RESEARCH & DEVELOPMENT

NCDOT Assessment of Automated Sign Retroreflectivity Measurement

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Abstract

The Institute for Transportation Research and Education at North Carolina State University conducted a follow-up study to a previous North Carolina Department of Transportation (NCDOT) project, comparing mobile inventory data collection vehicles to manually-collected data techniques. In the previous studies, sign retroreflectivity readings were either captured with low degrees of accuracy or not captured at all. The follow-up study focused mainly on automated sign retroreflectivity capture, but also looked at vendor capabilities regarding other sign features. The results show that vendors can accurately *locate* the majority of signs. However, while vendors were unable to consistently capture sign retroreflectivity readings within 10% accuracy, a comparison of MUTCD pass/fail ratings for signs for these vendors showed that they captured ground-mounted signs with 88% and 97% accuracy, and overhead signs with 100% accuracy. Combining the sign location rates and the accuracy of the pass/fail comparison results in an overall accuracy ranging from 63% to 70% which is comparable to the accuracy achieved by other sign management methods. Vendors also showed some consistency in capturing the lower retroreflectivity readings, which should be more important to the NCDOT, as MUTCD thresholds for failing signs are set at the lower level readings. Following location of the sign, vendors showed promise collecting many of the other sign features, such as MUTCD code and roadside orientation, which showed significant improvement from the previous study. This study shows that there is still room for improvement, but also exhibits the improvements that vendors have already made in capturing all sign features.

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1. INTRODUCTION

Mobile vehicle-based roadway data collection systems have proven to be effective in capturing various roadway asset data (*1, 2*), including pavement markings, guardrails, attenuators, bridges, and more. The location of many assets has also been proven to be easily captured by these units, including sign locations. However, in the past, sign retroreflectivity readings have been difficult for these mobile units to capture accurately (*1*). With the North Carolina Department of Transportation (NCDOT) maintaining approximately 79,000 roadway miles, this is important information to capture as there are thousands of signs in Wake County alone, and the current sign management practices in use across North Carolina are inefficient in one way or another. Also, the MUTCD had recently enacted requirements on minimum sign retroreflectivity, with compliance necessary by 2018; however, these requirements have since been removed. This however does not mean that agencies can become relaxed on managing signs, but rather reinforces the necessity of agencies to ensure that signs are visible, particularly at night when the rate of crashes increases despite lower traffic volumes. Likewise, as the MUTCD clearly desires more tangible and quantifiable sign management practices, as opposed to arbitrary inspections, accurate automated detection could prove to be more cost effective than other methods of sign management.

Due to the amount of signs maintained by the NCDOT, any inefficiency in sign management programs is magnified greatly; therefore, improving NCDOT sign management practices could significantly increase cost savings. An improvement in the reliability of sign retroreflectivity data gathered by mobile data collection units is one solution that is attainable and would serve the need of agencies to accurately and efficiently assess the condition of individual signs while enabling the agency to gather information on the other assets in place within a road's right of way. This could prove to be invaluable in maintaining the safety and condition of North Carolina's roadways. This project serves to determine the reliability of new automated sign management practices using asset detection vehicles, but also provides a brief evaluation of other current sign management methods which are in use.

1.1. Research Need

The Office of Asset Management at the NCDOT had previously identified five asset types with potential for automated data collection. These five areas are: drainage, guardrails, signs, pavement, and pavement markings/markers. Based on two prior research efforts of automated asset data collection vehicles, the majority of these assets were found within a reasonable degree of location and condition accuracy. However, while signs could be located and described with an acceptable amount of accuracy, the condition of signs was not accurate. Particularly, sign retroreflectivity measurements, which are the most reliable way to determine a sign's visibility, were not measured at all for the Asset Expo in 2010 due to the inability of the vendors to reliably collect this information (*1*), and could not be measured with any degree of consistency by the vendors chosen for the Asset Inventory study completed in 2012 (*2*).

This presented a problem in that, while these mobile data collection units could provide the NCDOT with a cost effective method for gathering data on many assets, one of the five assets most important to the NCDOT – signs – could not be collected with any amount of confidence. This is particularly problematic due to the sheer number of signs present on North Carolina roadways. In essence, employing these mobile units to gather asset inventory data for the NCDOT is only beneficial if signs are a part of the bundle of information being collected.

Fortunately, new technologies have been developed or improved since completing the Asset Inventory study in 2012. If one or more of these technologies proved to provide sign retroreflectivity readings within a reasonable amount of accuracy, this could open the door to contracting automated mobile data collection units in the future, which could result in a more cost effective and safer method of maintaining an asset inventory than the methods currently being used by NCDOT divisions across the state.

1.2. Scope and Objectives

The first goal of this project was to provide evidence on the viability of automated data collection vehicles in comparison to human collection methods for gathering sign data efficiently, accurately, and reliably. The findings from this effort are further compared to previous study findings in a more recent automated asset inventory project finished in 2013 to see how data are improving in this area (*2*). The second goal was to provide the NCDOT with information on various sign management methods currently in use within and outside of North Carolina, describing the applicability of each method for use by agencies across North Carolina. The literature on various manual methods currently employed and the precision of retroreflectivity using manual methods is also compared to automated methods to help determine the viability of automated methods in the future.

2. LITERATURE REVIEW

Retroreflectivity is used to describe how light is reflected back to its original source. One asset that contains such treatment is signs, which are very important for roadway safety and also reduce confusion while driving. However, current methods for analyzing the retroreflectivity of signs is time consuming and, in some cases, unsafe.

Five study methods are proposed to evaluate and maintain retroreflectivity *(3)*: 1) routine visual nighttime inspections, 2) retroreflectivity measurements, 3) expected life method, 4) the blanket replacement method, and 5) the control method. These five are categorized as assessment methods (1 and 2) and management methods (3, 4, and 5). Assessment methods evaluate individual signs by means of routine inspections and measurements. Method 1, routine nighttime inspection, is a typical method used because it is simple and safe. Method 2, field measurement, is the most accurate method but is time consuming and exposes staff to passing traffic. An example of the field measurement method is shown in Figure 1. Management methods are used to sustain sign retroreflectivity over time without having to assess individual signs. A brief discussion is available in the ITE Manual of Transportation Engineering Studies (*3*), but more in-depth discussion follows in this report. With respect to new management methods, there has been extensive research on the use of automated asset data collection vehicles to detect various roadway assets, including sign retroreflectivity.

Figure 1 Manual retroreflectivity measurement

Asset inventory of road signs consists of detecting, identifying, classifying, locating, and monitoring signs and sign conditions. Generally, automatically generated inventories of road signs have been created by means of processing photo logs, video logs, or right-of-way (ROW) images. The process is as follows: 1) images are taken from a traveling vehicle for a given highway segment or corridor and 2) images are post-processed using software in the lab which calibrates video to known distances in the field. Researchers have developed algorithms that extract road sign inventories by means of geometric recognition, color identification, and region of interest (ROI) detection *(4, 5, 6, 7, 8, 9)*. In addition to video and photography logging cameras, Global Position System (GPS) devices, distance measurement instruments (DMI), and inertial measurement units (IMU) have been implemented into data collection vehicles to track and locate road signs *(5, 10)*.

Moreover, sign inventories often take the condition of signs into account. Due to the new FHWA requirements, retroreflectivity standards have become increasingly important in recent years *(11)*. Originally, according to FHWA's 2009 edition of the Manual on Uniform Traffic Control Devices (MUTCD), all highway agencies had to establish and implement traffic sign assessment or management methods of maintaining minimum retroreflectivity levels by January 2012, which was later pushed back to June 2014. This compliance date requires that agencies have an assessment or management method implemented by this date, not that all signs below minimum retroreflectivity thresholds must be replaced by this date. The signs below the minimum levels are to be replaced as resources and priorities allow, per the FHWA website (*12)*.

Likewise, agencies are required to meet certain minimum retroreflectivity levels, which depend on sign type, by prioritizing regulatory and warning signs for replacement once they are below thresholds. While there is no specific date set for this replacement process, it should occur whenever these signs reach levels below the minimum retroreflectivity levels. While these standards have been known for the past few years, agencies like the NCDOT are still trying to determine the best method for ensuring compliance to these standards. The most common methods are described immediately below. Further discussion on what is being done across the country to determine the most cost-effective method follows.

2.1. Sign Management Methods

This section describes the maintenance methods available for ensuring nighttime sign visibility. It's content is derived from the National Cooperative Highway Research Program's (NCHRP) *Practices to Manage Traffic Sign Retroreflectivity* Synthesis report, which provides examples of effective practices that illustrate how agencies can meet retroreflectivity requirements (to meet visibility thresholds), the *Manual on Uniform Traffic Control Devices* (MUTCD), which defines standards used by road managers to install and maintain traffic control devices, and other studies that focus on sign retroreflectivity. The NCHRP synthesis report contains information from 40 state departments of transportation, which provide insight into the best practices of sign management. The MUTCD offers five traffic sign methods for maintaining nighttime sign visibility, which are discussed in this section.

This section is designed to provide succinct summaries for each of the five retroreflectivity maintenance methods (i.e. Visual Nighttime Inspection, Measured Sign Retroreflectivity, Expected Sign Life, Blanket Replacement, and Control Signs). It is organized to show a quick snapshot of the retroreflectivity accuracy, cost-effectiveness, and ease of implementation for each maintenance method. In addition, it provides a description of the method, implementation considerations, and the advantages and limitations of each method. Last, the synthesis of this write-up is provided in Appendix B for quick summary guidance.

2.1.1. Visual Nighttime Inspection

Study Description

Visual nighttime inspection is a common method for maintaining traffic sign retroreflectivity and guidelines for the inspection procedure have been documented for approximately 50 years. The retroreflectivity of an existing sign is assessed by a trained sign inspector conducting a visual inspection from a moving vehicle during nighttime conditions. Signs that are visually identified by the inspector to have retroreflectivity below the minimum levels are to be replaced.

Implementation Considerations

Visual nighttime inspection requires one individual, but is more effective with two; a dedicated inspector monitoring and recording sign failures and a focused driver following a predetermined inspection route. It is important that visual inspection take place during typical nighttime conditions and that viewing not be affected by adverse or inclement weather such as fog or rain. Interior vehicle lighting should be minimized so that the inspector's vision is not affected. The inspection can emulate how a normal driver would view a typical sign: at normal roadway speeds, from an appropriate travel lane, and at an adequate viewing distance. Sign failures and noteworthy comments are to be documented in a standardized procedure. The inspector can document his or her evaluations by means of written notes on an agency form, audio recording, or laptop computer. The duration of a nighttime inspection session must not exceed a period where inspector fatigue becomes an issue or where roadway conditions change, such as frost forming on a sign. Throughout inspections, it is important to be consistent with agency procedures and be able to document when the nighttime sign inspections have been completed.

Advantages

- Evaluates more than sign retroreflectivity, such as face uniformity, message legibility, sign support integrity, damage, knockdowns, vandalism, obscuring vegetation, general sign visibility, etc.
- Provides the opportunity to observe other roadway items such as raised pavement markers, pavement striping, delineators, and object markers
- Does not require advanced equipment or sophisticated computer programs
- Limits the amount of waste because only failed signs are targeted for replacement

Limitations

- Sign evaluation is subjective
- Inspectors need to be properly trained and one of the three supportive techniques (written notes, audio recording, or laptop/tablet) be used correctly
- Inspectors must be 60 years old or older to ensure representation of an array of visual acuity, although they must still have driver vision capabilities within the legal limits of the State
- Because nighttime inspection occurs during non-regular work hours, overtime and next-day scheduling may be a concern
- There are outside aspects that are difficult to control such as weather, moisture in the air, and oncoming vehicles' headlights

Case Studies

There have been a number of studies that have evaluated the visual nighttime inspection method. Case studies included in the National Cooperative Highway Research Program's *Practices to Manage Traffic Sign Retroreflectivity* Synthesis report are included below.

- **Indiana (*13*)** – Researchers compared the pass or fail decisions of sign inspectors with the retroreflectometer measurements captured in the field. There were 1,743 signs measured on roadways and inspectors were accurate in 88 percent of the pass/fail decisions. The study found that visual nighttime inspection was a reasonably accurate method with minimally trained personnel.
- **North Carolina (*14*)** – Similar to the Indiana study, researchers evaluated the accuracy of North Carolina DOT (NCDOT) staff evaluations by comparing the visual nighttime inspection pass or fail decisions with retroreflectivity measurements. The study collected retroreflectometer measurements of 1,057 inspected signs on various types of state roadways in five different counties. Overall, the analysis determined that the NCDOT sign inspectors were effective in identifying and removing signs that were below the minimum values, and that accuracy levels ranged from 54 percent to 83 percent.
- **Texas (*15*)** – In a statewide survey of Texas Department of Transportation (TxDOT) district sign maintenance offices, the researchers found that 80 percent of the districts conducted nighttime visual inspections and 65 percent also performed daytime inspections. Approximately 83 percent of the districts would implement visual inspection training when the proposed FHWA requirements took effect. Researches also conducted a cost-benefit analysis of several different sign maintenance methods and determined that visual inspection was one of the least expensive methods. In a follow-up study, TxDOT staff subjectively assessed 49 test signs during nighttime conditions. Only one test sign failed to meet the MUTCD minimums; however, the TxDOT staff rejected a total of 26 signs. For TxDOT staff, overall appearance and uniformity of the sign face were as important as the retroreflectivity levels, when considering accepting or rejecting a sign.
- **Washington State (*16*)** – Researchers trained observers to rate STOP and warning signs on two highway courses with a total of 130 traffic signs. The observers made correct ratings for 75 percent of the signs and, within the total incorrect responses, observers were more likely to replace an adequate sign than to accept a sign with insufficient retroreflectivity.

2.1.2. Measured Retroreflectivity

Study Description

For the measured retroreflectivity method, specialized equipment is used to obtain retroreflectivity values of sign faces. There are two ways to determine retroreflectivity values: (1) obtaining values through contact instruments, (2) obtaining values through non-contact instruments, which measure sign retroreflectivity from a distance. Contact instruments, commonly referred to as retroreflectometers, offer precise measurements, but their time requirements are considerable. Non-contact instruments, such as vehicle-based systems, offer speed and flexibility to the measurement process; however, their tradeoff thus far has been higher levels of uncertainty.

Implementation Considerations

Contact measurements require significant operator time. To be in compliance with the ASTM Standard Test Method E1709, a retroreflectometer operator must acquire a minimum of four retroreflectivity measurements per sign. In addition, contact measurement can be dangerous. Overhead signs, signs in high-traffic corridors, and other difficult to reach signs expose sign technicians to roadway hazards. Furthermore, individual retroreflectometer units can cost between $10,000 and $12,000; therefore assigning them to individual sign technicians is not typically feasible. In general, contact measurements appear to be best suited to complement another method.

Non-contact management measurement is still largely in the stage of development. However, much work has been done recently to enable vehicle-based systems to measure signs accurately at highway speeds. This study evaluates the viability of vehicle-based systems for measuring sign retroreflectivity.

Advantages of Contact-Device Measurement

- Readings can be directly compared with MUTCD minimum levels
- Measurements can be obtained during normal daytime work hours
- There may be little or no sign waste because signs near the end of their service life periods can be targeted and replaced

Limitations of Contact-Device Measurement

- Signs may be difficult to access because of physical barriers, sign height, and certain roadway conditions.
- Retroreflectometers cost between $10,000 and $12,000, often making them too expensive to provide to multiple sign technicians
- Sign measurement standards require four retroreflectivity measurements per sign, which makes contact measurement a time-intensive process

Advantages of Non-Contact (Automated) Device Measurement

- Retroreflectivity measurements can be taken at highway speeds
- Sign measurements can be matched with latitude and longitude coordinates to create a sign inventory that has sign locations with their corresponding retroreflectivity levels
- Does not expose sign technicians to dangerous measurement conditions

Limitations of Non-Contact (Automated) Device Measurement

- Technology is still largely in its development phase
- System-wide measurement on a per sign basis is expensive, if data on other assets are not collected as well
- The precision of retroreflectivity measurements may vary depending on landscape features

2.1.3. Expected Sign Life

Study Description

The expected sign life method aims to pinpoint the length of time that a certain sign sheeting material will be used in the field while remaining in compliance with minimum retroreflectivity requirements. For this method an agency may use sign sheeting warranties, test deck or field measurements, or empirical data from other regional studies to project an expected service life for signs. If using sign sheeting warranties to project service life, an agency replaces signs when their warranties have expired. If using test-deck or field measurements to project service life, an agency measures the retroreflectivity values of a group of signs in the field. Based on these values, an agency assigns a replacement date for signs of the same type. If using empirical data to project an expected service life for signs, an agency uses research findings to determine replacement data for signs. Once an agency determines how it will project its expected service life, it can develop its sign management system by: (1) establishing sign installation dates, (2) identifying and locating individual signs, (3) creating an organized inventory of signs, including their installation dates and when they need to be replaced.

Implementation Considerations

Agencies considering the expected life method need to thoroughly research the many options available before selecting a management system. An agency could take into consideration its level of resources, funding, staff demands and technical expertise. This method also requires great cooperation and buy-in from agency staff. If staff members are unwilling to fully support the system and keep the sign information up-to-date and accurate, then any investment could be wasted.

Advantages of Expected Sign Life

- This method can expedite and streamline signing operations
- This method provides asset management capabilities and enhanced tools for planning, scheduling, and budgeting purposes
- Sign replacement can be thoroughly documented

Limitations of Expected Sign Life

- Collecting sign inventory data and initially creating an expected sign life system can be an expensive and time-consuming process
- This method depends on accurate and up-to-date information of individual signs
- Administrative, maintenance, and upkeep cost can be high

2.1.4. Blanket Replacement

Study Description

The blanket replacement method is similar to the expected sign life method; the fundamental difference is that agencies assign a replacement date for a large group of signs (all on one date) as opposed to individual signs (over a span of different dates). Sign replacement can be based on either spatial or strategic data. Under a spatial replacement system, all signs within certain geography are replaced at a given date. Under a strategic system, all signs of a common characteristic, such as sheeting type, sign classification, and sign content, are replaced at a given date. Blanket replacement may incorporate both spatial and strategic characteristics by removing specific signs types in a certain area.

Implementation Considerations

A major advantage of the blanket replacement method is that it is relatively straightforward to implement. It does not require extensive personnel training, there is a low administrative cost, and a computer-based sign inventory system may not be a requirement. When implemented, agencies often stagger the blanket replacement schedule to simplify planning and budgeting. For example, consider an agency using Type III High-Intensity Beaded Sheeting that has a warranty of 10 years. In this instance, the agency may benefit from dividing its jurisdiction into ten different areas, where every year signs in one of the ten areas are replaced. Since an agency would know that roughly 10 percent of its signs would need to be replaced every year, it would help for planning, scheduling, and budgeting.

Advantages of Blanket Replacement

- Identifying signs and formulating the replacement schedule is simple and straightforward
- Administrative costs are low
- Regular replacement cycles can help with planning, scheduling, and budgeting

Limitations of Blanket Replacement

- There is a high possibility of premature sign replacements
- Operating costs and additional sign installation labor could be higher than with other methods

2.1.5. Control Signs

Study Description

For the control signs method, the performance of a sample set of signs is used to determine when signs in the field should be replaced. When the sample set, or control signs, approach the retroreflective minimums, all corresponding signs in the field are replaced. The control signs method requires a means of establishing a credible sample set, sign evaluation techniques, and a system to locate corresponding signs in the field.

Implementation Considerations

A sample set of signs should be representative of signs in the field. Carlson and Lupes (2003) recommend that a minimum of three signs per sheeting type should have their retroreflectivity levels measured as a “barometer” for sign conditions in the field. In addition, signs that are being tested should face different directions and be spaced at strategic intervals to account for different levels of exposure to light and other conditions. These considerations will help agencies determine how signs of a given sheeting type are performing in the field. Retroreflectivity measurements of these signs should be taken at intervals that meet an agency’s objectives and desired level of precision. Too little time between measurements of control signs may lead to the misuse of labor and resources, whereas long periods between readings may lead to inaccuracies in predicting service life in the field.

Advantages of Control Signs

- Region-specific measurements can be made on a year-to-year basis to measure sign performance without having to measure every sign in the field
- The extension of service life for a specific sign type can be validated through this method to minimize costs and resources
- Sign waste is limited as signs can be replaced after sign warranties have expired

Limitations of Control Signs

- There is no guarantee that the performance of a sample set of control signs is truly representative of the performance of other signs in the field
- Installing control signs, collecting measurements, and analyzing the data can be time-consuming and costly
- Agencies need to purchase or obtain a retroreflectometer
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2.2. Evaluating Management Methods

As the aforementioned management methods are widely accepted as the most common and useful methods to manage sign inventories, there have been numerous studies conducted evaluating the practicality of each method. As might be expected, they seem to point to using the nighttime visual inspection method.

One such study in North Carolina (*17*) found that the nighttime visual inspection method resulted in a lower percentage of signs not compliant with FHWA standards while also resulting in a lower cost per sign than the other methods researched, including measured retroreflectivity, expected sign life, and blanket replacement. This study found that the more effective methods at reducing non-compliant signs typically were the most expensive, namely blanket replacement and measured retroreflectivity. Likewise, the frequency of inspection affected the cost but also affected the percentage of non-compliant signs for the visual nighttime inspection and measured retroreflectivity methods; meaning if signs were inspected once per year, the cost would be significantly greater for each method, but the percentage of non-compliant signs would also be much lower than if they were only inspected once every three years.

Another study conducted in Utah suggested initially conducting a survey of a sample set of signs to determine agency compliance rates (*18*), while also suggesting blanket replacement of all Type I signs (*19*), as they were found to fail at a much higher rate and caused a significant increase in the number of non-compliant signs (91% compliant) in comparison to just Type III signs (97% compliant). Issues identified in these studies include the inability to accurately quantify sign damage, rotational significance, Type I failure rates, and a lack of installation dates. Ultimately, the research suggests using a visual inspection method or retroreflectivity measurement method during future evaluation periods.

However, not all experts agree on what method works best for sign management and assessment. A presentation developed by professionals in Minnesota has found that the cost effectiveness of each method depends on the size of an agency's sign inventory (*20*). Specifically, larger systems (>10,000 signs) should consider management methods like expected sign life, blanket replacement, or control signs as the most cost effective methods, whereas smaller systems might save more money using one of the two assessment methods presented: visual nighttime inspection or measured sign retroreflectivity. This presentation suggests that assessment methods cost the most up front, but save funds by allowing agencies to get the most out of their signs. On the contrary, the management methods save more up front by not requiring as much manpower or technology, but cannot take advantage of the full life of a sign.

2.3. Review of Automated Collection Processes

In trying to meet sign condition requirements, FHWA along with private vendors have been working to develop vehicle-based retroreflectometers. FHWA was first to introduce this technology in 2001, called the Sign Management and Retroreflectivity Tracking System (SMARTS) which was equipped with a high intensity flash source, cameras, a range-sensing device, and a GPS unit *(21)*. The system requires a driver and retroreflectometer operator. While the driver maneuvers through the inspection route, the operator aims the instrument towards oncoming traffic signs. At approximately 200 feet from each sign, the range finder triggers a xenon flash and cameras capture sign images. A computer produces a histogram of each sign's legend and background, which is used to calculate retroreflectivity. A record of sign locations, images, and retroreflectivity measurements are stored into a database for future processing. Unfortunately, as noted in multiple reports (*21*, *22*), the SMARTS technology did not prove to be effective in capturing sign retroreflectivity readings due to the continued inaccuracy of the automated readings in comparison to manually captured readings. This will not suffice, as the new standards require precision in the readings in order to meet minimum requirements.

More recently, vendors have implemented sensors and data collection devices to increase the accuracy of retroreflectivity measurements and make the process more automated. Private vendors were initially slow to implement this idea, likely due to the very challenging aspects of collecting this element while moving. However, vendors have been experimenting with various types of technology recently, including simply fine-tuning technology similar to SMARTS. In addition, with the onset of LiDAR, there have been methods developed that attempt to calibrate LiDAR to retroreflectivity measurements, with one such method being tested for this project. The vendors selected for this study use both of these techniques, among others, which should instill confidence in the ability of this project to test the leading technology available for automated sign retroreflectivity detection.

Researchers at Western Michigan University created a framework used to determine sign condition using image sensing technology (*23*). In this case, the ability to detect sign presence, as well as sign orientation and occlusion, and the presence of vandalism and/or deterioration, were all tested as a part of this project. The framework detected the various conditions at a rate of at least 86%, including deterioration condition, but note that this was based on “training” the software using a subset of the available sign pictures. Therefore, if conditions exist outside of the bounds of the training conditions, detection may be less accurate. Likewise, deterioration condition was simply identified as deteriorated or not. While the accuracy of detecting deterioration condition was above 87%, this is again based on what the researchers trained the software to see as deteriorated. Also note that light variation caused some issues with detection, which decreases confidence in the ability of this framework, as light conditions are not guaranteed in the field.

As previously stated, studies on the SMARTS vehicle did not prove effective or accurate in capturing retroreflectivity readings. Also, there doesn’t appear to be a great deal of research that has been conducted on automated detection of sign retroreflectivity. A TRID keyword search of “automated sign retroreflectivity” returned only five sources, with only one resulting project report being related to automated sign reading capture. However, this report found that sign retroreflectivity may not actually be the appropriate metric in determining sign visibility. The study was conducted by the University of Missouri-Rolla for the Transportation Research Board’s IDEA (Innovations Deserving Exploratory Analysis) Highway Program and stated that retroreflectivity was only good at predicting sign visibility for red signs, not as good at predicting visibility for green or blue signs, and not good at all at doing so for white, yellow or orange signs (*24*). This study measured the intensity of RGB (red-green-blue) color measured using a video camera connected to a laptop and claims these measurements more accurately reflect what the human eye observes, rather than retroreflectivity. Another more recent study, “Evaluation of Sign Retroreflectivity Measurements from the Advanced Mobile Asset Collection (AMAC) System” (*25*), also takes issue with using retroreflectivity to measure sign visibility. This study suggests that the luminance, or brightness, of traffic signs is a better indicator of sign visibility. The report states specifically that signs made with prismatic retroreflective materials can produce misleading results depending on the angle and proximity of the measurement. Particularly, if retroreflectivity is used to determine visibility, these types of signs appear to be more visible to nighttime drivers because retroreflectometers must be placed directly against the sign to measure retroreflectivity, but this report argues that the twist angle of the sign and distance from the roadway are not taken into account, which can drastically reduce the visibility of signs to drivers, not just in that signs facing the wrong direction are hard to see, but also that even slight twists greatly reduce sign visibility.

2.4. Gaps in Literature

Following review of the current literature, it appears that automated sign retroreflectivity data collection has not been thoroughly vetted. There has been a great deal of research in areas like automated pavement retroreflectivity detection (*26, 27*). This may be due to advances in technology that have resulted in more accurate readings of pavement retroreflectivity than in sign retroreflectivity. Also, much has been done in the area of automated sign detection (presence only), with a large focus on using recorded video or pictures to detect signs, and more recently reducing issues with large numbers of false negatives, i.e. not capturing an existing sign, due to occlusion or damage (*28*). Fortunately, recent advances in automated sign retroreflectivity detection have warranted funded research. These methods were thoroughly evaluated for this project.

3. METHODOLOGY

This chapter provides detail on the research methods used for experimental testing of automated sign collection against a control data set for sign features. The chapter discusses key topics such as vendor selection, communication with vendors, a description of the test route, and data collected. The following sections lay the groundwork that will aid in better understanding the findings of this research project.

3.1. Vendor Selection

The scope of this research project entailed the analysis of automated data collection vehicles similar to the 2008 Asset Expo *(1)* and the Asset Inventory project conducted from 2010 to 2012 *(2)*. The initial research project conducted in 2008 required vendors to drive a 90-mile course and provide data using their own financial resources. The team suspects that this lack of funding to vendors, along with scheduling conflicts with other contracted customers, may have led to some additional error in the data submissions. To alleviate this other potential bias, the NCDOT provided funds in the grant to cover costs incurred by the vendors for the 2010 Asset Inventory project. While the Asset Inventory project showed promise in the vendors' abilities to collect various other roadway assets, the feature that showed the least promise was sign retroreflectivity. This was unfortunate, as NCDOT has a great interest in evaluating vendors' abilities to collect this data, as sign replacement procedures and programs can be very costly in regards to loss of sign life and degradation in roadway safety.

Based on the two previous roadway asset projects, the research team contacted all prior vendors based on the premise to more accurately collect this data due to recent technology advances and provided them information on the upcoming research effort via email, encouraging them to consider submitting documentation for prequalification. In the interest of fairness to all potential vendors (known and unknown), a purchasing contract was issued by North Carolina State University. The process was two-fold. First, vendors were prequalified based on their potential to collect sign retroreflectivity data accurately. In total, six vendors responded to a memorandum which provided details about the project and requested a response to data the research team desired to collect along the course. Qualifications were then provided by each vendor. Based on the responses, three vendors were prequalified. One vendor, ESP, noted the ability to collect sign retroreflectivity using LiDAR equipment, which was of interest to the research team and DOT. The other two vendors, Facet and DBi, stated that they would collect the data using video technology patented by Facet. Facet used a newer LiDAR based technology and DBI used an older technology using photographic methods. Second, selected vendors were asked to provide a detailed cost estimate for their services. Due to the lack of available funds to study each prequalified vendor, the research team and NCDOT decided to select ESP to test the accuracy of LiDAR and DBi to test the patented video technology, because Facet sold their patent to DBi shortly after the project began. Shortly after selling their patent to DBi, Facet contacted the research team and requested to collect data free of charge using the newly developed LiDAR-based technology, which would be included in the data analysis of this project. Their main purpose was to test the accuracy of their equipment's ability to collect sheeting type, but they also provided "expected values" for retroreflectivity that were based mainly on three factors: the sheeting type, condition, and color of each sign. This is not their main method for capturing sign retroreflectivity, but it provided another dataset for comparison and could give a sense of the advancement in LiDAR technology in this field. Ultimately, this was a good scenario for the research team and Facet, as their new technology could be compared to their old technology.

3.2. Communication with Vendors

Communication with the vendors was limited to initially supplying a course catalog that outlined the 90-mile course and provided vendors with specific instructions on collecting and submitting their data. A sample dataset of 36 signs was provided to vendors to use for equipment calibration; however, unlike previous efforts, the research team did not assist in this calibration. Vendors were encouraged to carefully calibrate their equipment so as to ensure the closest possible match between vendor data and the data collected by ITRE staff. After calibration, vendors drove the entire 90-mile course and collected the required sign information, which was then submitted to ITRE as a final dataset. Upon receipt of the final dataset, the vendor data were compared to the same research team dataset for accuracy and comparison to the controlled manual dataset.

3.3. Methods of Data Collection

The inventory of sign data is simply a set of location points stored in a geodatabase. A full inventory of the sign data was collected along the 90-mile route by both the research team and the vendor, which includes a dataset of 806 signs captured by the research team, which is considered the basis for comparison for this project. The sign location was recorded by ITRE researchers using a smart phone application that provided latitude and longitude coordinates, which were verified using aerial imagery before storing the coordinates in a Microsoft Excel spreadsheet, and then displayed in ArcMap using a manual matching process. Sign retroreflectivity readings were manually captured using a handheld Tapco GR1 Retroreflectometer and were recorded in units of $mcd/m^2/lux$ (millicandela per square meter per lux – standard units for measuring retroreflectivity). The other sign metadata, described in the paragraph below, were collected as well and associated with the appropriate sign location. A geodatabase that included ITRE- and vendor-collected GPS points and a base map with aerial imagery was created and referenced in an ArcMap document for use in the manual matching process.

As inventory data were collected on each sign by the research team, various attributes of that sign such as dimensions, description, MUTCD code, and of course sign retroreflectivity readings were recorded manually. Once the data sheets were returned to the office, the attributes were stored with the locational data in an Excel spreadsheet, and then displayed with a unique identification number in ArcMap. A complete list of sign features collected by the research team and expected from the vendors is shown below in Table 1.

3.4. Instructions for Data Collection

To ensure the consistency of data collection efforts from the vendors and the research team, all data collection followed the guidelines provided by the Highway Sign Inventory and Retroreflectivity Data Collection Catalog, termed elsewhere in this report as the “catalog”. A complete version of the catalog is available in Appendix A: Data Collection Catalog. The purpose of the catalog was to provide clear guidelines on sign inventory collection and recording procedures. The data collection instruction manual also included general project information, including project team contacts at NCSU/ITRE, driving directions to the project route, data submission guidelines, and post-data collection debriefing information.

The instructions included specific details for the collection and reporting of individual sign features including mile posts along the test route, the latitude and longitude of each sign, the sign description and MUTCD code, and various other sign features. A complete list of sign features collected is below in Table 1.

Table 1 Collected Sign Features

Sign Feature	Feature Description
Course Milepost	Length in miles from the course starting point
Latitude and Longitude	Latitude-Longitude of sign base
Ground Mounted	Indicates if sign is ground mounted
Overhead	Indicates if sign is overhead
Number of Signs on Assembly	Indicates the total number of signs on that sign assembly
Sign Description	Indicates what information the sign is conveying
MUTCD Code	Provides the MUTCD code of the sign
Roadway Location	Indicates the location of the sign – Right, Left, or Overhead
Location on Assembly	Indicates where the sign is on the sign assembly – numbered top to bottom, left to right
Distance from Roadway	Indicates the distance from the base of the sign to the edge of the outside travel lane
Size	Width and Height, in inches, of the sign
Picture ID#	Provides the reference number for the picture of the sign from pictures provided by the vendor
Retroreflectivity	Measured retroreflectivity, in mcd/m^2/lux
Sheeting Type	Indicates the sign sheeting type, as provided in MUTCD – ASTM D4956-13 Glass Bead Types I, II, III and Micro-Prism Types I, III, IV, VIII, IX, XI
Comments	Any important comments about the sign itself or the sign support

3.5. Test Route Description

To determine the validity of the data received from the selected vendors, sign data were collected by the research team by visiting the site of each sign and manually gathering all of the necessary data. It should be noted that the sign latitude and longitude were gathered in the field, but were then verified using aerial imagery in Google Earth where they were then geolocated to correct for anomalies.

The data collection course consisted of roadways with various classification types, ranging from Rural Minor Arterial to Interstate, all based on guidelines provided in the FHWA Highway Functional Classification Concepts, Criteria and Procedures (*29*). By collecting data along a wide array of facility types, the team intended to collect data along facilities that are representative of the typical NCDOT-maintained facility. Note that unlike previous research conducted by ITRE on a test loop in Charlotte, NC, freeway ramp terminals were considered to be a part of the freeway being entered, instead of as separate entities. All facilities required the vendors to collect data in one direction of travel. Figure 2 shows the test course – a loop located in central North Carolina *(30)*.

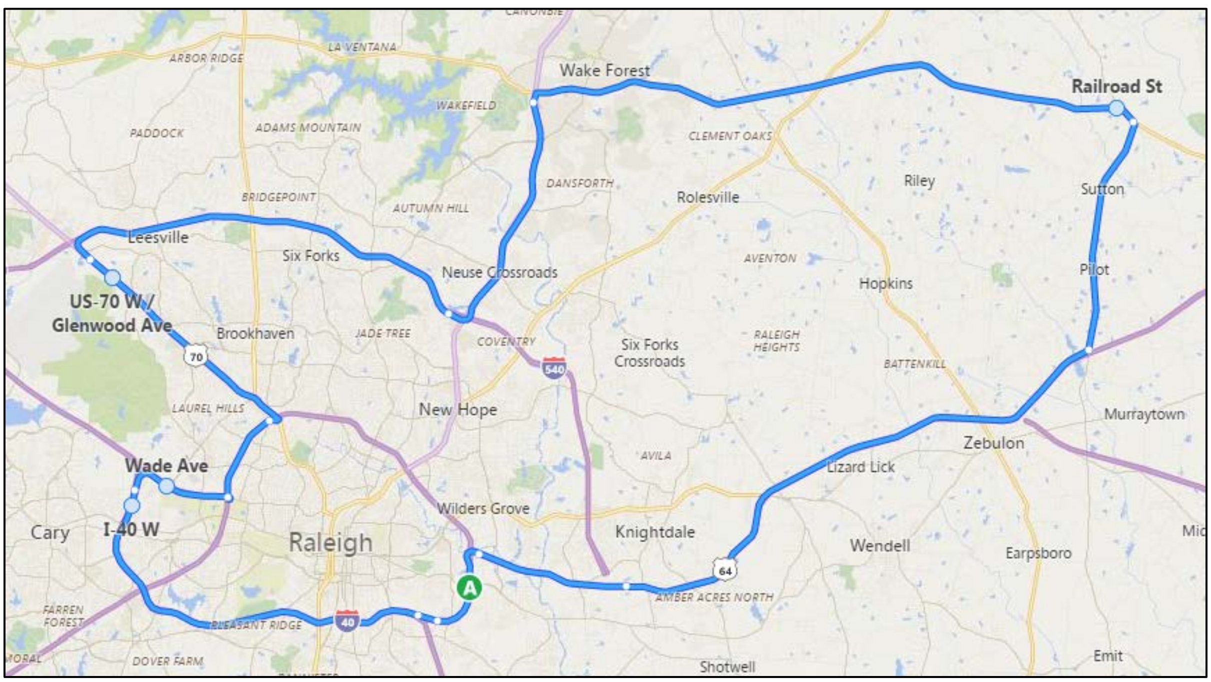

Figure 2 Overview of data collection course in central North Carolina (*30*)

The course started and ended at point A, starting by heading southwest along I-440 in a clockwise direction. In total, the course is 91.9 miles in length, with 51.9 miles being on an Interstate or Freeway facility, 8.7 miles being Urban Principal Arterial, 24.7 miles being Rural Principal Arterial, and 6.6 miles Rural Minor Arterial (Note: Railroad Street and Main Street in Bunn are also a part of the course, but consist of less than a mile of roadway, so they are included in the NC-98 analysis). The nine varying segments are noted in Table 2.

Table 2 Course description and location

Direction	Road	Course Type	Length (mi)
SB	I-440	Interstate	2.9
WB	I-40	Interstate	11.4
EB	Wade Ave	Freeway	3.0
NB	I-440	Interstate	2.8
WB	US-70	Urban Principal Arterial	8.7
EB	I-540	Interstate	12.0
NB	US-1	Rural Principal Arterial	7.4
EB	NC-98	Rural Principal Arterial	17.3
SB	NC-39	Rural Minor Arterial	6.6
WB	US-64	Freeway	19.8

Interstate/Freeway, Urban Principal Arterial, Rural Principal Arterial and Rural Minor Arterial roadways represent four types of facilities with typical traffic conditions in urban, suburban, and rural areas needed to complete project objectives, while also providing a representative sample of sign conditions. The team chose four arterials, US-70, US-1, NC-98, and NC-39 to ensure that the vendors could collect data during normal signal operations with queues. By choosing six different sections of freeway facility, the team was assured to capture varying congestion conditions in what is typically thought of as urban (I-440), suburban (I-40, I-540, Wade Avenue), and rural (US-64) freeways; and similarly for the arterials. This array of congestion levels and facility types ensured that the research team captured sign data on roadways that represent North Carolina freeways and arterials. Descriptions of the facilities are provided in the following sections.

3.5.1. Freeways

The North Carolina Department of Transportation was in the process of repairing the southeastern portion of Interstate 440 and the portion of Interstate 40 along the southern side of Raleigh as part of the "Fortify" construction project at the same time as this data collection effort, with approximately 10 miles in total being affected by this repair effort. These were the only two roadway segments affected by major construction during data collection.

The first phase of the Fortify project took place on the southeastern leg of I-440, which is where the Sign Retroreflectivity Project course started and ended, and began in May of 2013. It was not completed until the spring of 2015 and two of the three vendor data collection efforts on this part of I-440 for the project occurred in late 2014. Prior to the commencement of the sign data collection, this section of I-440, running from US-64 to I-40, contained 3-4 lanes in the direction of travel for the portion of roadway being studied for this project. However, due to the Fortify construction project, it was reduced to 2-3 lanes during collection of retroreflectivity data. The research team did not collect sign retroreflectivity data on signs within the work zone due to an inability to gain adequate access to all of these signs. However, this information was collected by the vendors. As is typical in construction zones, the I-440 Fortify corridor had concrete barriers on both sides of the travel lanes, or a combination of concrete barriers and construction traffic drums. The posted speed limit throughout this portion of the route was 55 miles per hour, although it typically has a posted speed limit of 65-70 miles per hour when operating at normal conditions with no construction in progress. The AADT is approximately 96,000 vehicles per day and there is only one interchange within this 2.9-mile segment of I-440. The first I-440 section of the course is classified as an Interstate, based on specifications provided by FHWA. Figure 3 below is a picture of the typical cross section of this part of I-440.

Figure 3 Typical I-440 Cross Section (Note: During Fortify construction; this is the first I-440 segment)

The second phase of the Fortify project focused on Interstate 40 and began in late 2014 and is not scheduled to be completed until late 2016. This was also the second leg of the project course. I-40, during normal operating conditions and no construction, operates with five lanes of traffic in the westbound direction from the merge with I-440 until just before Hammond Road, approximately 1.7 miles. At Hammond Road, this reduces to four lanes for the next four miles, approximately, until another lane drop reduces the number of lanes to three, approximately one mile past the Lake Wheeler Road interchange, with the cross section remaining at three lanes on I-40 for the majority of the remaining 6.5 miles of the corridor being studied. There were a total of 11.4 miles of I-40 studied for this project. All lanes outside of the work zone were 12 feet wide, while lanes inside of the work zone were 11 feet wide. Most of this corridor was reduced to three lanes during the second phase of the Fortify construction project; however, this only affected one vendor dataset, as the other two, as well as ITRE, collected data along the course prior to the second phase of Fortify beginning. Even though the corridor was not affected by lane drops during most of the data collection efforts, there was a lane shift that occurred prior to the second phase of Fortify, and concrete barriers were in place on both sides of the roadway along most of I-40 up to the US-1 interchange.

The US-1 interchange is where the Fortify construction stopped and beyond this point the cross section consisted of three lanes in the travel direction with paved shoulders of 12 feet or more in width. The entire I-40 corridor in this project consists of eight interchanges and the AADT of this segment ranged from 97,000 to 117,000. The speed limit through this portion of the Fortify construction zone was 60 miles per hour, increasing to 65 miles per hour at the end of the construction zone. Prior to the beginning of the Fortify project, the corridor had a posted speed of 65 miles per hour throughout this segment of I-40. The Fortify project did not affect the results of the ITRE-vendor data comparison, as these signs were excluded from analysis and were not captured in the ITRE dataset, per NCDOT instruction to not capture signs in work zones. I-40 is classified as an Interstate, per FHWA. Figure 4 below is a picture of the typical cross section of I-40.

Figure 4 Typical I-40 Cross Section (Note: During Fortify construction)

The third portion of the course, Wade Avenue from I-40 to I-440, is classified as a Freeway according to FHWA, as it has similar characteristics to an Interstate, such as grade separated interchanges, limited access, and high posted speeds. However, since it is not part of the Dwight D. Eisenhower Interstate System, it is a Freeway. The portion of Wade Avenue studied is three miles long, encompasses two full interchanges, and consists of two 12-foot lanes in the direction collected, with there often being a third auxiliary lane between entrance and exit ramps. The typical cross section had paved right-hand (outside) shoulders ranging from 10-12 feet in width, with grass and trees adjacent to the shoulder. The left-hand, or inside, shoulder was paved approximately 2-4 feet, with a 60-foot grass median and 3-strand cable separating the opposing travel directions. The AADT is approximately 60,000 vehicles per day, with a posted speed limit of 60 miles per hour. Figure 5 shows a picture of the typical cross section of the portion of Wade Avenue studied as a part of this project.

Figure 5 Typical Wade Avenue Cross Section

The fourth segment of roadway where data collection occurred was I-440 along the western side of Raleigh between Wade Avenue and US-70. This roadway is another Interstate, according to FHWA, and is 2.8 miles long and consists of two full interchanges. At the time of data collection, this roadway had a typical cross section of three 12-foot lanes, paved inside and outside shoulders 10-11 feet wide, a concrete barrier in the median adjacent to the inside shoulder, and alternating between steel guardrail in front of trees and grass adjacent to the outside shoulder. The speed limit was 60 miles per hour and the AADT was between 108,000 and 112,000 vehicles per day. Figure 6 below represents a typical cross section along this portion of I-440.

Figure 6 Typical I-440 Cross Section (Note: This is the second I-440 segment)

The sixth leg of the course was 12 miles of I-540, from US-70 to US-1, which is classified as an Interstate, according to FHWA. Almost all of this 12-mile stretch is three lanes wide, with all lanes being 12 feet wide. Likewise, there are paved shoulders on both sides of the road that are ten feet wide and a 40-foot grass median for nearly the entirety of this corridor, with a 3-strand cable in the middle of the median, as well as a grass and tree line beyond the outside shoulder. The AADT ranges from 75,000 to 90,000 vehicles per day and there are four full interchanges along this corridor. Also, the posted speed limit is 70 miles per hour. Figure 7 below provides a picture of the typical cross section along this corridor.

Figure 7 Typical I-540 Cross Section

The tenth and final leg of the course was US-64 from NC-39 to I-440, which is 19.8 miles long and is the only other leg classified as a Freeway. There are ten interchanges along this stretch of roadway, which has an approximate AADT of 75,000 vehicles per day in Wake County and likely fewer in Franklin County (the AADT maps referenced were not up to date for this portion of US-64). The cross section changes approximately halfway along the studied corridor from a two-lane configuration, from NC-39 to Rolesville Road, to a three-lane configuration from Rolesville Road to I-440. The two-lane portion has a typical cross section consisting of a 50-foot grass median with a 3-strand cable barrier, a paved inside shoulder that is four feet wide, two 12-foot lanes, a paved outside shoulder of 4 feet, and grass and a tree line adjacent to the outside shoulder. Figure 8 below is a picture of a typical cross section of the two-lane portion of this corridor. The three-lane portion has a typical cross section consisting of a 24-foot grass median with a 3-strand cable barrier, a paved inside shoulder that is 12 feet wide, three 12-foot lanes, an outside shoulder that is 12 feet wide, and a grass and tree line adjacent to the outside shoulder. Both portions of US-64 have a speed limit of 70 miles per hour. Figure 9 is a picture of a typical cross section of the three-lane portion of this corridor.

Figure 8 Typical US-64 Two Lane Cross Section

Figure 9 Typical US-64 Three Lane Cross Section

3.5.2. Arterials

The first arterial driven on the course was an 8.7-mile section of US-70, or Glenwood Avenue, from I-440 to I-540, which was the fifth leg of the course and is classified as an Urban Principal Arterial. The vast majority of this corridor consists of two to three 12-foot lanes and a posted speed of 45 miles per hour. There are long portions that have concrete curb and gutter on one or both sides, particularly in areas with frequent driveway access for shopping centers, sometimes with steel guardrail and sidewalk on the right-hand side of the road. There are also long portions of roadway that are more suburban and have paved shoulders that are two feet wide, with grass median and shoulders, as well as tree lines, being adjacent to the pavement. Signalized intersections are present along this corridor, with dedicated turn lanes and an AADT ranging from 33,000 to 77,000 vehicles per day. The figure below, Figure 10, shows the typical cross section of US-70.

Figure 10 Typical US-70 Cross Section

The seventh leg of the course, US-1 from I-540 to NC-98, is a Rural Principal Arterial, 7.4 miles in length, and has an AADT ranging from 43,000 to 56,000 vehicles per day. This course segment is predominately two lanes in the studied direction of travel, with standard 12-foot lanes and a speed limit of 55 miles per hour throughout. Most often, there is a 10-foot wide, paved outside shoulder with grass beyond the shoulder, a 4-foot wide, paved inside shoulder, and a 24- to 36-foot grass median. There are multiple at-grade signalized intersections along this corridor, as well as a number of dedicated turning lanes at these intersections. Figure 11 shows a picture of the typical cross section of this segment of US-1.

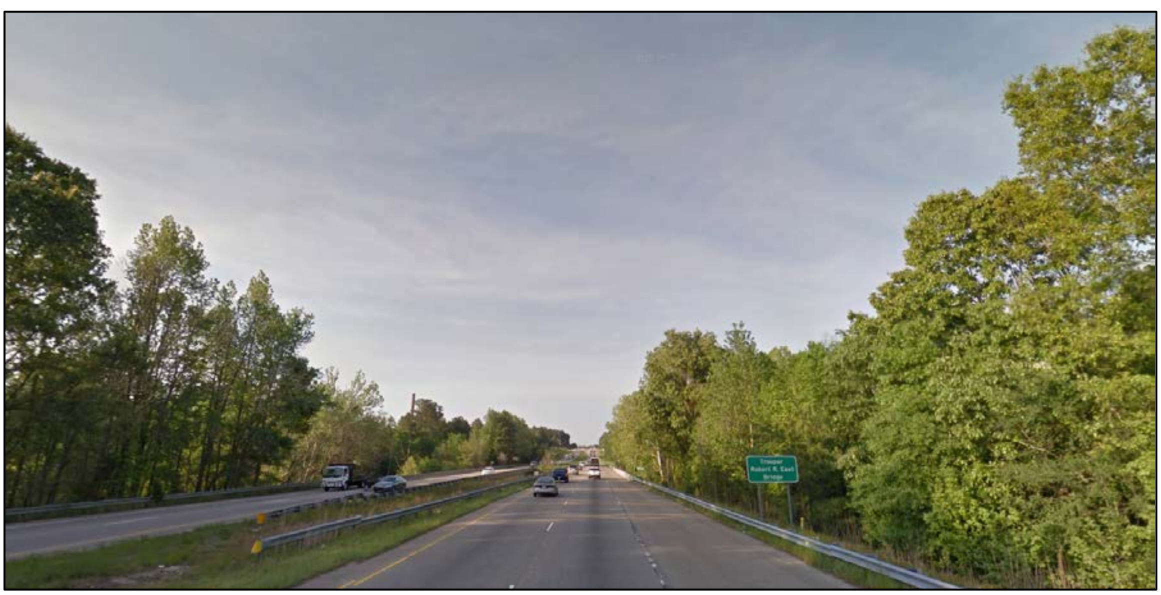

Figure 11 Typical US-1 Cross Section

A 17.3-mile stretch of NC-98 encompasses the eighth leg of the studied course, which is classified as a Rural Principal Arterial. The corridor starts as a four-lane roadway, but soon transitions to a two-lane highway for the majority of the corridor, with one 12-foot lane in each direction. Grass and trees line both sides of the road along the vast majority of this segment of the highway. This leg of the course stretches from US-1 to Railroad Street in Bunn, North Carolina, then along Main Street/NC-98 in Bunn until reaching NC-39. The Railroad Street and Main Street portions of the course total only 0.6 miles in length and are included as part of the NC-98 corridor, as Main Street is also considered NC-98 and NC-39 for this stretch of the road. While the initial four-lane segment of NC-98 has an AADT of approximately 23,000 vehicles per day, the majority of the corridor, which is two lanes, has an AADT ranging from 2,500 to 13,000 vehicles per day. The majority of this corridor has a posted speed of 55 miles per hour, with short segments short segments posted at 45 miles per hour, and Railroad Street and Main Street having a posted speed of 35 miles per hour. Figure 12 shows a representative cross section of the two-lane roadway of NC-98 studied as a part of this research project.

Figure 12 Typical NC-98 Cross Section

The last arterial and ninth segment of the course was NC-39, which is a Rural Minor Arterial. This roadway has a posted speed limit of 55 miles per hour for the majority of the corridor, with the exception being a small portion posted at 45 miles per hour. This road has one 12-foot lane per direction, grass shoulders on both sides, with tree lines and fields alternating beyond the grass shoulder. The available AADT for NC-39 ranges from 4,800 to 5,300 vehicles per day. A picture of a representative cross section for this portion of the course is provided below in Figure 13.

Figure 13 Typical NC-39 Cross Section

3.6. Data Collection

To effectively compare the data collection of mobile collection vehicles to manual data collection, two types of data collection were conducted: a research team manual data collection effort and data collection by three vendors with mobile data collection vehicles – DBi Services, ESP Associates, and Facet Technology Corporation. The research team and vendors completed data collection using the provided catalog along the predetermined test route described in the previous chapter. The data collection efforts of the vendors and the research team are detailed in this section of the report.

3.6.1. Research Team Data Collection

The research team data collection consisted of two efforts: 1) manual data collection along the test route and 2) supplemental data extraction from recent orthoimagery, aerial images, and video files. This section details the research team data collection and the resources utilized.

Manual Data Collection

The manual data collection by the research team took place along the test course with a team of two data collection technicians who commuted together to each site on multiple trips. Vehicles equipped with safety hazard lights were used for travel along the route and team members wore safety vests. Data were recorded via paper data collection forms and locations captured via smart phone applications, with the information gathered on each trip being manually entered into a database upon return to the office.

The research team data collection occurred on multiple trips and was gathered by students. As often as was possible, the research team data collection occurred during off-peak traffic conditions to reduce the number of conflicts between the vehicles transporting data collectors and traffic on the test route. Environmental conditions were clear with no precipitation and moderate temperatures during all research team data collection efforts.

The data collection occurred from May to November 2014, with trips ranging from a couple of hours long to full day trips. This is because the primary data collectors for this project were students, making data collection trips only possible based on student availability, which was sparse at times. Drivers maneuvered the vehicles to stop as often as needed to collect the necessary sign features. Most often, data collectors would park their vehicle and walk to a single sign or small collection of signs, then return to their vehicle to commute to the next sign. However, there were also a fair number of times that data collectors would walk to multiple signs at a time, for as much as a mile, depending on the location of the signs in relation to roadside barriers, vehicle pull-off locations, etc.

Research team data collectors were instructed in the use of the retroreflectometer and the data collection form, shown in Figure 14, in accordance with the data collection instructions. Researchers calibrated the retroreflectometer once per week in order to ensure the accuracy of the readings gathered by ITRE. The team members used a GPS location finder smart phone application to find the approximate location of each sign post, which was later verified using aerial imagery software to accurately determine the exact location of each sign. Team members were also instructed to take pictures of each individual sign and sign assembly to assist in referencing the correct data during post-processing. Close-up pictures were also taken of the sign sheeting in order to visually verify the appropriate MUTCD sheeting code during post-processing. Additional tools used by the research team were a measuring tape and measuring wheel to verify roadway offsets and dimensions of signs.

Course Segment:																		
Latitude Minutes (all 35 Degrees)	Longitude Minutes (all 78 Degrees)	# Signs on Assembly	Sign Description	Ground Mounted	Roadside Location	Assembly Location	Distance from Roadway		Size		Picture ID	Retroreflectivity					Same Sheeting	Comments
							Feet	Inches	Width (in)	Height (in)		Corner 1	Corner 2	Corner 3	Corner 4	Center		

Figure 14 Example of Data Collection Form

Supplemental Resources

Additional visual resources were used to supplement the research team's roadway asset database. These supplemental resources included supplemental online mapping tools, site visit photography, and videography of the test route with a GoPro camera mounted to the top of a vehicle.

3.6.2. Vendor Data Collection

Three separate data collection vehicle vendors (DBi Services, ESP Associates, P.A., and Facet Technology Corporation) were contracted by the research team. While the vehicle data collection equipment used to capture most of the sign features like sign dimensions, location, and roadway offsets are very similar, sign retroreflectivity readings were captured very differently by the vendors. ESP used LiDAR, while Facet and DBi used different patented retroreflectivity measurement technology to capture sign retroreflectivity readings. More discussion on these technologies follows. Figure 15 shows examples of typical data collection vehicles used for similar data collection efforts.

Figure 15 Typical data collection vehicles - DBi Services (*31*), ESP Associates, P.A. (*32*), and Facet Technology Corporation (*33*).

The vendors were instructed to travel only in the clockwise direction of the course, meaning they would only capture signs in one direction of travel. The short sections below describe when each vendor data collection took place, as well as the processes used for capturing sign data, and the final data submission. The research team provided a sample dataset to each vendor that they could use to calibrate their equipment in order to gather the most accurate readings. ITRE did not assist in the calibration of any vendor data. Vendors did not acquire the ITRE control dataset until after running the course, meaning they would calibrate their data after collection of the assets, making a simple adjustment to account for the difference between their methods and the research team's measurement methods.

DBi Services

DBi Services is based in Hazleton, Pennsylvania. The data collection vehicle used was the Advanced Mobile Asset Collection (AMAC) vehicle (Figure 15). DBi completed the mobile data collection in November 2014. After DBi calibrated their data, the final data set was submitted on December 10, 2014.

ESP Associates, P.A.

ESP Associates, P.A. is based in Fort Mill, South Carolina. The data collection vehicle used was a passenger truck with the MX8 Mobile Spatial Imaging System mounted on the back of the truck (Figure 15). ESP completed the mobile data collection on Tuesday, October 7, 2014. After ESP calibrated their data, the final data set was submitted on March 8, 2015.

Facet Technology Corporation

Facet Technology corporation is based in Eden Prairie, Minnesota. The data collection vehicle used is part of the Mobile360 vehicle fleet (Figure 15). Facet completed the mobile data collection the week of October 6-10, 2014. After Facet calibrated their data, the final data set was submitted on December 10, 2014. Note again that their retroreflectivity readings were expected values based on sign color, condition, and sheeting type.

3.6.3. Creation of Data Layers

The research team data were exported from the original Excel database to display in ArcMap 10, while the vendor data was provided in both Excel and GIS formats. A geodatabase of sign location and information was created, with all of the data being made observable in a GIS map. The map included a base map layer, a research team database layer, and a layer for each vendor-collected database.

Once the map was created, researchers began visual analysis of the sign data. To aid the visual analysis process, vendor data points were joined to the single closest research team data point, and this process was then completed in the opposite direction, with ITRE data points being joined to vendor data points. This process is explained in detail below. Figure 16 displays a screenshot of ArcMap 10, from which a researcher could begin verifying the location accuracy of vendor data in comparison to research team data.

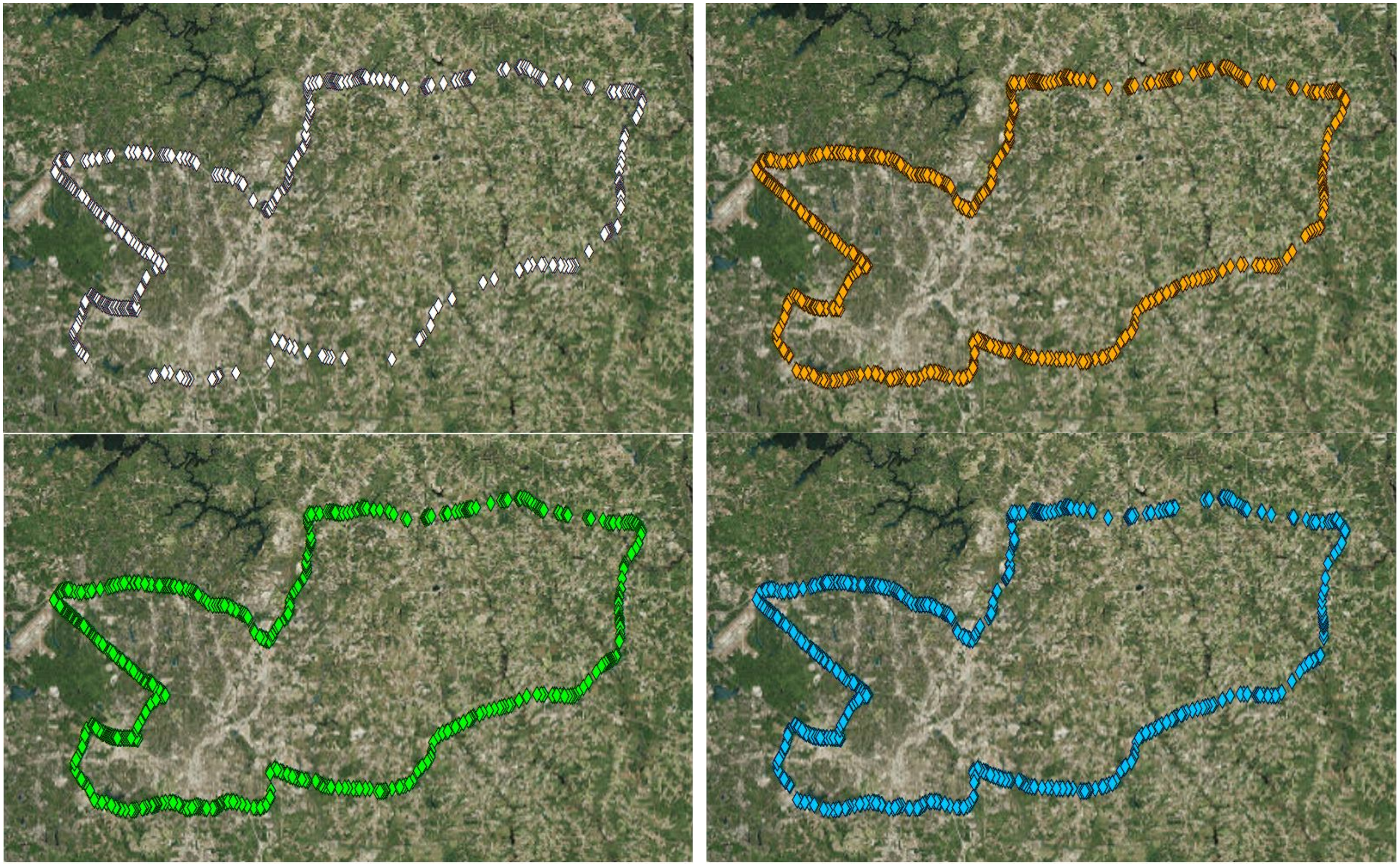

Figure 16 Visual analysis with ArcMap 10 (top left: ITRE, top right: DBi, bottom left: ESP, bottom right: Facet)

The top left portion of Figure 16 displays only the research team data, while the other three show the vendor data individually. The visual analysis begins by displaying both layers together and connecting the closest data points with the ArcMap join and relate features as Figure 17 shows.

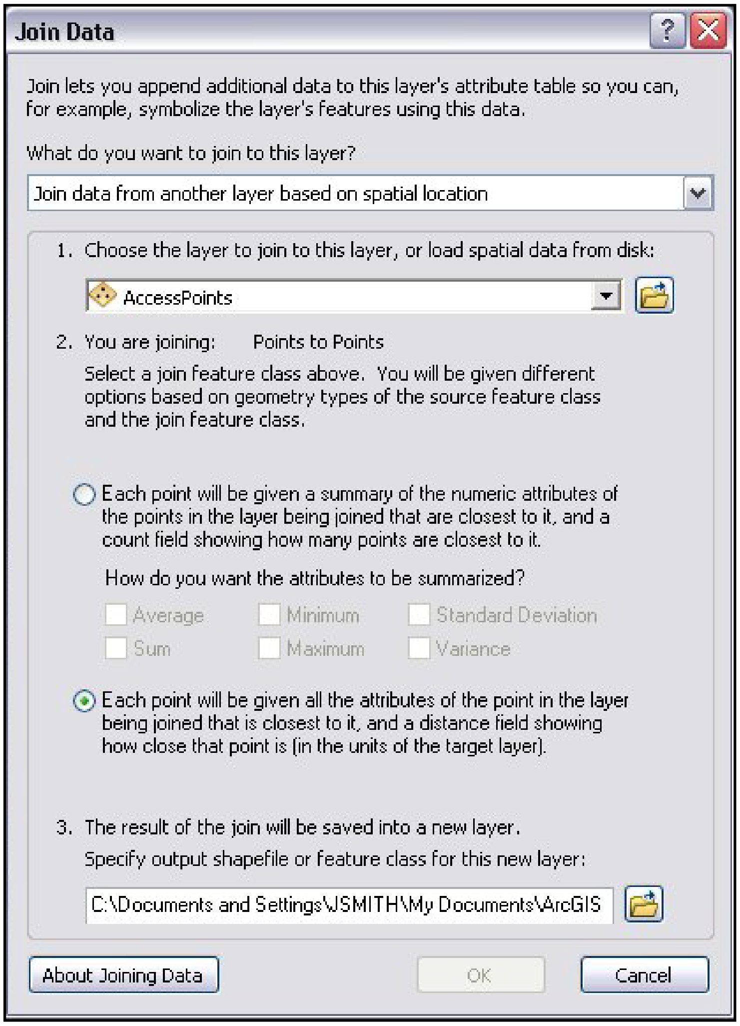

Figure 17 Join data window in ArcMap 10

The join feature created a new layer which the program will store in accordance to the type of join that has been created. Since the join feature only acts as a join to the specific layer selected, joins of data points could be done in a number of combinations. For this analysis, join layers were created both to the vendor data layer and to the research team data. The researchers compared vendor to research team (V2R) and research team to vendor (R2V), which results in two layers for each vendor data set. When V2R and R2V matches were the same, the match was considered a good match, with a very low likelihood it was a different point that should be matched. These points were still visually verified along with other points that did not meet these criteria, but this allowed for a faster visual verification process.

3.6.4. Locating Data Errors

While the joins help expose data limitations, searching for errors within the data was completed by observing various situations where joined data disguised errors in research team or vendor data sets. There are eight possible combinations of data collection scenarios, both positive and negative, that can be seen within a joined data set as Table 3 shows.

Table 3 Possible Data Collection Scenarios

Scenario	*Asset is Present*		Scenario	*Asset is Not Present*	
1	R	V	**5**	R	V
2	R		**6**		V
3		V	**7**	R	
4			**8**		

R = Research Team data point or line reported
V = Vendor data point or line reported

Table 3 displays eight scenarios within the two data sets (V = Vendor, R = Research Team). An “R” or “V” indicated in the columns represent a “hit” in the data set, i.e., the respective data collection set has identified an asset at some location, regardless of its accuracy. The column “asset is present” represents data points that are actually present on the course, regardless of whether or not the data sets have a record of that asset. The column “asset is not present” represents data points that are not on the course, regardless of data set entry notation.

The validity of the research team collected dataset was assumed as true, as members of the research team visited each sign in the ITRE database and collected sign information and retroreflectivity readings using a calibrated tool provided by the NCDOT, with location information being verified using online mapping tools. Because of this assumed accuracy, Scenarios 3, 4, 5, and 7 are deemed implausible.

Scenario 1 and 8 are the best possible scenarios for analysis of assets, where a sign is either present or it is not, and both the vendor and research data reflects the truth in each scenario. This is called a true positive (Scenario 1 when the sign is present) or true negative (Scenario 8 when the sign is not present) for both the vendor and research team data point, as illustrated in Figure 18A. In the case of Scenario 8, there are an infinite amount of points where assets are not present and are not marked as true negatives.

Scenarios 2 and 6 represent errors made by the vendor during data collection. Scenario 2 reflects when the vendor has failed to correctly identify the presence of a data point (a false negative). Scenario 6 is a false positive: a sign is not present, but the vendor has incorrectly noted a sign in that location. Note that the research team was directed by the NCDOT to not capture some signs such as street name signs, and therefore the vendor could have captured these signs without having a match in the ITRE dataset. Likewise, as overhead signs require a bucket truck in order to manually capture retroreflectivity, only 30 overhead signs were captured by the research team, all along Glenwood Avenue, meaning each vendor dataset should theoretically have more overhead signs than the ITRE dataset. Street name signs have been filtered out of the vendor raw datasets and will not be considered in the comparison, while only the overhead signs captured by the research team are considered for comparison between datasets. However, neither of these scenarios indicates a false positive. Scenarios 2 and 6 are illustrated in Figure 18A and B.

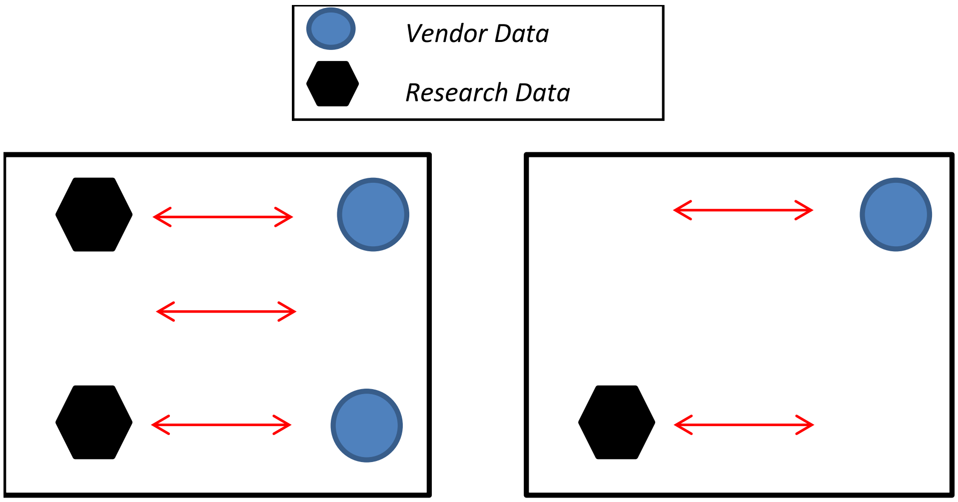

Figure 18 A) true positives and a true negative (left); B) a false positive and a false negative (right)

Given the possible scenarios described above, the research team sought to systematically remove any errors within the research dataset by revealing possible errors, namely sign location coordinates, as well as reveal vendor errors for comparison. Once research datasets had been relieved of any errors by checking disputed data with multiple sources, the research team recognized possible error types of vendor data and initiated revealing those errors by creating both V2R and R2V joins, and then noted the number and type of errors located.
Two possible types of errors can exist in the raw dataset:

- Vendor false negatives (Scenario 2) – the vendor has failed to place a data point where a sign actually exists.
- Vendor false positive (Scenario 6) – The vendor has placed a data point where there is no existing sign.

Vendor false negatives were revealed through V2R joins. Figure 19 visualizes V2R matches using the join feature created by the software, which results in the join of A to 1, B to 3, and C to 3.

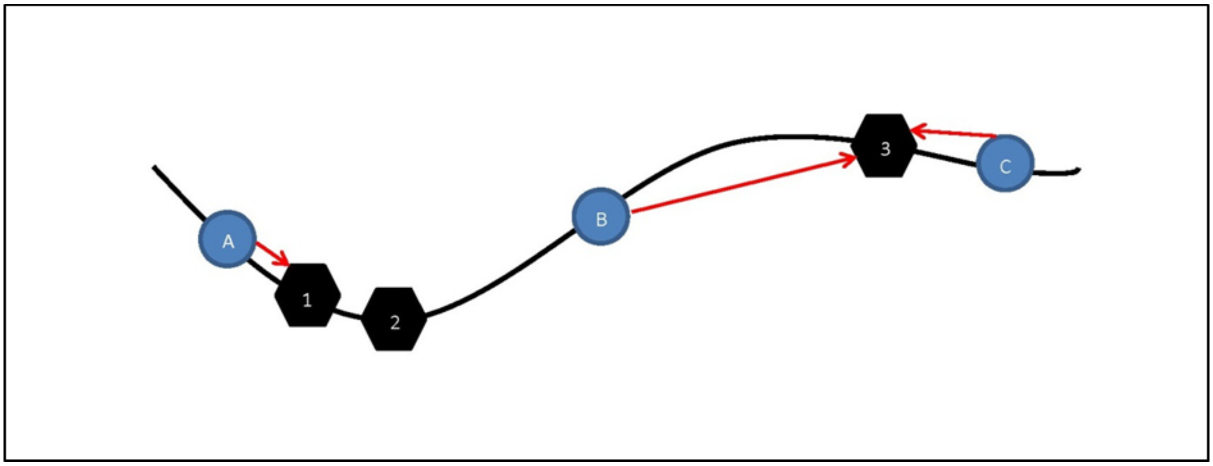

FIGURE 19 VENDOR TO RESEARCH (V2R) JOIN (VENDOR DATA POINT IN CIRCLE AND RESEARCH DATA POINT IN HEXGAON)

The multiple joins of the vendor data to research data point 3 in Figure 19 reveals a vendor false negative at research point 2. There is not a research point in close proximity to the vendor point B; therefore, this point is joined to the closest data point, research point 3. The second error in Figure 19, a vendor false positive denoted by vendor point B, is not clear to the researcher as a result of the join tool output being observed. Note that vendor false positives were too difficult to capture, as all vendors captured more signs than ITRE because the ITRE dataset did not include street signs; therefore, it would've been difficult to distinguish between a vendor identifying a street sign or truly capturing a non-existent sign.

The examples provided in Figure 19 prompted the research team to visually confirm the presence of a false negative or positive, or both, in the dataset. If the joined sets were evaluated independently of one another, errors may not have been discovered in one joined data set that could have been discovered in the other joined data set. Vendor false negatives and false positives were revealed through simple manual comparison after both join processes were completed. As stated previously, if both join processes between a vendor dataset and the research team's dataset indicated a match, these points were linked together in the comparison database, with all other points needing visual confirmation based on sign location and information. Once points that were unmatched during the automated process were reviewed and matched, if possible, the unique identifiers of the ITRE and vendor databases were linked. Students were tasked with reviewing all datasets for accuracy and indicating which signs matched between ITRE and vendor datasets, including the points combined in the automated process. While this was somewhat time consuming and monotonous, this ensured confidence in the results of the sign data comparison.

3.6.5. Data Cleansing and Analysis

Following the final submittal of the vendors' data collection efforts, a final data analysis was conducted by the research team. This analysis compared the data collection of the vendors to the research team by visually observing the location of signs collected, the attributes requested for each sign, and condition assessments completed. In summary, preparation of data analysis included:

1. Creation of a geodatabase organization system for ease of data filing and location;
2. Import of vendor and research datasets to ArcMap 10;
3. Display of vendor and research datasets on appropriate layers;
4. Special variation/error elimination through the ArcMap join tool or visual analysis; and
5. Export of final, true matches into a spreadsheet and geodatabase feature class layers.

This database is provided as one of the electronic deliverables at the conclusion of the project.

Once the matches were made between the research dataset and the vendor datasets, the process of joining the datasets was repeated, providing the research team with the distance between the matching points, as well as the difference between the retroreflectivity readings and a comparison of other collected sign metadata.

4. RESULTS

The findings from this research study are summarized in the following paragraphs. These include discussions on ITRE-vendor sign location comparisons, vendor retroreflectivity reading accuracy, and analysis of signage and sheeting type versus sign retroreflectivity. Note that any comparison of sign features is based solely on signs whose location matched the ITRE dataset.

4.1. Sign Location

Although much research has already been conducted on the ability of automated mobile asset units to correctly identify the location of signs, this is still of vital importance, as an inability of the vendors to identify at least the majority of signs present on the course would negate the possibility of detecting retroreflectivity of the same. Clearly, without being able to identify signs, vendors would not be able to capture the condition of the signs, or any other sign attributes, either.

It is important to once again note that ITRE did not to collect street signs or any signs within construction zones, particularly those inside of construction areas along I-40 and I-440 where the “Fortify” construction project was taking place.

ITRE manually captured all sign metadata using appropriately calibrated and accurate equipment; therefore, the manual data collection effort is considered the “ground truth” for which to compare the vendor data. Sign location was gathered using a GPS smartphone application, and although the accuracy of readings from such an application is not perfect, all locations were verified and geolocated using publicly available aerial imagery like Google Earth to retain precision in location (*34*). This information was entered into a database that was imported into ArcGIS software to allow for easy comparison between ITRE and vendor data.

Location data for each vendor in comparison to ITRE location data are provided in Table 4. A location match does not indicate that the ITRE and vendor signs have the exact same coordinates, but simply that the vendor sign is the same as the ITRE sign, meaning it's been verified based on general location and description. Further information regarding the accuracy of the location of the matched signs between each vendor and ITRE is shown in Table 5. This table provides the average distance between the vendor's signs and their respective ITRE signs, as well as the variance, or standard deviation, of these distances.

Table 4 ITRE-Vendor sign location comparison

Research Sample		Reported			Location Correctly Matched					
		DBi	*ESP*	*Facet*	*DBi*		*ESP*		*Facet*	
Ground	772	870	1015	927	505	65%	619	80%	623	81%
Overhead	34	219	246	227	22	65%	32	94%	22	65%
Total	806	1089	1261	1154	527	65%	651	81%	645	80%

Table 5 Comparison of average distances between matched ITRE and vendor signs

Signs	**DBi**			**ESP**			**Facet**		
	Research Matched	Average (ft)	Standard Deviation (ft)	Research Matched	Average (ft)	Standard Deviation (ft)	Research Matched	Average (ft)	Standard Deviation (ft)
Ground-mounted	505	24	88	619	16	19	623	19	10
Overhead	22	63	151	32	46	19	22	20	15

All vendors reported finding more ground-mounted and overhead signs than ITRE. This was to be expected, as each vendor captured street signs and the vendors also captured all overhead signs along the course. It was infeasible for ITRE to capture sign retroreflectivity readings of all overhead signs, as this required a bucket truck and work zone traffic control; therefore, the research team only captured retroreflectivity readings of a small subset of 30 overhead signs. This number was chosen because it is the threshold for which adequate statistical certainty can be attained when conducting comparisons between two datasets. Also, note that originally the research had gathered other sign information prior to capturing sign retroreflectivity readings, but did not actually capture the readings on each of the located signs, bringing the total number of ITRE overhead signs included in the location analysis to 34 signs.

In summary, ESP performed best among the vendors at accurately capturing the combination of ground-mounted and overhead signs (81%), but had higher variances in distances than Facet between their signs and ITRE signs. Facet captured slightly more ground-mounted signs (623 versus 619), but fewer overhead signs (22 versus 32), than ESP while having the lowest variances of all three vendors. DBi had the lowest accuracy among the vendors in terms of location matching for ground mounted signs, but performed the same as Facet in capturing overhead signs (both vendors collected 22 overhead signs). DBi also produced the largest variances between their signs and ITRE signs, meaning their sign locations vary greatly from the matched ITRE signs. All three vendors had similar average distances between their respective ground-mounted signs and the ITRE signs that matched them, while Facet produced much smaller average distances between their overhead signs and ITRE-matched overhead signs in comparison to the other two vendors. It is not presently obvious what may have caused the vendors to not be able to detect each sign that ITRE captured.

Also, there is no apparent trend between the vendors as to which signs were easier or more difficult to capture.

4.2. Sign Retroreflectivity

Once a sign is identified, the vendors used various technology and software to capture sign retroreflectivity readings specific to the sign. After a vendor completed the entire course, the vendor dataset was provided to ITRE for final analysis and comparison to the ITRE dataset. This analysis included, most importantly, comparison of sign retroreflectivity readings between ITRE and vendor data. This includes a direct comparison of sign retroreflectivity readings, as well as a comparison of "pass" or "fail" based on MUTCD criteria. It is important to remember that Facet indicated that their readings were expected values based on the sheeting type, color, and condition of each sign, but it was still important to test this technology for the sake of the NCDOT.

4.2.1. Retroreflectivity Direct Comparison

Initially, a direct comparison was conducted between the retroreflectivity readings obtained by ITRE and those captured by the vendors. This test employed a buffer of 10% in relation to the ITRE readings, meaning a vendor's reading was considered accurate if it was within 10% of the ITRE reading. Note that only two of the vendors provided retroreflectivity readings that could be used for comparison to the ITRE readings, DBi and Facet, with Facet's not being direct measurements. ESP captured readings using LiDAR-based technology, which produced a unique unit of sign "reflectiveness"; however, after ESP received the research team's calibration sign dataset, they informed the research team that there was no correlation to the calibration signs. To confirm this, the research team conducted a statistical analysis of the ESP dataset and found a p-value of 0.5748 and a correlation coefficient of -0.0229, which indicates very poor correlation. Therefore, the ESP sign retroreflectivity readings were omitted from this comparison. Note: Although the use of traditional readings using LiDAR "reflectiveness" was not useful in this case, other LiDAR-based technologies were still tested such as the one Facet employed for this study.

Table 6 below shows a summary of the comparison of the retroreflectivity readings captured by the research team and these two vendors. Neither vendor's readings produced many matches, with DBi matching 18% of the ITRE readings and Facet matching 21%.

Table 6 Sign retroreflectivity direct comparison

Vendor	Location-Matched Ground Sample	Within ± 10% of ITRE reading	
DBi	490	86	18%
Facet	601	126	21%

It is unclear currently why the vendors struggled to capture retroreflectivity readings within 10% of the ITRE readings. However, keep in mind that this threshold was set simply for comparison purposes and was not established by the NCDOT. When looking at the cumulative distribution of the readings provided by DBi and Facet, they had approximately the same percentage of signs within 15% of the research team's readings (20%), but approximately 62% of the DBi readings were within 30% of the ITRE readings, whereas Facet had approximately 54% of their readings within 30% of the ITRE readings. Likewise, 83% of the DBi readings were within 50% of the ITRE readings, and approximately 72% of the readings produced by Facet were within 50% of the ITRE readings. This can all be seen in Figure 20 and Figure 21 below.

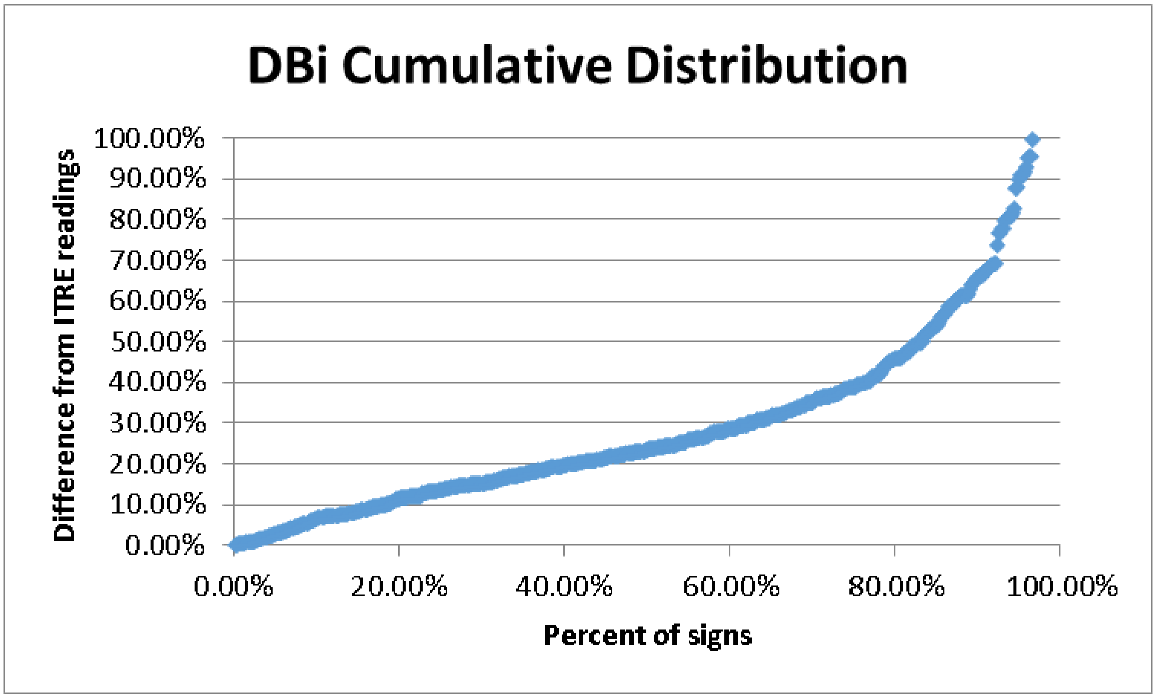

Figure 20 Cumulative distribution of DBi readings versus ITRE readings

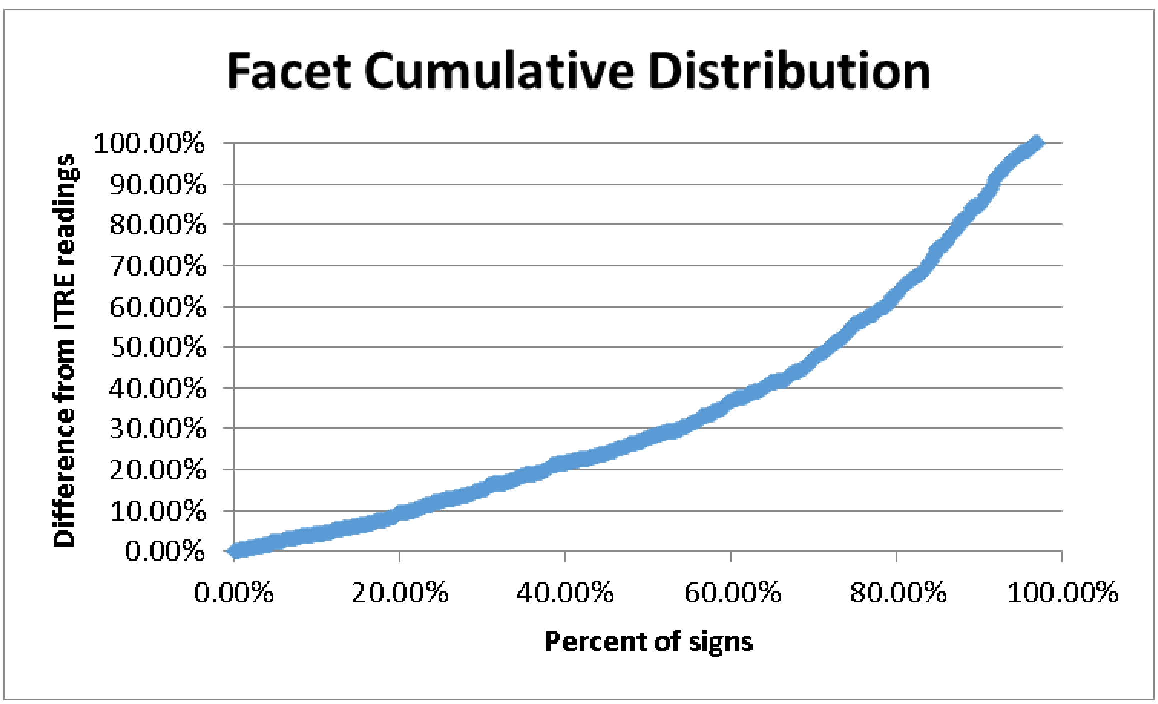

Figure 21 Cumulative distribution of Facet readings versus ITRE readings

When plotting the vendor readings versus the ITRE readings, some interesting observations are made. Mainly, the vendors seem to have generally acceptable accuracy and consistency within the range of 0-400 mcd/m^2/lux, as can be seen in Figure 22 through Figure 27. However, once outside of this range, the vendor data drifts greatly from the ITRE readings. Both vendors that provided readings indicated that their equipment is calibrated to the lower retroreflectivity values, as these are where the MUTCD passing and failing thresholds are present. Each figure has a black 45-degree line that represents a one-to-one comparison of ITRE and vendor readings (which is desirable), and the individual vendor comparison figures also have various trend lines showing a comparison of the data trend to the 45-degree line. While the simple linear trend line is comparable to the polynomial trend line as an accurate predictor of the data for DBi, a combination of two linear trend lines, or the polynomial trend line, is most accurate for Facet. Facet's readings appear to crest just above 500 mcd/m^2/lux, which further shows the importance placed on the lower retroreflectivity readings in comparison to the higher readings. Figure 22 and Figure 23 show the ITRE-vendor comparison separately, while Figure 24 combines the two vendor datasets.

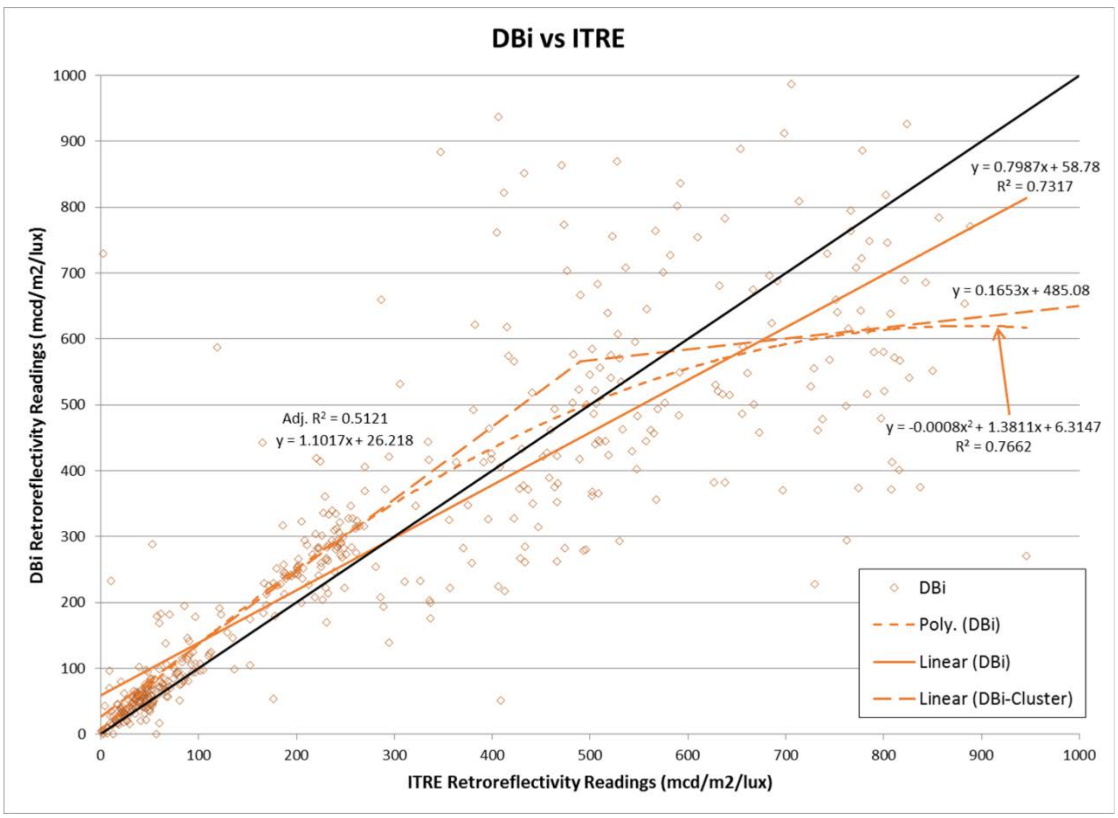

Figure 22 DBi readings versus ITRE readings

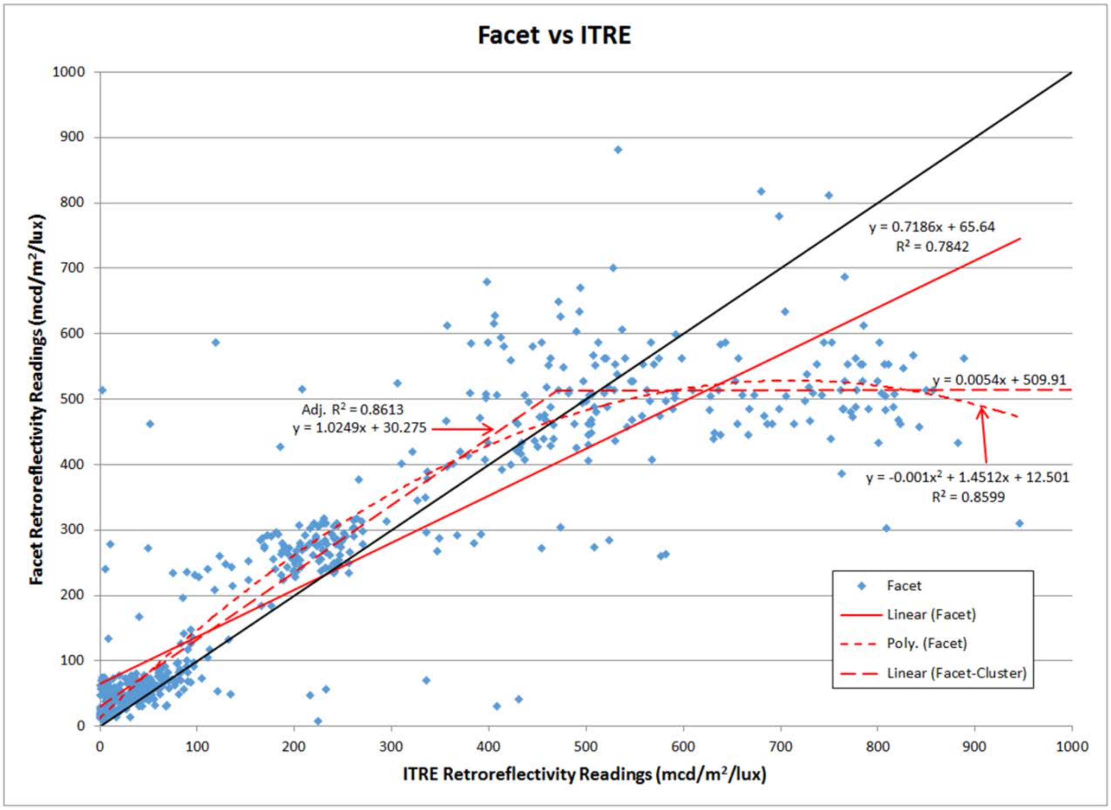

Figure 23 Facet readings versus ITRE readings

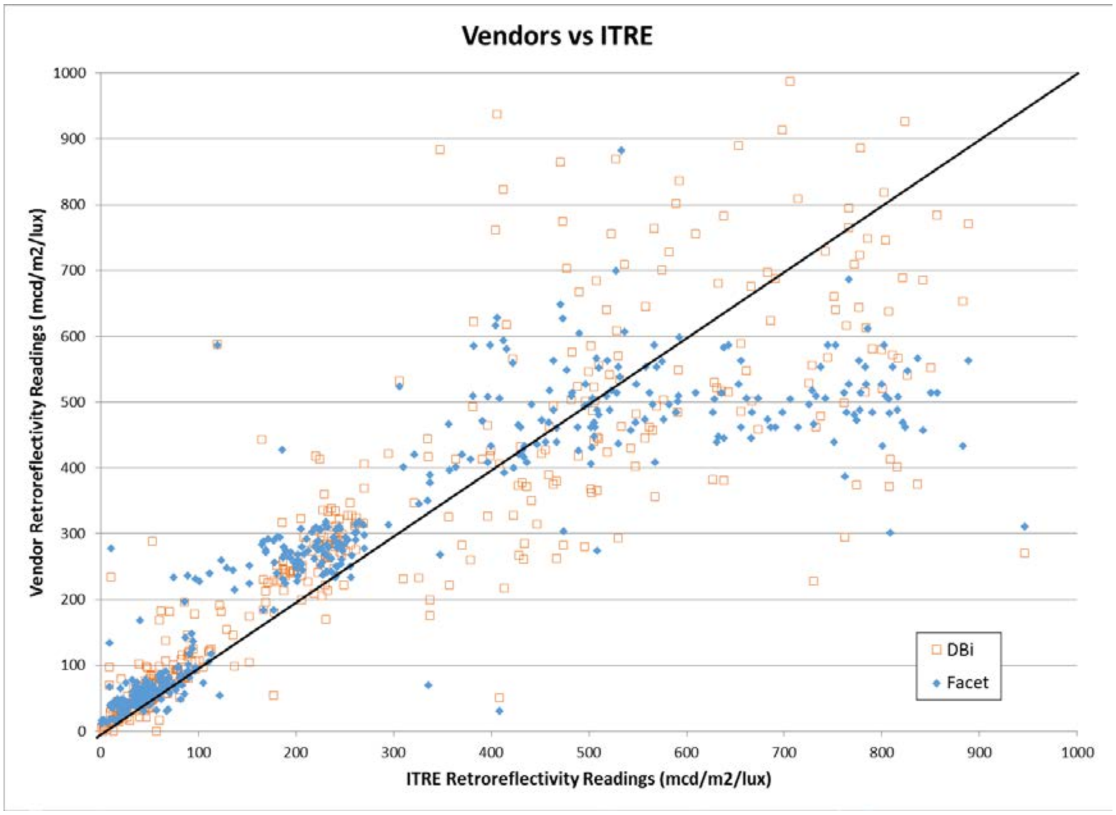

Figure 24 Combined vendor readings versus ITRE readings

Figure 25, Figure 26, and Figure 27 are similar, except that they display a smaller range of retroreflectivity readings (0-400 mcd/m^2/lux). This provides a better picture of the accuracy and consistency achieved by the vendors in this range. This range was chosen because the lower values may be of more importance to the NCDOT than the higher values, mainly because the MUTCD standards for retroreflectivity are low values (generally no higher than 75 mcd/m^2/lux, with the exception of the white on green signs, as seen in Table 7 below); therefore, greater accuracy at lower readings is presumed to be more important than at higher readings. The research team postulates that the vendor equipment is calibrated for the lower to mid-range retroreflectivity readings. A closer inspection of the DBi trend line shows that DBi consistently overestimates in this range, by as little as 14 mcd/m^2/lux at the top of the graph to as much as 23 at the bottom of the graph. Facet's trend line shows that their data also overestimates at a consistent 27 mcd/m^2/lux.

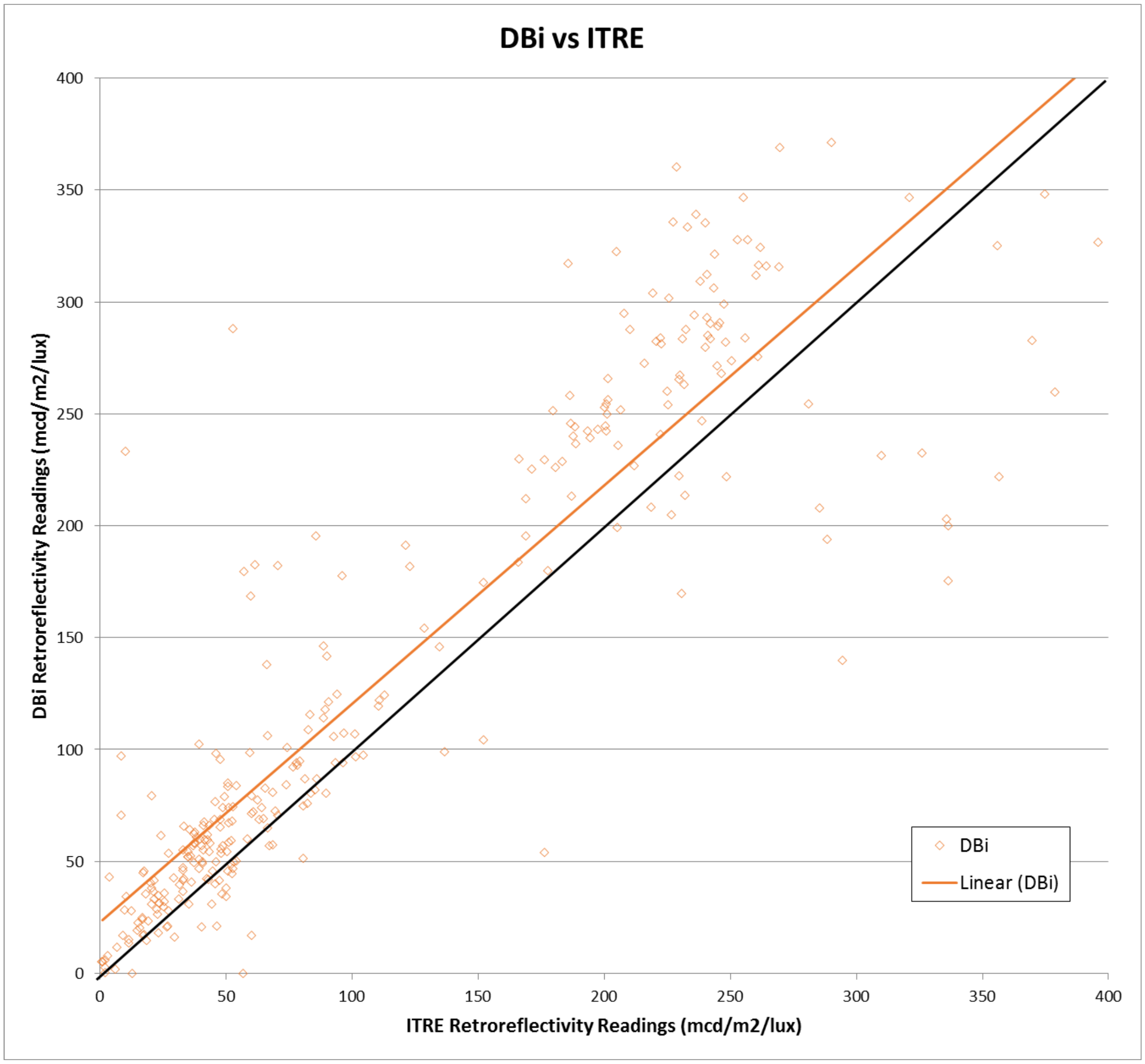

Figure 25 DBi readings versus ITRE readings (0-400 mcd/m^2/lux)

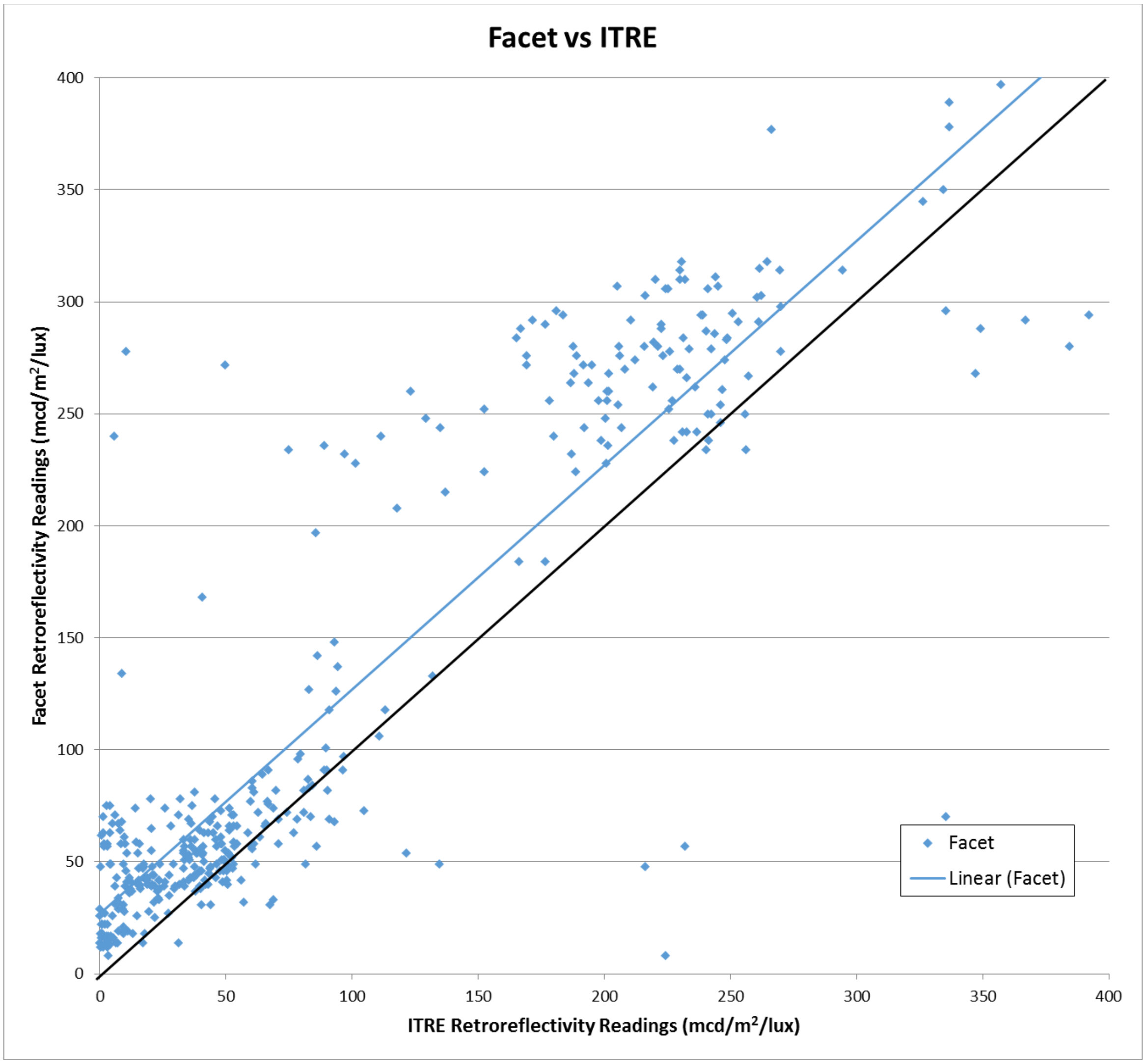

Figure 26 Facet readings versus ITRE readings (0-400 mcd/m²/lux)

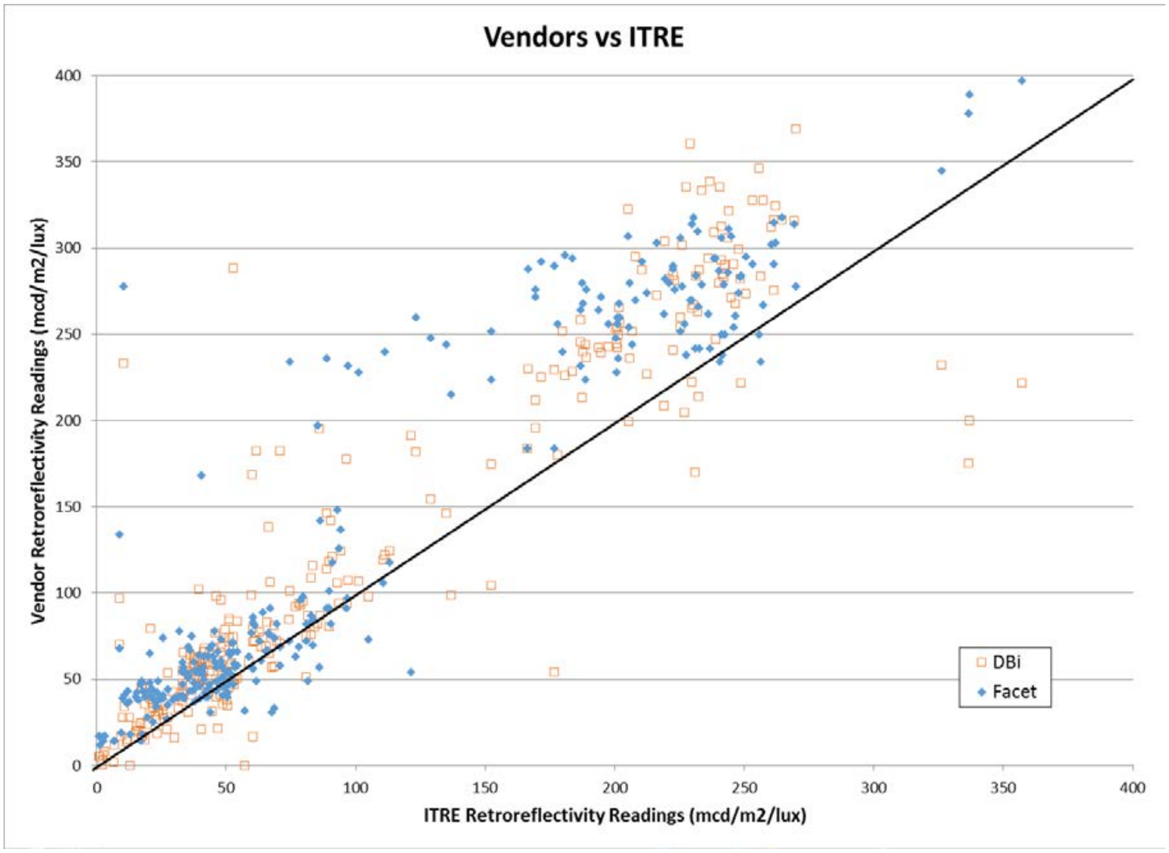

Figure 27 Combined vendor readings versus ITRE readings (0-400 mcd/m^2/lux)

When looking closely at the two clusters of signs shown for each vendor in Figure 25 and Figure 26, it can be observed that the lower cluster (between 0 and 150 mcd/m^2/lux) contains the following sign colors: blue, brown, green, orange, red, white, and yellow. However, while the orange, white, and yellow signs in this group make up 0% (orange), 32% (white) and 34% (yellow) of the total number of these colored signs in the overall sample, the blue, brown, green and red signs in this group make up between 90% and 100% of the overall total of these colored signs in the overall sample, indicating that signs of these colors have much lower retroreflectivity readings than those of orange, white, and yellow signs. Likewise, the upper cluster (150-300 mcd/m^2/lux) on both of these charts contains only orange, white, and yellow signs, generally at low percentages of the overall total number of these signs in the entire sample (21% and 25% of white and yellow signs, respectively, and seven of the nine orange signs). Another observation made of the lower cluster of signs is that 90-100% of signs greater than 20 square feet in size have retroreflectivity readings of 150 mcd/m^2/lux or less. This is likely because these large signs are much more costly to replace, while also typically being guide signs or informational signs, which are not as important to driver safety as warning or regulatory signs.

4.2.2. Retroreflectivity Pass/Fail Comparison

The research team also conducted a comparison of the MUTCD pass/fail rates of the ITRE and the vendor data. Table 7 indicates the passing thresholds for sign retroreflectivity based on sign color.

Any sign below these thresholds is considered failing based on MUTCD standards and should be replaced. The ITRE sample size for retroreflectivity reading matches is smaller than the sample used for location matching since only location-matched signs with retroreflectivity readings were included in the analysis, meaning that some vendor and ITRE signs without readings or without matches were not used in this comparison.

Table 7 MUTCD pass/fail criteria (*35*)

Sign Color	Sheeting Type (ASTM D4956-04) [1]				Additional Criteria
	Beaded Sheeting			Prismatic Sheeting	
	I	II	III	III, IV, VI, VII, VIII, IX, X	
White on Green	W* G ≥ 7	W* G ≥ 15	W* G ≥ 25	W ≥ 250; G ≥ 15	Overhead
	W* G ≥ 7	W ≥ 120; G ≥ 15			Ground-mounted
Black on Yellow or Black on Orange	Y*; O*	Y ≥ 50; O ≥ 50			(2)
	Y*; O*	Y ≥ 75; O ≥ 75			(3)
White on Red	W ≥ 35; R ≥ 7				(4)
Black on White	W ≥ 50				—

°and an entrance angle of -4.0°.

(2) For text and fine symbol signs measuring at least 1200 mm (48 in) and for all sizes of bold symbol signs

(3) For text and fine symbol signs measuring less than 1200 mm (48 in)

(4) Minimum Sign Contrast Ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)

* This sheeting type shall not be used for this color for this application.

The vendors performed significantly better when comparing the data based on MUTCD pass/fail criteria. Both vendors had 100% accuracy when using the MUTCD pass/fail criteria in relation to their respective location-matched overhead signs and achieved accuracies of 97% and 88% for location-matched ground-mounted signs. See Table 8 below for a summary of the vendor performance when using the MUTCD pass/fail criteria for comparison between the vendor and ITRE datasets.

Table 8 Sign MUTCD pass/fail comparison

Research Sample		DBi			
		Matched		*Not Matched*	
Ground	431	419	97%	12	3%
Overhead	20	20	100%	0	0%
Research Sample		**Facet**			
		Matched		*Not Matched*	
Ground	527	463	88%	64	12%
Overhead	20	20	100%	0	0%

4.3. Other Sign Features

Other features captured by the research team and the vendors were the roadside orientation, MUTCD code, and sign description of a sample of signs. These data were only captured on a subset of ITRE signs, as this information was gathered separately from the original data collection effort.

The vendors were more accurate at identifying the location of ground-mounted signs on the right side of the road than the left side, as seen in the rows labeled “Roadside Orientation” in the top section of Table 9. Presumably, this is because of one of two reasons: signs are more often located on the right side of the road, therefore vendor equipment is calibrated to focus on that side of the roadway, or simply because the vendors traveled in the right lane when collecting the data. Of the vendors’ respective location-matched signs, all three vendors produced similar data in capturing approximately 100% of the right side signs and 86-89% of the signs on the left side of the road or in the median.

For the MUTCD code comparison, the variables associated with the MUTCD code were separated for the purposes of comparison; meaning the initial letter, number to the left of the dash symbol, and number to the right of the dash symbol were all compared separately. Of the comparable research data sample of ground-mounted signs, DBi correctly captured 71-75% of each variable, with ESP capturing 84-89% and Facet capturing 69-100%. For overhead signs, the results of each vendor were fairly similar to that of the ground-mounted signs, as seen in the top section of Table 9.

The last feature compared between the ITRE subsample and the vendor datasets was sign description. Vendors were able to appropriately identify the sign description of 100% of each location-matched sign.

The data collected in the previous study (*2*) is provided in the bottom section of Table 9 for comparison to the most recent results. Overall, the roadside orientation and sign description results remain approximately the same in comparison to the previous study. However, the most recent MUTCD code comparison results are a significant improvement over the results produced in 2010. The biggest problem with the most recent vendor data is the sometimes poor ability to locate signs. However, once signs are located, vendors showed high degrees of accuracy when compared to the ITRE dataset, which is a marked improvement over the results obtained in 2010. This is best observed when looking at Figure 28 and Figure 29. The top, lighter portion of each bar represents the amount of signs the vendors were not able to locate, while the middle, darker portion represents the signs that were located but not accurately identified. The bottom, striped portion of each bar represents the signs that were located with features being accurately identified.

Table 9 Other sign features - 2016 versus 2010

Sign Position	Feature Category	Feature Description	Total Research Sample	DBi				ESP				Facet			
				Location Matches		Asset Type Matches		Location Matches		Asset Type Matches		Location Matches		Asset Type Matches	
2016 Ground-mounted Signs	Roadside Orientation	*Right*	621	424	68%	419	99%	524	84%	522	100%	533	86%	532	100%
		Median	151	81	54%	72	89%	95	63%	82	86%	90	60%	78	87%
	MUTCD Code	*Letter*	92	56	61%	42	75%	81	88%	72	89%	78	85%	78	100%
		Number				42	75%			71	88%			57	73%
		After Dash				40	71%			68	84%			54	69%
	Description	*Description*	772	504	65%	504	100%	619	80%	593	96%	623	81%	623	100%
2016 Overhead Signs	MUTCD Code	*Letter*	25	17	68%	12	71%	25	100%	20	80%	18	72%	15	83%
		Number				13	76%			20	80%			15	83%
		After Dash				12	71%			17	68%			14	78%
	Description	*Description*	34	22	65%	22	100%	32	94%	32	100%	22	65%	22	100%

Sign Position	Feature Category	Feature Description	Total Research Sample	Pathways				Fugro			
				Location Matches		Asset Type Matches		Location Matches		Asset Type Matches	
2010 Ground-mounted Signs	Roadside Orientation	*Right*	352	328	93%	302	92%	259	74%	253	98%
		Median	157	147	94%	123	84%	139	89%	133	96%
	MUTCD Code	*Letter*	481	449	93%	309	69%	364	76%	267	73%
		Number				249	55%			265	73%
		After Dash				247	55%			240	66%
	Description	*Description*	505	471	93%	455	97%	379	75%	374	99%
2010 Overhead Signs	MUTCD Code	*Letter*	60	42	70%	13	31%	45	75%	14	31%
		Number				4	10%			13	29%
		After Dash				2	5%			8	18%
	Description	*Description*	85	56	66%	56	100%	58	68%	50	86%

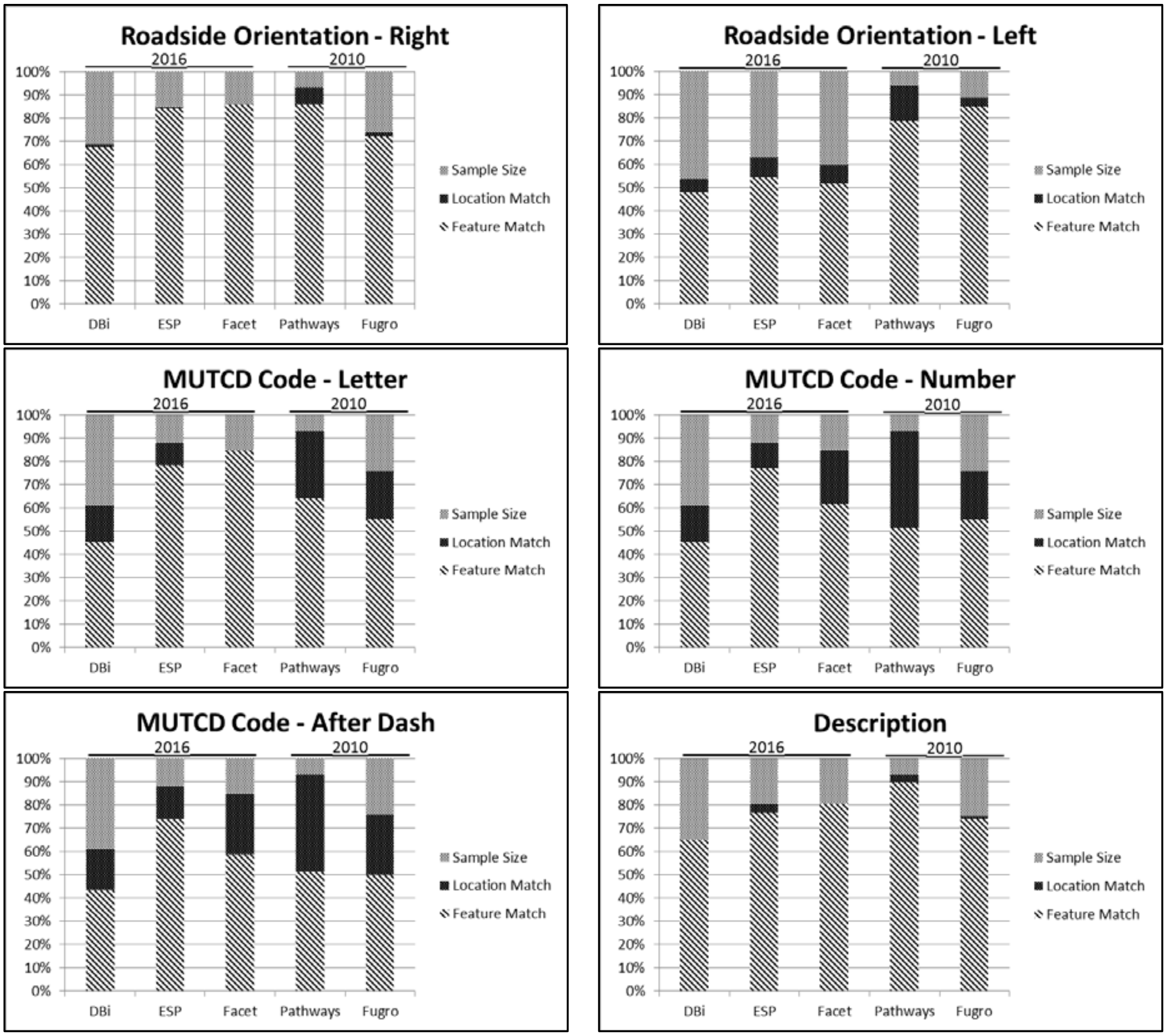

Figure 28 Other sign features for ground-mounted signs

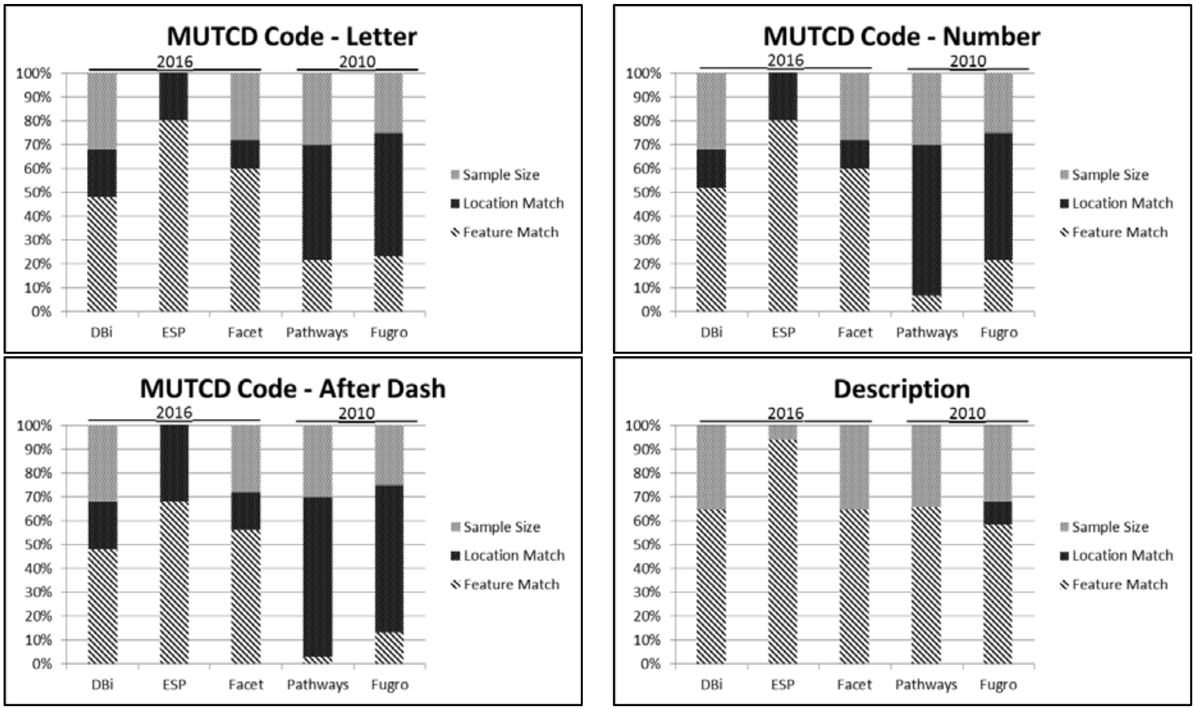

Figure 29 Other sign features for overhead signs

4.4. Sheeting Type

The research team also collected the sheeting type of 187 signs along the course. The sheeting types gathered by the research team are based on the most recent ASTM sheeting specification, ASTM D4956-13. The criteria are provided on the FHWA website (*35*). Of the signs with matching locations, DBi matched 35% of the sign sheeting types and Facet matched 75%. ESP did not provide the sheeting type as a part of their dataset. This information can be seen below in Table 10.

Table 10 Sheeting type comparison between ITRE and vendor signs

Feature	Total Research Sample	Dbi				ESP				Facet			
		Location Matches		*Feature Matches*		*Location Matches*		*Feature Matches*		*Location Matches*		*Feature Matches*	
Sheeting Type	187	100	53%	35	35%	Sheeting Type Not Provided				154	82%	116	75%

5. SUPPLEMENTAL INFORMATION

The following information is regarding analysis conducted by the research team that is beyond the original project scope. These analyses were only conducted on the ITRE datasets, not the vendor datasets.

5.1. Sheeting Type Condition versus Age

ITRE conducted a test on a subsample of ground-mounted signs from the ITRE dataset to determine the relationship between sheeting type and retroreflectivity readings based on the age of the sign. This subsample of signs was from portions of the original test course along Glenwood Avenue and

Wade Avenue in Raleigh, and only included signs on these roadways that had installation dates on the back of the sign. This data collection occurred independent of the original data collection effort, as the original dataset did not include the installation date of the signs. The results of this analysis returned expected values and further validate the data captured by the research team. This analysis was only conducted on the ITRE datasets and not any of the vendor datasets.

As expected, the results of this analysis show that as a sign ages, its retroreflectivity diminishes. Retroreflectivity readings drop sharply for both glass bead and micro-prism sign sheeting five years after they are installed. The average retroreflectivity reading for the subsample of signs that are five to ten years old is 446.13 mcd/m^2/lux compared to 514.65 mcd/m^2/lux for signs less than five years old. The average retroreflectivity reading for the subsample of signs that are greater than ten years old is 47.07 mcd/m^2/lux. Likewise, the average reading for glass bead signs is 78.48 mcd/m^2/lux, with micro-prism signs having much higher retroreflectivity readings, as expected, averaging at 545.25 mcd/m^2/lux. The table below, Table 11, is a summary table of the findings of this analysis. Figure 30 and Figure 31 show the relationship of retroreflectivity readings to age for glass bead sheeting and micro-prism sheeting, respectively, along with confidence intervals for each year. The confidence intervals are wide for some of the younger sign groups because of higher standard deviations combined with a low sample size, but these charts provide some idea of how the age of the signs affects the sign retroreflectivity.

Table 11 ITRE ground-mounted signs - age and sheeting type

Age	**Number of signs**	**Average retroreflectivity**
<5 years	8	514.65
5-10 years	59	446.13
>10 years	73	47.07
Total	140	241.96
Sheeting Type	**Number of signs**	**Average retroreflectivity**
Glass Bead	116	78.48
Microprism	71	545.25

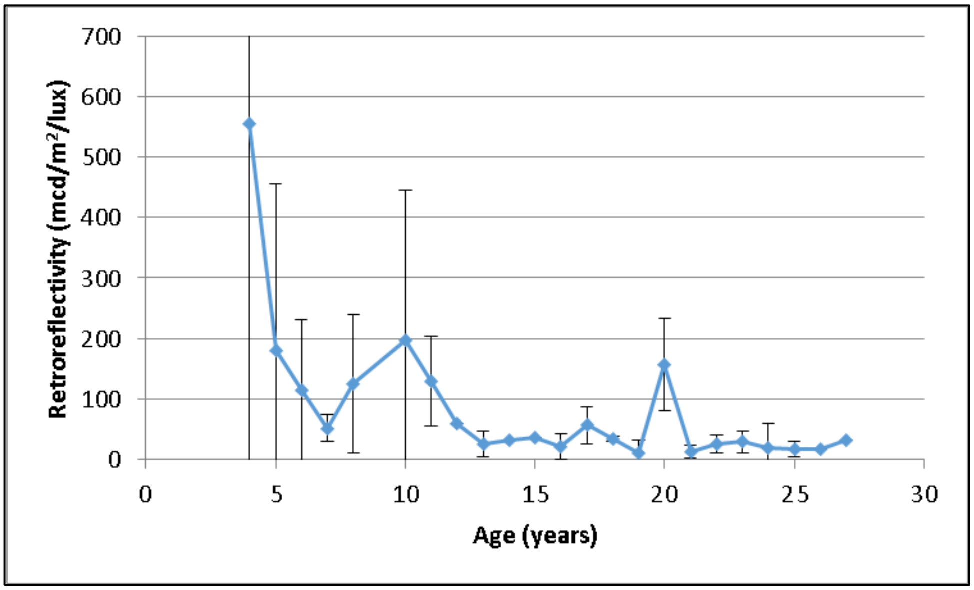

Figure 30 Age vs. retroreflectivity for glass bead sheeting

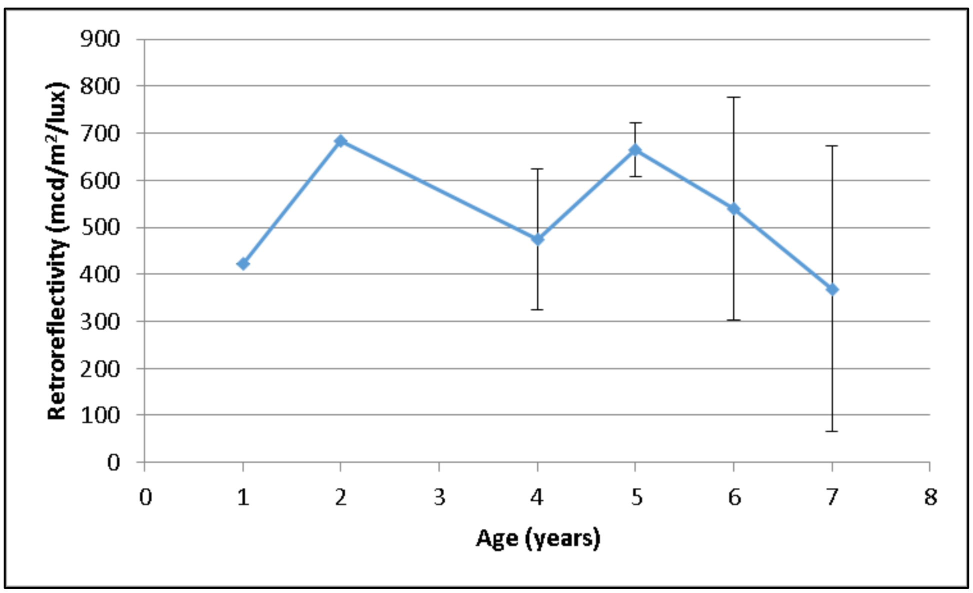

Figure 31 Age vs. retroreflectivity for micro-prism sheeting

5.2. Characteristics of Missed Signs

As can be ascertained from the various tables above, one of the biggest problems facing the automated sign management process is locating signs. The other processes still need improvement, but sign location is one of the bigger struggles for vendors, while also being the most vital aspect of automated sign data collection. This can best be seen in Figure 32, which shows that the accuracy of the determination of a passing or failing sign, once a sign has been located, is comparable to the visual nighttime method studied previously, but automated location of signs still needs improvement. The current process of autonomously locating and evaluating signs still results in only moderately lower accuracy than the more common visual nighttime inspection results described in Chapter 2, and in the case of the research conducted in Texas, actually produced better accuracy. The “pass/fail correct” category represents signs that were located and correctly identified as passing or failing. The “pass/fail incorrect” category represents the signs were located and incorrectly identified as passing or failing. The “located – no retro” category represents signs that were located but were missing retroreflectivity readings – either by the vendor or ITRE. The last category shown, “not located”, represents the signs that were not located correctly by the vendor. ESP was not included in this chart because they did not provide retroreflectivity readings.

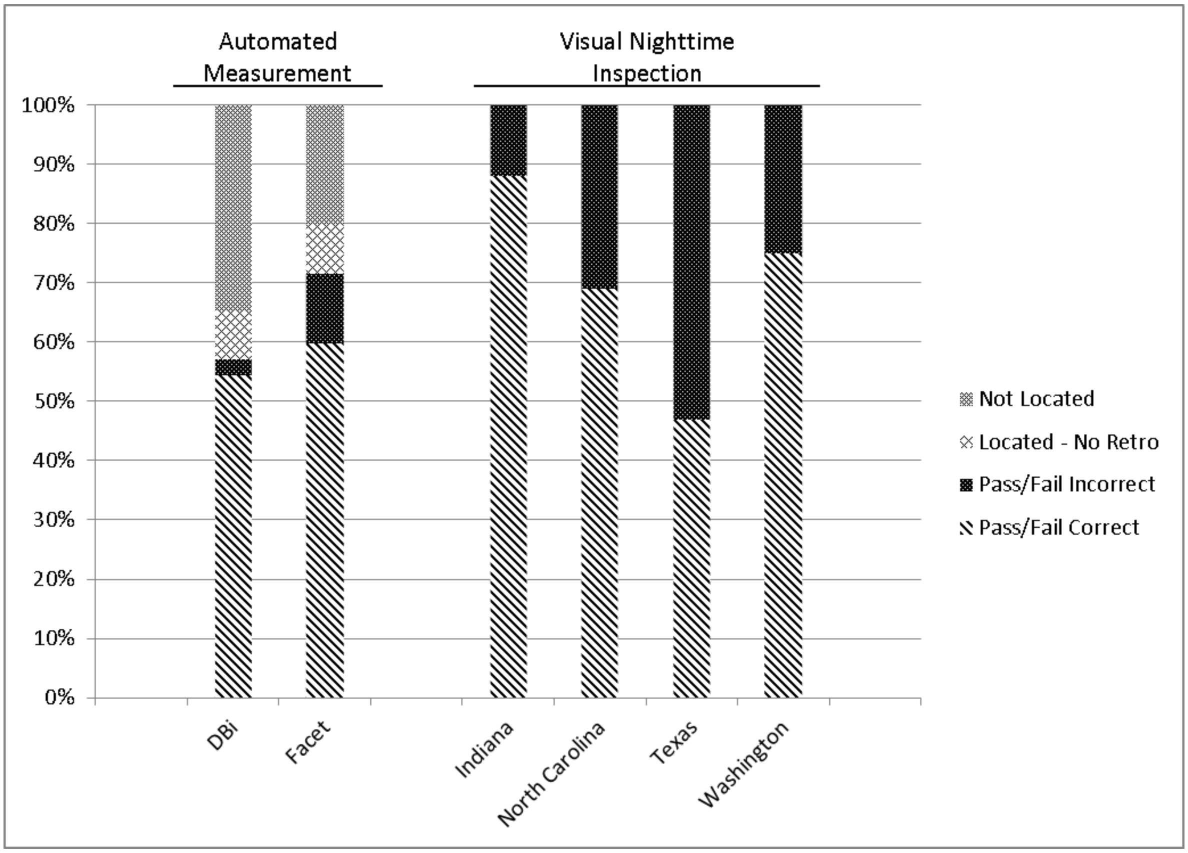

Figure 32 Accuracy of automated measurement versus visual nighttime inspection

Regarding the inability to locate some signs, the research team analyzed the datasets of each of the vendors to determine the characteristics of this problem and was able to observe some trends that may point to why some signs weren’t located by these vendors. The data are summarized in Table 12 below. The varying total sample sizes for each feature are due to feature information not being available for all signs captured. This table shows that there are no obvious discrepancies between the various criteria in the following sign features: number of signs on an assembly, sign color, and sign type.

Table 12 Vendor location accuracy based on various sign features

			DBi		ESP		Facet		Vendor Average
Sign Feature	**Criteria**	**Total Sample**	**# Correct**	**Percent Correct**	**# Correct**	**Percent Correct**	**# Correct**	**Percent Correct**	**Percent Correct**
# Signs on Assembly	One	419	290	69%	344	82%	334	80%	77%
	Multiple	335	200	60%	261	78%	274	82%	73%
Color	Blue	62	44	71%	58	94%	56	90%	85%
	Brown	9	6	67%	8	89%	9	100%	85%
	Green	84	60	71%	82	98%	77	92%	87%
	Orange	9	9	100%	0	0%	1	11%	37%
	Red	23	15	65%	8	35%	14	61%	54%
	White	303	206	68%	280	92%	269	89%	83%
	Yellow	226	141	62%	156	69%	167	74%	68%
Sign Type	D - Directional	4	3	75%	4	100%	3	75%	83%
	M - Detour	9	1	11%	6	67%	7	78%	52%
	R - Regulatory	51	32	63%	45	88%	43	84%	78%
	W - Warning	25	19	76%	25	100%	23	92%	89%
Road Side	Left	150	80	53%	94	63%	89	59%	58%
	Right	604	410	68%	511	85%	519	86%	79%
Distance from Roadway (ft)	5	80	52	65%	59	74%	63	79%	73%
	10	180	124	69%	147	82%	151	84%	78%
	15	190	119	63%	150	79%	147	77%	73%
	20	132	83	63%	104	79%	107	81%	74%
	25	107	73	68%	88	82%	89	83%	78%
	30	62	52	84%	58	94%	58	94%	90%
Sign Size (sq ft)	1.5	15	5	33%	4	27%	8	53%	38%
	3	124	65	52%	83	67%	86	69%	63%
	6	164	106	65%	128	78%	137	84%	75%
	9	121	83	69%	97	80%	98	81%	77%
	12	57	44	77%	52	91%	50	88%	85%
	15	25	10	40%	24	96%	21	84%	73%
	18	90	59	66%	68	76%	69	77%	73%
	21	62	48	77%	57	92%	52	84%	84%
	>21	67	55	82%	66	99%	65	97%	93%

However, there appears to be possible reasons for missed signs when observing the other three features. For instance, signs on the left side of the road may be more difficult to capture than signs on the right side, which may be due to a couple of different reasons, including the position of the data collection vehicles as they traveled the course or the equipment calibration. This is noticed when looking closely at the red signs that were missed. These were looked at in particular because red signs are warning signs, which are some of the most important signs in the roadway vicinity. The vendors struggled with red signs in comparison to the other sign colors, but this may be because 16 of the 23 red signs on the course are on the left side of the road. Likewise, almost all of the signs missed by each of the vendors are on the left side of the road. Ultimately, the research team presumes that vendors drive in the right lane or calibrate their equipment for the right side of the roadway, as it is more common to see signs on the right side of the road than the left. Likewise, the distance from the roadway and the sign size appear to influence the ability of these vendors to capture signs. Smaller signs were generally more difficult to capture than larger signs, especially as they got farther from the roadway. Of the 52 signs missed by all three vendors, the average sign size is 5.6 square feet. Table 13 below shows that as the sign size decreased, the vendors had higher differences between the percentages of missed signs and the overall percentage of signs in the ITRE sample size, further indicating that smaller signs were more difficult for vendors to capture.

Table 13 Percentage of signs missed versus sign size

		Total missed	≤20 sq ft	≤10 sq ft	≤5 sq ft
Vendor	DBi	264	91%	68%	49%
	ESP	149	100%	81%	61%
	Facet	146	96%	72%	51%
ITRE	*671 total signs*		87%	62%	40%

It appears as though signs further from the roadway as a whole were easier to capture than those closer to the roadway, but this is likely because the sign size is increased when they are placed further from the road, increasing the likelihood that sign size influences sign capture more than distance from the roadway. These three features are presented together in Figure 33. Sign size appears to play a role in sign capture for each of the three vendors. However, the distance the sign is from the roadway seemingly plays a larger role in sign capture for DBi than for Facet and may influence sign capture the least for ESP.

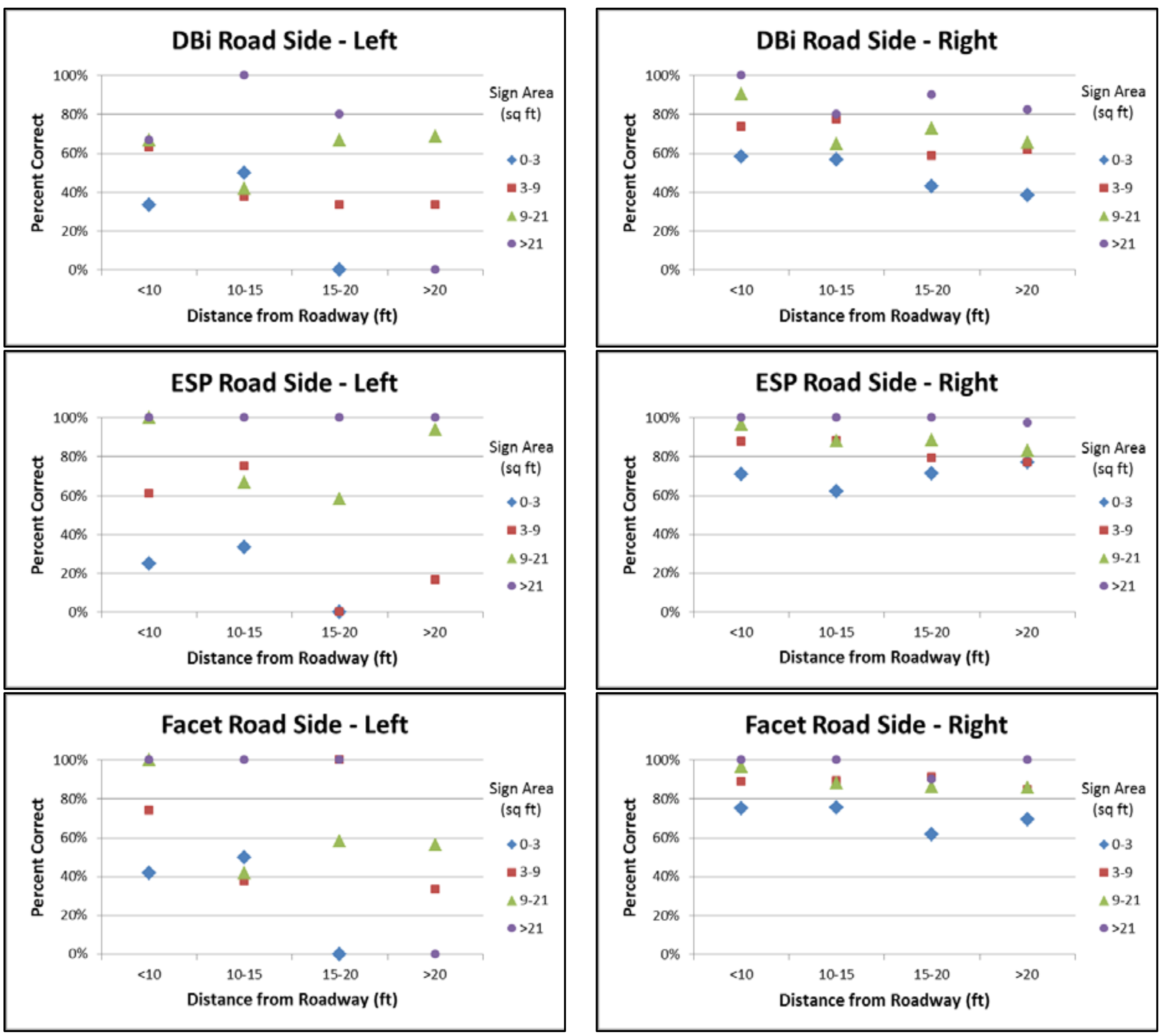

Figure 33 Vendor accuracy based on side of road, distance from roadway, and sign size

6. FINDINGS & CONCLUSIONS

The specific aims for this project were to provide NCDOT with evidence on the viability of automated data collection vehicles in comparison to human collection methods to gather sign inventory data efficiently, accurately, and reliably. Previous studies to compare manual to mobile inventory data collection showed some promise in collecting other assets, but no vendor proved to be capable of providing adequate, accurate sign information, particularly with regards to sign retroreflectivity. For this particular effort, vendors were able to concentrate their efforts on sign information without needing to capture other asset information, as was necessary in previous projects.

This research project evaluated the potential of three mobile asset data collection vendors to collect location and feature attributes of roadway signage along a 90-mile test course. Although similar research has been conducted previously, most recently in the 2010 Asset Inventory project *(2)*, this project only evaluated the potential of vendors to accurately capture sign features important to the NCDOT. The foundation for any asset data collection program is physically *locating the attribute*. Two of the three vendors were able to capture accurate sign locations at a rate of approximately 80%, with the third vendor matching over 65% of sign locations correctly.

Generally speaking, the vendors showed promise in collecting many sign features, but could benefit from improving their abilities to identify signs. However, of high importance to the NCDOT is the fact that one of the two vendors that captured retroreflectivity, Facet, was able to accurately identify appropriate MUTCD retroreflectivity pass/fail ratings of 88% of comparable signs on the test course even without using their standard sign retroreflectivity capture equipment, with the other, DBi, achieving 97% accuracy. This is assumed to be because of the accuracy and consistency achieved by the vendors within the lower range of retroreflectivity values, possibly due to the way vendors calibrate their equipment and data. However, DBi was not able to capture as many sign locations as Facet. There is still room for improvement, but this shows the potential for using automated asset collection vehicles in the future as improvements are made. The third vendor, ESP, was not able to capture sign condition in a comparable format because of the use of their own units for sign reflectivity. This also meant the MUTCD pass/fail criteria could not be used in the analysis either. However, ESP did perform the best in locating the signs, which is very important to the automated sign management process. ESP would benefit from converting their units into retroreflectivity readings or, at the very least, including pass/fail data (which are still based on retroreflectivity units), as this will be more beneficial to the NCDOT and likely other agencies.

When combining the location and pass/fail accuracy of DBi and Facet, they achieve an overall accuracy of approximately 54% and 60%, respectively. As stated above, if the location errors were corrected and all signs were captured by the vendors, an accuracy of 88-97% is possible. Comparing the current numbers to the accuracy achieved by the visual nighttime inspection method discussed in Section 2.1.1 shows that the automated method has similar accuracy. While some of the case studies mentioned saw accuracies ranging from 83% to 88%, others only saw an accuracy of 47% to 75%, which is comparable to the level of accuracy achieved by the vendors in this study. If vendors can improve their abilities to accurately locate signs even moderately, this method might become the preferred method of agencies when combined with the vendors’ abilities to capture other assets.

In short, the automated sign management method has drastically improved in a short time period, as evidenced by the respectable degree of accuracy obtained by the vendors in this study in comparison to the failure of vendors to accurately capture sign data in the first and second studies conducted in 2008 and 2010. With continued improvement, this may soon become the most efficient method for accurately managing and maintaining sign inventories.

7. OPPORTUNITIES FOR FUTURE RESEARCH

Because this study was so specialized, future research opportunities will be based almost solely on advances in sign retroreflectivity capture technology. As the technology progresses and agencies test the technology, special attention should be made to manually capture sign information prior to testing these technologies. However, a study that might be beneficial to the NCDOT would be to review the processes of other state agencies in inventorying signs. A major hang up in the data analyses was the inability to quickly identify sign matches between the ITRE and vendor datasets. This problem might be corrected if signs had a unique identifier present on the sign that vendors could capture through automation, enabling efficient sign inventorying.

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9. APPENDICES

9.1. Appendix A: Data Collection Catalog

Vendors,

Welcome to the 2014 Sign Inventory and Retroreflectivity Data Collection (here after referred to as “Sign Retro”) test track. We thank you for your participation in this research effort and know you are excited to take this opportunity to showcase the services your company has to offer. NCDOT has identified a challenging 90-mile course in central North Carolina. This course covers various roadway types and terrain and should prove to be a quality test track for comparing your data to manually-collected data.

This catalog provides general information regarding the upcoming Sign Retro analysis in summer 2014. Specifically, you will find points of contact, general information, driving directions, a data collection sheet, format and supplemental information on how to collect the necessary data. If at any time you have questions about some part of this process, please feel free to call the appropriate contact person. Good luck and we look forward to seeing you at the Sign Retro analysis.

TABLE OF CONTENTS

General Information

The purpose of this document is to make sure that you, the project data collection participants, have all the information you need to provide data which represents the best possible look at the capabilities of your equipment. Project staff members are striving to ensure that this exercise is as fair and productive as possible. If there is anything that you need from the project staff during data collection, during post-processing, or leading up to the project itself that would help us all achieve our objectives, please ask.

Project Contacts. This catalog contains a list of project team contacts at ITRE. All questions regarding the project should be directed to an ITRE team member.

Driving Directions. Lane-by-lane driving directions follow on Page 5 of this catalog. The course will begin at the interchange of Poole Road and I-440. For data consistency purposes, please follow these directions as precisely as possible. You should not collect data in any roadway work zones you may encounter. Please drive the course just once.

Post Data Collection. After driving the course, we ask that you call your designated project staff person for a quick debrief. We would like to know that you finished the course successfully and whether you encountered problems. Also call this staff person in the event that weather or some other circumstance interrupts your drive of the course.

Data Submission & Acknowledgement of NCDOT Data Ownership. Detailed data submission is included on Pages 13 and 14 of the Catalog. Note that some fields are left blank in this example, but all data fields shown in the example should be collected and the form should be filled out for all collected data. Additionally, we ask for acknowledgement that the NCDOT will become the owner of the data that you submit to the Project. Please complete and return the form found on Page 26 of the Catalog.

Thank you for participating in this project!

ITRE Project Contacts

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Course Details

Directions begin at the interchange of Poole Road and the I-440 southbound on-ramp.

- Head south on I-440 (1.9 mi)
- Merge onto I-40W (11.4 mi)
- Take exit 289 toward US-1N/Wade Ave (0.8 mi)
- Merge onto Wade Ave (2.2 mi)
- Take exit onto I-440 E/US 1N toward Wake Forest/Rocky Mt (2.8 mi)
- Take exit 7 for US 70W (0.3 mi)
- Turn left onto Glenwood Ave (8.4 mi)
- Take the Westgate Rd ramp to I-540/I040/Lumley Rd (0.3 mi)
- Continue to I-540 E (11.7 mi)
- Take exit 16 to merge onto US-1N/Capital Blvd (6.0)
- Keep left to stay on US-1N/Capital Blvd (1.4 mi)
- Turn right onto NC 98 E./Wake Forest (0.2)
- Turn right onto NC 98 E. Bypass (2.8 mi)
- Continue straight onto NC 98 E. (13.7 mi)
- Turn right onto Railroad St (0.2 mi)
- Turn right onto S. Main St (0.4 mi)
- Take the 3rd right onto NC-39 S/Main St (6.6 mi)
- Turn right to merge onto US-64 W (19.8 mi)
- Keep left at fork, follow signs for I-440 E/I-40/US-64 W (1.0 mi)
- Take exit 15 for Poole Rd.

The course is a total 90.6 miles long. Figure 2 shows the course you will be required to collect sign data along for this project. You will drive the course in a clock-wise direction, collecting data only in one direction of travel (i.e. one side of the road).

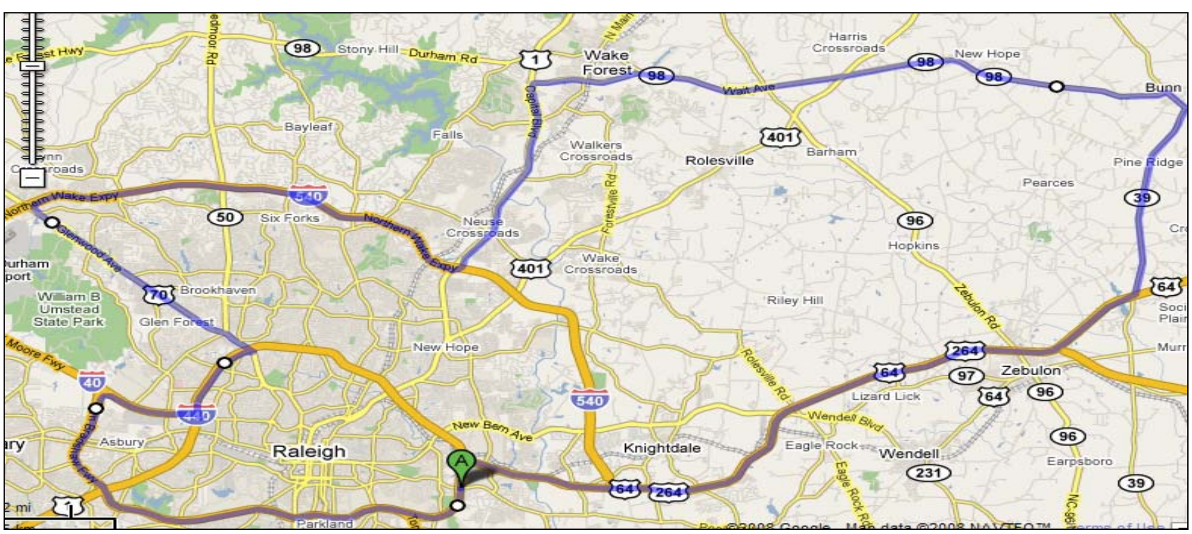


Exhibit 1. Course Map

One or more short segments of the course will be utilized for calibration purposes. At any time during the process, if the vendor so desires, the research team will provide sign data along these segments for the purposes of calibration. The format utilized will be consistent with that shown in Exhibit 8.

Instructions for Submitting Data

Data Submission and Deadlines. A single submission of data is all that is required. Submit all data to each of the team members at ITRE. See Page 4 for contact information.

1. At the vendor's request, the research team will provide retroreflectivity of signs along one or more short sections. This is for your information only and ITRE staff will not be involved in the calibration process. However, you are welcome to ask any questions you may have about these segments, the sign attributes, equipment used, etc. and ITRE will reply appropriately.

2. The final submission of data along the course is due one month from the date the course is run. Any late submissions should be pre-approved by one of the research team members.

Communication/Management. To prevent any confusion during data collection, we would like to stress the importance of familiarization with NCDOT's data collection methods. As noted in the cover letter, our objective is to be as informative as possible. Therefore, if there is any confusion during the pilot data collection or post-processing please contact a member of the research team.

Format. Data should be submitted electronically in two (2) formats by removable media or FTP site:

1. ArcGIS Shape files or Geodatabase
2. Microsoft Office Excel Spreadsheets

Specific descriptions, photo examples, and instructions of each data element are found in the data collection sheet provided for your use in the following section. Please complete all data collection as shown and ask questions if clarification is necessary. Where mileposts are required, please start at 0.00 where the Poole Road on-ramp and I-440 meet at the bottom of the ramp (pavement marking gore) and run continuously through the course.

In each table, one row of data will pertain to one particular item being measured (e.g., each sign). Data items should be listed in each table sequentially, as encountered in your drive along the course, using the mile posting system starting at the on-ramp of Poole Blvd, along with the appropriate latitude and longitude of the sign location. This document provides detailed definitions and desired units of measure for each variable and data element in the following table. Always be as precise as possible.

Photographs. Pictures are encouraged where data elements may need further evidence provided. This will also help with subjectivity during the analysis. The team recommends using the picture ID number in the data sheet so the research team can easily reference those as needed.

Units. Generally, English units of measure will be requested unless the current custom for that particular variable is to use metric units.

Accuracy. In your data submission, please provide the team with the tolerances for sign data collected if a unit of length is required (i.e. sign size, location).

Traffic Signs

Feature Description

Signs control traffic and convey information. To be effective, signs must be visible and legible to both vehicular and pedestrian traffic. If not, the result may be motorist confusion and error.

Data Collection Instructions

Traffic signs intended for the direction of travel should be collected along the entire test route in the direction of travel.

Data Collection Fields

Location: The location points include the **course milepost**, **latitude**, and **longitude.** Each individual sign on an assembly will have its own row and be located, regardless of the fact that the sign is a part of the assembly. All points should be geolocated to the base of the sign structure, and not the actual location of the sign or along the vehicle path of travel within the lane.

Assembly Type: The assembly will be described as **Overhead** or **Ground Mounted** by placing an "x" in the appropriate field. An overhead assembly will be a sign installed on any overhead mast or overhead span wire. All other signs will be noted as Ground Mounted.

Number of Signs on Assembly: Note the number of signs on the entire assembly at this point location. If signs are on the same assembly, they are noted as being together. For instance, in our example, the first sign assembly has seven signs, each having a separate row but indicating it is a part of the same assembly by having the number of signs along with the same latitude and longitude and milepost. Note that this also applies to overhead signs on the same assembly.

Sign Description: Provide a description of the sign marking.

MUTCD Code: Refer to Appendix A: Excerpts from 2009 MUTCD for each sign's code.

Roadway Location: **Right, Median, or Overhead.** A sign assembly on a rigid structure from the right or median with a mast arm overhead is considered an Overhead location (see Exhibits 4 and 5).

Location on Assembly: Numbered "1" through "9". This refers to the location of the particular sign in question on the assembly it is attached to, and therefore is only relevant if there are multiple signs on the assembly. The expected standard is to number the signs from left to right, top to bottom. For example, if there are six signs on a particular assembly (two rows of three signs), the middle sign on the bottom row would be numbered "5" in this field of the table. An example of this is also shown in Exhibit 2.

<u>Distance from Roadway:</u> Measure the distance from the edge of the outside lane line to the center of the sign assembly (feet). If on the right side of the road, the referenced lane line is the white line farthest to the right on the roadway. If the sign is in the median, the referenced lane line is the white line farthest to the left on the roadway. If the sign is an overhead sign, leave this field blank.

<u>Width:</u> Measure the **width** of the **sign (inches)**.

<u>Height:</u> Measure the **height** of the **sign (inches)**.

<u>Picture ID#:</u> Provide a database of images of each sign assembly with reference numbers assigned to each picture. The numbering will start at 1 for the first assembly measured, then progress in numerical order as the vendor progresses through the course.

<u>Retroreflectivity:</u> Measure the retroreflectivity (mcd/m^2/lux) of the sign using a retroreflectometer or another related device. A sign with a retroreflective surface will direct all of the reflected light back towards the light source rather than disperse it in all directions. Note that some signs have equal amounts of different colors, like the NC Highway 98 sign in Exhibit 6 below. In this case, the vendor would measure the white portion of the sign and disregard the black portion as this is just meant to contrast the white and is not retroreflective. Likewise, signs like the one seen in Exhibit 7 below, which can be seen on the ends of attenuators and at bridges, should be collected in a similar fashion to the NC-98 sign in Exhibit 6, with black being the contrast color and yellow being the color collected. Do this in all similar cases. Also, there will be signs that have different colors over large amounts of surface area; in these cases, collect the retroreflectivity readings of the primary background color. An example of the locations where the retro readings were gathered by the research team on these types of signs can be seen in Exhibit 5 as red dots. Notice that although a large portion of the sign is yellow, green is the predominant color, so that is the color to be collected.

<u>Sheeting Type:</u> This refers to the type of sheeting material used to make this sign, as specified by MUTCD.

<u>Comments:</u> Use this field to describe anything that may appear out of the ordinary and to denote any damage to the sign.

Note: The following exhibits are referenced in the example data collection spreadsheet, Exhibit 8.

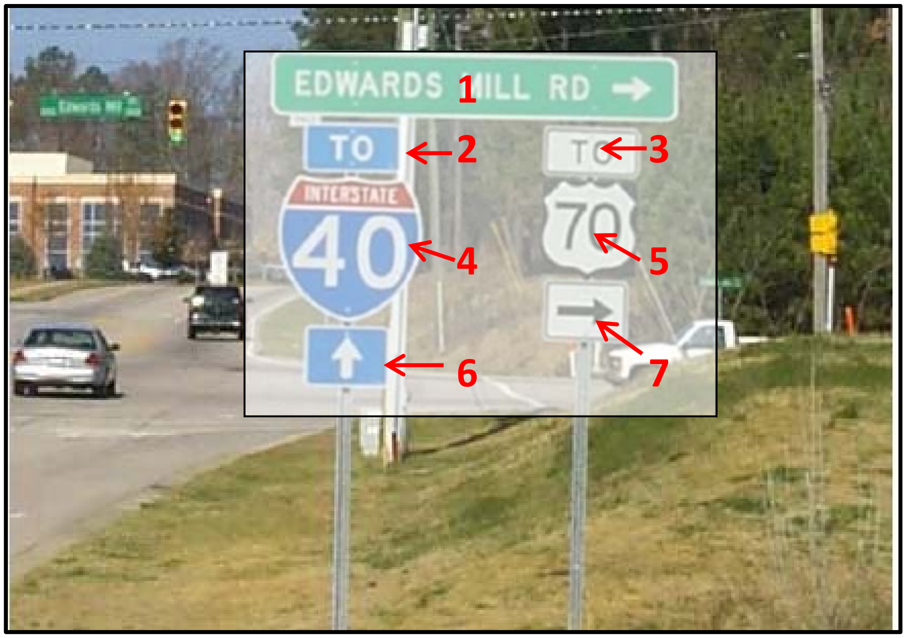


Exhibit 2. Ground-Mounted Traffic Signs

Exhibit 3. Ground-Mounted Traffic Sign

Exhibit 4. Overhead Traffic Signs

Exhibit 5. Overhead Traffic Signs

Exhibit 6. Ground-Mounted Traffic Sign

Exhibit 7. Ground-Mounted Traffic Sign

Exhibit 8. Data Collection Format and Example

Traffic Signs																
Course Milepost	Latitude	Longitude	Ground Mounted	Overhead	Number of Signs on Assembly	Sign Description	MUTCD Code	Roadway Location	Location on Assembly	Dist. from Roadway (ft)	Size		Picture ID#	Retro-reflectivity (mcd/m^2/lux)	Sheeting Type	Comments
											Width (in)	Height (in)				
17.26 (Exhibit 2)	35.76803	78.65948	x		7	Edwards Mill Rd	D3-2	Right	1		120	30		200		
17.26 (Exhibit 2)	35.76803	78.65948	x		7	To	M4-5	Right	2		24	24		98		
17.26 (Exhibit 2)	35.76803	78.65948	x		7	To	M4-5	Right	3		24	12		112		
17.26 (Exhibit 2)	35.76803	78.65948	x		7	I-40	M1-1	Right	4		16	12		102		
17.26 (Exhibit 2)	35.76803	78.65948	x		7	US 70	M1-4	Right	5		24	12		77		
17.26 (Exhibit 2)	35.76803	78.65948	x		7	Forward Arrow	M6-3	Right	6		24	24		84		
17.26 (Exhibit 2)	35.76803	78.65948	x		7	Right Arrow	M6-1	Right	7		16	12		97		
18.90 (Exhibit 3)	35.76808	78.65956	x		1	Speed Limit 45	R2-1	Right	1		30	30		154		Knocked Over
19.00 (Exhibit 4)	35.76803	78.65948		x	5	Exit 36	E1-5	Overhead	1		96	60		98		
19.00 (Exhibit 4)	35.76803	78.65948		x	5	16 to 74	M2-2	Overhead	2		42	12		112		

19.00 (Exhibit 4)	35.7680 3	78.65948		x	5	Lane Ends 1000’	W4-2	Overhead	3		42	48		102		
19.00 (Exhibit 4)	35.7680 3	78.65948		x	5	Exit 35	E1-5	Overhead	4		42	12		114		
19.00 (Exhibit 4)	35.7680 3	78.65948		x	5	Glenwood Dr. Exit Only	E11-1c	Overhead	5		96	30		115		
20.54 (Exhibit 5)	35.7685 3	78.65962		x	2	Exit 49	E1-5	Overhead	1		96	42		84		
20.54 (Exhibit 5)	35.7685 3	78.65962		x	2	Speedway Blvd - Concorde Mills Blvd.	M2-2	Overhead	2		42	12		97		

Appendix A: Excerpts from 2009 MUTCD

Table 2B-1. Regulatory Sign and Plaque Sizes (Sheet 1 of 4)

Sign or Plaque	Sign Designation	Section	Conventional Road		Expressway	Freeway	Minimum	Oversized
			Single Lane	Multi-Lane				
Stop	R1-1	2B.05	30 x 30*	36 x 36	36 x 36	—	30 x 30*	48 x 48
Yield	R1-2	2B.08	36x36x36*	48x48x48	48x48x48	60x60x60	30x30x30*	—
To Oncoming Traffic (plaque)	R1-2aP	2B.10	24 x 18	24 x 18	36 x 30	48 x 36	24 x 18	—
All Way (plaque)	R1-3P	2B.05	18 x 6	18 x 6	—	—	—	30 x 12
Yield Here to Peds	R1-5	2B.11	—	36 x 36	—	—	—	36 x 36
Yield Here to Pedestrians	R1-5a	2B.11	—	36 x 48	—	—	—	36 x 48
Stop Here for Peds	R1-5b	2B.11	—	36 x 36	—	—	—	36 x 36
Stop Here for Pedestrians	R1-5c	2B.11	—	36 x 48	—	—	—	36 x 48
In-Street Ped Crossing	R1-6,6a	2B.12	12 x 36	12 x 36	—	—	—	—
Overhead Ped Crossing	R1-9,9a	2B.12	90 x 24	90 x 24	—	—	—	—
Except Right Turn (plaque)	R1-10P	2B.05	24 x 18	24 x 18	—	—	—	—
Speed Limit	R2-1	2B.13	24 x 30*	30 x 36	36 x 48	48 x 60	18 x 24*	30 x 36
Truck Speed Limit (plaque)	R2-2P	2B.14	24 x 24	24 x 24	36 x 36	48 x 48	—	36 x 36
Night Speed Limit (plaque)	R2-3P	2B.15	24 x 24	24 x 24	36 x 36	48 x 48	—	36 x 36
Minimum Speed Limit (plaque)	R2-4P	2B.16	24 x 30	24 x 30	36 x 48	48 x 60	—	36 x 48
Combined Speed Limit	R2-4a	2B.16	24 x 48	24 x 48	36 x 72	48 x 96	—	36 x 72
Unless Otherwise Posted (plaque)	R2-5P	2B.13	24 x 18	24 x 18	—	—	—	—
Citywide (plaque)	R2-5aP	2B.13	24 x 6	24 x 6	—	—	—	—
Neighborhood (plaque)	R2-5bP	2B.13	24 x 6	24 x 6	—	—	—	—
Residential (plaque)	R2-5cP	2B.13	24 x 6	24 x 6	—	—	—	—
Fines Higher (plaque)	R2-6P	2B.17	24 x 18	24 x 18	36 x 24	48 x 36	—	36 x 24
Fines Double (plaque)	R2-6aP	2B.17	24 x 18	24 x 18	36 x 24	48 x 36	—	36 x 24
$XX Fine (plaque)	R2-6bP	2B.17	24 x 18	24 x 18	36 x 24	48 x 36	—	36 x 24
Begin Higher Fines Zone	R2-10	2B.17	24 x 30	24 x 30	36 x 48	48 x 60	—	36 x 48
End Higher Fines Zone	R2-11	2B.17	24 x 30	24 x 30	36 x 48	48 x 60	—	36 x 48
Movement Prohibition	R3-1,2,3,4,18,27	2B.18	24 x 24*	36 x 36	36 x 36	—	—	48 x 48
Mandatory Movement Lane Control	R3-5,5a	2B.20	30 x 36	30 x 36	—	—	—	—
Left Lane (plaque)	R3-5bP	2B.20	30 x 12	30 x 12	—	—	—	—
HOV 2+ (plaque)	R3-5cP	2B.20	24 x 12	24 x 12	—	—	—	—
Taxi Lane (plaque)	R3-5dP	2B.20	30 x 12	30 x 12	—	—	—	—
Center Lane (plaque)	R3-5eP	2B.20	30 x 12	30 x 12	—	—	—	—
Right Lane (plaque)	R3-5fP	2B.20	30 x 12	30 x 12	—	—	—	—
Bus Lane (plaque)	R3-5gP	2B.20	30 x 12	30 x 12	—	—	—	—
Optional Movement Lane Control	R3-6	2B.21	30 x 36	30 x 36	—	—	—	—
Right (Left) Lane Must Turn Right (Left)	R3-7	2B.20	30 x 30*	36 x 36	—	—	—	—
Advance Intersection Lane Control	R3-8,8a,8b	2B.22	Varies x 30	Varies x 30	—	—	—	Varies x 36
Two-Way Left Turn Only (overhead)	R3-9a	2B.24	30 x 36	30 x 36	—	—	—	—
Two-Way Left Turn Only (post-mounted)	R3-9b	2B.24	24 x 36	24 x 36	—	—	—	36 x 48
BEGIN	R3-9cP	2B.25	30 x 12	30 x 12	—	—	—	—
END	R3-9dP	2B.25	30 x 12	30 x 12	—	—	—	—
Reversible Lane Control (symbol)	R3-9e	2B.26	108 x 48	108 x 48	—	—	—	—
Reversible Lane Control (post-mounted)	R3-9f	2B.26	30 x 42*	36 x 54	—	—	—	—
Advance Reversible Lane Control Transition Signing	R3-9g,9h	2B.26	108 x 36	108 x 36	—	—	—	—
End Reverse Lane	R3-9i	2B.26	108 x 48	108 x 48	—	—	—	—
Begin Right (Left) Turn Lane	R3-20	2B.20	24 x 36	24 x 36	—	—	—	—
All Turns (U Turn) from Right Lane	R3-23,23a	2B.27	60 x 36	60 x 36	—	—	—	—
All Turns (U Turn) with arrow	R3-24,24b, 25,25b,26a	2B.27	72 x 18	72 x 18	—	—	—	—
U and Left Turns with arrow	R3-24a,25a,26	2B.27	60 x 24	60 x 24	—	—	—	—
Right Lane Must Exit	R3-33	2B.23	—	—	78 x 36	78 x 36	—	—

Table 2B-1. Regulatory Sign and Plaque Sizes (Sheet 2 of 4)

Sign or Plaque	Sign Designation	Section	Conventional Road		Expressway	Freeway	Minimum	Oversized
			Single Lane	Multi-Lane				
Do Not Pass	R4-1	2B.28	24 x 30	24 x 30	36 x 48	48 x 60	18 x 24	36 x 48
Pass With Care	R4-2	2B.29	24 x 30	24 x 30	36 x 48	48 x 60	18 x 24	36 x 48
Slower Traffic Keep Right	R4-3	2B.30	24 x 30	24 x 30	36 x 48	48 x 60	18 x 24	36 x 48
Trucks Use Right Lane	R4-5	2B.31	24 x 30	24 x 30	36 x 48	48 x 60	—	36 x 48
Keep Right	R4-7,7a,7b	2B.32	24 x 30	24 x 30	36 x 48	48 x 60	18 x 24	36 x 48
Narrow Keep Right	R4-7c	2B.32	18 x 30	18 x 30	—	—	—	—
Keep Left	R4-8,8a,8b	2B.32	24 x 30	24 x 30	36 x 48	48 x 60	18 x 24	36 x 48
Narrow Keep Left	R4-8c	2B.32	18 x 30	18 x 30	—	—	—	—
Stay in Lane	R4-9	2B.33	24 x 30	24 x 30	36 x 48	48 x 60	18 x 24	36 x 48
Runaway Vehicles Only	R4-10	2B.34	48 x 48	48 x 48	—	—	—	—
Slow Vehicles with XX or More Following Vehicles Must Use Turn-Out	R4-12	2B.35	42 x 24	42 x 24	—	—	—	—
Slow Vehicles Must Use Turn-Out Ahead	R4-13	2B.35	42 x 24	42 x 24	—	—	—	—
Slow Vehicles Must Turn Out	R4-14	2B.35	30 x 42	30 x 42	—	—	—	—
Keep Right Except to Pass	R4-16	2B.30	24 x 30	24 x 30	36 x 48	48 x 60	18 x 24	36 x 48
Do Not Drive on Shoulder	R4-17	2B.36	24 x 30	24 x 30	36 x 48	48 x 60	18 x 24	36 x 48
Do Not Pass on Shoulder	R4-18	2B.36	24 x 30	24 x 30	36 x 48	48 x 60	18 x 24	36 x 48
Do Not Enter	R5-1	2B.37	30 x 30*	36 x 36	36 x 36	48 x 48	—	36 x 36
Wrong Way	R5-1a	2B.38	36 x 24*	42 x 30	36 x 24*	42 x 30	30 x 18*	42 x 30
No Trucks	R5-2,2a	2B.39	24 x 24	24 x 24	30 x 30	36 x 36	—	36 x 36
No Motor Vehicles	R5-3	2B.39	24 x 24	24 x 24	—	—	24 x 24	—
No Commercial Vehicles	R5-4	2B.39	24 x 30	24 x 30	36 x 48	36 x 48	—	—
No Vehicles with Lugs	R5-5	2B.39	24 x 30	24 x 30	36 x 48	48 x 60	—	—
No Bicycles	R5-6	2B.39	24 x 24	24 x 24	30 x 30	36 x 36	24 x 24	48 x 48
No Non-Motorized Traffic	R5-7	2B.39	30 x 24	30 x 24	42 x 24	48 x 30	—	42 x 24
No Motor-Driven Cycles	R5-8	2B.39	30 x 24	30 x 24	42 x 24	48 x 30	—	42 x 24
No Pedestrians, Bicycles, Motor-Driven Cycles	R5-10a	2B.39	30 x 36	30 x 36	—	—	—	—
No Pedestrians or Bicycles	R5-10b	2B.39	30 x 18	30 x 18	—	—	—	—
No Pedestrians	R5-10c	2B.39	24 x 12	24 x 12	—	—	—	—
Authorized Vehicles Only	R5-11	2B.39	30 x 24	30 x 24	—	—	—	—
One Way	R6-1	2B.40	36 x 12*	54 x 18	54 x 18	54 x 18	—	54 x 18
One Way	R6-2	2B.40	24 x 30*	30 x 36	36 x 48	48 x 60	18 x 24*	36 x 48
Divided Highway Crossing	R6-3,3a	2B.42	30 x 24	30 x 24	36 x 30	—	—	36 x 30
Roundabout Directional (2 chevrons)	R6-4	2B.43	30 x 24	30 x 24	—	—	—	—
Roundabout Directional (3 chevrons)	R6-4a	2B.43	48 x 24	48 x 24	—	—	—	—
Roundabout Directional (4 chevrons)	R6-4b	2B.43	60 x 24	60 x 24	—	—	—	—
Roundabout Circulation (plaque)	R6-5P	2B.44	30 x 30	30 x 30	—	—	—	—
BEGIN ONE WAY	R6-6	2B.40	24 x 30	30 x 36	—	—	—	—
END ONE WAY	R6-7	2B.40	24 x 30	30 x 36	—	—	—	—
Parking Restrictions	R7-1, 2,2a,3,4,5,6,7,8, 21,21a,22,23, 23a,107,108	2B.46	12 x 18	12 x 18	—	—	—	—
Van Accessible (plaque)	R7-8P	2B.46	18 x 9	18 x 9	—	—	—	—
Fee Station	R7-20	2B.46	24 x 18	24 x 18	—	—	—	—
No Parking (with transit logo)	R7-107a	2B.46	12 x 30	12 x 30	—	—	—	—
No Parking/Restricted Parking (combined sign)	R7-200	2B.46	24 x 18	24 x 18	—	—	—	—
No Parking/Restricted Parking (combined sign)	R7-200a	2B.46	12 x 30	12 x 30	—	—	—	—
Tow Away Zone (plaque)	R7-201P,201aP	2B.46	12 x 6	12 x 6	—	—	—	—
This Side of Sign (plaque)	R7-202P	2B.46	12 x 6	12 x 6	—	—	—	—

Table 2B-1. Regulatory Sign and Plaque Sizes (Sheet 3 of 4)

Sign or Plaque	Sign Designation	Section	Conventional Road Single Lane	Conventional Road Multi-Lane	Expressway	Freeway	Minimum	Oversized
Emergency Snow Route	R7-203	2B.46	18 x 24	18 x 24	—	—	—	24 x 30
No Parking on Pavement	R8-1	2B.46	24 x 30	24 x 30	36 x 48	48 x 60	—	36 x 48
No Parking Except on Shoulder	R8-2	2B.46	24 x 30	24 x 30	36 x 48	48 x 60	—	36 x 48
No Parking (symbol)	R8-3	2B.46	24 x 24*	30 x 30	36 x 36	48 x 48	12 x 12*	36 x 36
No Parking	R8-3a	2B.46	24 x 30	24 x 30	36 x 36	48 x 48	18 x 24	36 x 36
Except Sundays and Holidays (plaque)	R8-3bP	2B.46	24 x 18	24 x 18	—	—	12 x 9	30 x 24
On Pavement (plaque)	R8-3cP	2B.46	24 x 18	24 x 18	—	—	12 x 9	30 x 24
On Bridge (plaque)	R8-3dP	2B.46	24 x 18	24 x 18	—	—	12 x 9	30 x 24
On Tracks (plaque)	R8-3eP	2B.46	12 x 9	12 x 9	—	—	—	30 x 24
Except on Shoulder (plaque)	R8-3fP	2B.46	24 x 18	24 x 18	—	—	12 x 9	30 x 24
Loading Zone (plaque)	R8-3gP	2B.46	24 x 18	24 x 18	—	—	12 x 9	30 x 24
Times of Day (plaque)	R8-3hP	2B.46	24 x 18	24 x 18	—	—	12 x 9	30 x 24
Emergency Parking Only	R8-4	2B.49	30 x 24	30 x 24	30 x 24	48 x 36	—	48 x 36
No Stopping on Pavement	R8-5	2B.46	24 x 30	24 x 30	36 x 48	48 x 60	—	36 x 48
No Stopping Except on Shoulder	R8-6	2B.46	24 x 30	24 x 30	36 x 48	48 x 60	—	36 x 48
Emergency Stopping Only	R8-7	2B.49	30 x 24	30 x 24	48 x 36	48 x 36	—	48 x 36
Walk on Left Facing Traffic	R9-1	2B.50	18 x 24	18 x 24	—	—	—	—
Cross Only at Crosswalks	R9-2	2B.51	12 x 18	12 x 18	—	—	—	—
No Pedestrian Crossing (symbol)	R9-3	2B.51	18 x 18	18 x 18	24 x 24	30 x 30	—	30 x 30
No Pedestrian Crossing	R9-3a	2B.51	12 x 18	12 x 18	—	—	—	—
Use Crosswalk (plaque)	R9-3bP	2B.51	18 x 12	18 x 12	—	—	—	—
No Hitchhiking (symbol)	R9-4	2B.50	18 x 18	18 x 18	—	—	—	24 x 24
No Hitchhiking	R9-4a	2B.50	18 x 24	18 x 24	—	—	12 x 18	—
No Skaters	R9-13	2B.39	18 x 18	18 x 18	24 x 24	30 x 30	—	30 x 30
No Equestrians	R9-14	2B.39	18 x 18	18 x 18	24 x 24	30 x 30	—	30 x 30
Cross Only On Green	R10-1	2B.52	12 x 18	12 x 18	—	—	—	—
Pedestrian Signs and Plaques	R10-2, 3,3b,3c,3d,4	2B.52	9 x 12	9 x 12	—	—	—	—
Pedestrian Signs	R10-3a,3e,3f, 3g,3h,3i,4a	2B.52	9 x 15	9 x 15	—	—	—	—
Left on Green Arrow Only	R10-5	2B.53	30 x 36	30 x 36	48 x 60	—	24 x 30	48 x 60
Stop Here on Red	R10-6	2B.53	24 x 36	24 x 36	—	—	—	36 x 48
Stop Here on Red	R10-6a	2B.53	24 x 30	24 x 30	—	—	—	36 x 42
Do Not Block Intersection	R10-7	2B.53	24 x 30	24 x 30	—	—	—	—
Use Lane with Green Arrow	R10-8	2B.53	36 x 42	36 x 42	36 x 42	—	—	60 x 72
Left (Right) Turn Signal	R10-10	2B.53	30 x 36	30 x 36	—	—	—	—
No Turn on Red	R10-11	2B.54	24 x 30*	36 x 48	—	—	—	36 x 48
No Turn on Red	R10-11a	2B.54	30 x 36*	36 x 48	—	—	—	—
No Turn on Red	R10-11b	2B.54	36 x 36	36 x 36	—	—	—	—
No Turn on Red Except From Right Lane	R10-11c	2B.54	30 x 42	30 x 42	—	—	—	—
No Turn on Red From This Lane	R10-11d	2B.54	30 x 42	30 x 42	—	—	—	—
Left Turn Yield on Green	R10-12	2B.53	30 x 36	30 x 36	—	—	—	—
Emergency Signal	R10-13	2B.53	42 x 30	42 x 30	—	—	—	—
Emergency Signal - Stop on Flashing Red	R10-14	2B.53	36 x 42	36 x 42	—	—	—	—
Emergency Signal - Stop on Flashing Red (overhead)	R10-14a	2B.53	60 x 24	60 x 24	—	—	—	—
Turning Vehicles Yield to Peds	R10-15	2B.53	30 x 30	30 x 30	—	—	—	—
U-Turn Yield to Right Turn	R10-16	2B.53	30 x 36	30 x 36	—	—	—	—
Right on Red Arrow After Stop	R10-17a	2B.54	36 x 48	36 x 48	—	—	—	—
Traffic Laws Photo Enforced	R10-18	2B.55	36 x 24	36 x 24	48 x 30	54 x 36	—	54 x 36
Photo Enforced (symbol plaque)	R10-19P	2B.55	24 x 12	24 x 12	36 x 18	48 x 24	—	48 x 24
Photo Enforced (plaque)	R10-19aP	2B.55	24 x 18	24 x 18	36 x 30	48 x 36	—	48 x 36
MON—FRI (and times) (3 lines) (plaque)	R10-20aP	2B.53	24 x 24	24 x 24	—	—	—	—

Table 2B-1. Regulatory Sign and Plaque Sizes (Sheet 4 of 4)

Sign or Plaque	Sign Designation	Section	Conventional Road		Expressway	Freeway	Minimum	Oversized
			Single Lane	Multi-Lane				
SUNDAY (and times) (2 lines) (plaque)	R10-20aP	2B.53	24 x 18	24 x 18	—	—	—	—
Crosswalk, Stop on Red	R10-23	2B.53	24 x 30	24 x 30	—	—	—	—
Push Button To Turn On Warning Lights	R10-25	2B.52	9 x 12	9 x 12	—	—	—	—
Left Turn Yield on Flashing Red Arrow After Stop	R10-27	2B.53	30 x 36	30 x 36	—	—	—	—
XX Vehicles Per Green	R10-28	2B.56	24 x 30	24 x 30	—	—	—	—
XX Vehicles Per Green Each Lane	R10-29	2B.56	36 x 24	36 x 24	—	—	—	—
Right Turn on Red Must Yield to U-Turn	R10-30	2B.54	30 x 36	30 x 36	—	—	—	—
At Signal (plaque)	R10-31P	2B.53	24 x 9	24 x 9	—	—	—	—
Push Button for 2 Seconds for Extra Crossing Time	R10-32P	2B.52	9 x 12	9 x 12	—	—	—	—
Keep Off Median	R11-1	2B.57	24 x 30	24 x 30	—	—	—	—
Road Closed	R11-2	2B.58	48 x 30	48 x 30	—	—	—	—
Road Closed - Local Traffic Only	R11-3a,3b,4	2B.58	60 x 30	60 x 30	—	—	—	—
Weight Limit	R12-1,2	2B.59	24 x 30	24 x 30	36 x 48	—	—	36 x 48
Weight Limit	R12-3	2B.59	24 x 36	24 x 36	—	—	—	—
Weight Limit	R12-4	2B.59	36 x 24	36 x 24	—	—	—	—
Weight Limit	R12-5	2B.59	24 x 36	24 x 36	36 x 48	48 x 60	—	—
Weigh Station	R13-1	2B.60	72 x 54	72 x 54	96 x 72	120 x 90	—	—
Truck Route	R14-1	2B.61	24 x 18	24 x 18	—	—	—	—
Hazardous Material	R14-2,3	2B.62	24 x 24	24 x 24	30 x 30	36 x 36	—	42 x 42
National Network	R14-4,5	2B.63	30 x 30	30 x 30	36 x 36	36 x 36	—	42 x 42
Fender Bender Move Vehicles	R16-4	2B.65	36 x 24	36 x 24	48 x 36	60 x 48	—	48 x 36
Lights On When Using Wipers or Raining	R16-5,6	2B.64	24 x 30	24 x 30	36 x 48	48 x 60	—	36 x 48
Turn On Headlights Next XX Miles	R16-7	2B.64	48 x 15	48 x 15	72 x 24	96 x 30	—	72 x 24
Turn On, Check Headlights	R16-8,9	2B.64	30 x 15	30 x 15	48 x 24	60 x 30	—	48 x 24
Begin, End Daytime Headlight Section	R16-10,11	2B.64	48 x 15	48 x 15	72 x 24	96 x 30	—	72 x 24

* See Table 9B-1 for minimum size required for signs on bicycle facilities

Notes: 1. Larger signs may be used when appropriate
2. Dimensions in inches are shown as width x height

Table 2C-1. Categories of Warning Signs and Plaques

Category	Group	Section	Signs or Plaques	Sign Designations
Roadway Related	Changes in Horizontal Alignment	2C.07	Turn, Curve, Reverse Turn, Reverse Curve, Winding Road, Hairpin Curve, 270-Degree Curve	W1-1,2,3,4,5,11,15
		2C.08	Advisory Speed	W13-1P
		2C.09	Chevron Alignment	W1-8
		2C.10	Combination Horizontal Alignment/Advisory Speed	W1-1a,2a
		2C.11	Combination Horizontal Alignment/Intersection	W1-10,10a,10b,10c,10d
		2C.12	Large Arrow (one direction)	W1-6
		2C.13	Truck Rollover	W1-13
		2C.14	Advisory Exit or Ramp Speed	W13-2,3
		2C.15	Combination Horizontal Alignment/Advisory Exit or Ramp Speed	W13-6,7
	Vertical Alignment	2C.16	Hill	W7-1,1a,2P,2bP,3P,3aP,3bP
		2C.17	Truck Escape Ramp	W7-4,4b,4c,4dP,4eP,4fP
		2C.18	Hill Blocks View	W7-6
	Cross Section	2C.19	Road Narrows	W5-1
		2C.20,21	Narrow Bridge, One Lane Bridge	W5-2,3
		2C.22,23,25	Divided Highway, Divided Highway Ends, Double Arrow	W6-1,2; W12-1
		2C.24	Freeway or Expressway Ends, All Traffic Must Exit	W19-1,2,3,4,5
		2C.26	Dead End, No Outlet	W14-1,1a,2,2a
		2C.27	Low Clearance	W12-2,2a
	Roadway Surface Condition	2C.28,29	Bump, Dip, Speed Hump	W8-1,2; W17-1
		2C.30	Pavement Ends	W8-3
		2C.31	Shoulder, Uneven Lanes	W8-4,9,11,17,17P,23,25
		2C.32	Slippery When Wet, Loose Gravel, Rough Road, Bridge Ices Before Road, Fallen Rocks	W8-5,7,8,13,14
		2C.33	Grooved Pavement, Metal Bridge Deck	W8-15,15P,16
		2C.34	No Center Line	W8-12
	Weather	2C.35	Road May Flood, Flood Gauge, Gusty Winds Area, Fog Area	W8-18,19,21,22
Traffic Related	Advance Traffic Control	2C.36-39	Stop Ahead, Yield Ahead, Signal Ahead, Be Prepared To Stop, Speed Reduction, Drawbridge Ahead, Ramp Meter Ahead	W3-1,2,3,4,5,5a,6,7,8
	Traffic Flow	2C.40-45	Merge, No Merge Area, Lane Ends, Added Lane, Two-Way Traffic, Right Lane Exit Only Ahead, No Passing Zone	W4-1,2,3,5,5P,6; W6-3; W9-1,2,7; W14-3
	Intersections	2C.46	Cross Road, Side Road, T, Y, Circular Intersection, Side Roads	W2-1,2,3,4,5,6,7,8; W16-12P,17P
		2C.47	Large Arrow (two directions)	W1-7
		2C.48	Oncoming Extended Green	W25-1,2
	Vehicular Traffic	2C.49	Truck Crossing, Truck (symbol), Emergency Vehicle, Tractor, Bicycle, Golf Cart, Horse-Drawn Vehicle, Trail Crossing	W8-6; W11-1,5,5a,8,10, 11,12P,14,15,15P,15a; W16-13P
	Non-Vehicular	2C.50,51	Pedestrian, Deer, Cattle, Snowmobile, Equestrian, Wheelchair, Large Animals, Playground	W11-2,3,4,6,7,9,16,17,18,19, 20,21,22; W15-1; W16-13P
	New	2C.52	New Traffic Pattern Ahead	W23-2
Other Supplemental Plaques	Location	2C.53	Downward Diagonal Arrow, Ahead	W16-7P,9P
	HOV	2C.53	High-Occupancy Vehicle	W16-11P
	Distance	2C.55	XX Feet, XX Miles, Next XX Feet, Next XX Miles	W7-3aP; W16-2P,2aP,3P,3aP,4P
	Arrow	2C.56	Advance Arrow, Directional Arrow	W16-5P,6P
	Street Name Plaque	2C.58	Advance Street Name	W16-8P,8aP
	Intersection	2C.59	Cross Traffic Does Not Stop	W4-4P,4aP,4bP
	Share The Road	2C.60	Share The Road	W16-1P
	Photo Enforced	2C.61	Photo Enforced	W16-10P,10aP
	New	2C.62	New	W16-15P

Table 2C-2. Warning Sign and Plaque Sizes (Sheet 1 of 3)

Sign or Plaque	Sign Designation	Section	Conventional Road		Expressway	Freeway	Minimum	Oversized
			Single Lane	Multi-Lane				
Horizontal Alignment	W1-1,2,3,4,5	2C.07	30 x 30*	36 x 36	36 x 36	36 x 36	—	48 x 48
Combination Horizontal Alignment/Advisory Speed	W1-1a,2a	2C.10	36 x 36	36 x 36	48 x 48	48 x 48	—	48 x 48
One-Direction Large Arrow	W1-6	2C.12	48 x 24	48 x 24	60 x 30	60 x 30	—	60 x 30
Two-Direction Large Arrow	W1-7	2C.47	48 x 24	48 x 24	—	—	—	60 x 30
Chevron Alignment	W1-8	2C.09	18 x 24	18 x 24	30 x 36	36 x 48	—	24 x 30
Combination Horizontal Alignment/Intersection	W1-10,10a, 10b,10c,10d, 10e	2C.11	36 x 36	36 x 36	36 x 36	48 x 48	—	—
Hairpin Curve	W1-11	2C.07	30 x 30	30 x 30	36 x 36	48 x 48	—	48 x 48
Truck Rollover	W1-13	2C.13	36 x 36	36 x 36	36 x 36	48 x 48	—	36 x 36
270-degree Loop	W1-15	2C.07	30 x 30	30 x 30	36 x 36	48 x 48	—	48 x 48
Intersection Warning	W2-1, 2,3,4,5,6,7,8	2C.46	30 x 30	30 x 30	36 x 36	—	24 x 24	48 x 48
Advanced Traffic Control	W3-1,2,3	2C.36	30 x 30	30 x 30	48 x 48	48 x 48	30 x 30	—
Be Prepared to Stop	W3-4	2C.36	36 x 36	36 x 36	48 x 48	48 x 48	30 x 30	—
Reduced Speed Limit Ahead	W3-5	2C.38	36 x 36	36 x 36	48 x 48	48 x 48	—	—
XX MPH Speed Zone Ahead	W3-5a	2C.38	36 x 36	36 x 36	48 x 48	48 x 48	—	—
Draw Bridge	W3-6	2C.39	36 x 36	36 x 36	48 x 48	—	—	60 x 60
Ramp Meter Ahead	W3-7	2C.37	36 x 36	36 x 36	—	—	—	—
Ramp Metered When Flashing	W3-8	2C.37	36 x 36	36 x 36	—	—	—	—
Merge	W4-1	2C.40	36 x 36	36 x 36	48 x 48	48 x 48	30 x 30*	—
Lane Ends	W4-2	2C.42	36 x 36	36 x 36	48 x 48	48 x 48	30 x 30*	—
Added Lane	W4-3	2C.41	36 x 36	36 x 36	48 x 48	48 x 48	30 x 30*	—
Cross Traffic Does Not Stop (plaque)	W4-4P	2C.59	24 x 12	24 x 12	36 x 18	—	—	48 x 24
Traffic From Left (Right) Does Not Stop (plaque)	W4-4aP	2C.59	24 x 12	24 x 12	36 x 18	—	—	48 x 24
Oncoming Traffic Does Not Stop (plaque)	W4-4bP	2C.59	24 x 12	24 x 12	36 x 18	—	—	48 x 24
Entering Roadway Merge	W4-5	2C.40	36 x 36	36 x 36	48 x 48	—	—	—
No Merge Area (plaque)	W4-5P	2C.40	18 x 24	18 x 24	24 x 30	—	—	—
Entering Roadway Added Lane	W4-6	2C.41	36 x 36	36 x 36	48 x 48	—	—	—
Road Narrows	W5-1	2C.19	36 x 36	36 x 36	48 x 48	48 x 48	30 x 30*	—
Narrow Bridge	W5-2	2C.20	36 x 36	36 x 36	48 x 48	48 x 48	30 x 30*	—
One Lane Bridge	W5-3	2C.21	36 x 36	36 x 36	48 x 48	48 x 48	30 x 30*	—
Divided Highway	W6-1	2C.22	36 x 36	36 x 36	48 x 48	48 x 48	—	—
Divided Highway Ends	W6-2	2C.23	36 x 36	36 x 36	48 x 48	48 x 48	—	—
Two-Way Traffic	W6-3	2C.44	36 x 36	36 x 36	48 x 48	48 x 48	—	—
Hill	W7-1	2C.16	30 x 30*	36 x 36	36 x 36	36 x 36	24 x 24*	48 x 48
Hill with Grade	W7-1a	2C.16	30 x 30*	36 x 36	36 x 36	36 x 36	24 x 24*	48 x 48
Use Low Gear (plaque)	W7-2P	2C.57	24 x 18	24 x 18	—	—	—	—
Trucks Use Lower Gear (plaque)	W7-2bP	2C.57	24 x 18	24 x 18	—	—	—	—
XX% Grade (plaque)	W7-3P	2C.57	24 x 18	24 x 18	—	—	—	—
Next XX Miles (plaque)	W7-3aP	2C.55	24 x 18	24 x 18	—	—	—	—
XX% Grade, XX Miles (plaque)	W7-3bP	2C.57	24 x 18	24 x 18	—	—	—	—
Runaway Truck Ramp XX Miles	W7-4	2C.17	78 x 48	78 x 48	78 x 48	78 x 48	—	—
Runaway Truck Ramp (with arrow)	W7-4b	2C.17	78 x 60	78 x 60	78 x 60	78 x 60	—	—
Truck Escape Ramp	W7-4c	2C.17	78 x 60	78 x 60	78 x 60	78 x 60	—	—
Sand, Gravel, Paved (plaques)	W7-4dP, 4eP,4fP	2C.17	24 x 12	24 x 12	24 x 12	24 x 12	—	—
Hill Blocks View	W7-6	2C.18	30 x 30*	36 x 36	36 x 36	—	—	48 x 48
Bump or Dip	W8-1,2	2C.28	30 x 30*	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48

Table 2C-2. Warning Sign and Plaque Sizes (Sheet 2 of 3)

Sign or Plaque	Sign Designation	Section	Conventional Road		Expressway	Freeway	Minimum	Oversized
			Single Lane	Multi-Lane				
Pavement Ends	W8-3	2C.30	36 x 36	36 x 36	48 x 48	—	30 x 30*	—
Soft Shoulder	W8-4	2C.31	36 x 36	36 x 36	48 x 48	48 x 48	24 x 24*	48 x 48
Slippery When Wet	W8-5	2C.32	30 x 30*	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Road Condition (plaques)	W8-5P,5bP,5cP	2C.32	24 x 18	24 x 18	30 x 24	36 x 30	—	36 x 30
Ice	W8-5aP	2C.32	24 x 12	24 x 12	30 x 18	30 x 18	—	—
Truck Crossing	W8-6	2C.49	36 x 36	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Loose Gravel	W8-7	2C.32	36 x 36	36 x 36	36 x 36	—	24 x 24*	48 x 48
Rough Road	W8-8	2C.32	36 x 36	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Low Shoulder	W8-9	2C.31	36 x 36	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Uneven Lanes	W8-11	2C.32	36 x 36	36 x 36	36 x 36	48 x 48	—	48 x 48
No Center Line	W8-12	2C.34	36 x 36	36 x 36	36 x 36	48 x 48	—	—
Bridge Ices Before Road	W8-13	2C.32	36 x 36	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Fallen Rocks	W8-14	2C.32	30 x 30*	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Grooved Pavement	W8-15	2C.33	30 x 30*	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Motorcycle (plaque)	W8-15P	2C.33	24 x 18	24 x 18	30 x 24	36 x 30	—	36 x 30
Metal Bridge Deck	W8-16	2C.33	30 x 30*	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Shoulder Drop Off (symbol)	W8-17	2C.31	30 x 30*	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Shoulder Drop-Off (plaque)	W8-17P	2C.31	24 x 18	24 x 18	30 x 24	36 x 30	—	36 x 30
Road May Flood	W8-18	2C.35	36 x 36	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Flood Gauge	W8-19	2C.35	12 x 72	12 x 72	—	—	—	—
Gusty Winds Area	W8-21	2C.35	36 x 36	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Fog Area	W8-22	2C.35	36 x 36	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
No Shoulder	W8-23	2C.31	36 x 36	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Shoulder Ends	W8-25	2C.31	30 x 30*	36 x 36	36 x 36	48 x 48	24 x 24*	48 x 48
Left (Right) Lane Ends	W9-1	2C.42	36 x 36	36 x 36	36 x 36	48 x 48	30 x 30*	48 x 48
Lane Ends Merge Left (Right)	W9-2	2C.42	36 x 36	36 x 36	36 x 36	48 x 48	30 x 30*	48 x 48
Right (Left) Lane Exit Only Ahead	W9-7	2C.43	132 x 72	132 x 72	132 x 72	132 x 72	—	—
Bicycle	W11-1	2C.49	30 x 30	30 x 30	36 x 36	—	24 x 24*	48 x 48
Pedestrian	W11-2	2C.50	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Large Animals	W11-3,4,16,17,18,19,20,21,22	2C.50	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Farm Vehicle	W11-5,5a	2C.49	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Snowmobile	W11-6	2C.50	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Equestrian	W11-7	2C.50	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Emergency Vehicle	W11-8	2C.49	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Handicapped	W11-9	2C.50	30 x 30*	36 x 36	36 x 36	—	—	48 x 48
Truck	W11-10	2C.49	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Golf Cart	W11-11	2C.49	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Emergency Signal Ahead (plaque)	W11-12P	2C.49	36 x 30	36 x 30	36 x 30	—	—	—
Horse-Drawn Vehicle	W11-14	2C.49	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Bicycle / Pedestrian	W11-15	2C.49	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Trail Crossing	W11-15a	2C.49	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Trail X-ing (plaque)	W11-15P	2C.49	24 x 18	24 x 18	30 x 24	—	—	36 x 30
Double Arrow	W12-1	2C.25	30 x 30*	36 x 36	36 x 36	—	—	—
Low Clearance (with arrows)	W12-2	2C.27	36 x 36	36 x 36	48 x 48	48 x 48	30 x 30*	—
Low Clearance	W12-2a	2C.27	78 x 24	78 x 24	—	—	—	—
Advisory Speed (plaque)	W13-1P	2C.08	18 x 18	18 x 18	24 x 24	30 x 30	—	30 x 30
Advisory Exit or Ramp Speed	W13-2,3	2C.14	24 x 30	24 x 30	36 x 48	36 x 48	—	48 x 60
Combination Horizontal Alignment/Advisory Exit or Ramp Speed	W13-6,7	2C.15	24 x 42	24 x 42	36 x 60	36 x 60	—	48 x 84
Dead End, No Outlet	W14-1,2	2C.26	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48

Table 2C-2. Warning Sign and Plaque Sizes (Sheet 3 of 3)

Sign or Plaque	Sign Designation	Section	Conventional Road		Expressway	Freeway	Minimum	Oversized
			Single Lane	Multi-Lane				
Dead End, No Outlet (with arrow)	W14-1a,2a	2C.26	36 x 8	36 x 8	—	—	—	—
No Passing Zone (pennant)	W14-3	2C.45	48 x 48 x 36	48 x 48 x 36	—	—	40 x 40 x 30	64 x 64 x 48
Playground	W15-1	2C.51	30 x 30*	36 x 36	36 x 36	—	24 x 24*	48 x 48
Share the Road (plaque)	W16-1P	2C.60	18 x 24	18 x 24	24 x 30	—	—	24 x 30
XX Feet	W16-2P	2C.55	24 x 18	24 x 18	—	—	—	30 x 24
XX Ft	W16-2aP	2C.55	24 x 12	24 x 12	—	—	—	30 x 18
XX Miles (2-line plaque)	W16-3P	2C.55	30 x 24	30 x 24	—	—	—	—
XX Miles (1-line plaque)	W16-3aP	2C.55	30 x 12	30 x 12	—	—	—	—
Next XX Feet (plaque)	W16-4P	2C.55	30 x 24	30 x 24	—	—	—	—
Supplemental Arrow (plaque)	W16-5P,6P	2C.56	24 x 18	24 x 18	—	—	—	—
Downward Diagonal Arrow (plaque)	W16-7P	2C.50	24 x 12	24 x 12	—	—	—	30 x 18
Advance Street Name (1-line plaque)	W16-8P	2C.58	Varies x 8	Varies x 8	—	—	—	—
Advance Street Name (2-line plaque)	W16-8aP	2C.58	Varies x 15	Varies x 15	—	—	—	—
Ahead (plaque)	W16-9P	2C.50	24 x 12	24 x 12	30 x 18	—	—	—
Photo Enforced (symbol plaque)	W16-10P	2C.61	24 x 12	24 x 12	36 x 18	—	—	48 x 24
Photo Enforced (plaque)	W16-10aP	2C.61	24 x 18	24 x 18	36 x 30	—	—	48 x 36
HOV (plaque)	W16-11P	2G.09	24 x 12	24 x 12	30 x 18	—	—	30 x 18
Traffic Circle (plaque)	W16-12P	2C.46	24 x 18	24 x 18	—	—	—	—
When Flashing (plaque)	W16-13P	2C.50	24 x 18	24 x 18	—	—	—	—
New (plaque)	W16-15P	2C.62	24 x 12	24 x 12	—	—	—	—
Roundabout (plaque)	W16-17P	2C.46	24 x 12	24 x 12	—	—	—	—
NOTICE	W16-18P	2A.15	24 x 12	24 x 12	—	—	—	—
Speed Hump	W17-1	2C.29	30 x 30*	36 x 36	—	—	24 x 24*	48 x 48
Freeway Ends XX Miles	W19-1	2C.24	—	—	—	144 x 48	—	—
Expressway Ends XX Miles	W19-2	2C.24	—	—	144 x 48	—	—	—
Freeway Ends	W19-3	2C.24	—	—	—	48 x 48	—	—
Expressway Ends	W19-4	2C.24	—	—	48 x 48	—	—	—
All Traffic Must Exit	W19-5	2C.24	—	—	90 x 48	90 x 48	—	—
New Traffic Pattern Ahead	W23-2	2C.52	36 x 36	36 x 36	—	—	—	—
Traffic Signal Extended Green	W25-1,2	2C.48	24 x 30	24 x 30	—	—	—	—

* The minimum size required for diamond-shaped warning signs facing traffic on multi-lane conventional roads shall be 36 x 36 per Section 2C.04

Notes: 1. Larger signs may be used when appropriate
2. Dimensions in inches are shown as width x height

Table 2D-1. Conventional Road Guide Sign Sizes

Sign	Sign Designation	Section	Conventional Road	Minimum	Oversized
Interstate Route Sign (1 or 2 digits)	M1-1	2D.11	24 x 24	24 x 24	36 x 36
Interstate Route Sign (3 digits)	M1-1	2D.11	30 x 24	30 x 24	45 x 36
Off-Interstate Route Sign (1 or 2 digits)	M1-2,3	2D.11	24 x 24	24 x 24	36 x 36
Off-Interstate Route Sign (3 digits)	M1-2,3	2D.11	30 x 24	30 x 24	45 x 36
U.S. Route Sign (1 or 2 digits)	M1-4	2D.11	24 x 24	24 x 24	36 x 36
U.S. Route Sign (3 digits)	M1-4	2D.11	30 x 24	30 x 24	45 x 36
State Route Sign (1 or 2 digits)	M1-5	2D.11	24 x 24	24 x 24	36 x 36
State Route Sign (3 digits)	M1-5	2D.11	30 x 24	30 x 24	45 x 36
County Route Sign (1, 2, or 3 digits)	M1-6	2D.11	24 x 24	24 x 24	36 x 36
Forest Route (1, 2, or 3 digits)	M1-7	2D.11	24 x 24	18 x 18	36 x 36
Junction	M2-1	2D.13	21 x 15	21 x 15	30 x 21
Combination Junction (2 route signs)	M2-2	2D.14	60 x 48*	—	—
Cardinal Direction	M3-1,2,3,4	2D.15	24 x 12	24 x 12	36 x 18
Alternate	M4-1,1a	2D.17	24 x 12	24 x 12	36 x 18
By-Pass	M4-2	2D.18	24 x 12	24 x 12	36 x 18
Business	M4-3	2D.19	24 x 12	24 x 12	36 x 18
Truck	M4-4	2D.20	24 x 12	24 x 12	36 x 18
To	M4-5	2D.21	24 x 12	24 x 12	36 x 18
End	M4-6	2D.22	24 x 12	24 x 12	36 x 18
Temporary	M4-7,7a	2D.24	24 x 12	24 x 12	36 x 18
Begin	M4-14	2D.23	24 x 12	24 x 12	36 x 18
Advance Turn Arrow	M5-1,2,3	2D.28	21 x 15	21 x 15	—
Lane Designation	M5-4,5,6	2D.33	24 x 18	24 x 18	36 x 24
Directional Arrow	M6-1,2,2a,3,4, 5,6,7	2D.29	21 x 15	21 x 15	30 x 21
Destination (1 line)	D1-1	2D.39	Varies x 18	Varies x 18	—
Destination and Distance (1 line)	D1-1a	2D.39	Varies x 18	Varies x 18	—
Circular Intersection Destination (1 line)	D1-1d	2D.40	Varies x 18	Varies x 18	—
Circular Intersection Departure Guide	D1-1e	2D.40	Varies x 42*	—	—
Destination (2 lines)	D1-2	2D.39	Varies x 30	Varies x 30	—
Destination and Distance (2 lines)	D1-2a	2D.39	Varies x 30	Varies x 30	—
Circular Intersection Destination (2 lines)	D1-2d	2D.40	Varies x 30	Varies x 30	—
Destination (3 lines)	D1-3	2D.39	Varies x 42	Varies x 42	—
Destination and Distance (3 lines)	D1-3a	2D.39	Varies x 42	Varies x 42	—
Circular Intersection Destination (3 lines)	D1-3d	2D.40	Varies x 42	Varies x 42	—
Distance (1 line)	D2-1	2D.43	Varies x 18	Varies x 18	—
Distance (2 lines)	D2-2	2D.43	Varies x 30	Varies x 30	—
Distance (3 lines)	D2-3	2D.43	Varies x 42	Varies x 42	—
Street Name (1 line)	D3-1,1a	2D.45	Varies x 12	Varies x 8	Varies x 18
Advance Street Name (2 lines)	D3-2	2D.46	Varies x 30*	—	—
Advance Street Name (3 lines)	D3-2	2D.46	Varies x 42*	—	—
Advance Street Name (4 lines)	D3-2	2D.46	Varies x 60*	—	—
Parking Area	D4-1	2D.49	30 x 24	18 x 15	—
Park - Ride	D4-2	2D.50	30 x 36	24 x 30	36 x 48
National Scenic Byways	D6-4	2D.56	24 x 24	24 x 24	—
National Scenic Byways	D6-4a	2D.56	24 x 12	24 x 12	—
Weigh Station XX Miles	D8-1	2D.51	78 x 60	60 x 48	96 x 72
Weigh Station Next Right	D8-2	2D.51	84 x 72	66 x 54	108 x 90
Weigh Station (with arrow)	D8-3	2D.51	66 x 60	48 x 42	84 x 78
Crossover	D13-1,2	2D.55	60 x 30	60 x 30	78 x 42
Freeway Entrance	D13-3	2D.48	48 x 30	48 x 30	—
Freeway Entrance (with arrow)	D13-3a	2D.48	48 x 42	48 x 42	—
Combination Lane Use / Destination	D15-1	2D.35	Varies x 96	Varies x 96	—
Next Truck Lane XX Miles	D17-1	2D.53	42 x 48	42 x 48	60 x 66
Truck Lane XX Miles	D17-2	2D.53	42 x 42	42 x 42	60 x 54
Slow Vehicle Turn-Out XX Miles	D17-7	2D.54	72 x 42	72 x 42	96 x 54

*The size shown is for a typical sign. The size should be appropriately based on the amount of legend required for the sign.

Table 2E-1. Freeway or Expressway Guide Sign and Plaque Sizes (Sheet 1 of 2)

Sign or Plaque	Sign Designation	Section	Minimum Size
Exit Number (plaque)			
1-, 2-Digit Exit Number	E1-5P	2E.31	114 x 30
3-Digit Exit Number	E1-5P	2E.31	132 x 30
1-, 2-Digit Exit Number (with single letter suffix)	E1-5P	2E.31	138 x 30
3-Digit Exit Number (with single letter suffix)	E1-5P	2E.31	156 x 30
1-, 2-Digit Exit Number (with dual letter suffix)	E1-5P	2E.31	168 x 30
3-Digit Exit Number (with dual letter suffix)	E1-5P	2E.31	186 x 30
Left (plaque)	E1-5aP	2E.33	72 x 30
Left Exit Number (plaque)			
1-, 2-Digit Exit Number	E1-5bP	2E.31	114 x 54
3-Digit Exit Number	E1-5bP	2E.31	132 x 54
1-, 2-Digit Exit Number (with single letter suffix)	E1-5bP	2E.31	138 x 54
3-Digit Exit Number (with single letter suffix)	E1-5bP	2E.31	156 x 54
1-, 2-Digit Exit Number (with dual letter suffix)	E1-5bP	2E.31	168 x 54
3-Digit Exit Number (with dual letter suffix)	E1-5bP	2E.31	186 x 54
Next Exit XX Miles (1 line)	—	2E.34	Varies x 24
Next Exit XX Miles (2 lines)	—	2E.34	Varies x 36
Exit Gore (no exit number)	E5-1	2E.37	72 x 60
Exit Gore (with exit number)			
1-, 2-Digit Exit Number	E5-1a	2E.37	78 x 60
3-Digit Exit Number	E5-1a	2E.37	96 x 60
1-Digit Exit Number (with single letter suffix)	E5-1a	2E.37	90 x 60
2-Digit Exit Number (with single letter suffix)	E5-1a	2E.37	108 x 60
3-Digit Exit Number (with single letter suffix)	E5-1a	2E.37	126 x 60
1-Digit Exit Number (with dual letter suffix)	E5-1a	2E.37	120 x 60
2-Digit Exit Number (with dual letter suffix)	E5-1a	2E.37	138 x 60
3-Digit Exit Number (with dual letter suffix)	E5-1a	2E.37	156 x 60
Exit Number (plaque)			
1-, 2-Digit Exit Number	E5-1bP	2E.37	42 x 30
3-Digit Exit Number	E5-1bP	2E.37	60 x 30
1-Digit Exit Number (with single letter suffix)	E5-1bP	2E.37	48 x 30
1-Digit Exit Number (with dual letter suffix)	E5-1bP	2E.37	72 x 30
2-Digit Exit Number (with single or dual letter suffix)	E5-1bP	2E.37	72 x 30
3-Digit Exit Number (with single or dual letter suffix)	E5-1bP	2E.37	72 x 30
Narrow Exit Gore	E5-1c	2E.37	60 x 90*
Pull-Through	E6-2	2E.12	Varies x 120*
Pull-Through	E6-2a	2E.12	Varies x 90*
Exit Only (with arrow)	E11-1,1d	2E.24	174** x 36
Exit	E11-1a	2E.24	66 x 18
Only	E11-1b	2E.24	66 x 18
Exit Only	E11-1c	2E.24	120 x 18
Exit Only (with two arrows)	E11-1e,1f	2E.24	222** x 36
Left	E11-2	2E.40	60 x 18
Exit Gore Advisory Speed (plaque)	E13-1P	2E.37	72 x 24
Exit Direction Advisory Speed	E13-2	2E.36	162 x 24
Interstate Route Sign (1 or 2 digits)	M1-1	2E.27	36 x 36
Interstate Route Sign (3 digits)	M1-1	2E.27	45 x 36
Off-Interstate Route Sign (1 or 2 digits)	M1-2,3	2E.27	36 x 36
Off-Interstate Route Sign (3 digits)	M1-2,3	2E.27	45 x 36
U.S. Route Sign (1 or 2 digits)	M1-4	2E.27	36 x 36
U.S. Route Sign (3 digits)	M1-4	2E.27	45 x 36
State Route Sign (1 or 2 digits)	M1-5	2D.11	36 x 36

Table 2E-1. Freeway or Expressway Guide Sign and Plaque Sizes (Sheet 2 of 2)

Sign or Plaque	Sign Designation	Section	Minimum Size
State Route Sign (3 digits)	M1-5	2D.11	45 x 36
County Route Sign (1, 2, or 3 digits)	M1-6	2D.11	36 x 36
Forest Route (1, 2, or 3 digits)	M1-7	2D.11	36 x 36
Eisenhower Interstate System	M1-10,10a	2E.28	36 x 36
Junction	M2-1	2D.13	30 x 21
Combination Junction (2 route signs)	M2-2	2D.14	60 x 48*
Cardinal Direction	M3-1,2,3,4	2D.15	36 x 18
Alternate	M4-1,1a	2D.17	36 x 18
By-Pass	M4-2	2D.18	36 x 18
Business	M4-3	2D.19	36 x 18
Truck	M4-4	2D.20	36 x 18
To	M4-5	2D.21	36 x 18
End	M4-6	2D.22	36 x 18
Temporary	M4-7,7a	2D.24	36 x 18
Begin	M4-14	2D.23	36 x 18
Advance Turn Arrow	M5-1,2,3	2D.26	30 x 21
Lane Designation	M5-4,5,6	2D.27	36 x 24
Directional Arrow	M6-1,2,2a,3,4,5,6,7	2D.28	30 x 21
Destination (1 line)	D1-1	2D.37	Varies x 30
Destination and Distance (1 line)	D1-1a	2D.37	Varies x 30
Destination (2 lines)	D1-2	2D.37	Varies x 54
Destination and Distance (2 lines)	D1-2a	2D.37	Varies x 54
Destination (3 lines)	D1-3	2D.37	Varies x 72
Destination and Distance (3 lines)	D1-3a	2D.37	Varies x 72
Distance (1 line)	D2-1	2D.41	Varies x 30
Distance (2 lines)	D2-2	2D.41	Varies x 54
Distance (3 lines)	D2-3	2D.41	Varies x 72
Street Name	D3-1,1a	2D.43	Varies x 18
Advance Street Name (2 lines)	D3-2	2D.44	Varies x 42*
Advance Street Name (3 lines)	D3-2	2D.44	Varies x 66*
Advance Street Name (4 lines)	D3-2	2D.44	Varies x 84*
Park - Ride	D4-2	2D.48	36 x 48
National Scenic Byways	D6-4	2D.55	24 x 24
National Scenic Byways	D6-4a	2D.55	24 x 12
Weigh Station XX Miles	D8-1	2E.54	96 x 72 (F) 78 x 60 (E)
Weigh Station Next Right	D8-2	2E.54	108 x 90 (F) 84 x 72 (E)
Weigh Station (with arrow)	D8-3	2E.54	84 x 78 (F) 66 x 60 (E)
Crossover	D13-1,2	2D.54	78 x 42
Freeway Entrance	D13-3	2D.46	48 x 30
Freeway Entrance (with arrow)	D13-3a	2D.46	48 x 42
Combination Lane Use / Destination	D15-1	2D.33	Varies x 96
Next Truck Lane XX Miles	D17-1	2D.51	60 x 66
Truck Lane XX Miles	D17-2	2D.51	60 x 54
Slow Vehicle Turn-Out XX Miles	D17-7	2D.52	96 x 54

* The size shown is for a typical sign as illustrated in the figures in Chapters 2D and 2E. The size should be determined based on the amount of legend required for the sign.

** The width shown represents the minimum dimension. The width shall be increased as appropriate to match the width of the guide sign.

Notes: 1. Larger signs may be used when appropriate
2. Dimensions in inches are shown as width x height
3. Where two sizes are shown, the larger size is for freeways (F) and the smaller size is for expressways (E)

Appendix B: Acknowledgement of Data Ownership Form

Transfer of Data Ownership Form

I, ______________________________ **(Print Name)**, acknowledge that the data submitted as part of NCDOT 2014-32 research project "Comparison of Data Collection Vehicles to Human Collection Methods" are henceforth the property of the NCDOT and ITRE.

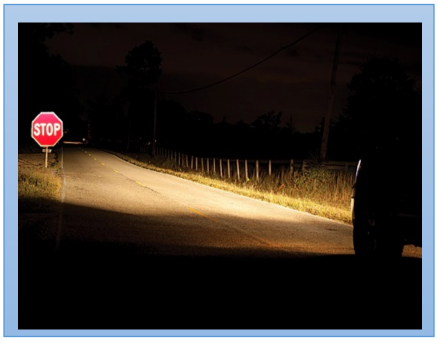
Signature: ___________________________

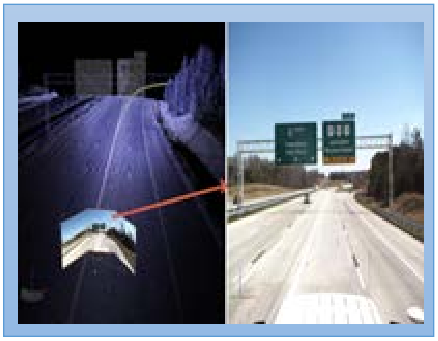
Title: ___________________________

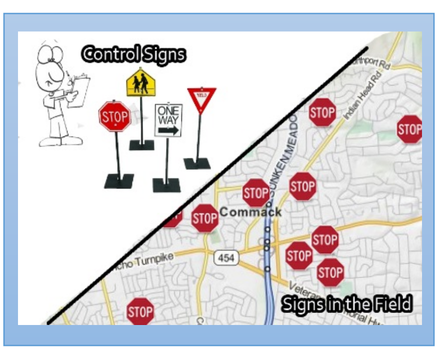
Company: ______________________

Date: ___________________________

9.1. Appendix B: Sign Inventory Methods – Quick Guide







Sign Retroreflectivity Maintenance Methods

This section describes the maintenance methods available for ensuring nighttime sign visibility. It's content is derived from the National Cooperative Highway Research Program's (NCHRP) *Practices to Manage Traffic Sign Retroreflectivity* Synthesis report, which aims to provide examples of effective practices that illustrate how agencies can meet retroreflectivity requirements (to meet visibility thresholds), the *Manual on Uniform Traffic Control Devices* (MUTCD), which defines standards used by road managers to install and maintain traffic control devices, and other studies that focus on sign retroflectivity. The NCHRP synthesis report contains information from 40 state departments of transportation, which provide insight into the best practices of sign management. The MUTCD offers five traffic sign methods for maintaining nighttime sign visibility, which are discussed in this section.

This section is designed to provide succinct summaries for of each of the five retroreflectivity maintenance methods (i.e. Visual Nighttime Inspection, Measured Sign Retroreflectivity, Expected Sign Life, Blanket Replacement, and Control Signs). It is organized to show a quick snapshot of the retroreflectivity accuracy, cost-effectiveness, and ease of implementation for each maintenance method. In addition, it provides a description of the method, implementation considerations, the advantages and limitations of each method.

VISUAL NIGHTTIME INSPECTION

Study Description

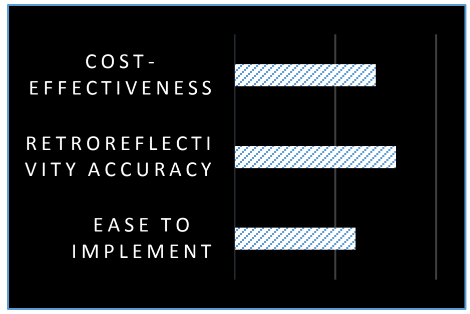
Visual nighttime inspection is a common method for maintaining traffic sign retroreflectivity and guidelines for the inspection procedure have been documented for approximately 50 years. The retroreflectivity of an existing sign is assessed by a trained sign inspector conducting a visual inspection from a moving vehicle during nighttime conditions. Signs that are visually identified by the inspector to have retroreflectivity below the minimum levels are to be replaced.

Implementation Considerations

Visual nighttime inspection requires one individual, but is more effective with two; a dedicated inspector monitoring and recording sign failures and a focused driver following a predetermined inspection route. It is important that visual inspection take place during typical nighttime conditions and that viewing not be affected by adverse or inclement weather such as fog or rain. Interior vehicle lighting should be minimized so that the inspector's vision is not affected. The inspection can emulate how a normal driver would view a typical sign: at normal roadway speeds, from an appropriate travel lane, and at an adequate viewing distance. Sign failures and noteworthy comments are to be documented in a standardized procedure. The inspector can document his or her evaluations by means of written notes on an agency form, audio recording, or laptop computer. The duration of a nighttime inspection session must not exceed a period where inspector fatigue becomes an issue or where roadway conditions change, such as frost forming on a sign. Throughout the inspections, it is important to be consistent with agency procedures and be able to document when the nighttime sign inspections have been completed.

Key Considerations

- Method is subjective, yet fairly accurate
- Sign inspectors generally error on the side of caution
- Does not require expensive equipment



During a visual nighttime inspection a technician shines his/her headlights on a sign and makes a determination whether or not that sign should be replaced.

Advantages

- Evaluates more than sign retroreflectivity, such as face uniformity, message legibility, sign support integrity, damage, knockdowns, vandalism, obscuring vegetation, general sign visibility, etc.
- Provides the opportunity to observe other roadway items such as raised pavement markers, pavement striping, delineators, and object markers.
- Does not require advanced equipment or sophisticated computer programs.
- Limits the low amount of waste because only failed signs are targeted for replacement.

Limitations

- Sign evaluation is subjective.
- Inspectors need to be properly trained and one of the three supportive techniques be used correctly.
- Because nighttime inspection occurs during non-regular work hours, overtime and next-day scheduling may be a concern.

- There are outside aspects that are difficult to control such as weather, moisture in the air, and oncoming vehicles headlights.

Case Studies

There have been a number of studies that have evaluated the visual nighttime inspection method. Case studies included in the National Cooperative Highway Research Program's *Practices to Manage Traffic Sign Retroreflectivity* Synthesis report are included below.

- **Indiana** – Researchers compared the pass or fail decisions of sign inspectors with the infield retroreflectometer measurements. There were 1,743 signs measured on roadways and inspectors were accurate in 88 percent of the pass/fail decisions. The study found that visual nighttime inspection was a reasonably accurate method with minimally trained personnel.
- **North Carolina** – Similar to the Indiana study, researchers evaluated the accuracy of North Carolina DOT (NCDOT) staff evaluations by comparing the visual nighttime inspection pass or fail decisions with retroreflectivity measurements. The study collected retroreflectometer measurements of 1,057 inspected signs on various types of state roadways in five different counties. Overall, the analysis determined that the NCDOT sign inspectors were effective in identifying and removing signs that were below the minimum values, and that accuracy levels ranged from 54 percent to 83 percent.
- **Texas** – In a statewide survey of Texas Department of Transportation (TxDOT) district sign maintenance offices, the researchers found that 80 percent of the districts conducted nighttime visual inspections and 65 percent also performed daytime inspections. Approximately 83 percent of the districts would implement visual inspection training when the proposed FHWA requirements took effect. Researches alsoe conducted a cost-benefit analysis of several different sign maintenance methods and determined that visual inspection was one of the least expensive methods. In a follow-up study, TxDOT staff subjectively assessed 49 test signs during nighttime conditions. Only one test sign failed to meet the MUTCD minimums; however, the TxDOT staff rejected a total of 26 signs. For TxDOT staff, overall appearance and uniformity of the sign face were as important as the retroreflectivity levels, when considering to accept or reject a sign.
- **Washington State –** Researchers trained observers to rate STOP and warning signs on two highway courses with a total of 130 traffic signs. The observers made correct ratings for 75 percent of the signs and, within the total incorrect responses, observers were more likely to replace an adequate sign than to accept a sign with insufficient retroreflectivity.

Reference

Ré, Jonathan M. and Carlson, Paul (2012). *Practices to Manage Traffic Sign Retroreflectivity*: *A Synthesis of Highway Practice*. NCHRP Synthesis 431. National Cooperative Highway Research Program.

MEASURED RETROREFLECTIVITY

Study Description

For the measured retroreflectivity method, specialized equipment is used to obtain retroreflectivity values of sign faces. There are two ways to determine retrorefectivity values: (1) obtaining values through contact instruments, (2) obtaining values through non-contact instruments, which measure sign retroreflectivity from a distance. Contact instruments, commonly referred to as retrorflectometers, offer precise measurements, but their time requirements are considerable. Non-contact instruments, such as vehicle-based systems, offer speed and flexibility to the measurement process; however, their tradeoff is higher levels of uncertainty.

Implementation Considerations

Contact measurements require significant operator time. To be in compliance with the ASTM Standard Test Method E1709, a retroreflectometer operator must acquire a minimum of four retroreflectivity measurements per sign. In addition, contact measurement can be dangerous. Overhead signs, signs in high-traffic corridors, and other difficult to reach signs expose sign technicians to roadway hazards. Furthermore, individual retroreflectometer units can cost between $10,000 and $12,000; therefore assigning them to individual sign technicians is not typically feasible. In general, contact measurements appear to be best suited to complement another method.

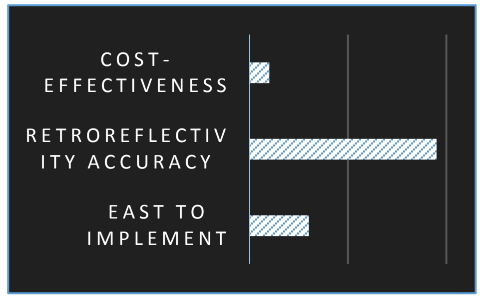
Non-contact management measurement is still largely in its takeoff stage of development. However, much work has been done recently to enable vehicle-based systems to measure signs accurately at highway speeds. This study evaluates the viability of vehicle-based systems for measuring sign retroreflectivity.

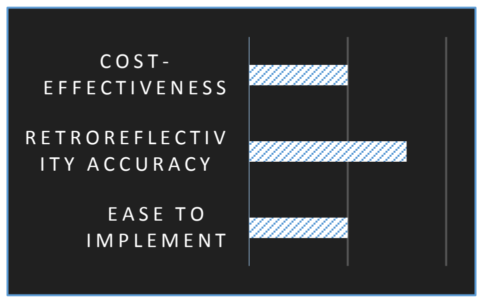
Contact-Device Advantages

- Readings can be directly compared with MUTCD minimum levels
- Measurements can be obtained during normal daytime work hours
- There may be little or no sign waste because signs near the end of their service life periods can be targeted and replaced

Key Considerations

- Contact method is accurate but results in exorbitant time costs
- Noncontact method is still largely untested, and often very expensive





Upper chart: contact method
Lower chart: non-contact method

Above: A vehicle is used to measure sign retroreflectivity.

Right: A handheld retroreflectometer is used to measure sign retroreflectivity.

Contact-Device Limitations

- Signs may be difficult to access because of physical barriers, sign height, and certain roadway conditions.
- Retroreflectometers cost between $10,000 and $12,000 making them too expensive to provide to multiple sign technicians
- Sign measurement standards require four retroreflectivity measurements per sign, which makes contact measurement an extremely time-intensive process

Non-Contact Device Advantages

- Retroreflectivity measurements can be taken at highway speeds
- Sign measurements can be matched with latitude and longitude coordinates to create a sign inventory that has sign locations with their corresponding retroreflectivity levels
- Does not expose sign technicians to dangerous measurement conditions

Non-Contact Device Limitations

- Technology is still largely in its takeoff phase
- System-wide measurement on a per sign basis is expensive, if data on other assets are not collected as well
- The precision of retroreflectivity measurements may vary depending on landscape features

Reference

Ré, Jonathan M. and Carlson, Paul (2012). *Practices to Manage Traffic Sign Retroreflectivity*: *A Synthesis of Highway Practice*. NCHRP Synthesis 431. National Cooperative Highway Research Program.

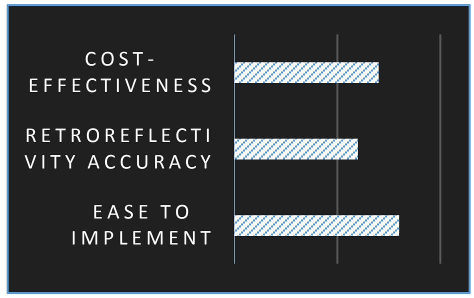
EXPECTED SIGN LIFE

Study Description

The expected sign life method aims to pinpoint the length of time that a certain sign sheeting material will be used in the field while remaining in compliance with minimum retroreflectivity requirements. For this method an agency may use sign sheeting warranties[1], test deck or field measurements[2], or empirical data from other regional studies to project an expected service life for signs[3]. Once an agency determines how it will project its expected service life, it can develop its sign management system by: (1) establishing sign installation dates, (2) identifying and locating individual signs, (3) creating an organized inventory of signs, including their installation dates and when they need to be replaced.

Key Considerations

- Implementation of this method limits administrative costs
- Signs are often replaced before the end of their service life



Signs are replaced based on their warranties using the expected sign life method.

Implementation Considerations

Agencies considering the expected life method need to thoroughly research the many options available before selecting a management system. An agency could take into consideration its level of resources, funding, staff demands and technical expertise. This method also requires great cooperation and buy-in from agency staff. If staff are not willing to fully support the system and keep the sign information up-to-date and accurate, then any investment could be wasted.

Advantages of Expected Sign Life

- This method can expedite and streamline signing operations
- This method provides asset management capabilities and enhanced tools for planning, scheduling, and budgeting purposes.
- Sign replacement can be thoroughly documented

Limitations of Expected Sign Life

- Collecting sign inventory data and initially creating an expected sign life system can be an expensive and time-consuming process
- This method depends on accurate and up-to-date information of individual signs
- Administrative, maintenance, and upkeep cost can be high

Reference

Ré, Jonathan M. and Carlson, Paul (2012). *Practices to Manage Traffic Sign Retroreflectivity: A Synthesis of Highway Practice*. NCHRP Synthesis 431. National Cooperative Highway Research Program.

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[1] If using sign sheeting warranties to project service life, an agency replaces signs when their warranties have expired.

[2] If using test-deck or field measurements to project service life, an agency measures the retroreflectivity values of a group of signs in the field. Based on these values, an agency assigns a replacement date for signs of the same type.

[3] If using empirical data to project an expected service life for signs, an agency uses research findings to determine replacement data for signs.

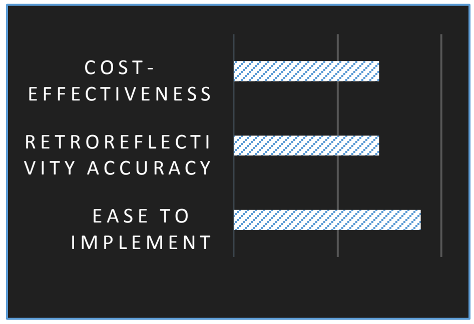
BLANKET REPLACEMENT

Study Description

The blanket replacement method is similar to the expected sign life method; the fundamental difference is that agencies assign a replacement date for a large group of signs (all on one date) as opposed to individual signs (over a span of different dates). Sign replacement can be based on either spatial or strategic data. Under a spatial replacement system, all signs within a certain geography are replaced at a given date. Under a strategic system, all signs of a common characteristic, such as sheeting type, sign classification, and sign content, are replaced at a given date. Blanket replacement may incorporate both spatial and strategic characteristics by removing specific signs types in a certain area.

Key Considerations

- Implementation requires minimal administrative effort
- Method results in signs being replaced before reaching the end of their service life



The image above shows a blanket replacement map and schedule.

Implementation Considerations

A major advantage of the blanket replacement method is that it is relatively straightforward to implement. It does not require personnel training, there is a low administrative cost, and a computer-based sign inventory system may not be a requirement. When implemented, agencies often stagger the blanket replacement schedule to simplify planning and budgeting. For example, consider an agency using Type III High-Intensity Beaded Sheeting that has a warranty of 10 years. In this instance, the agency may benefit from dividing its jurisdiction into ten different areas, where every year signs in one of the ten areas are replaced. Since an agency would know that roughly 10 percent of its signs would need to be replaced every year, it would help for planning, scheduling, and budgeting.

Advantages of Blanket Replacement

- Identifying signs and formulating the replacement schedule is simple and straightforward
- Administrative costs are low
- Regular replacement cycles can help with planning, scheduling, and budgeting

Limitations of Blanket Replacement

- There is a high possibility of premature sign replacements
- Operating costs and additional sign installation labor could be higher than with other methods.

Reference

Ré, Jonathan M. and Carlson, Paul (2012). *Practices to Manage Traffic Sign Retroreflectivity*: *A Synthesis of Highway Practice*. NCHRP Synthesis 431. National Cooperative Highway Research Program.

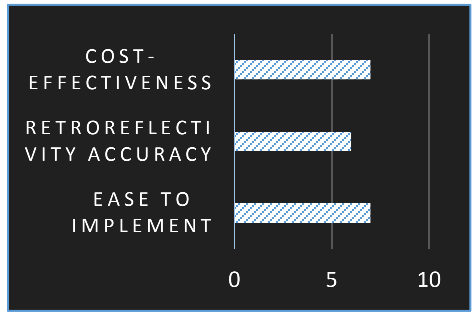
CONTROL SIGNS

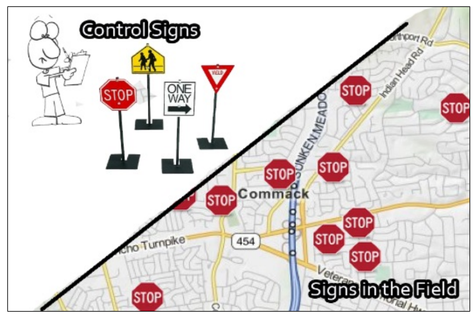
Study Description

For the control signs method, the performance of a sample set of signs is used to determine when signs in the field should be replaced. When the sample set, or control signs, approach the retroreflective minimums, all corresponding signs in the field are replaced. The control signs method requires a means of establishing a credible sample set, sign evaluation techniques, and a system to locate corresponding signs in the field.

Key Considerations

- Enables agencies to stretch the service-life of their signs
- Retroreflectivity readings from the set of control signs may vary substantially from those in the field





The retroreflectivity levels for a sample set of signs is measured and signs in the field are replaced based on those measurements.

Implementation Considerations

A sample set of signs should be representative of signs in the field. Carlson and Lupes (2003) recommend that a minimum of three signs per sheeting type should have their retroreflectivity levels measured as a "barometer" for sign conditions in the field. In addition, signs that are being tested should face different directions and be spaced at strategic intervals to account for different levels of exposure to light and other conditions. These considerations will help agencies determine how signs of a given sheeting type are performing in the field. Retroreflectivity measurements of these signs should be taken at intervals that meet an agency's objectives and desired level of precision. Too little time between measurements of control signs may lead to the misuse of labor and resources, whereas long periods between readings may lead to inaccuracies in predicting service life in the field.

Advantages of Control Signs

- Region-specific measurements can be made on a year-to-year basis to measure sign performance without having to measure every sign in the field
- The extension of service life for a specific sign type can be validated through this method to minimize costs and resources
- Sign waste is limited as signs can be replaced after sign warranties have expired

Limitations of Control Signs

- There is no guarantee that the performance of a sample set of control signs is truly representative of the performance of other signs in the field
- Installing control signs, collecting measurements, and analyzing the data can be time-consuming and costly
- Agencies need to purchase or obtain a retroreflectometer

Reference

Ré, Jonathan M. and Carlson, Paul (2012). *Practices to Manage Traffic Sign Retroreflectivity*: *A Synthesis of Highway Practice*. NCHRP Synthesis 431. National Cooperative Highway Research Program.