu_i \neq 0$$

For which:
μ_1 is the mean speed recorded at a vehicle detector during Phase 1, and
μ_i are the mean speeds recorded at a vehicle detector during subsequent phases.

In order to reject the null hypothesis, a detector must experience a change in mean vehicle speed that has a statistical significance of 95% or greater ($p < .05$), based on the t-table.

As shown in Table 4, Phase 1 consisted of 1,486 daytime speed profiles and 282 nighttime speed profiles. Phase 2A included 527 daytime speed profiles and 132 nighttime speed profiles. The significant difference in quantity between daytime and nighttime data was due to far fewer vehicles traveling through the crossing at night.

Table 4. Sample population sizes from each phase

Sample Populations		
Phase Name	Daytime Sample Population	Nighttime Sample Population
Phase 1	1,486	282
Phase 2A	527	132
Phase 2B	789	128
Phase 3	1,116	282

Speed profiles that contained instances of low-speed vehicles were adjusted using a conservative correction. The conservative correction method involved identifying vehicles which traveled at speeds less than 12 mph (for which the radar did not obtain a measurement), and assigning them a value of 12 mph. This reduced the mean vehicle speed at a detector by taking into account low-speed vehicles that were not registered by the radar. It is a conservative method because it does not assume that all low-speed vehicles came to a complete stop. The most significant

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[3] The decision to use Welch's test was supported by Graeme D. Ruxton's 2006 paper, which states that the Welch's corrected unpaired t-test is no more likely to result in a Type I or II error than the student t-test, even when samples possess equivalent variances.

impact of this correction was seen at detectors 3 and 4, where vehicles often reached a negligible speed immediately before the crossing.

Data was analyzed in the following order:

The mean of each data set was calculated using the formula:

$$(3)\ \overline{x} = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

Where:
$\overline{x}$ is the mean vehicle speed at a vehicle detector and
n is the sample size

The standard deviation of each data set was then calculated using the n-1 method for a sample of the population:

$$(4)\ s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}},$$

Where:
s is the sample standard deviation and
x_i is the ith vehicle speed recorded at a vehicle detector

Variance was calculated by raising the standard deviation to the second power (s^2).

The sample mean values and standard deviations were used to model the normal probability distributions for each detector over a range of speeds from 0 mph to 60 mph. These models were used to determine if the observed values conformed to a normal distribution. This comparison was performed for each of the vehicle detectors from each phase.

The results for the Phase 1 daytime data sets are shown in Figures 16 through 19, below. The histograms for the remaining phases are found in Appendix A.

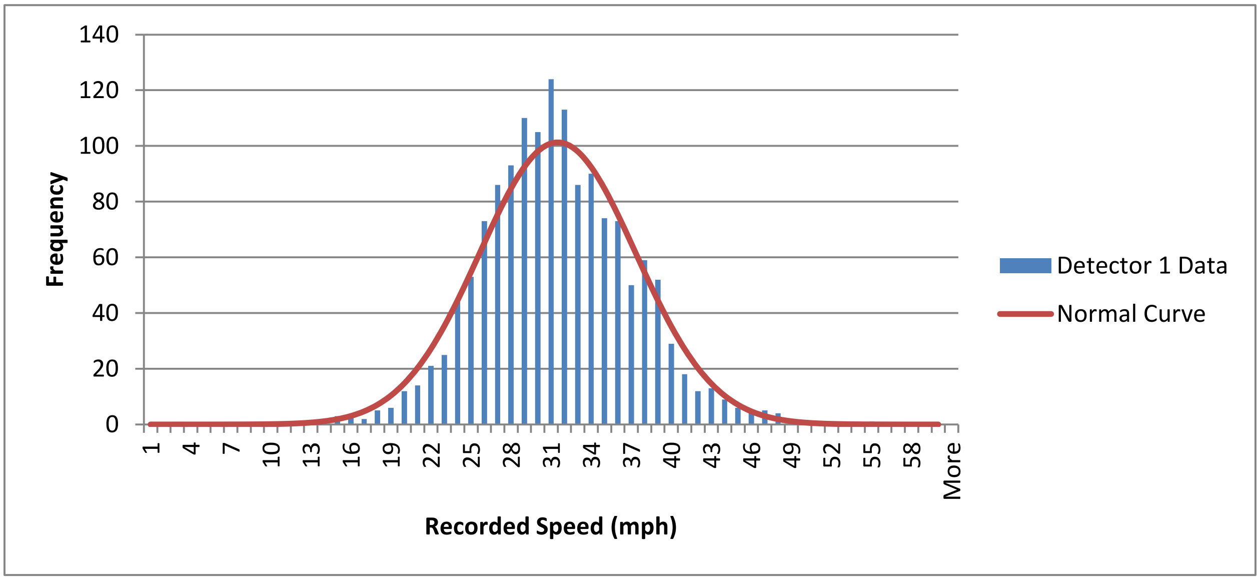

Figure 16. Comparison of Phase 1- Detector 1 Data to a Normal Distribution

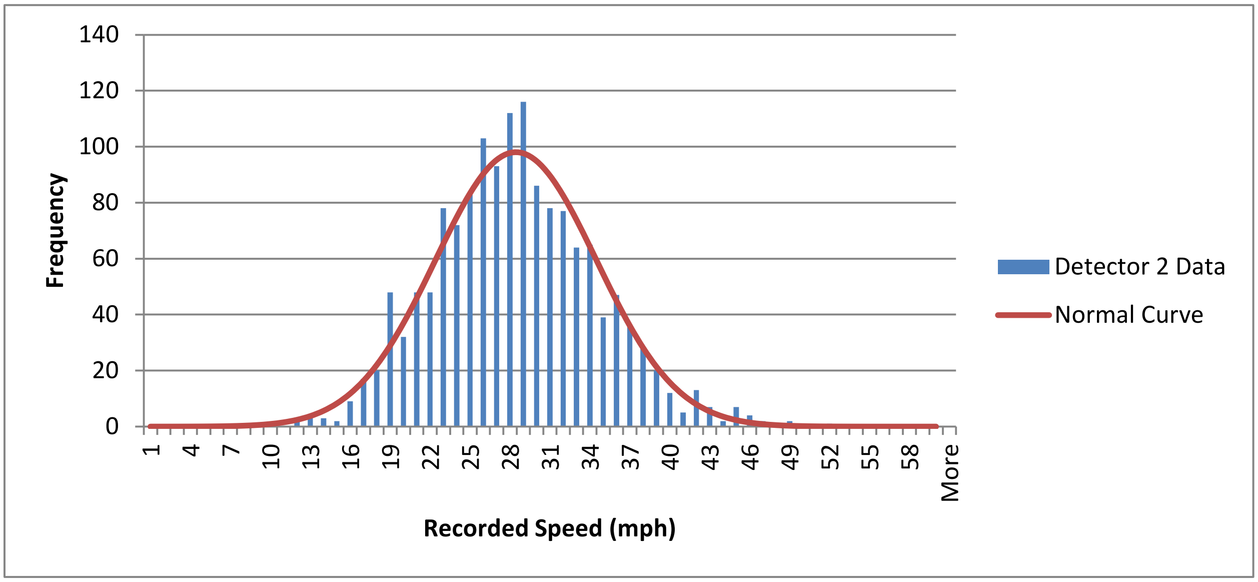

Figure 17. Comparison of Phase 1- Detector 2 Data to a Normal Distribution

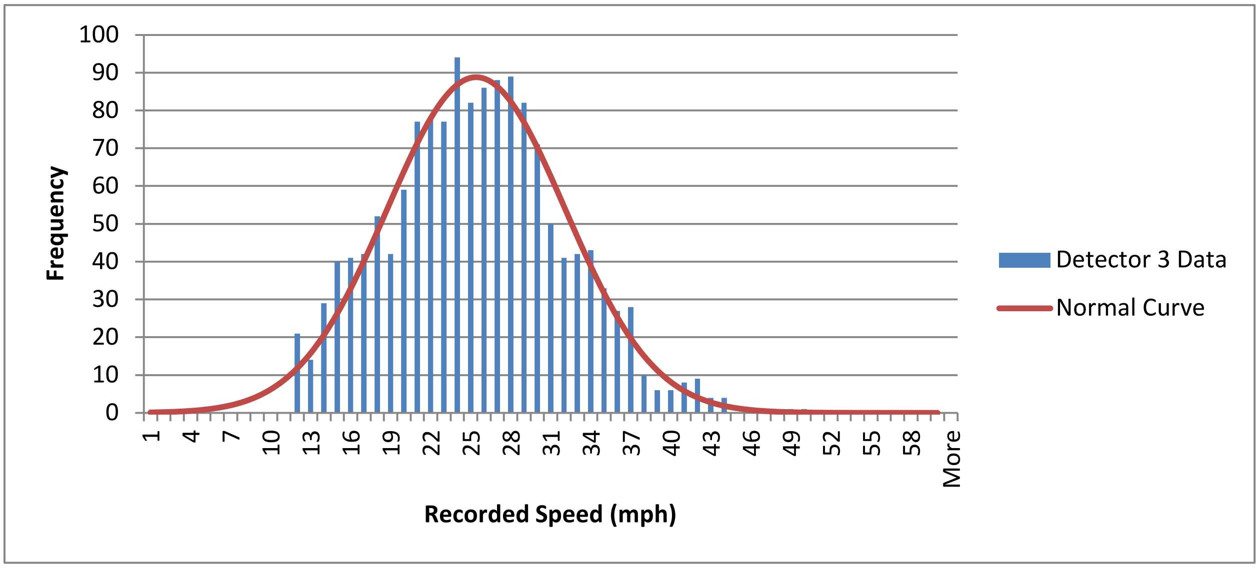

Figure 18. Comparison of Phase 1- Detector 3 Data to a Normal Distribution

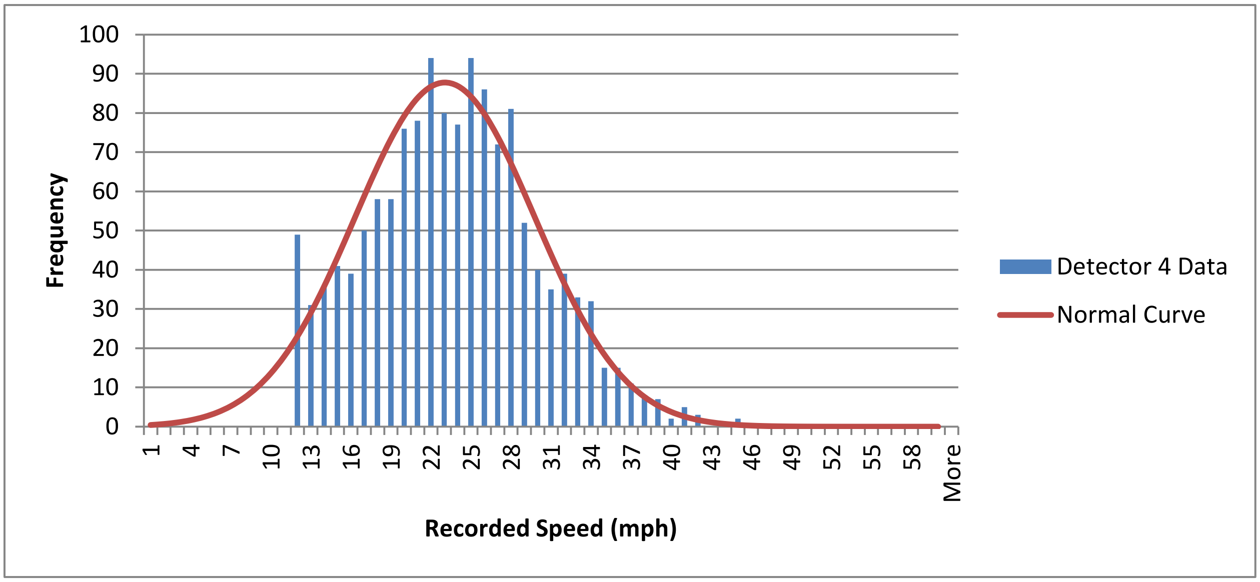

Figure 19. Comparison of Phase 1- Detector 4 Data to a Normal Distribution

As previously explained, vehicle speeds less than 12 mph were below the minimum speed detection threshold of the radar. This was primarily observed at detectors 3 and 4, as shown by the absence of data points in the lower tails of Figures 18 and 19. Had these events been measured, it is highly likely that the tails would have been symmetrical. This limitation did not significantly affect detectors 1 or 2.

Since the data sets appeared to be normally distributed, a t-test for statistical significance was performed. A two-sample t_{stat} value was found using the Welch's corrected unpaired t-test, with the following equation:

$$(5)\ t_{stat} = \frac{(\bar{x}_1 - \bar{x}_i)}{\sqrt{\frac{{s_1}^2}{n_1} + \frac{{s_i}^2}{n_i}}}$$

where
$\bar{x}_1$ is the mean vehicle speed at detectors in Phase 1
$\bar{x}_i$ is the mean vehicle speed at detectors in subsequent phases
s_1 is the standard deviation of Phase 1
s_i is the standard deviation of subsequent phases
n_1 is the sample size of Phase 1 and
n_i is the sample size of subsequent phases, respectively.

The t_{stat} value was used to obtain a *p*-value from the t-table.

4. Results

This section compares the vehicle speed profiles across all phases of the study. The daytime and nighttime results are presented separately.

Data analyzed in this study consisted of vehicle speed profiles that were not affected by weather, lighting, or traffic conditions.

4.1 Mean Value Comparisons

The daytime data collected at the crossing, shown in Tables 5-8, indicates that mean vehicles speeds exhibited little change between Phases 1 and 2A, decreased consistently between Phases 2A and 2B, and then rose in Phase 3. Among all three phases, there appeared to be an inverse correlation between increases in sample standard deviation/variance values and distance from the crossing. This is most likely due to the range of braking patterns exhibited by drivers at detectors 3 and 4. As expected, the number of low-speed vehicles at a given detector was inversely related to the distance of the detector to the crossing.

Table 5. Daytime Speed Data from Phase 1

Baseline Speed Data – Daytime (n=1,486)					
Detector Name	Distance from Crossing (feet)	Number of Low-speed Vehicles	Mean Vehicle Speed (mph)	Standard Deviation	Variance
Detector 1	202.5	0	31.45	5.65	31.97
Detector 2	137.5	0	28.45	6.05	36.56
Detector 3	72.5	8	25.42	6.68	44.58
Detector 4	12.5	87	23.05	6.76	45.64

Table 6. Daytime Speed Data from Phase 2A

LED Enhanced Crossbuck Speed Data – Daytime (n=527)					
Detector Name	Distance from Crossing (feet)	Number of Low-speed Vehicles	Mean Vehicle Speed (mph)	Standard Deviation	Variance
Detector 1	202.5	0	31.92	5.86	34.37
Detector 2	137.5	0	28.87	6.07	36.89
Detector 3	72.5	8	25.32	6.55	42.89
Detector 4	12.5	37	22.64	6.76	45.65

Table 7. Daytime Speed Data from Phase 2B

LED Enhanced Crossbuck Speed Data – Daytime (n=789)					
Detector Name	Distance from Crossing (feet)	Number of Low-speed Vehicles	Mean Vehicle Speed (mph)	Standard Deviation	Variance
Detector 1	202.5	0	30.71	5.76	33.35
Detector 2	137.5	0	27.64	6.11	37.31
Detector 3	72.5	5	24.56	6.86	47.13
Detector 4	12.5	66	22.43	6.64	44.05

Table 8. Daytime Speed Data from Phase 3

LED Enhanced Advance Warning and Crossbuck Speed Data - Daytime (n=1,116)					
Detector Name	Distance from Crossing (feet)	Number of Low-speed Vehicles	Mean Vehicle Speed (mph)	Standard Deviation	Variance
Detector 1	202.5	1	32.44	5.97	35.70
Detector 2	137.5	1	29.30	6.52	42.48
Detector 3	72.5	20	25.88	7.22	52.37
Detector 4	12.5	96	23.33	7.18	51.58

The nighttime vehicle data, shown in Tables 9-12, displayed a different trend than the daytime data. Mean vehicle speeds decreased between Phases 1 and 2A, increased between Phases 2A and 2B, and increased above the baseline values in Phase 3. A sizeable increase in standard deviation/variance occurred between Phases 2A and 2B. This indicated that the addition of the centerline may have produced a temporary increase in the dispersion of vehicle speeds. These values returned to approximate baseline levels in Phase 3, suggesting a novelty effect that diminished over time. Low-speed vehicle trends remained similar to those observed during the daytime.

Table 9. Nighttime Speed Data from Phase 1

Baseline Speed Data – Nighttime (n=282)					
Detector Name	Distance from Crossing (feet)	Number of Low-speed Vehicles	Mean Vehicle Speed (mph)	Standard Deviation	Variance
Detector 1	202.5	0	32.97	7.20	51.87
Detector 2	137.5	1	30.55	7.09	50.22
Detector 3	72.5	2	27.56	7.29	53.09
Detector 4	12.5	8	24.92	7.48	55.98

Table 10. Nighttime Speed Data from Phase 2A

LED Enhanced Crossbuck Speed Data – Nighttime (n=132)					
Detector Name	Distance from Crossing (feet)	Number of Low-speed Vehicles	Mean Vehicle Speed (mph)	Standard Deviation	Variance
Detector 1	202.5	1	30.02	7.86	61.82
Detector 2	137.5	4	27.46	7.40	54.83
Detector 3	72.5	10	24.24	7.46	55.71
Detector 4	12.5	17	22.03	7.13	50.81

Table 11. Nighttime Speed Data from Phase 2B

LED Enhanced Crossbuck Speed Data – Nighttime (n=128)					
Detector Name	Distance from Crossing (feet)	Number of Low-speed Vehicles	Mean Vehicle Speed (mph)	Standard Deviation	Variance
Detector 1	202.5	1	31.97	8.50	72.20
Detector 2	137.5	1	29.38	8.35	69.73
Detector 3	72.5	2	26.62	8.41	70.73
Detector 4	12.5	7	24.79	8.10	65.57

Table 12. Nighttime Speed Data from Phase 3

LED Enhanced Advance Warning and Crossbuck Speed Data – Nighttime (n=282)					
Detector Name	Distance from Crossing (feet)	Number of Low-speed Vehicles	Mean Vehicle Speed (mph)	Standard Deviation	Variance
Detector 1	202.5	0	33.86	7.00	49.00
Detector 2	137.5	0	30.76	7.27	52.80
Detector 3	72.5	3	27.77	7.79	60.61
Detector 4	12.5	16	25.57	7.83	61.24

4.2 Investigation of inconsistent data trends

As described in Section 3.6, an unexpected increase in mean vehicle speed occurred between Phases 2 and 3. It was speculated that much of this effect occurred when a centerline was added to Lakewood Drive during Phase 2. To test this theory, a comparison of Phase 2A and 2B's mean speeds was performed and a significant decrease in speed occurred at three detectors during the daytime (as seen in Tables 13 and 14), while a significant increase in speed occurred at three detectors during the nighttime. This seems to indicate that the addition of the centerline had varying but substantial effects on mean vehicle speeds.

Table 13. Comparison of Phases 2A and 2B Daytime Data

Phase 2A (n=527) and Phase 2B (n=789) Comparison - Daytime							
Detector Name	Distance from Crossing (feet)	Phase 2A Mean Speed (mph)	Phase 2B Mean Speed (mph)	$\bar{x}_{2A} - \bar{x}_{2B}$	*t*-value	*p*-value	Significant*
Detector 1	202.5	31.92	30.71	1.21	3.702	< 0.001	YES
Detector 2	137.5	28.87	27.64	1.23	3.603	< 0.001	YES
Detector 3	72.5	25.32	24.56	0.76	1.984	< 0.05	YES
Detector 4	12.5	22.64	22.43	0.21	0.556	> 0.40	NO

*Significant at 95% Confidence Level

Table 14. Comparison of Phases 2A and 2B Nighttime Data

Phase 2A (n=132) and Phase 2B (n=128) Comparison - Nighttime							
Detector Name	Distance from Crossing (feet)	Phase 2A Mean Speed (mph)	Phase 2B Mean Speed (mph)	$\bar{x}_{2A} - \bar{x}_{2B}$	*t*-value	*p*-value	Significant*
Detector 1	202.5	30.02	31.97	-1.95	-1.915	> 0.05	NO
Detector 2	137.5	27.46	29.38	-1.92	-1.960	0.05	YES
Detector 3	72.5	24.24	26.62	-2.37	-2.406	< 0.02	YES
Detector 4	12.5	22.03	24.79	-2.76	-2.913	< 0.01	YES

*Significant at 95% Confidence Level

4.3 Statistical Analysis Results

Since Phase 2B and Phase 3 data were collected after the addition of the centerline on October 1st, only Phase 1 and Phase 2A were compared. As shown in Table 15, there was no statistically significant change in mean vehicle speeds at any detectors during the daytime. Table 16 shows that, during the nighttime, all four detectors experienced significant decreases in mean vehicle speed. These nighttime speed decreases averaged 3.06 mph.

Table 15. Comparison of Phases 1 and 2A Daytime Data

Phase 1 (n=1486) and Phase 2A (n=527) Comparison - Daytime							
Detector Name	Distance from Crossing (feet)	Phase 1 Mean Speed (mph)	Phase 2A Mean Speed (mph)	$\bar{x}_{1} - \bar{x}_{2A}$	*t*-value	*p*-value	Significant*
Detector 1	202.5	31.45	31.92	-0.47	-1.596	> 0.10	NO
Detector 2	137.5	28.45	28.87	-0.42	-1.390	> 0.15	NO
Detector 3	72.5	25.42	25.32	0.10	0.285	> 0.40	NO
Detector 4	12.5	23.05	22.64	0.41	1.202	> 0.20	NO

*Significant at 95% Confidence Level

Table 16. Comparison of Phases 1 and 2A Nighttime Data

Phase 1 (n=282) and Phase 2A (n=132) Comparison - Nighttime							
Detector Name	Distance from Crossing (feet)	Phase 1 Mean Speed (mph)	Phase 2A Mean Speed (mph)	$\bar{x}_1 - \bar{x}_{2A}$	*t*-value	*p*-value	Significant*
Detector 1	202.5	32.97	30.02	2.95	3.651	< 0.001	YES
Detector 2	137.5	30.55	27.46	3.09	4.003	< 0.001	YES
Detector 3	72.5	27.56	24.24	3.32	4.242	< 0.001	YES
Detector 4	12.5	24.92	22.03	2.89	3.786	< 0.001	YES

*Significant at 95% Confidence Level

5. Discussion

The objective of this research was to measure the impact of a phased introduction of LED sign technology on motor vehicle speed profiles. The experimental approach was to compare the baseline data from Phase1 with the LED Crossbuck data from Phase 2 and the data in from the tandem LED Crossbuck/AWS configuration in Phase 3.

Under ideal conditions, any statistically significant change in a dependent variable (motor vehicle speed profiles) would correlate to fluctuations in a single independent variable (the LED signs). In most controlled field tests, a small amount of experimental error and bias will occur due to the presence of uncontrollable variables. The effect of these variables should be mitigated so that the study results accurately reflect the impact of the independent variable. The addition of the centerline on Lakewood Drive introduced an experimental error into the test environment that weakened the correlation between motor vehicle speed profiles and the presence of the LED signs.

When the centerline was added to Lakewood Drive on October 1st, a statistically significant change in mean vehicle speeds was observed. This effect is believed to have been caused primarily by the addition of the centerline. This theory is supported by the findings of other researchers who have investigated the impact of pavement markings on vehicle speeds. One such study, conducted in Connecticut, found that the addition of a highway edgeline marking led vehicle speeds to increase at nighttime and decrease during the daytime ("Night Guide", 1955). Another report, which contained a meta-analysis of 14 centerline pavement marking studies, showed that the addition of a centerline to a previously unmarked roadway had an effect on speeds ranging from -1.2 mph to +5.6 mph with an average change of +1.9 mph (Davidse, van Driel, & Goldenbeld, 2004). The meta-analysis did not distinguish between daytime and nighttime measurements. Based on this evidence, the vehicle speed fluctuations observed on Lakewood Drive, shown in Section 4.2, appear reasonable.

Because the test environment was altered, only data collected before the introduction of the centerline was considered reliable and, as a result, conclusions were limited. For instance, the additional effect of the LED enhanced AWS could not be measured due to the addition of a second independent variable (the centerline) at the time of data collection. It was possible, however, to formulate conclusions about the LED Crossbuck sign based on useable data from Phase 2A.

5.1 Comparison of Phase 1 and Phase 2A Data

During daytime conditions, none of the detectors exhibited statistically significant changes in mean vehicle speed after the LED enhanced Crossbuck sign was activated (Table 13). Conversely, all detectors experienced a decrease in nighttime mean vehicle speed between Phases 1and 2A, which ranged from 2.89 mph at detector 4 to 3.32 mph at detector 3. The results (Table 14) were statistically significant at the 99.9% confidence level. At this level of confidence it is highly probable that the LED enhanced Crossbuck signs were responsible for the reductions in mean vehicle speeds.

The decrease in nighttime mean vehicle speeds after the activation of the LED enhanced Crossbuck sign was followed by an abrupt increase after the centerline was added to Lakewood

Drive. Although possible, there is little likelihood that such a pronounced change in the mean vehicle speeds (Table 12) occurred at random rather than as a result of the addition of the centerline. The decreases in the daytime mean vehicle speeds after the centerline was introduced, (Table 11) probably occurred as a result of the decrease in lane width (Stein & Neuman, 2007).

5.2 Comparison of Phase 2B and Phase 3 Data

After the centerline was added on October 1st, the comparison of the tandem LED system with the LED-enhanced Crossbuck sign was precluded. Therefore, a significance test was not used to compare Phases 2B and 3. However, the mean vehicle speeds for all four detectors did display a general increase during both daytime and nighttime. Possible explanations for this trend include:

- The novelty effect from the LED enhanced Crossbuck sign at night diminished
- The motorist population adjusted to the narrower road lanes
- The presence of the LED AWS led to increased visibility of highway centerline and lanes

While any or all of these explanations may be valid, the fact that they occurred concurrently prevented any characterization of the impact of the LED sign tandem design.

5.3 Other Factors

A key assumption of the study was that a one month novelty period would allow motorists to become accustomed to the changes that were made to the test environment. The novelty periods in this study were assigned based on relevant literature and the time constraints of the project schedule (Gates, Hawkins, Chrysler, Carlson, Holick, and Spiegelman, 2004) (Smiley, 2012) (Weidemann, Kwon, Lund, and Boder, 2011). If the novelty period was too short, then the data collected may have been more of a snapshot instead of a measurement of the impact caused by the LED enhanced signs.

Another possible explanation for the results relates to seasonal tourism trends in the surrounding area. The Phase 1 and 2A-2B data sets were collected from August to early October, which coincided with the summer and fall tourism seasons. Phase 3 data was collected late into the month of October, after both seasons had presumably ended. As a result, a more diverse motorist population may have been captured during Phases 1 and 2A-2B, whereas Phase 3 would have consisted almost exclusively of local drivers. This variation in driver populations could be responsible for the higher speeds observed in Phase 3.

Along with the possible impact of tourism, daylight hours grew progressively shorter between Phases 1 and 3. When the Phase 1 novelty period ended on the 22nd of July, sunrise occurred at 5:23AM, compared to 7:24AM on the last day of Phase 3 data collection. This shift in sunrise and sunset times meant that the daily commutes of many drivers changed from daytime to nighttime events as the study progressed. The sunrise and sunset times for the start of each data collection period as well as the total hours of daylight are shown in Table 17.

Table 17. Sunrise and Sunset Times for Phases 1, 2, and 3

Sunrise and Sunset Table			
	Phase 1	Phase 2	Phase 3
Date	07/26/2013	09/26/2013	10/16/2013
Sunrise	05:31 AM	06:44 AM	07:09 AM
Sunset	08:26 PM	06:42 PM	06:06 PM
Total daylight hours	14:55	11:58	10:57

Figure 20 shows the daytime mean vehicle speed at each detector as a percentage of the mean vehicle speed at Detector 1. The plots show that Phase 2A exhibited a greater decrease in speed at Detector 3 (1%) and Detector 4 (2.5%) as compared to Phase 1. This suggests that the LED enhanced Crossbuck signs had an effect on vehicle speeds within 100 feet of the crossing.

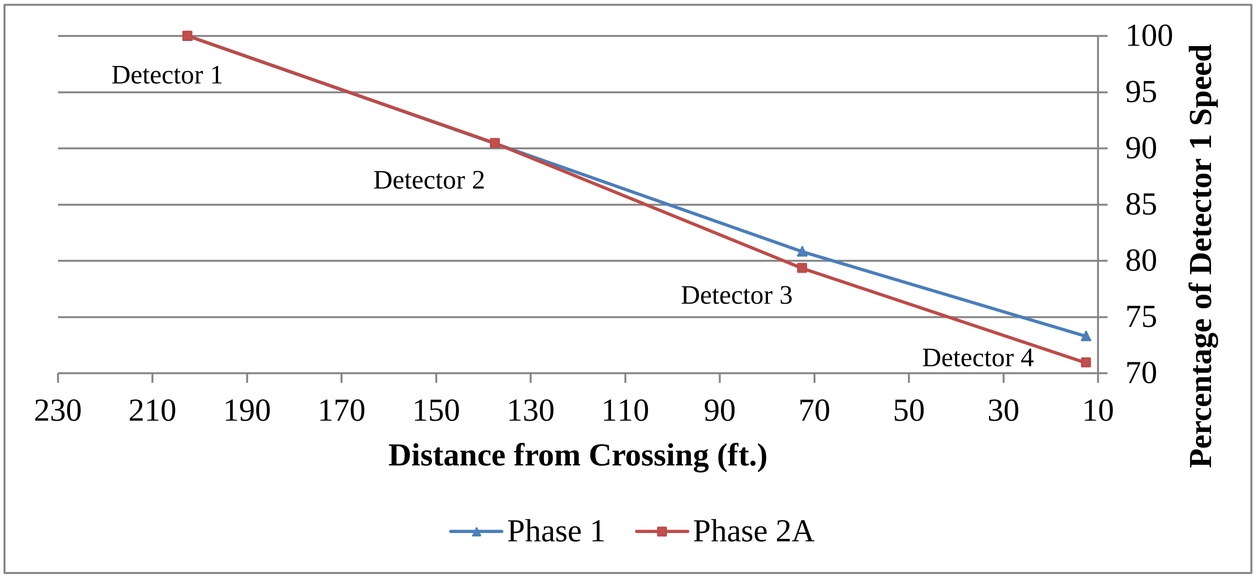

Figure 20. Rate of Mean Speed Decrease over the Detection Zone as a Percentage of the Detector 1 Mean Speed for Daytime Data

Figure 21 shows the nighttime mean vehicle speed at each detector as a percentage of the mean vehicle speed at Detector 1. The plots show that Phase 2A exhibited a greater decrease in speed than Phase 1 at Detector 2 (1.2%), Detector 3 (2.85%), and Detector 4 (2.25%). The data shows that the impact of the LED enhanced Crossbuck signs was greater at night than during the day.

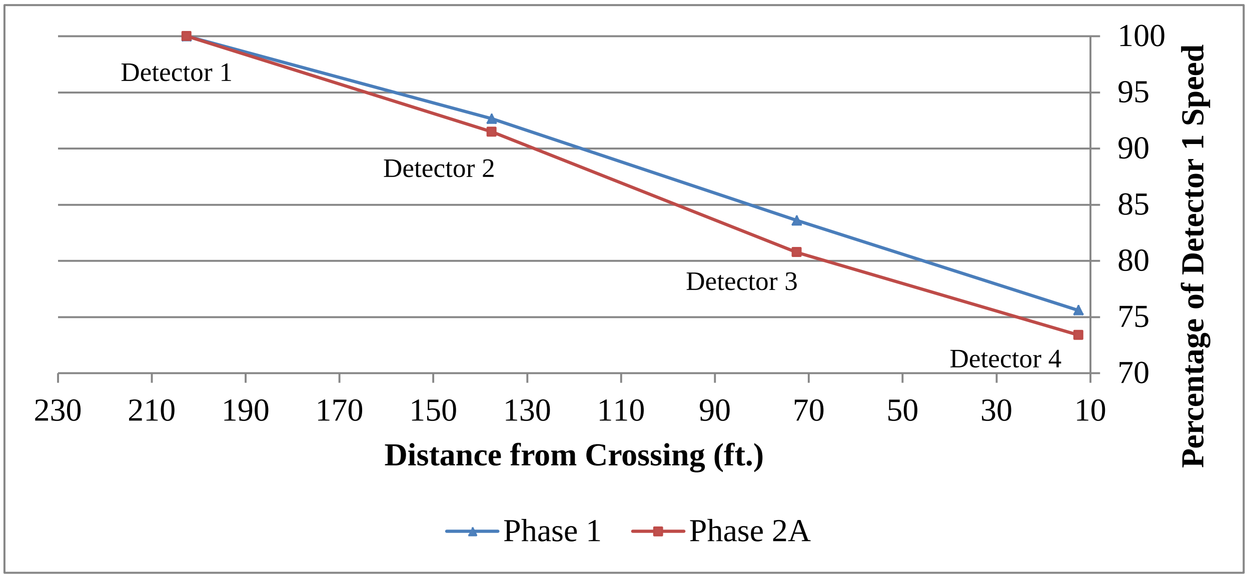

Figure 21. Rate of Mean Speed Decrease over the Detection Zone as a Percentage of the Detector 1 Mean Speed for Nighttime Data

5.4 Vehicle Classification Analysis

Before the team discovered the added centerline, it was posited that seasonal variation in the vehicle composition during the course of the analysis was partially responsible for the counterintuitive daytime results observed in Phases 2 and 3. This theory was considered especially plausible since Lakewood Drive serves a large number of boating enthusiasts who tow their vessels to a nearby boat launch during the June to September timeframe. A decrease in this group may have occurred as the summer concluded, causing the composition of the vehicle classes, and the resulting mean vehicle speeds, to fluctuate. Given the effect of the centerline on the Phase 2B and Phase 3 results, only the vehicle compositions of Phase 1 and 2A were compared. For each phase, a 3-day sample of daytime data from one Saturday, one Sunday, and one Monday was selected. The Phase 1 and 2A samples consisted of 701 and 501 vehicles, respectively. The vehicle class designations are shown in Table 18.

Table 18. Vehicle class designation as used in the classification analysis

Vehicle Class Designations	
Class	**Description**
A – Light Vehicle	Pick-up trucks, SUVs, Autos, Vans, and Minivans
B – Light Vehicle with Trailer	Any Class A vehicle with a trailer in tow
C – Commercial Vehicle	Semi-Truck, Delivery truck, and moving vans/trucks
D – Commercial Vehicle with Trailer	Any Class C vehicle with a trailer in tow
E – Bus	Public and private buses
F – Recreational Vehicles	Motor vehicles intended for leisure activity (does not include trailers)
G – Motorcycles	2-wheeled motorized vehicles
H – Other	Any vehicle not included in the previous class descriptions

Class A vehicles represented the vast majority of all vehicles traversing Lakewood Drive during the daytime in Phases 1 and 2A (Table 19). Class B was the only other vehicle class that was more than about 1% of the total sample population. Vehicle classes C through H represented less than 3% of the sample population, when combined.

Table 19. Sample Population by Vehicle Class Composition

Percentage of Sample Population by Vehicle Class								
	Class A	Class B	Class C	Class D	Class E	Class F	Class G	Class H
Phase 1 – (n = 701)	90.73%	6.42%	0.57%	0.57%	0.29%	0.14%	1.14%	0.14%
Phase 2A – (n = 501)	89.22%	8.38%	0.80%	0.60%	0.00%	0.00%	0.80%	0.20%

Based on the results of the analysis, it seems unlikely that vehicle class played an important role in the study. While vehicles from classes B through H did tend to travel more slowly through the crossing, they only represented about 10% of the sample population in each phase. Although the size of these classes increased slightly between Phases 1 and 2A, daytime vehicle speeds remained unchanged (Table 15).

6. Conclusions

In order to formulate conclusions from the results, it is first necessary to state the limitations of the study:

- The radar speed measurements were rounded down to the nearest integer
- Vehicle detector timestamps did not include fractions of seconds
- The use of video analysis to discern vehicle location at night was complicated by the effect of headlight bloom
- Daytime samples were very large, with degrees of freedom approaching infinity
- Nighttime data sample sets were much smaller than daytime data sets
- The detection zone for the crossing approach was only 190 feet long, preventing direct measurement of the effect of the LED enhanced AWSs
- A double-yellow centerline lane marking was added to Lakewood Drive during Phase 2 data collection
- No analysis of potential change in driver situational awareness, which may not necessarily reflect in change in speed

When the Phase 1 and Phase 2A mean vehicle speeds were compared, a statistically significant decrease of 2.9-3.3 mph at night was observed as a result of the installation of the LED-enhanced Crossbuck sign. The decreases were statistically significant at all vehicle detectors. No statistically significant increase or decrease in mean vehicle speeds was observed during the day.

While the results of the Phase 1-Phase 2A comparison appeared promising, the addition of the centerline prevented the measurement of any long-term trends attributed to the LED-enhanced AWS technology. Also, the centerline treatment prevented the comparison of the tandem LED sign configuration from Phase 3 with the baseline configuration.

6.1 Recommendations

While the initial results of the evaluation were promising, a human factors study is recommended to characterize the effects of the LED sign technology on driver behavior.

7. References

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Appendix A. Histograms

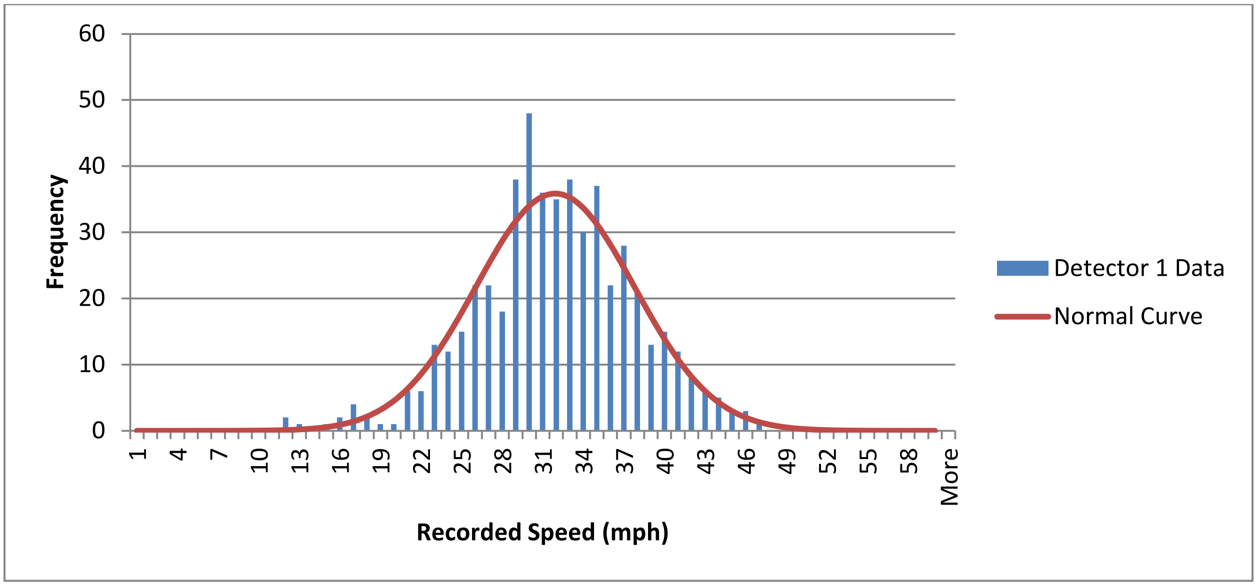

Figure A-1. A comparison of Phase 2A Detector 1 daytime data to a normal distribution

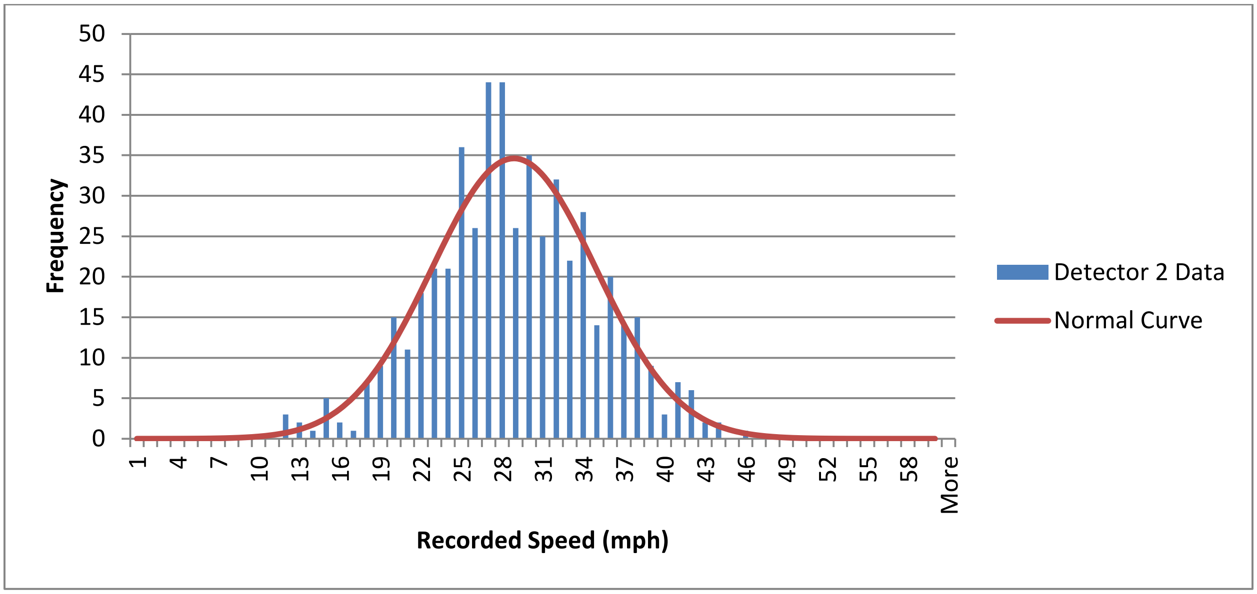

Figure A-2. A comparison of Phase 2A Detector 2 daytime data to a normal distribution

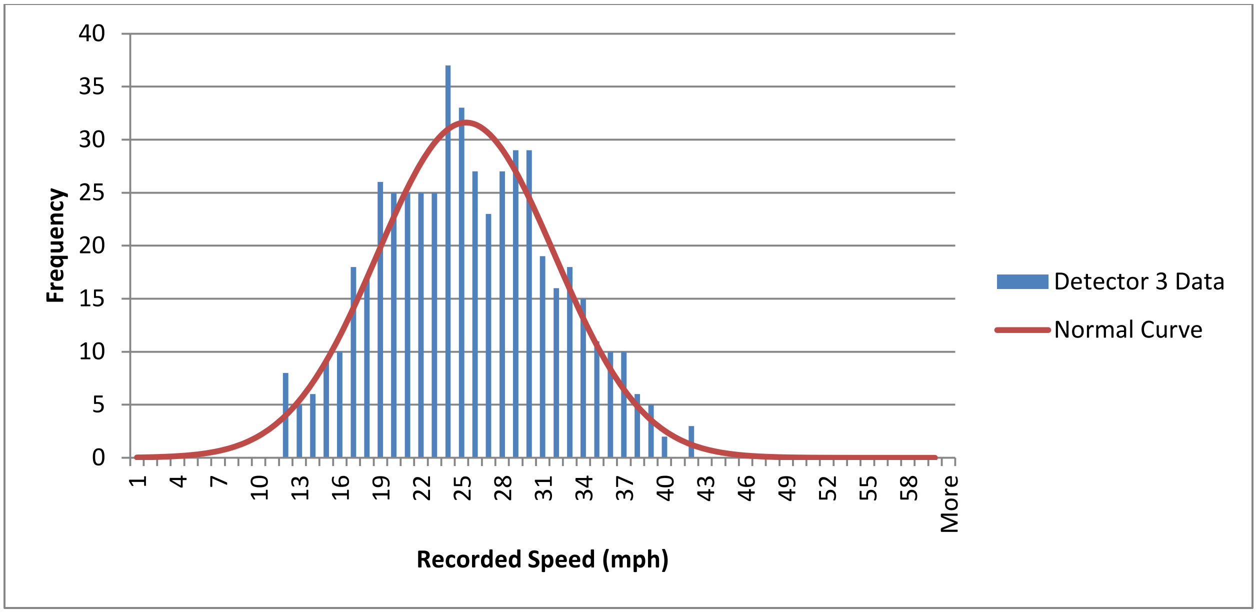

Figure A-3. A comparison of Phase 2A Detector 3 daytime data to a normal distribution

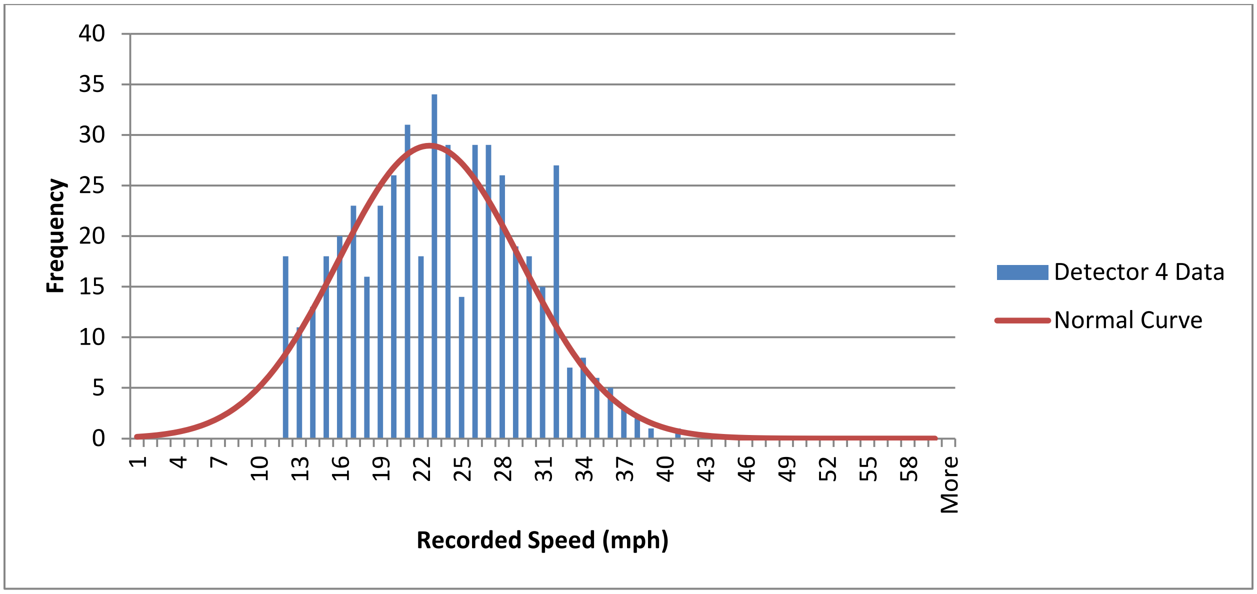

Figure A-4. A comparison of Phase 2A Detector 4 daytime data to a normal distribution

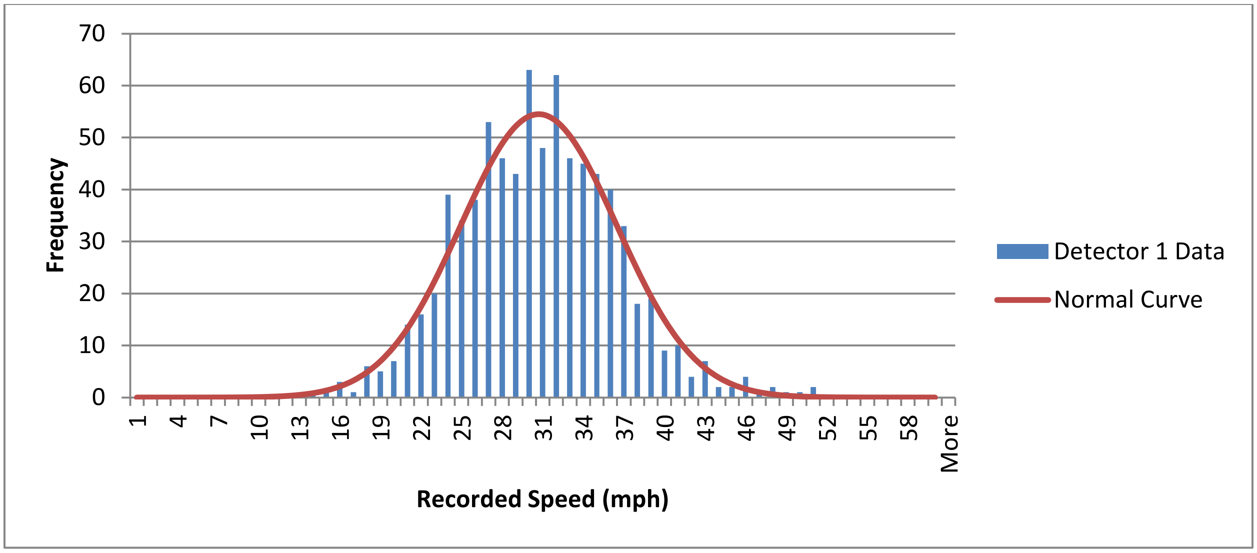

Figure A-5. A comparison of Phase 2B Detector 1 daytime data to a normal distribution

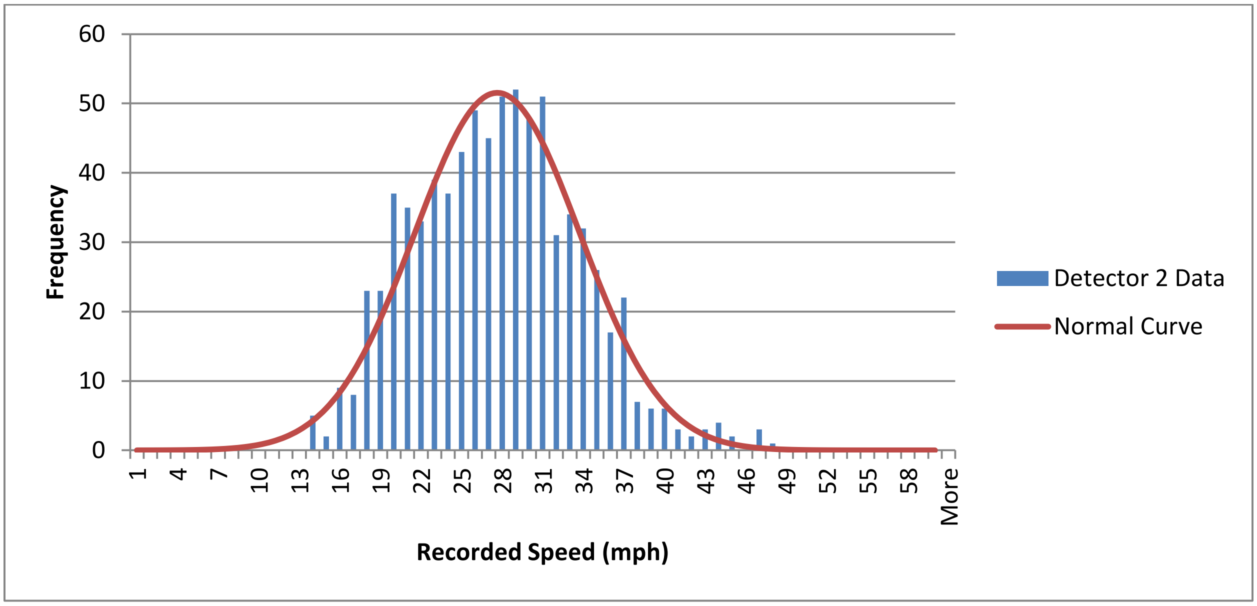

Figure A-6. A comparison of Phase 2B Detector 2 daytime data to a normal distribution

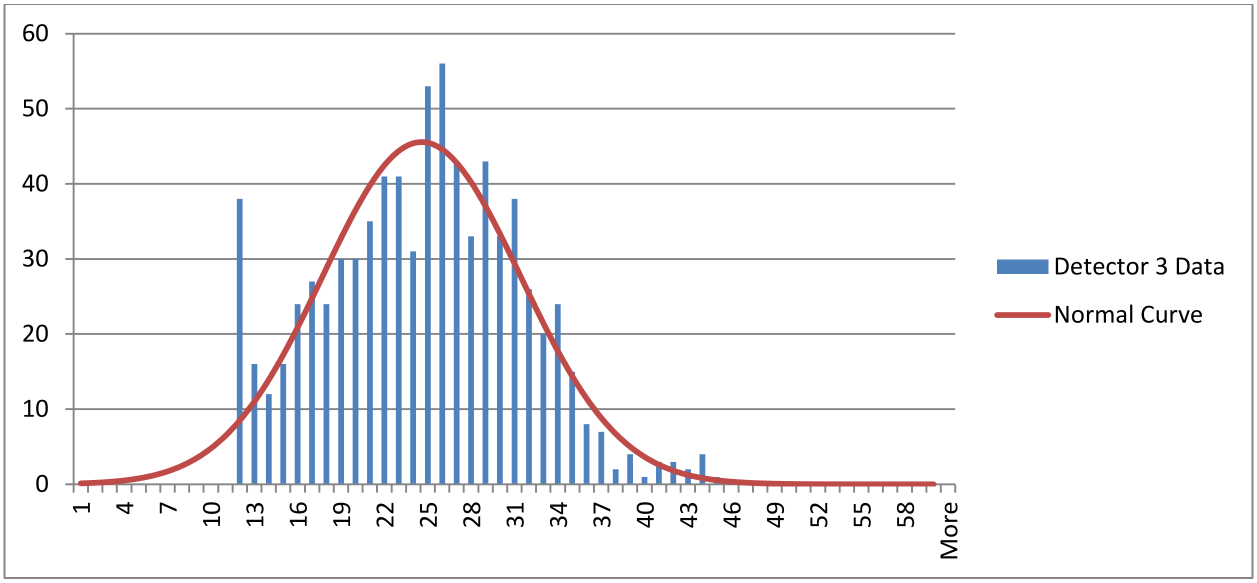

Figure A-7. A comparison of Phase 2B Detector 3 daytime data to a normal distribution

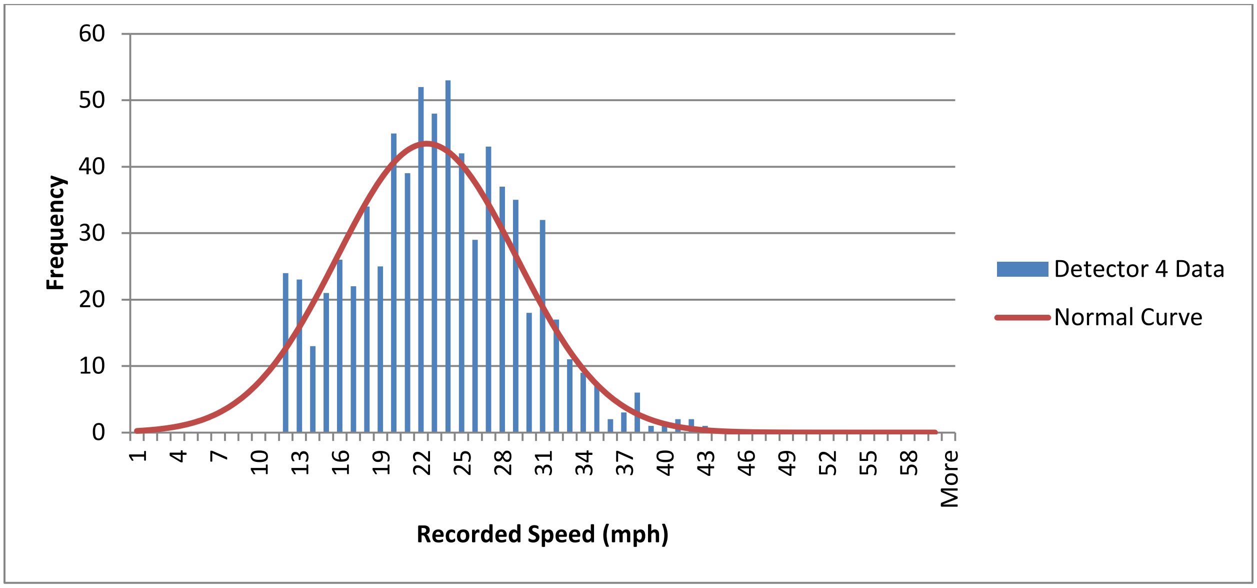

Figure A-8. A comparison of Phase 2B Detector 4 daytime data to a normal distribution

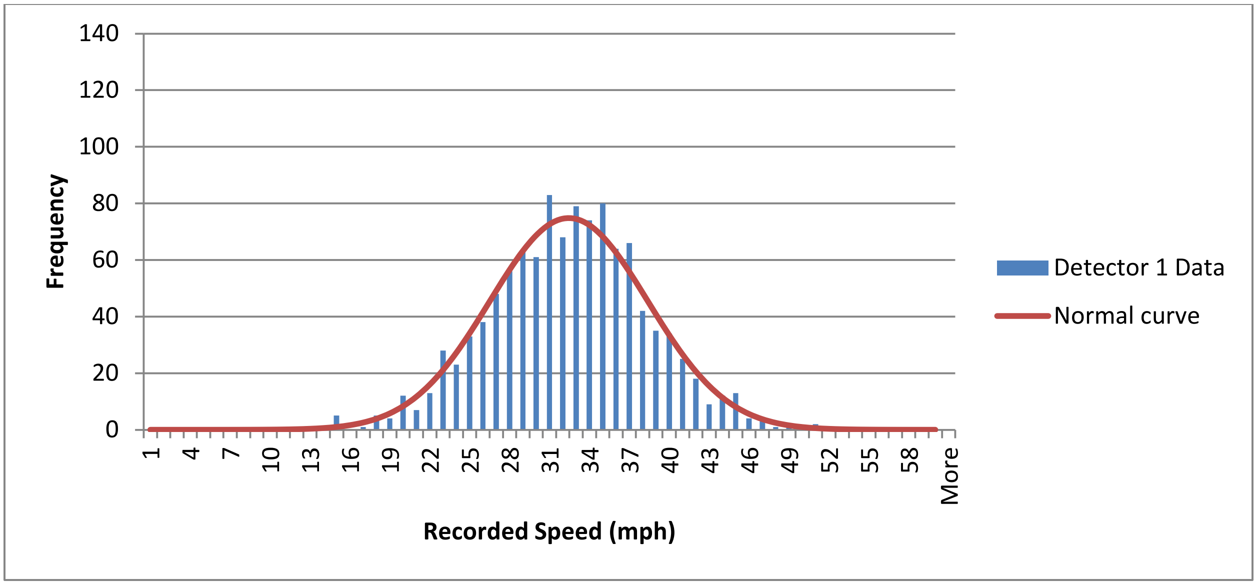

Figure A-9. A comparison of Phase 3 Detector 1 daytime data to a normal distribution

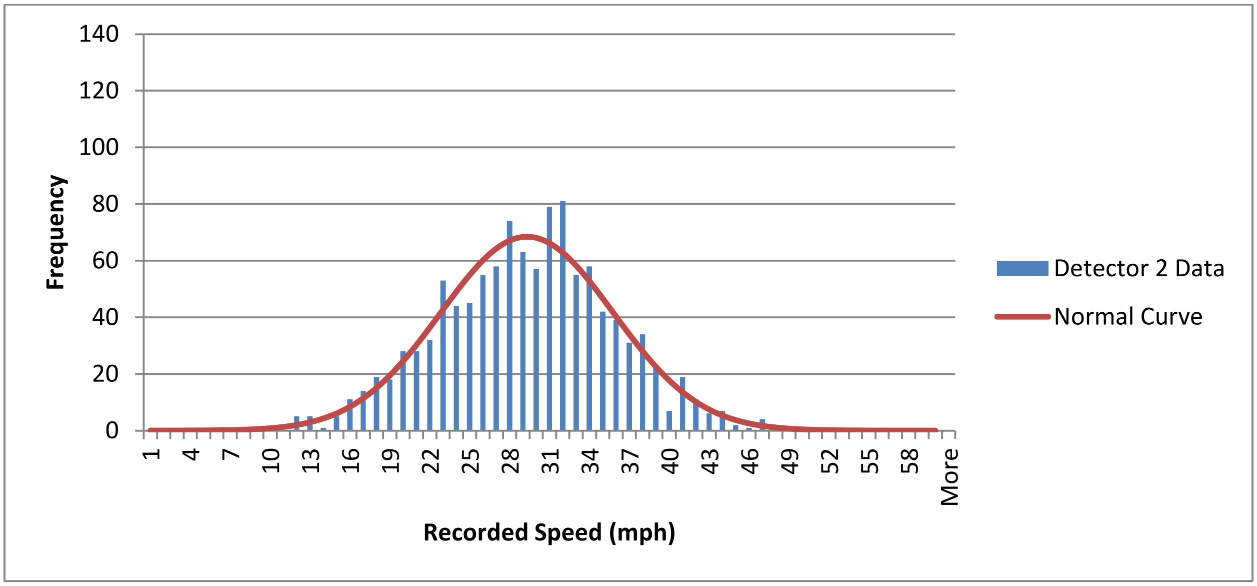

Figure A-10. A comparison of Phase 3 Detector 2 daytime data to a normal distribution

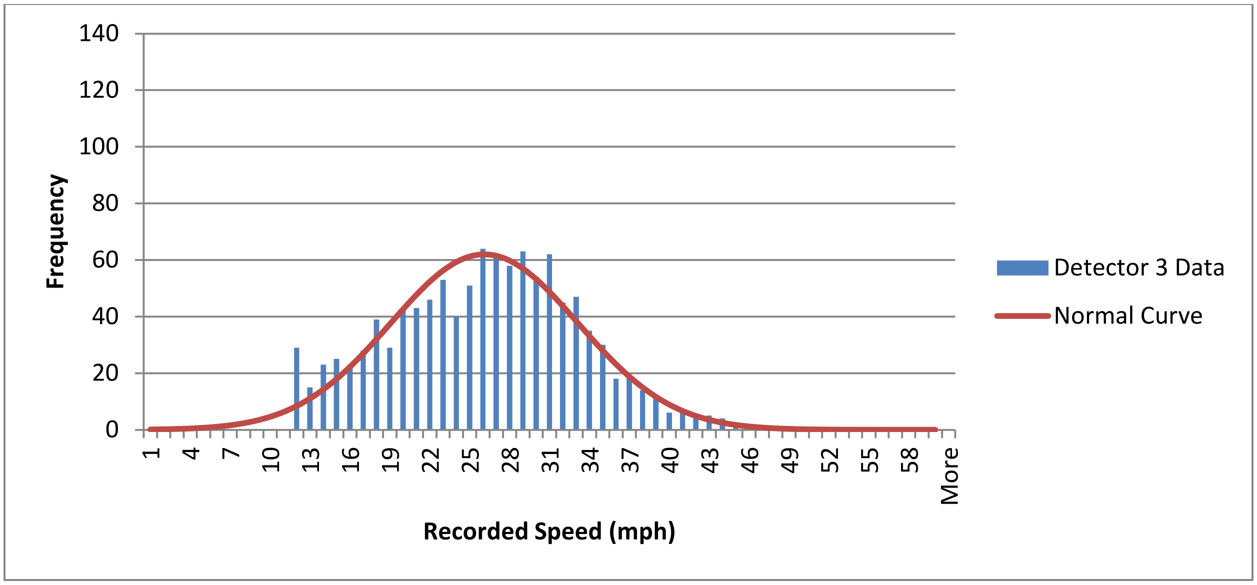

Figure A-11. A comparison of Phase 3 Detector 3 daytime data to a normal distribution

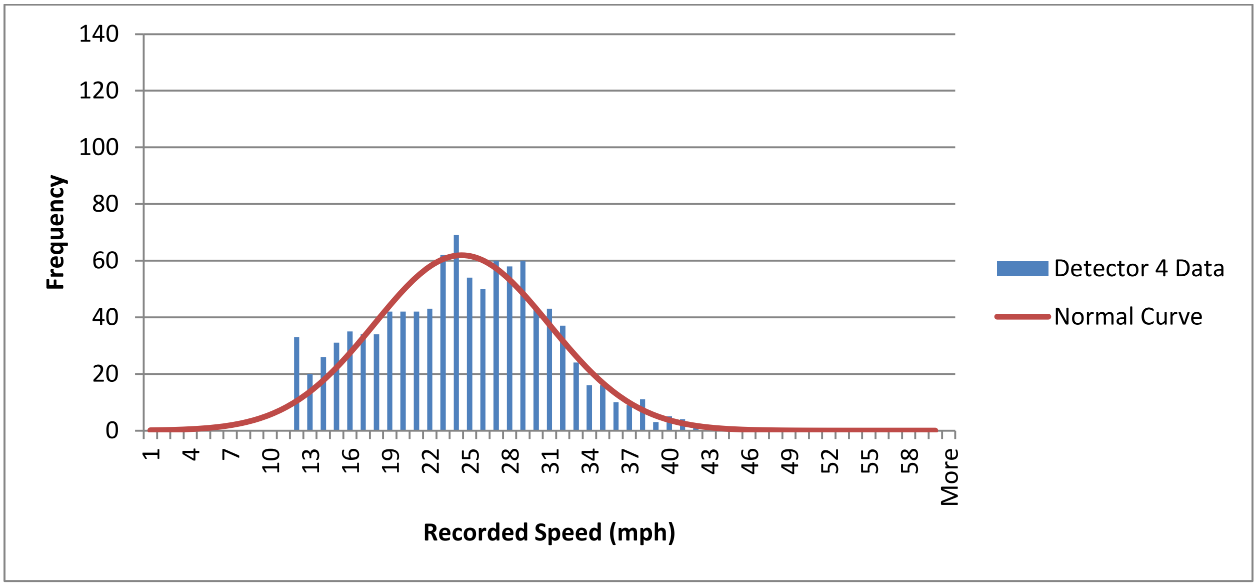

Figure A-12. A comparison of Phase 3 Detector 4 daytime data to a normal distribution

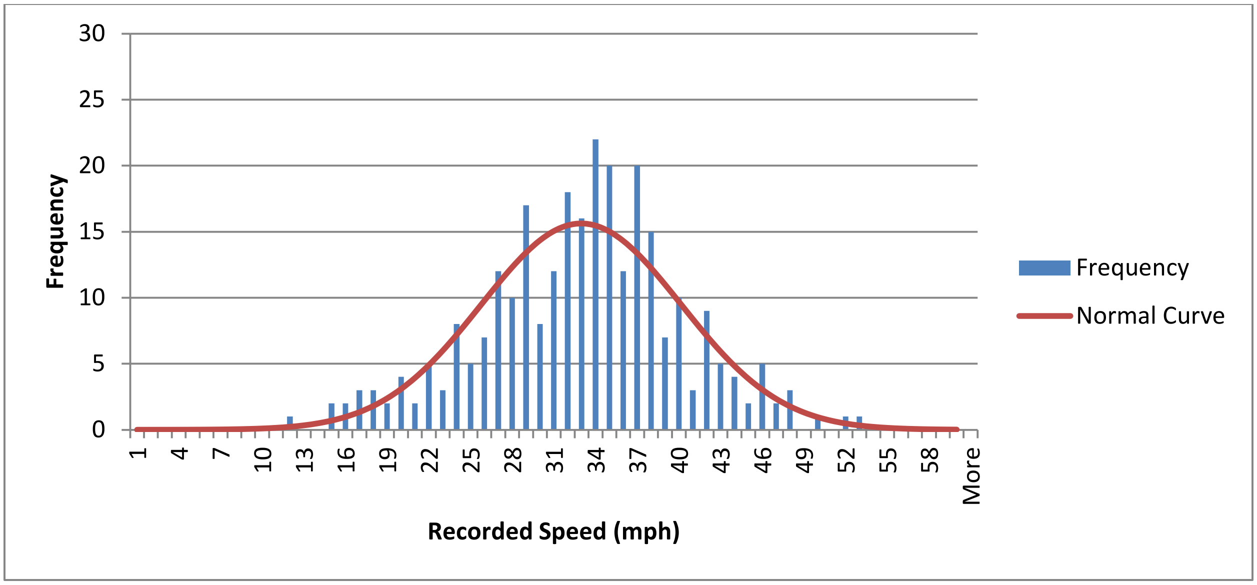

Figure A-13. A comparison of Phase 1 Detector 1 nighttime data to a normal distribution

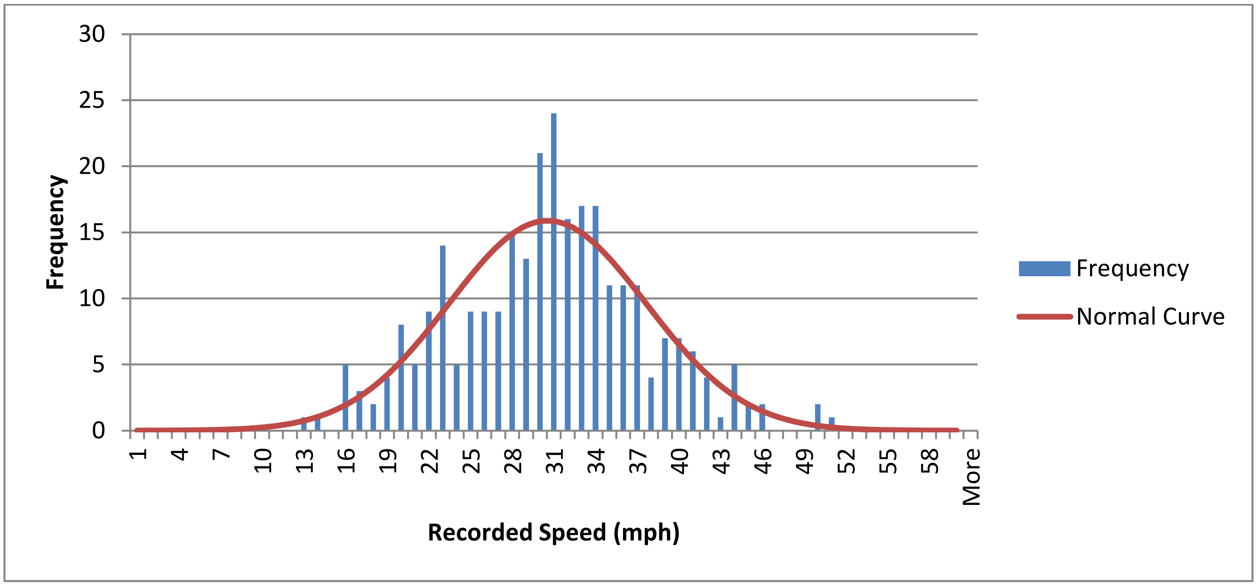

Figure A-14. A comparison of Phase 1 Detector 2 nighttime data to a normal distribution

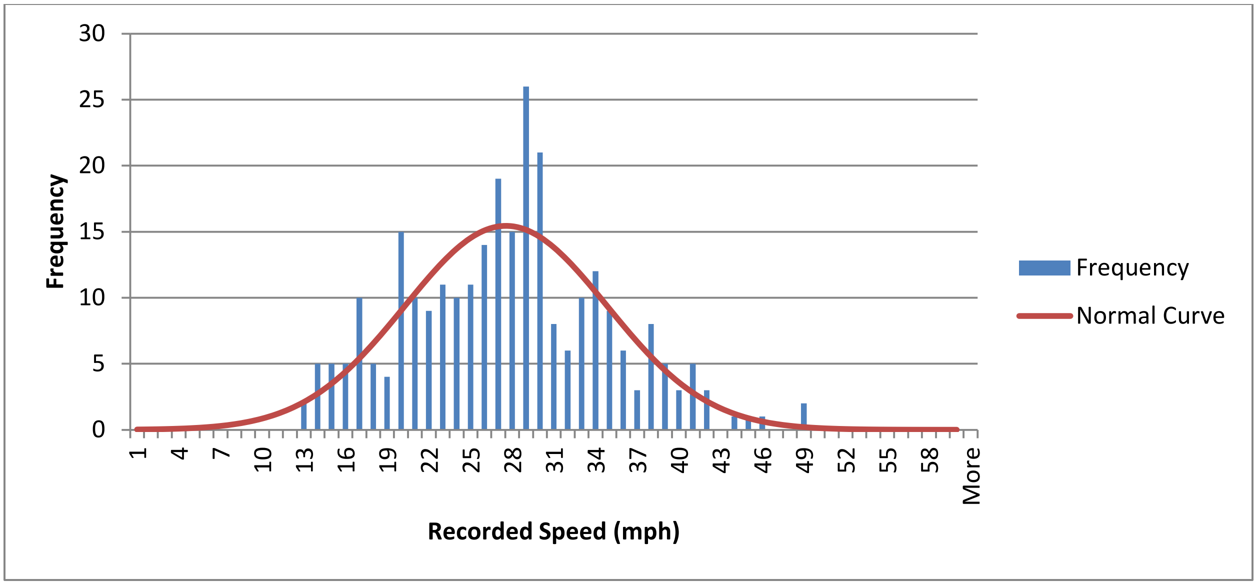

Figure A-15. A comparison of Phase 1 Detector 3 nighttime data to a normal distribution

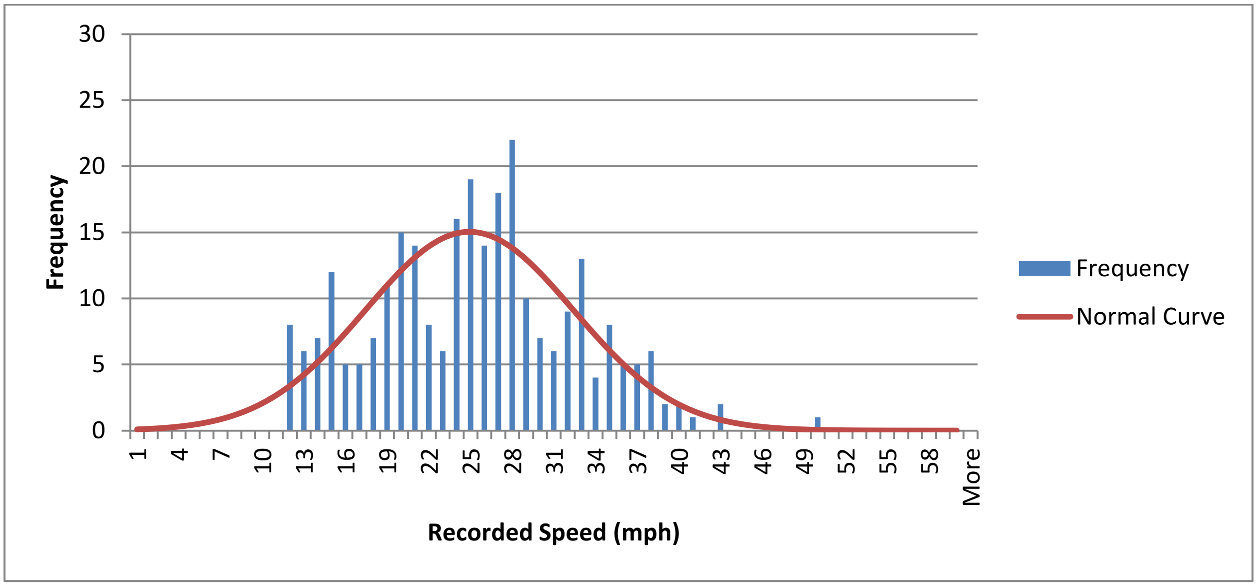

Figure A-16. A comparison of Phase 1 Detector 4 nighttime data to a normal distribution

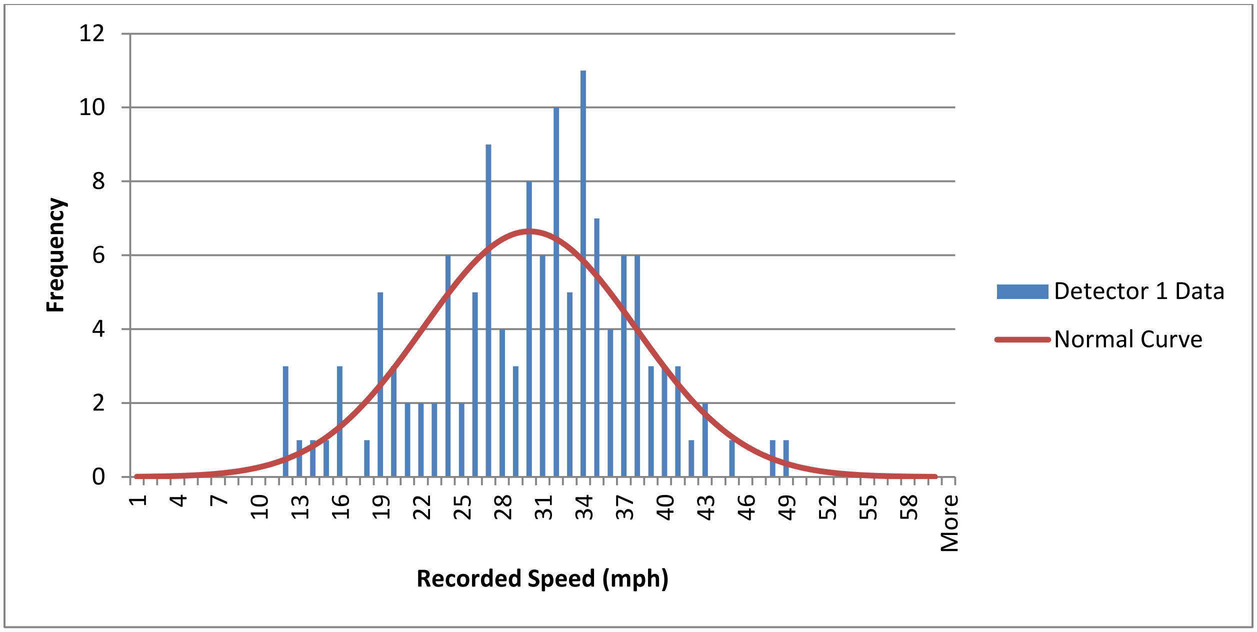

Figure A-17. A comparison of Phase 2A Detector 1 nighttime data to a normal distribution

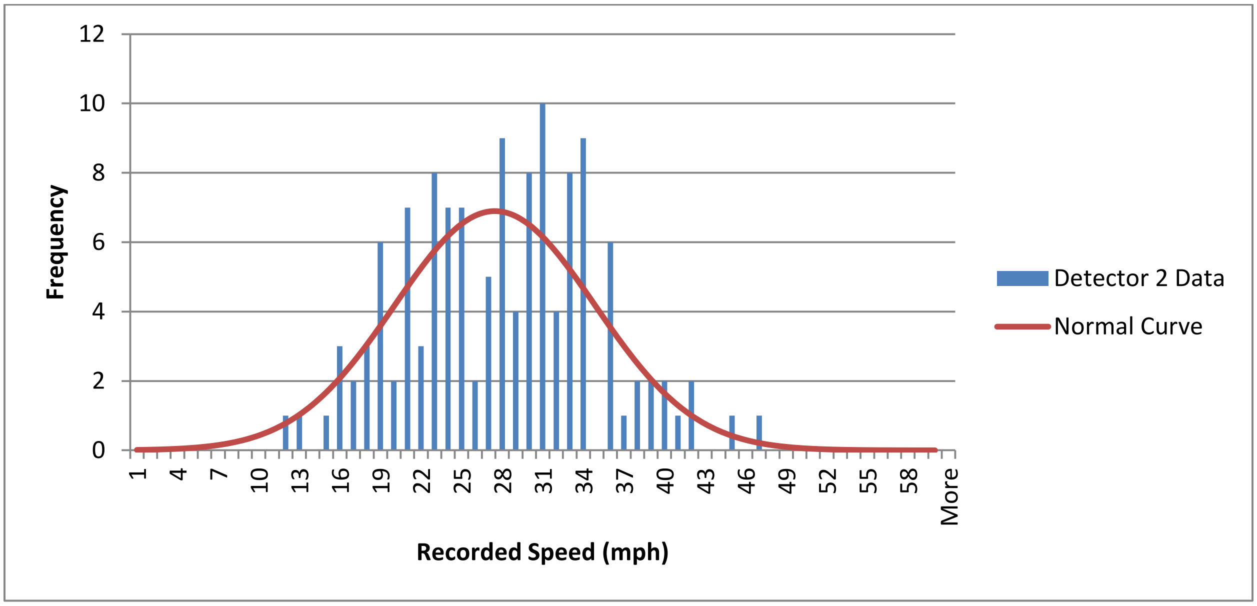

Figure A-18. A comparison of Phase 2A Detector 2 nighttime data to a normal distribution

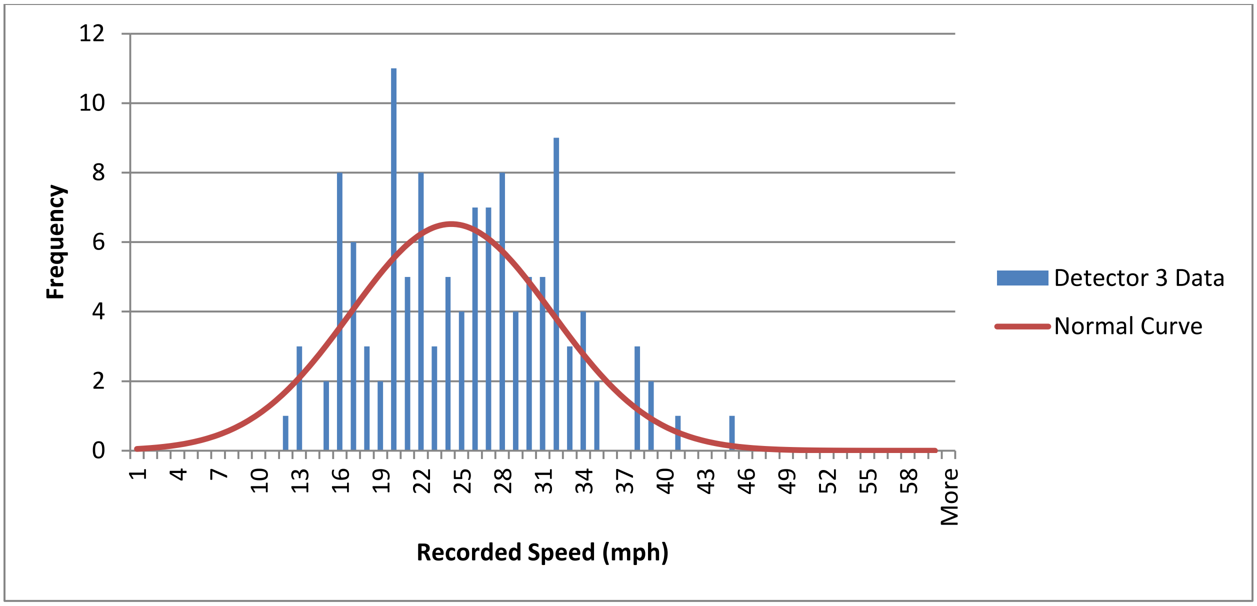

Figure A-19. A comparison of Phase 2A Detector 3 nighttime data to a normal distribution

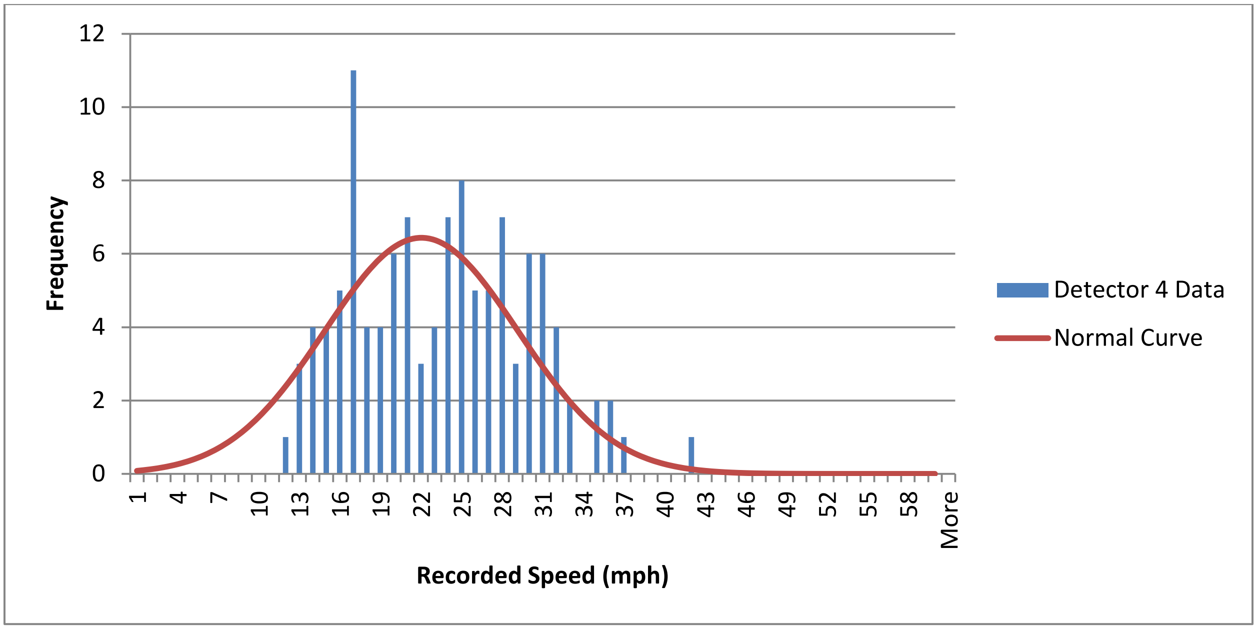

Figure A-20. A comparison of Phase 2A Detector 4 nighttime data to a normal distribution

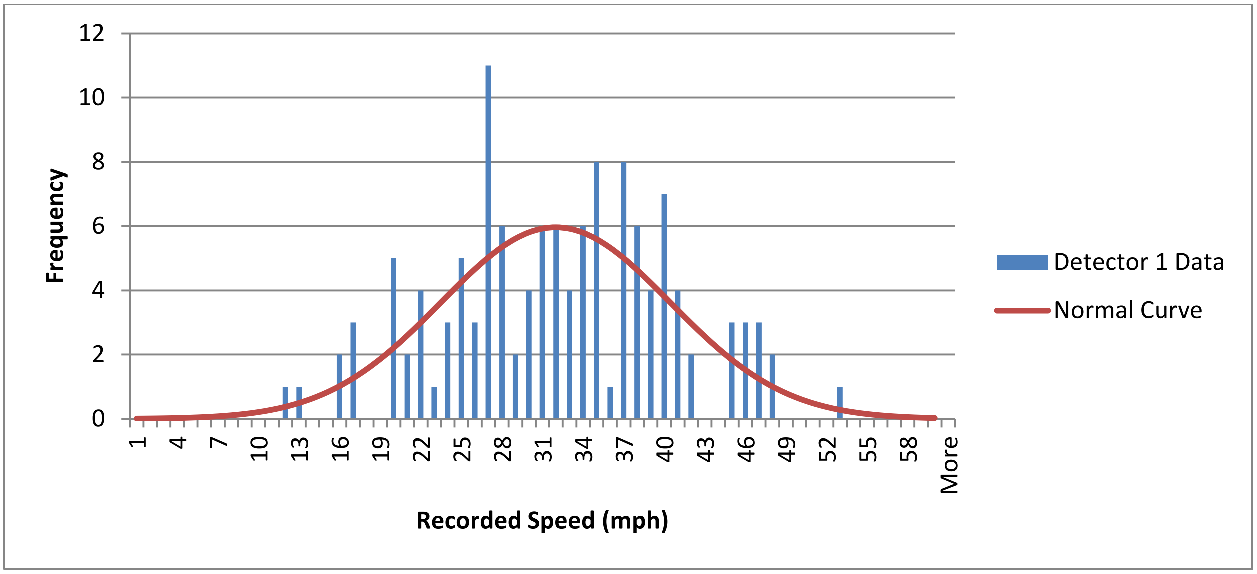

Figure A-21. A comparison of Phase 2B Detector 1 nighttime data to a normal distribution

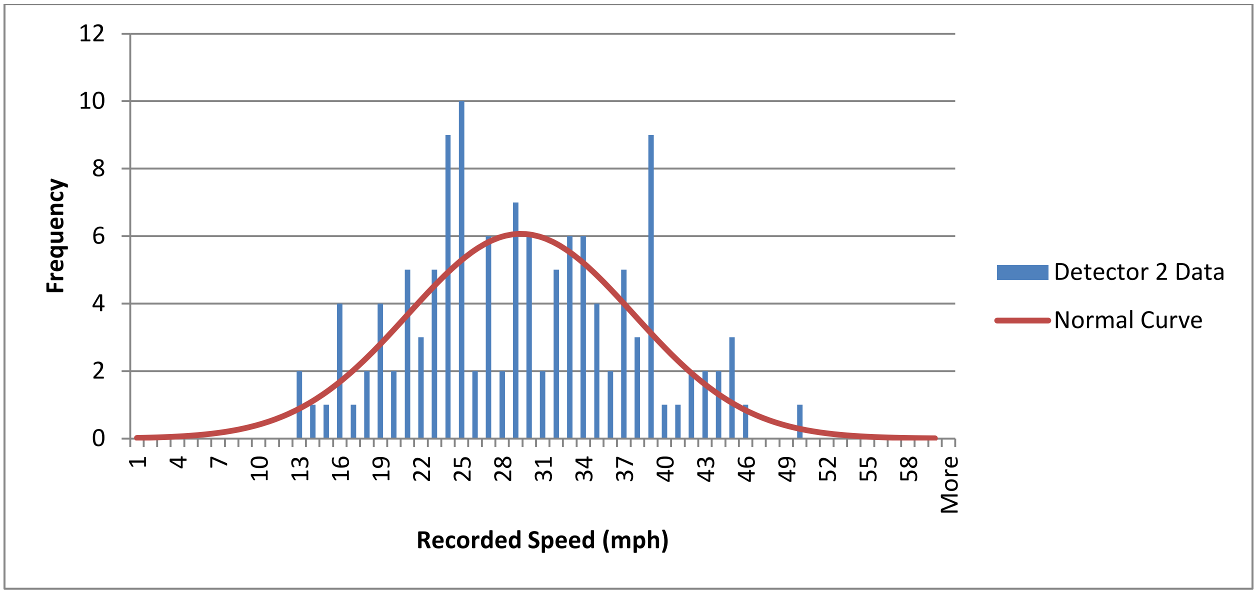

Figure A-22. A comparison of Phase 2B Detector 2 nighttime data to a normal distribution

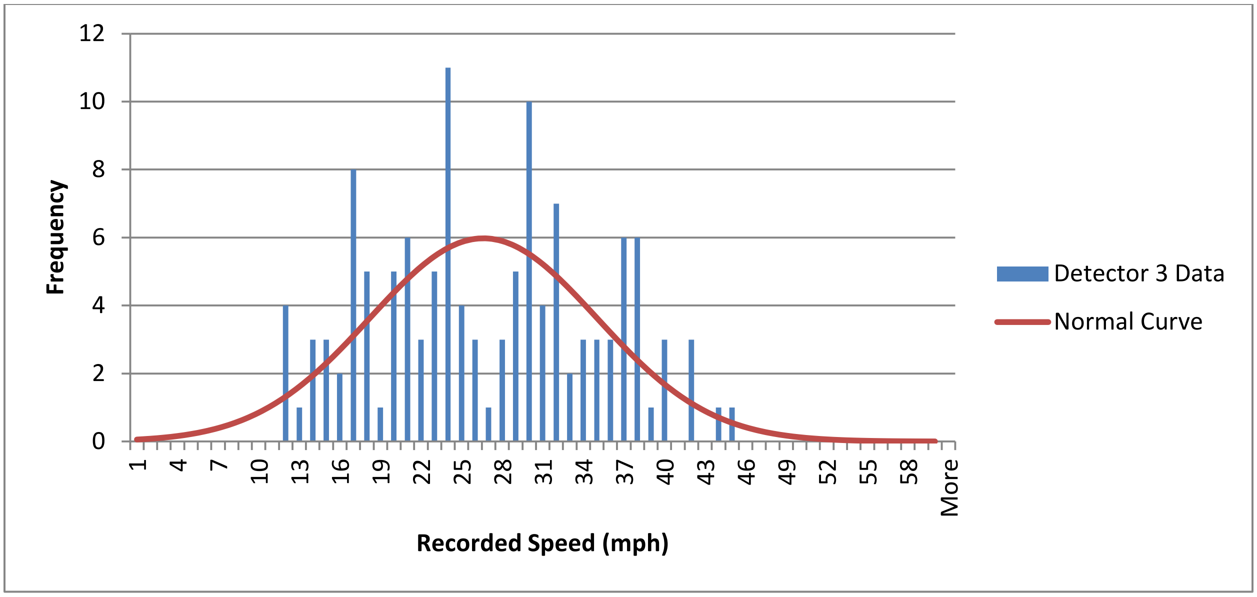

Figure A-23. A comparison of Phase 2B Detector 3 nighttime data to a normal distribution

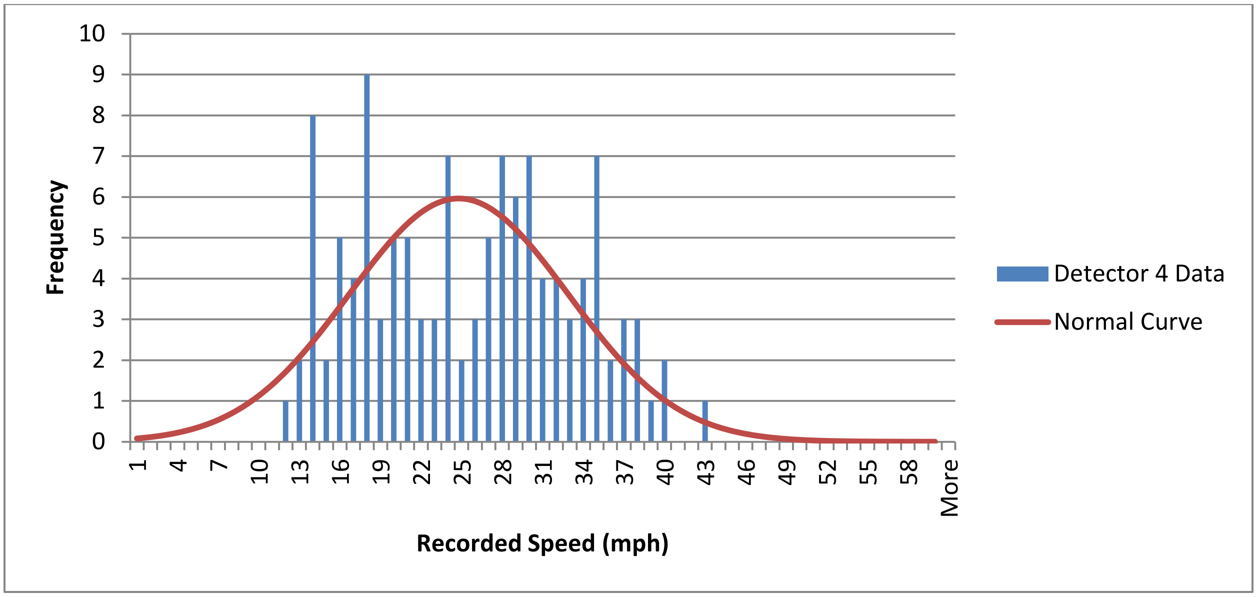

Figure A-24. A comparison of Phase 2B Detector 4 nighttime data to a normal distribution

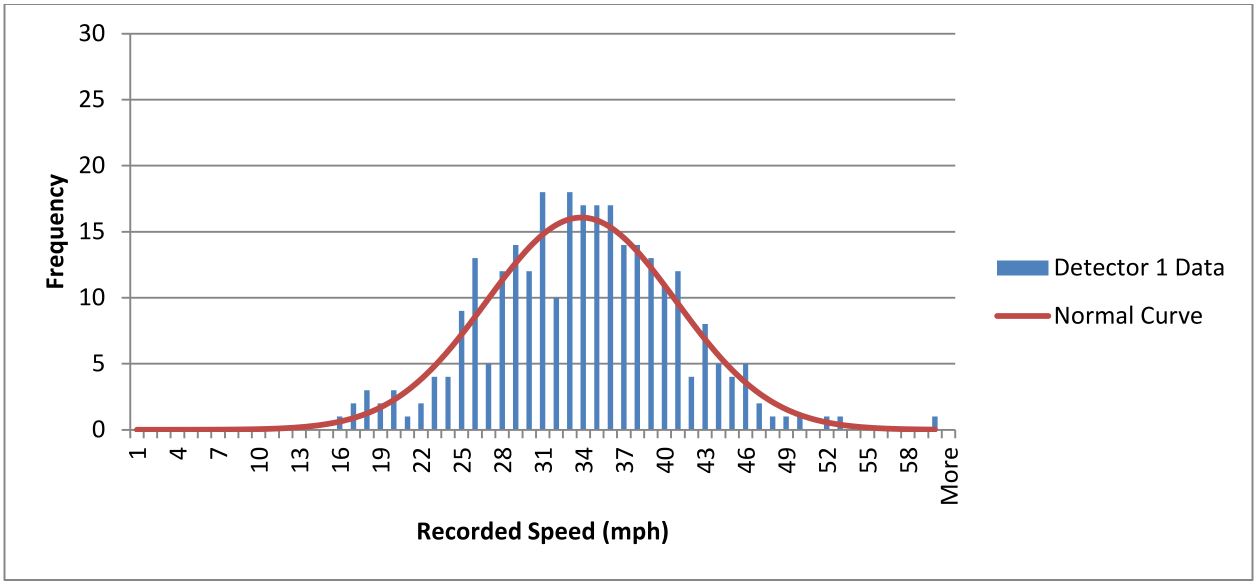

Figure A-25. A comparison of Phase 3 Detector 1 nighttime data to a normal distribution

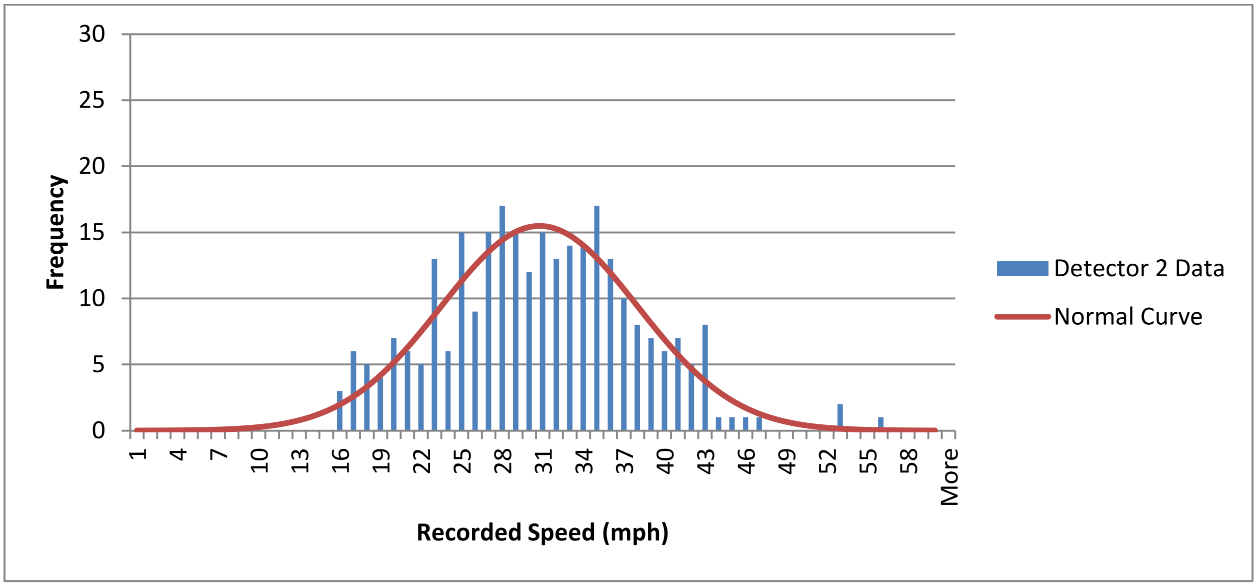

Figure A-26. A comparison of Phase 3 Detector 2 nighttime data to a normal distribution

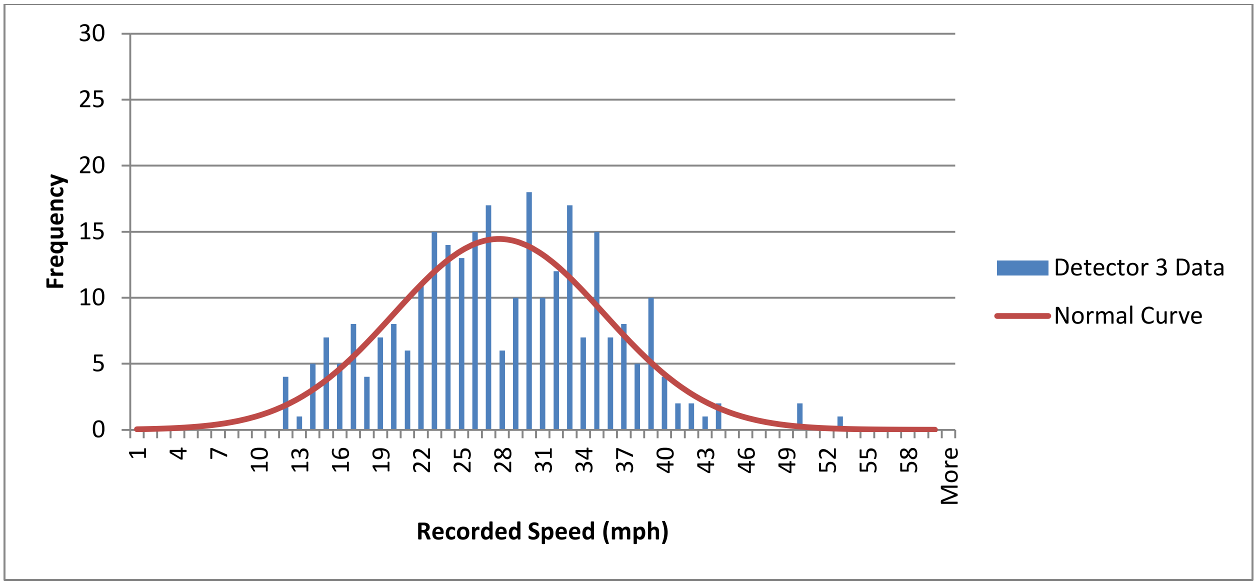

Figure A-27. A comparison of Phase 3 Detector 3 nighttime data to a normal distribution

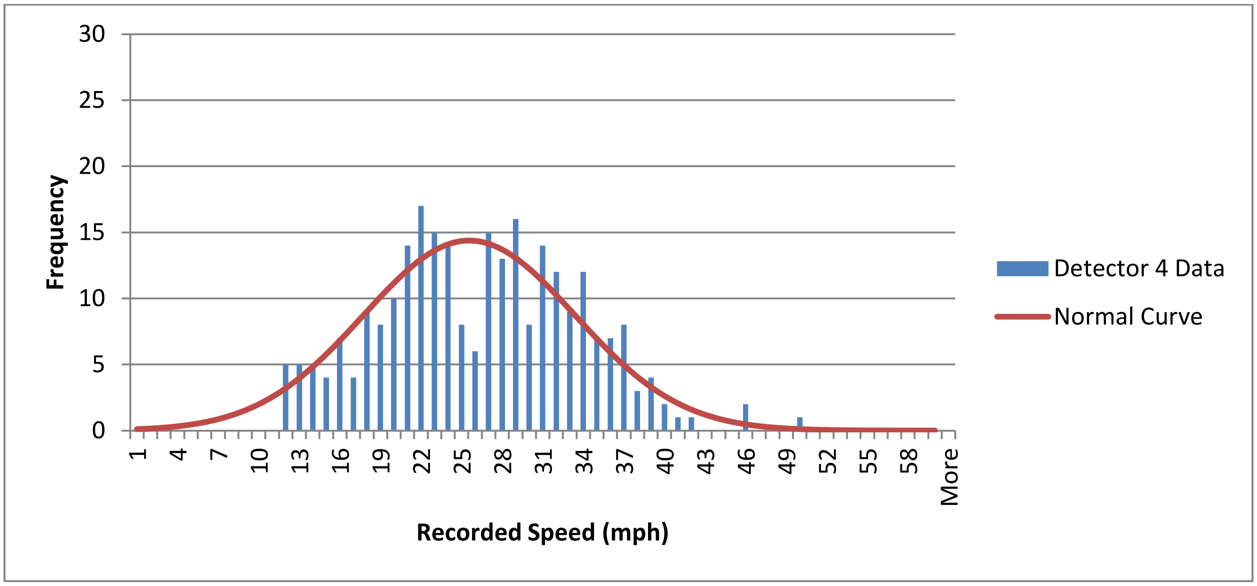

Figure A-28. A comparison of Phase 3 Detector 4 nighttime data to a normal distribution

Abbreviations and Acronyms

AADT	Annual Average Daily Traffic
CN	Canadian National
CTC	Campbell Technology Corporation
FRA	Federal Railroad Administration
IDEA	Innovations Deserving Exploratory Analysis
LED	Light-Emitting Diode
MDFD	Mobile Driver Feedback Device
MPH	Miles Per Hour
MUTCD	Manual on Uniform Traffic Control Devices
MVP	Machine Vision Processing
NECR	New England Central Railroad
PTZ	Pan-Tilt-Zoom
TM	Traffic Moment
TRB	Transportation Research Board
U.S. DOT	United States Department of Transportation
USNO	United Stated Naval Observatory
VDC	Volts Direct Current