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16. Abstract This project was established to provide a means of conducting limited scope evaluations of numerous traffic control device issues. During the fourth year of the project, researchers completed assessments of five issues: developing an automated process for identifying the start and end of no-passing zones, developing guidelines for the use of pedestrian countdown signals, evaluating the performance of lead-free yellow thermoplastic pavement markings, developing improved guidelines for accessibility issues associated with traffic signalization, and continuing development of the <i>Work Zone Impacts Handbook</i> . The automated no-passing zone activity developed a prototype method of using Global Positioning System (GPS) coordinates to identify the start and end of no-passing zones based on vertical alignment. The activity on pedestrian countdown signals synthesized available information to develop some initial guidelines. The signal accessibility and work zone impacts' activities are producing separate documents that address those issues.					
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**EVALUATION OF TRAFFIC CONTROL DEVICES:  
FOURTH-YEAR ACTIVITIES**

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## **DISCLAIMER**

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# **CHAPTER 1: INTRODUCTION**

## **INTRODUCTION**

Traffic control devices provide one of the primary means of communicating vital information to road users. Traffic control devices notify road users of regulations and provide warning and guidance needed for the safe, uniform, and efficient operation of all elements of the traffic stream. There are three basic types of traffic control devices: signs, markings, and signals. These devices promote highway safety and efficiency by providing for orderly movement on streets and highways.

Traffic control devices have been a part of the roadway system almost since the beginning of automobile travel. Throughout that time, research has evaluated various aspects of the design, operation, placement, and maintenance of traffic control devices. Although there have been many different studies over the decades, recent improvements in materials, increases in demands and conflicts for drivers, higher operating speeds, and advances in technologies have created continuing needs for the evaluation of traffic control devices. Some of these research needs are significant and are addressed through stand-alone research studies at state and national levels. Other needs are smaller in scope (funding- or duration-wise) but not smaller in significance.

Unlike many other elements of the surface transportation system (like construction activities, structures, geometric alignment, and pavement structures), the service life of traffic control devices is relatively short (typically anywhere from 2 to 12 years). This shorter life increases the relative turnover of devices and presents increased opportunity for implementing research findings. The shorter life also creates the opportunity for incorporating material and technology improvements at more frequent intervals. Also, the capital cost of traffic control devices is usually less than that of these other elements. Research on traffic control devices can also be (but is not always) less expensive than research on other infrastructure elements of the system because of the lower capital costs of the devices.

The traditional Texas Department of Transportation (TxDOT) research program planning cycle requires about a year to plan a research project and at least a year to conduct and report the results (often two or more years). With respect to traffic control devices, this type of program is

best suited to addressing longer-range traffic control device issues where an implementation decision can wait two or more years for the research results.

In recent years, elected officials have also become more involved in passing ordinances and legislation that directly relate to traffic control devices. Examples include: creating the logo signing program, establishing signing guidelines for traffic generators such as shopping malls, and revising the *Manual on Uniform Traffic Control Devices* (MUTCD) to include specific signs. When these initiatives are initially proposed, TxDOT has a very limited time to respond to the concept. While the advantages and disadvantages of a specific initiative may be apparent, there may not be specific data upon which to base the response. Due to the limited available time, such data cannot be developed within the traditional research program planning cycle.

As a result of these factors (smaller scope, shorter service life, lower capital costs, and the typical research program planning cycle), some traffic control device research needs are not addressed in a traditional research program because they do not justify being addressed in a stand-alone project that addresses only one issue. This research project addresses these types of traffic control device research needs. This project is important because it provides TxDOT with the ability to:

- address important traffic control device issues that are not sufficiently large (either funding- or duration-wise) to justify research funding as a stand-alone project,
- respond to traffic control device research needs in a timely manner by modifying the research work plan at any time to add or delete activities (subject to standard contract modification procedures),
- effectively respond to legislative initiatives associated with traffic control devices,
- conduct traffic control device evaluations associated with a request for permission to experiment submitted to the Federal Highway Administration (FHWA) (see MUTCD Section 1A.10),
- address numerous issues within the scope of a single project,
- address many research needs within each year of the project, and
- conduct preliminary evaluations of traffic control device performance issues to determine the need for a full-scale (or stand-alone) research effort.

## FIRST-YEAR RESEARCH ACTIVITIES

During the first year of this research project, the research team undertook the research activities listed in [Table 1-1](#). The first-year report describes the research efforts, results, and recommendations associated with these activities (*1*). [Table 1-1](#) also presents brief descriptions of the results of the first-year efforts, along with the current implementation status.

**Table 1-1. First-Year Activities.**

<b>Activity</b>	<b>Result</b>	<b>Status</b>
Evaluate the effectiveness of dual logos.	Indicated that there is no evidence that the limited use of dual logos would be a problem.	TxDOT implemented dual logos with the logo signing contract that went into effect January 1, 2007.
Assess the impacts of rear-facing school speed limit beacons.	Found that rear-facing beacons improve compliance.	TxDOT incorporated rear-facing beacons in the 2006 Texas MUTCD.
Evaluate the impacts of improving Speed Limit sign conspicuity.	Found some indication that the red border improves compliance, but the data were not conclusive.	The effort was continued into the second and third years, and the results are described in each of those reports.
Crash-test a sign support structure.	The support structure failed the test.	The support structure was redesigned, and additional crash tests were conducted outside of this project. These crash tests were successful. FHWA has approved the redesign support, and it is being used in Texas.
Evaluate the benefits of retroreflective signal backplates.	There was no apparent benefit to using the retroreflective backplate at the study location.	FHWA issued an interim rule that allows the use of backplates under specific circumstances. Retroreflective backplates have been included in the 2006 Texas MUTCD.
Develop improved methods for locating no-passing zones.	Provided descriptions of multiple methods for determining the start and end of no-passing zones, but provided no testing of the accuracy of the methods.	A fourth-year activity looked at the feasibility of using Global Positioning System (GPS) data to establish no-passing zones and is described in this report.

## SECOND-YEAR RESEARCH ACTIVITIES

During the second year of this research project, the research team undertook the research activities listed in [Table 1-2](#). The second-year report describes the research efforts, results, and recommendations associated with these activities (2). [Table 1-2](#) also presents brief descriptions of the results of the second-year efforts, along with the current implementation status.

**Table 1-2. Second-Year Activities.**

<b>Activity</b>	<b>Result</b>	<b>Status</b>
Evaluate the effectiveness of an extinguishable message Left Turn Yield sign.	Found the sign significantly reduced crashes and conflicts at the one location studied.	TxDOT plans to identify the benefits of the treatment in a letter to districts.
Evaluate the impacts of improving Speed Limit sign conspicuity.	There were significant long-term benefits to using the supplemental red border evaluated in the first year.	Long-term benefits of the revised sign design evaluated in the third year.
Evaluate the benefits of dew-resistant retroreflective sheeting.	Dew-resistant sheeting reduces the formation of dew on the sign face and improves nighttime visibility of the sign.	TxDOT should conduct field testing of the prototype material to evaluate long-term performance.

## THIRD-YEAR RESEARCH ACTIVITIES

During the third year of this research project, the research team undertook the research activities listed in [Table 1-3](#). The third-year report describes the research efforts, results, and recommendations associated with these activities (3). [Table 1-3](#) also presents brief descriptions of the results of the third-year efforts, along with the current implementation status.

**Table 1-3. Third-Year Activities.**

<b>Activity</b>	<b>Result</b>	<b>Status</b>
Evaluate the impacts of improving Speed Limit sign conspicuity.	Use of red border reduces vehicles speeds when used where the speed limit decreases.	TxDOT is evaluating potential implementation as a change in the MUTCD.
Develop recommendations for sign and marking design for super high-speed roadways.	Recommended using a 22 inch minimum legend for freeway signs and 6 inch wide pavement marking.	To be determined.
Comparison of marking retroreflectivity measurements using portable and handheld instruments.	Portable and mobile measurements are consistent with one another if both retroreflectometers are properly calibrated and operated correctly.	None.
Update the TxDOT Traffic Signal Warrant Guidelines.	An updated warrant guide was developed.	To be distributed by TxDOT.
Evaluate lateral placement of rumble strips on two-lane highways.	Not sufficient available information to address the issue.	The issue will be addressed in detail in Project 0-5577.
Begin development of the Work Zone Impacts Handbook.	Handbook development initiated.	Work on Handbook will continue in fourth year.

#### **FOURTH-YEAR RESEARCH ACTIVITIES**

During the fourth year of this research project, the research team undertook the following research activities:

- Develop an automated process for identifying the start and end of no-passing zones ([Chapter 2](#)).
- Develop guidelines for the use of pedestrian countdown signals ([Chapter 3](#)).
- Evaluate the performance of lead-free yellow thermoplastic pavement markings ([Chapter 4](#)).
- Develop improved guidelines for accessibility issues associated with traffic signalization ([Chapter 5](#)).
- Continue development of the *Work Zone Impacts Handbook* ([Chapter 5](#)).

This report describes these activities in the chapters indicated in parentheses. Chapter 6 provides an overall summary for the fourth year. Each of the chapters in this report has been prepared so that it can be distributed as a stand-alone document if desired.

## **REFERENCES**

1. Rose, E.R., H.G. Hawkins, A.J. Holick, and R.P. Bligh. *Evaluation of Traffic Control Devices: First Year Activities*. FHWA/TX-05/0-4701-1, Texas Transportation Institute, The Texas A&M University System, College Station, Texas, October 2004.
2. Hawkins Jr., H.G., R. Garg, P.J. Carlson, and A.J. Holick. *Evaluation of Traffic Control Devices: Second Year Activities*. FHWA/TX-06/0-4701-2, Texas Transportation Institute, The Texas A&M University System, College Station, Texas, October 2005.
3. Hawkins Jr., H.G., M.A. Sneed, and C.L. Williams. *Evaluation of Traffic Control Devices: Third Year Activities*. FHWA/TX-07/0-4701-3, Texas Transportation Institute, The Texas A&M University System, College Station, Texas, October 2006.



## **CHAPTER 2: AUTOMATED LOCATION OF NO-PASSING ZONES USING GPS**

### **INTRODUCTION**

The passing maneuver is one of the most difficult movements to perform on two-lane roadways because a driver must enter the lane of opposing traffic to complete the maneuver. State and local authorities have been charged with the duty of locating areas on two-lane roadways where the passing maneuver might be hazardous (1). The American Association of State Highway and Transportation Officials' (AASHTO) *A Policy on Geometric Design of Highways and Streets* states the following concerning passing maneuvers:

*“If passing is to be accomplished safely, the passing driver should be able to see a sufficient distance ahead, clear of traffic, to complete the passing maneuver without cutting off the passed vehicle before meeting an opposing vehicle that appears during the maneuver” (2).*

To guide local authorities, AASHTO provides recommendations for the design of passing zones and the *Manual on Uniform Traffic Control Devices* (MUTCD) has standards for marking no-passing zones. From AASHTO's definition on passing maneuvers it can be reasoned that a no-passing zone should occur where there is insufficient sight distance to safely complete a pass. On this subject the MUTCD states:

*“On two-way, two- or three-lane roadways where centerline markings are installed, no-passing zones shall be established at vertical and horizontal curves and other locations where an engineering study indicates that passing must be prohibited because of inadequate sight distances or other special conditions” (3).*

Furthermore, the MUTCD provides standards on what the minimum required passing sight distances should be in order to possibly complete a passing maneuver. The minimum required passing sight distances are given for varying speeds. If sight distance for a driver is less than the MUTCD's required minimum sight distance, then a no-passing zone must be marked (3).

Locating and marking no-passing zones on two-way two-lane roadways is the focus of this chapter. Currently many methods are available to agencies by which they can locate and mark no-passing zones. However, there is still a need for more efficient, accurate, and safer

methods for locating no-passing zones. As such, the researchers investigated the possibility of using GPS technology for locating no-passing zones. This chapter contains the study objectives of the research, background information on the subject, a description of the system development and no-passing zone algorithm, lists of testing sites, results from testing, and conclusions and recommendations.

### **Study Objectives**

The goal of this research is to develop a system that allows field crews to utilize GPS technology to locate and mark no-passing zones on two-lane roadways caused by sight obstructions due to a roadway's vertical alignment. The concept is to allow field crews to mount a GPS unit in a vehicle, drive a roadway to collect horizontal and vertical data on the roadway, and then calculate the location of no-passing zones. The objectives necessary for accomplishing this goal are listed below.

- Identify the means by which to model the vertical profile of a roadway from collected GPS data.
- Create an algorithm for locating no-passing zones based on a roadway's modeled vertical profile.

### **BACKGROUND INFORMATION**

Previously it was mentioned that there are many different methods for locating no-passing zones on two-lane roadways. The first-year activities of the *Evaluation of Traffic Control Devices* study looked into the methods currently available to state departments of transportation (DOT) for locating no-passing zones (4). The methods discussed were as follows:

- Plans Review Method,
- Eyeball Method,
- Speed and Distance Method,
- Walking Methods,
- Single-Vehicle Method,
- Multivehicle Methods, and
- Videolog or Photolog Methods.

The first-year study also completed a small informal survey to determine which methods DOTs use to locate no-passing zones. Although there was no one clear-cut method used, the trends seemed to show that DOTs use single- or multi-vehicle methods that utilize some combination of distance measuring instruments and human sight to locate no-passing zones. The vehicle methods do get work crews out of the roadway, as compared to traditional walking methods, but they still rely on human intervention to determine when and where to start and end no-passing zones. Using GPS, the work crews will be able to get out of the roadway, as with the single- and multi-vehicle methods, but this method will also eliminate much of the human intervention required when using single- and multi-vehicle methods.

The focus of this chapter is development of a system that uses GPS technology to automatically locate no-passing zones. GPS is a positioning system developed by the Department of Defense in the 1970s for military uses. It is composed of three segments, which are defined as space, control, and user. The space segment consists of the GPS satellites that orbit the Earth. The control segment consists of base stations that track and send corrections to the GPS satellites, while the user segment is the receiver of the satellite signals. Through known satellite positions and triangulation, positional data can be obtained. However, GPS positional data are not always exact. Errors do occur and can be grouped into three general categories: errors that occur at the satellites, errors at the receiver, and errors due to atmospheric conditions (5). As a result of these errors, smooth GPS representations of roadway profiles are difficult to obtain, especially when data are collected from a moving vehicle, which is the selected method of collection for the locating of no-passing zones in this study.

In order to automatically locate no-passing zones using GPS, two steps must be accomplished. First, after collecting GPS data on a roadway a smooth representation or geometric model of a roadway's vertical profile must be created. Second, an algorithm must be developed that uses the information from the previous step to define where the no-passing zones are located based on restrictions in sight distance. The Kansas DOT and Kansas State University (KSU) have developed methods for creating three-dimensional (3-D) geometric models of roadways from GPS data (6). The Kansas work was used to rank roads based on sight deficiencies to help select potential projects to complete. The work was not used for actual field location of no-passing zones by field crews.

## **SYSTEM DEVELOPMENT**

Locating no-passing zones using GPS data requires completion of two steps, modeling a roadway's vertical profile and developing a no-passing zone location algorithm. The work completed thus far in these two areas is summarized and discussed below.

### **Vertical Profile Model**

GPS data collected from a moving vehicle are not smooth. As discussed earlier, GPS has errors inherent to the system. These errors can be minimized through various methods. Many of these methods utilize local base stations on a project's site. The base stations allow comparison of collected data at the base station and actual or true data at the base station. These comparisons allow determination of local error, which then enables corrections to be applied to data collected from a moving vehicle. However, due to the nature of this particular application, it is not reasonable to set up a base station at each site. The current proposed solution is to use a private satellite correction service to help offset some of the errors. This correction service is discussed later in more detail.

Despite the use of the satellite correction service, GPS data still show jumps in elevation due to adding and dropping satellites, as well as inaccuracies that cannot be corrected. Because of these problems, the GPS data must be smoothed in order to produce a smooth vertical profile. Roadway profiles, especially long segments, are unique in that they consist of multiple combinations of tangents and parabolic curves. These multiple segments do not lend themselves to being modeled or smoothed by a single function. As a result, local regression methods were selected for smoothing GPS data. More specifically, robust Loess regression was used.

Loess regression is a locally weighted nonparametric regression method. A span of points on either side of a test point is weighted. Data points closer to the test point are more heavily weighted than points that are near the edge of the span. A new value for the test point is then calculated using the surrounding weighted points and regression analysis. Loess regression can use either linear or quadratic fitting. Quadratic fitting was chosen for this application because of the parabolic curves in the geometric design of vertical roadway profiles. Because Loess regression is a localized method, only small segments of a roadway are evaluated at a time, allowing the shape of a roadway's vertical profile to remain intact. This is where the span distance surrounding the test point becomes important. This span defines what length of any single stretch of roadway should be considered in the smoothing of a single data point (7).

After smoothing the GPS data via Loess regression, cubic spline fitting functions are applied to model the data. Cubic splines are piecewise polynomials and are ideal for this application because, as discussed above, the profile of a roadway cannot be treated as a continuous function (8). The profile needs to be broken into identifiable segments. The cubic splines allow this to be accomplished. The reason for using the cubic spline functions in addition to the Loess regression smoothing process is that the collected GPS data points are not evenly spaced at station intervals along the roadway that are useful for the no-passing zone algorithm. By using cubic splines, functions that model the GPS data can be calculated. These functions allow elevations on the roadway profile to be calculated at evenly spaced station intervals. These evenly spaced stations and elevations can then be used in the no-passing zone algorithm to determine the locations of no-passing zones.

Before GPS data can be smoothed, they must be converted into a usable form. Typically, horizontal GPS data are reported in latitude and longitude while vertical data are reported in meters above sea level. Researchers selected the useable form defined by the Texas Centric Mapping System/Lambert Conformal (TCMS/LC) (9), a statewide mapping system that allows the same system to be used across the state. The details of the system can be found in [Appendix A](#). After conversion, longitude and latitude become northing and easting. TCMS/LC data can be reported in either metric or U.S. customary units. Researchers selected U.S. customary units as the desired output in this project. In summary, in order to create a smooth vertical profile of a roadway the following steps were completed.

1. Convert GPS data from longitudes and latitudes into northing and easting.
2. Calculate station values along the horizontal plane from northing and easting data.
3. Smooth vertical data using Loess regression.
4. Model the data using cubic splines.
5. Output data in station and elevation format for use in the no-passing zone algorithm.

### **No-Passing Zone Algorithm**

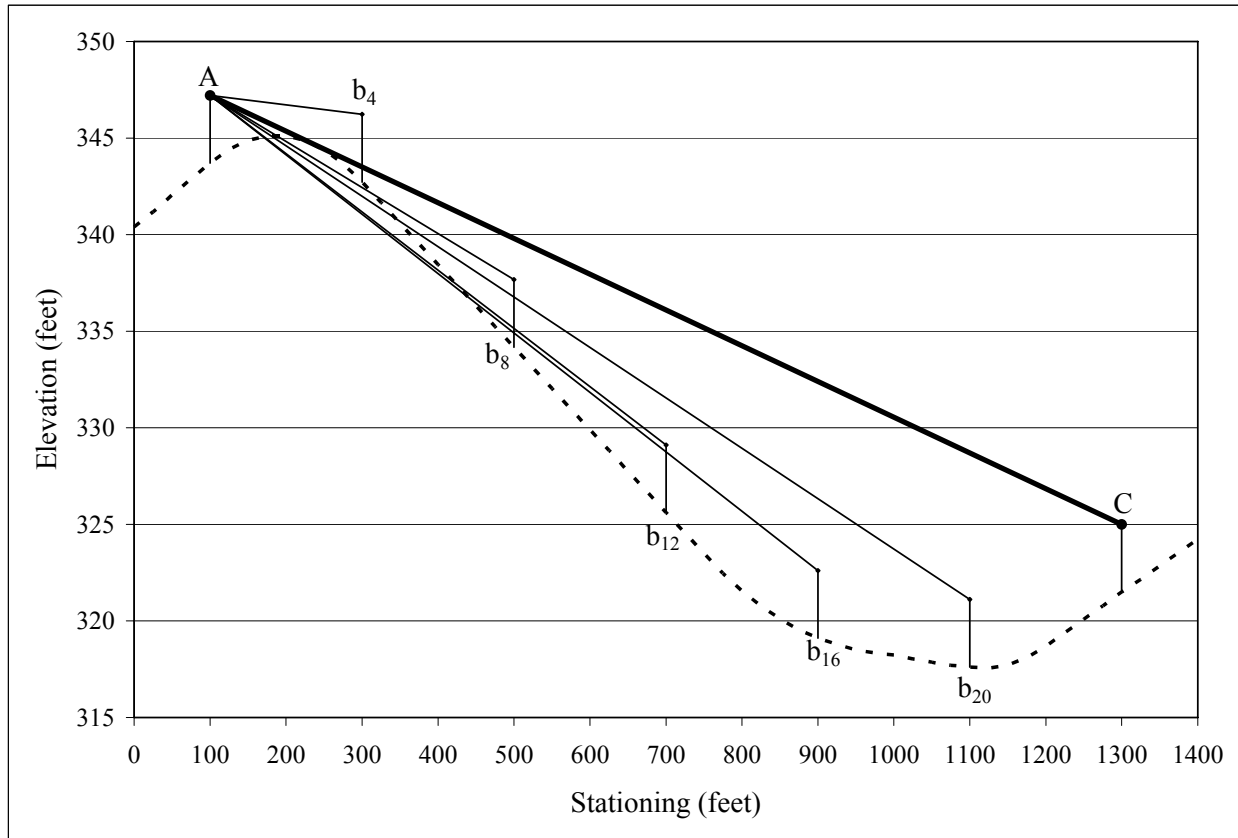
No-passing zones are based on instances where sight distance is restricted. The MUTCD defines sight distance, as needed for a pass, on a vertical curve in the following manner:

*“[T]he distance at which an object 3.5 ft above the pavement surface can be seen from a point 3.5 ft above the surface” (3).*

The MUTCD does not specify whether the definition of distance for vertical passing sight distance is a two-dimensional or three-dimensional distance, unlike the definition they use for horizontal sight distance, which is along the centerline of the road. Since MUTCD does not define it, researchers used the distance along the centerline of the road, the same as that of the horizontal passing sight distance. This was done for two reasons. First, it provided for easier and more simplified calculations in the no-passing zone algorithm and second, because it is more conservative.

Based on the MUTCD definition, at any point where the pavement surface restricts a driver to having sight distance less than the minimum required passing sight distance, a no-passing zone will be established. Accordingly, the developed no-passing zone algorithm is an iterative process based on the fact that a no-passing zone will be present anytime the pavement surface elevation is above the needed sightline.

In this iterative process, there are two separate and distinct intervals. The first interval is that of testing points to determine if they should be identified as a no-passing zone or passing zone location. In general this point is referred to as point A. The algorithm changes the station of point A iteratively so that it tests points every 10 feet along the roadway. The second interval pertains to testing each iterative location of A that is located every 10 feet along the roadway. A secondary point, referred to as  $b_i$ , is selected 50 feet from point A. The interval between point A and point  $b_i$  is tested for sight restrictions. If the algorithm does not find a sight restriction, then another interval from the next  $b_i$ , 50 feet further down the roadway from the current point A, whose location has not been changed, is tested for sight restrictions. Assuming no sight restrictions are found in each successive interval from A to the increasing station of  $b_i$ , the algorithm repeats the process until it reaches a distance equal to the minimum sight distance as set by the MUTCD. The point at this location is called point C. A visual depiction of this process is presented in [Figure 2-1](#).



**Figure 2-1. No-Passing Algorithm Iteration Example.**

The algorithm, in general terms, calculates the theoretical sightline for each interval from point A to point  $b_i$  as follows. First, it adds 3.5 feet to the roadway elevations at point A and point  $b_i$ . The line between these two points, which are 3.5 feet above the pavement surface in space, is the theoretical sightline. Next, it determines the equation of the line between these two points, where stationing is the independent variable and elevation is the dependent variable (y). After determining the equation of this line, the algorithm identifies 10-foot station increments and their elevations between point A and the ending station of the theoretical sightline, which is point  $b_i$ . These elevations are then compared to the corresponding roadway elevations at those precise stations as determined by the geometric model with the help of the smoothing process. If over the entire sightline station span the sightline elevations are greater than the roadway profile, then there are no sight restrictions in this interval. However, if at any station a roadway pavement elevation is greater than its corresponding sightline elevation, a no-passing zone exists. If this is the case, the loop of checking successive A- $b_i$  intervals is broken. This process is

repeated from the beginning of the project to the end of the project. Once finished, the beginning and ending of no-passing zones will be established.

As mentioned above, [Figure 2-1](#) depicts the no-passing zone algorithm process for a roadway with a speed limit equal to 70 mph. Point A is the point in question for determining if there is a sight restriction at that position. Point C is 1200 feet away from point A and represents the minimum required passing sight distance as set by the MUTCD. In [Figure 2-1](#) not all of the  $b_i$  intervals are shown. This is done so that the general trend can be understood without cluttering the figure. Points  $b_4$ ,  $b_8$ ,  $b_{12}$ ,  $b_{16}$ ,  $b_{20}$  are distances of 200, 400, 600, 800, and 1000 feet, respectively, from point A.

[Figure 2-1](#) shows the importance of this iterative process. If only the sight line from point A to point C was tested, the location at point A would have been identified as a passing zone. However, as seen in sightlines  $Ab_8$ ,  $Ab_{12}$ ,  $Ab_{16}$ , and  $Ab_{20}$  there are sight restrictions at these locations and point A should be identified as a no-passing zone location. This iterative process helps to identify possible sight dips in the roadway.

## **SYSTEM TESTING**

The vertical profile smoothing model and the no-passing zone algorithm had to be tested. This section outlines how this was carried out. The data collection testing sites, process, equipment, and methodology are provided below.

### **Testing Sites**

Researchers evaluated only no-passing zones caused by sight restrictions in the vertical profile in this research. As such, ideal sites for testing needed to have straight alignments and significant enough elevation changes in the vertical profile to require no-passing zones. Area Engineers in the Texas Department of Transportation (TxDOT) Bryan District were contacted and asked for recommendations of roadway segments that met these requirements. From this initial inquiry, several roadway segments were identified and these segments were then driven by the researchers. After driving the recommended sites, researchers chose three locations for testing. The three test sites were segments on Farm-to-Market (FM) roads 50, 912, and 1940.

The portion of FM 50 that was used for testing is in Washington County, south of College Station, Texas. The actual test segment is approximately 8.5 miles long and runs from the town of Independence to the intersection of SH 105, which is east of Brenham, Texas. This



is a two-lane roadway way that is consistently straight in the horizontal alignment with a few horizontal curves.

FM 912 is also in Washington County and is approximately 11 miles east on SH 105 from the intersection of FM 50 and SH 105. This is a two-lane roadway with no shoulders. The test segment is approximately 3 miles long and runs from the intersection of FM 912 and SH 105 to the intersection of FM 912 and FM 1155. The horizontal alignment of this test section is straight. There are no horizontal curves.

The last test section, FM 1940, is in Robertson County, which is north of Brazos County. The test section is approximately 7 miles long and runs in a north and south direction from Old San Antonio Road to Riley Grain Road. This is again a two-lane road and except for a few isolated horizontal curves near Riley Grain Road, this test segment is straight.

These three locations provided ideal locations for testing and evaluating the developed no-passing zone location system. They have significant enough elevation changes to restrict sight distances so that no-passing zones must be delineated and they are straight enough that the no-passing zones cannot be caused by horizontal sight obstructions, or at least the large majority cannot. The researchers did note locations on the roadways where horizontal curves do cause sight restrictions, or at least suggest to researchers that they might cause sight restrictions.

### **Data Collection Equipment**

Horizontal and vertical GPS data for each of the roadways were collected during multiple runs on each of the roadways. Additionally, the existing pavement markings for no-passing zones were identified so they could be compared to locations of the no-passing zones determined from the automated method.

Data collection was performed using the instrumented vehicle that has been assembled by the Texas Transportation Institute. The instrumented vehicle is a 2006 Toyota Highlander equipped with a Dewetron computer, Trimble 232 DMS GPS unit, distance measuring instrument (DMI), and video collection capabilities. These tools allowed collection of GPS data along with video data of the roadway with DMI readings superimposed on the screen.

The Trimble 232 DMS GPS unit with differential GPS (DGPS) antenna can receive the OmniSTAR Virtual Base Station differential correction service. This is a commercial measurement domain wide area differential GPS (5). OmniSTAR maintains a network of base stations across the country that receive GPS signals. Because the locations of the base stations

are known, corrections can be calculated to improve the accuracy of the received GPS signal. These corrections are beamed back to OmniSTAR satellites, which then broadcast the corrections to individual GPS units, such as the Trimble 232 DMS unit, improving the accuracy of the data collected by the individual GPS units.

## **Methodology**

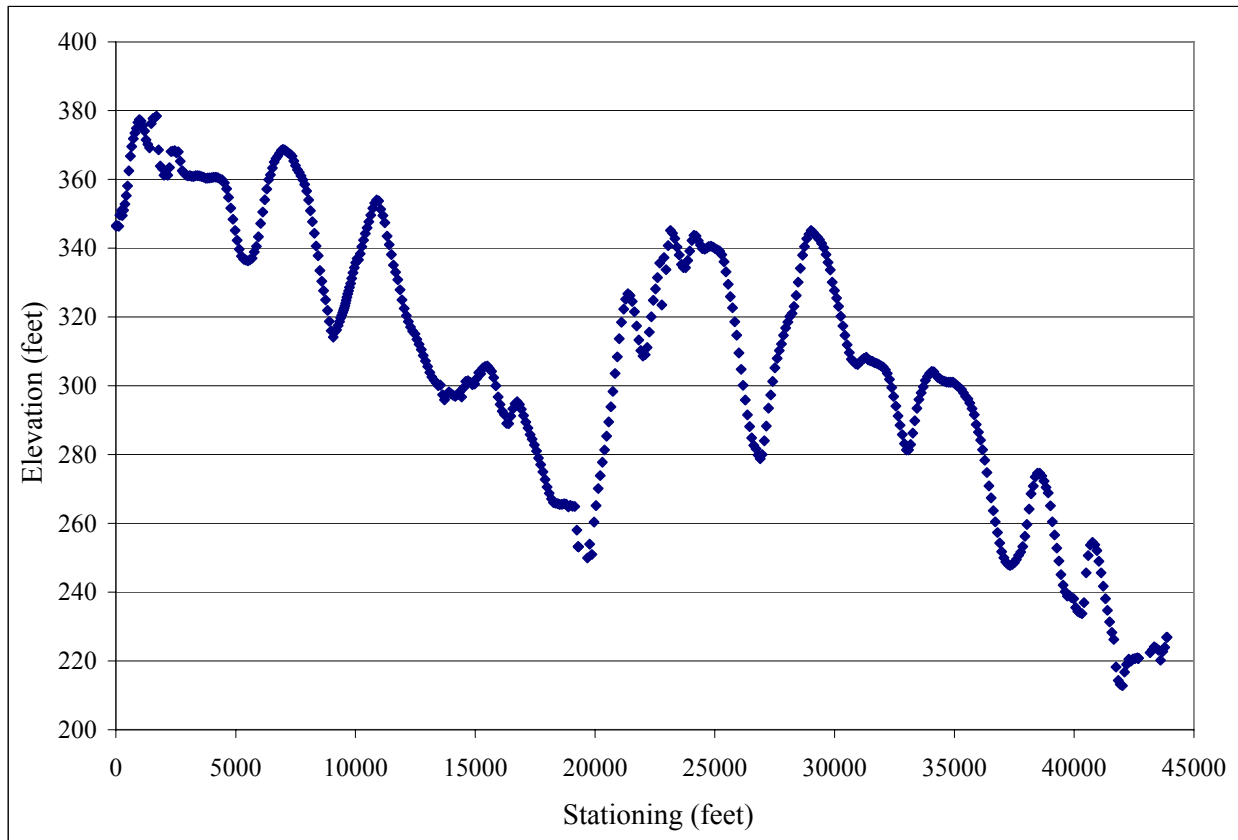
At each testing site four runs were made in each travel direction of the roadway. A running start was taken with the instrumented vehicle before the starting location. When the instrumented vehicle crossed the beginning point, DMI was begun. While driving, once the target speed of 60 mph was reached the cruise control was set in order to maintain a steady speed. Video data were collected in unison with horizontal and vertical GPS roadway data. This allowed visual verification of the terrain and recording of existing pavement markings since DMI distances were superimposed on the collected video.

Software called Dewesoft was used in the data collection process. Along with allowing the researchers to collect video, DMI, and GPS data that were easily referenced to one another, the Dewesoft software allowed the researchers to record events. Using this tool an event was recorded at the beginning of the run, at the end of the run, and every time the pavement markings changed between passing and no-passing zones. Also, while driving, the researchers made observations concerning whether the no-passing zones were the result of vertical curves only, horizontal curves only, or combinations of both. The collected GPS data were run through the developed automated no-passing zone location method and compared to the existing no-passing zones identified using the recorded video and DMI distances. Using DMI and video data at speeds of 60 mph, it was not possible to identify the exact starting and ending points of the run or starting and ending points of passing and no-passing zones within a single run. Therefore it was difficult to obtain the absolute location of the existing markings. However, by averaging DMI video results from the four runs in each travel direction of each road, the lengths and locations of the existing no-passing zones were obtained. These provided the basis for comparing the results of the no-passing zone algorithm presented in the next section.

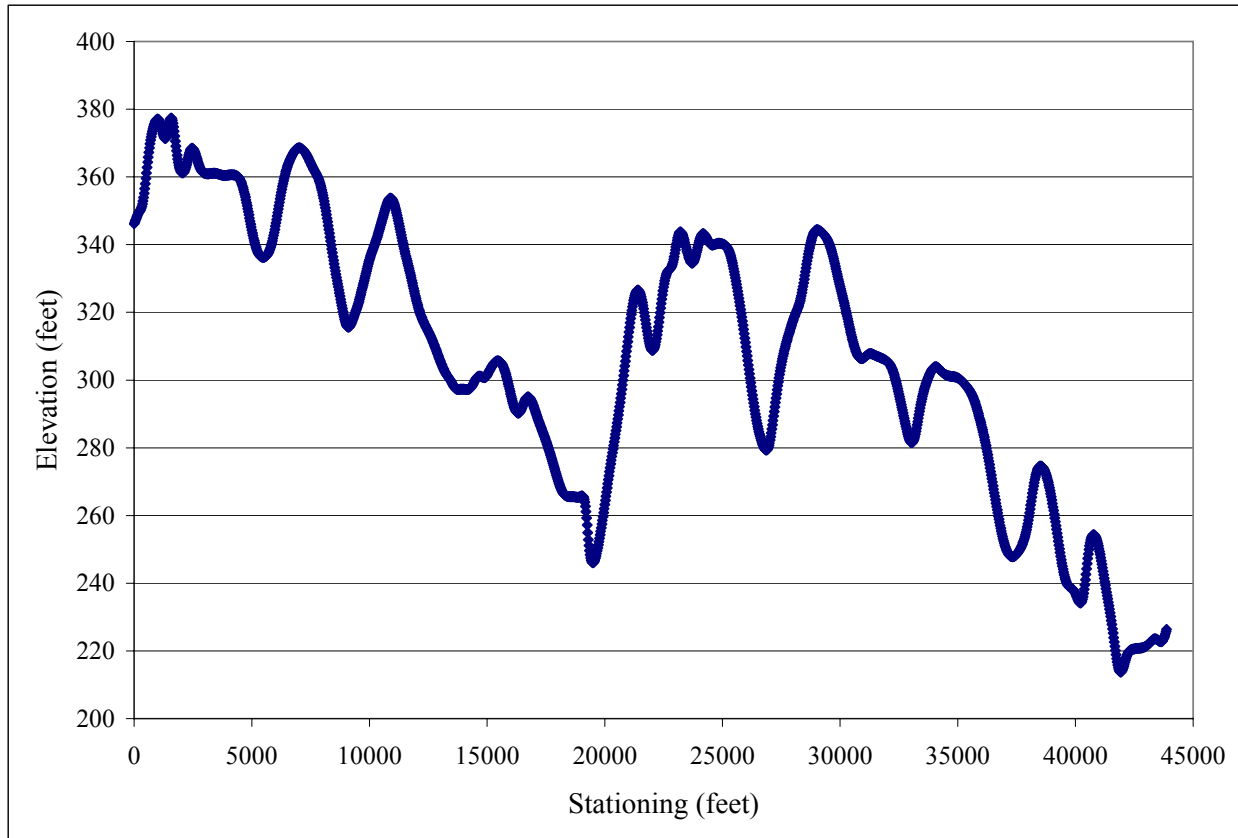
## **RESULTS**

Presented in this section are the results of the no-passing algorithm for each of the tested roadways. [Figure 2-2](#) is an example of roadway profile obtained from raw GPS data, and [Figure](#)

2-3 is an example of the resulting profile from smoothed GPS data. These are given as examples of figures that are found in Appendix A for the runs of the tested roads in each of their major directions of travel. These figures are important because they help explain the no-passing zone algorithm results that are reported in this section and will be referenced as such. Figure 2-2 below is the roadway profile of the raw GPS data for run 1 in the southbound direction of FM 50.



**Figure 2-2. FM 50 Southbound Run 1 Raw GPS Data.**



**Figure 2-3. FM 50 Southbound Run 1 Smoothed Data.**

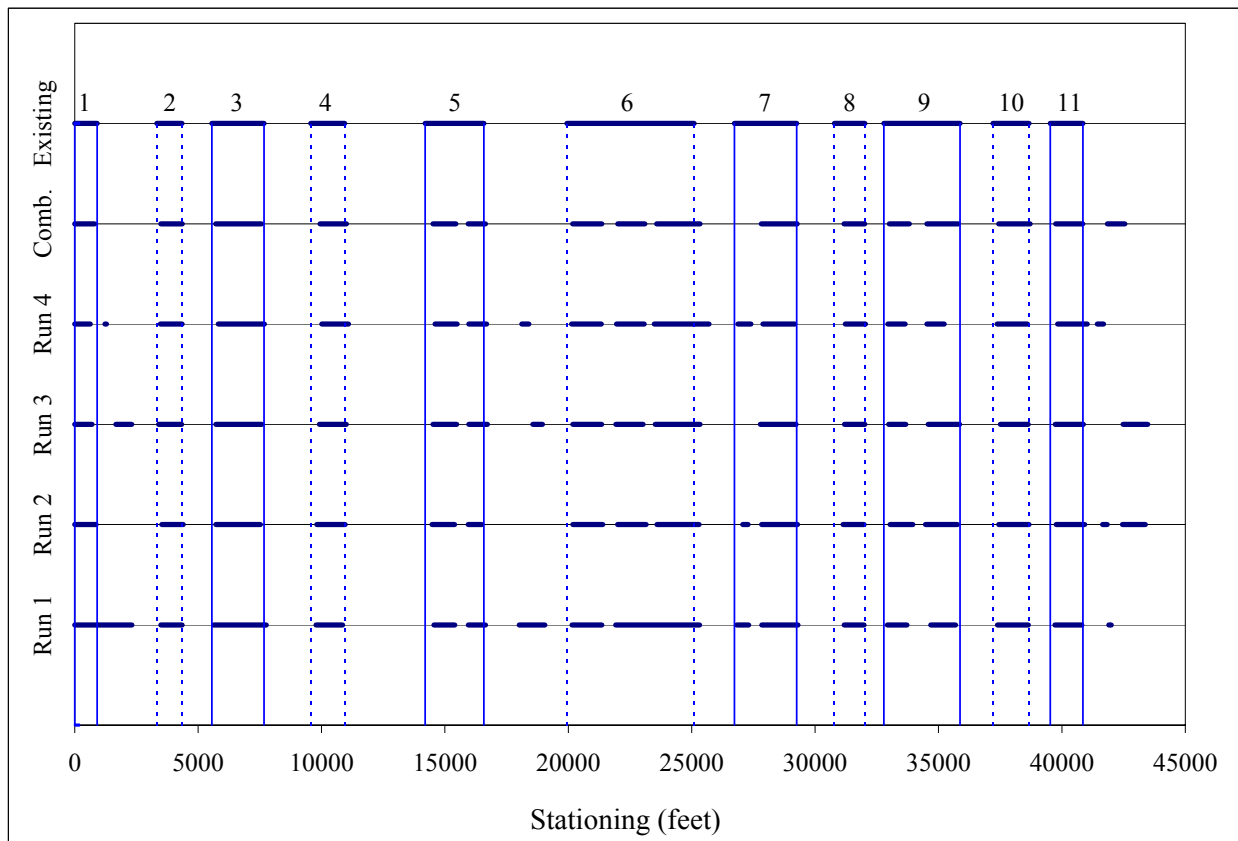
Figure 2-3 is the smoothed representation of the FM 50 run 1 southbound data. These plots give examples of how the smoothing process smooths the GPS data and gives consistent elevation data at constant interval stations on the roadway. However, it will be seen that in some cases the error in the GPS data is beyond the scope of the smoothing process and leads to incorrect location of no-passing zones.

In addition to the profiles mentioned above, Appendix A also contains profiles of the combined smoothed runs and the plan sheet profiles of the roadways. The combined smoothed profiles are the result of using the developed smoothing process and no-passing algorithm on all runs in a single direction at the same time.

### **FM 50 Southbound**

Figure 2-4 shows the results of the collected roadway GPS data for the southbound direction of FM 50 processing using the no-passing algorithm. In Figure 2-4 the horizontal line segments represent the location of no-passing zones according to stations. Runs 1, 2, 3, and 4 are results computed from the no-passing zone algorithm for each single run. In Figure 2-4

“Comb.” refers to the no-passing algorithm results from combining the data from runs 1, 2, 3, and 4. Additionally, “Existing” refers to the actual no-passing zone markings observed from DMI distances on the video taken during data collection. Also, in [Figure 2-4](#) the vertical lines (solid and dashed) are for reference purposes only. These lines represent the existing markings as seen at the top of the figure and are used to help delineate how well the no-passing zone algorithm performed on each of the runs. The pairs of solid and dashed lines represent individual no-passing zones. To further delineate the no-passing zones and help in distinguishing them in discussion they have been sequentially numbered at the top of the figure as the stationing increases.



**Figure 2-4. FM 50 Southbound No-Passing Zones.**

[Figure 2-4](#) shows definite matches between the existing no-passing zone locations and those found from the GPS data using the no-passing zone algorithm. However, there are definite differences as well. For example, between no-passing zones 5 and 6, runs 1, 3, and 4 show no-passing zone segments. These segments occur due to inaccuracies and inconsistencies in the

GPS data. Figures 2-2, A-3, and A-5 all show jumps in the data at this location that are inconsistent with Figure A-8, which is the plan sheet profile of the southbound direction of FM 50. The smoothing process cannot adequately eliminate these jumps and, as a result, after smoothing it looks as if small vertical curves are located in this area. The effect is that the no-passing zone algorithm detects sight distance restrictions and establishes a no-passing zone. Alternatively, run 2 does not have any jumps in the GPS data at this location and more adequately represents the roadway. This can be seen by comparing Figures A-1 and A-8.

Other differences appear on runs 1 and 3 following existing no-passing zone 1. Run 1's first no-passing zone extends well beyond the existing markings and run 3 shows a short no-passing zone segment between no-passing zones 1 and 2. Figures 2-2 and A-3 show that the data at these locations are not smooth, in contrast to Figure A-8, which is the plan sheet profile. Again, the unsmoothed data point variability is too great for the smoothing process to overcome and the result is incorrect no-passing zone lengths.

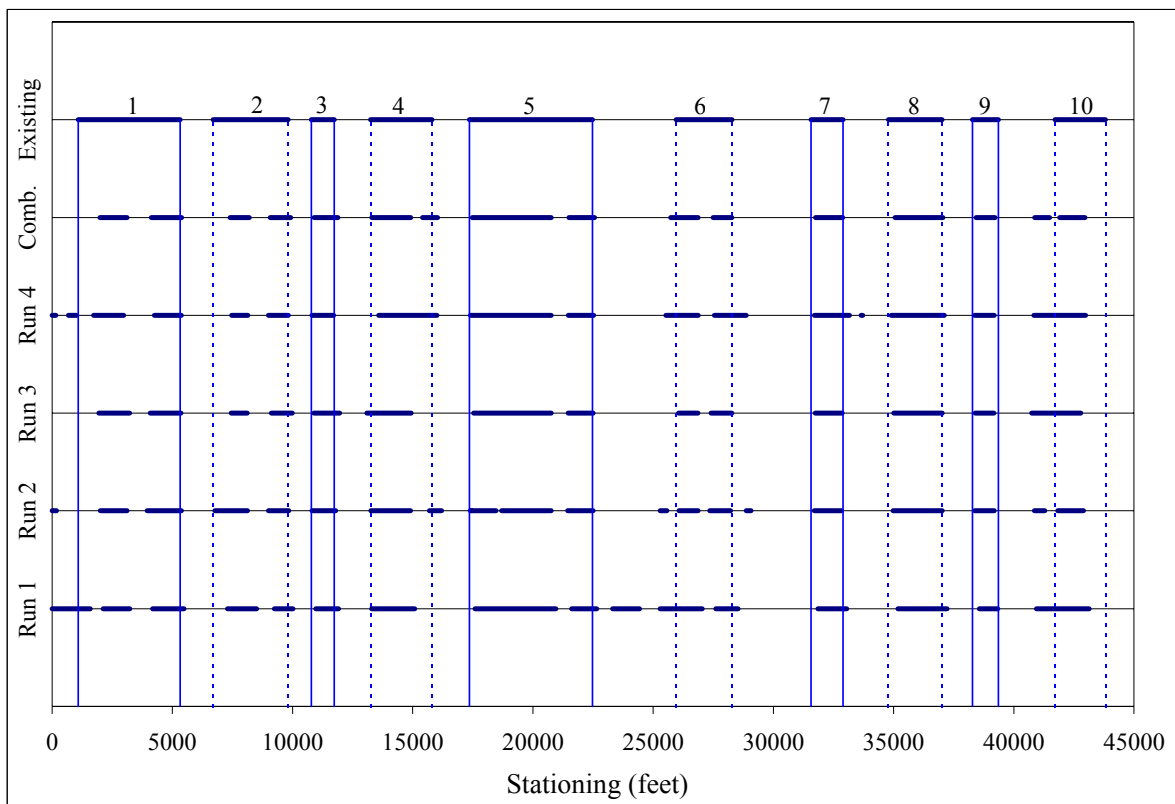
On FM 50 in the roadway segment tested researchers noted at least two significant horizontal curves while driving the roadway that could affect sight distance. Those two horizontal curves occurred in no-passing zones 1 and 7. In the first no-passing zone runs 2, 3, and 4 end slightly before the end of the existing no-passing zone. This pattern suggests that the horizontal curve may have contributed to some of the differences between the existing and calculated distances. As for the seventh no-passing zone, researchers are of the opinion that it does not have significant impact because the vertical geometry of the roadway after the curve is still such that sight distance is most likely restricted due to the roadway and not horizontal objects. However, it is difficult to quantify the effect of those horizontal curves because they occurred in conjunction with vertical curves. Since the no-passing algorithm currently only adjusts for no-passing zones caused by vertical alignments, these instances just need to be noted.

Among the trends that are similar between the existing and calculated no-passing zones there are small gaps between no-passing zones where there should be continuous no-passing zones. For example, on run 3 in existing no-passing zone 6, the algorithm shows three separate no-passing zones, which is not the case. This is a common occurrence among all of the roadway segments and runs and is discussed in the conclusions of this chapter.

## FM 50 Northbound

Figure 2-5 presents the no-passing zone algorithm results for the runs in the northbound direction of FM 50. Once again the general trends seem to be captured by the no-passing zone location process. However, the term “general” should be emphasized. There are notable differences, especially on run 1 before the first no-passing zone and between no-passing zones 5 and 6.

When examining the GPS profile for run 1 in Figure A-9, major discrepancies can be found around stations 25+00 and 250+00. The GPS data show decreases in elevation that are not present in the plan sheet profile shown in Figure A-18. These elevation decreases are modeled in the smoothing process, causing the no-passing algorithm to establish no-passing zones at these locations where they should not be.



**Figure 2-5. FM 50 Northbound No-Passing Zones.**

As for run 2, GPS data inconsistencies can be seen in Figure A-11 at the beginning of the run, surrounding station 25+00, and in the stationing between 400+00 and 450+00. These all correspond to locations on Figure 2-5 where no-passing zones were found where they should not

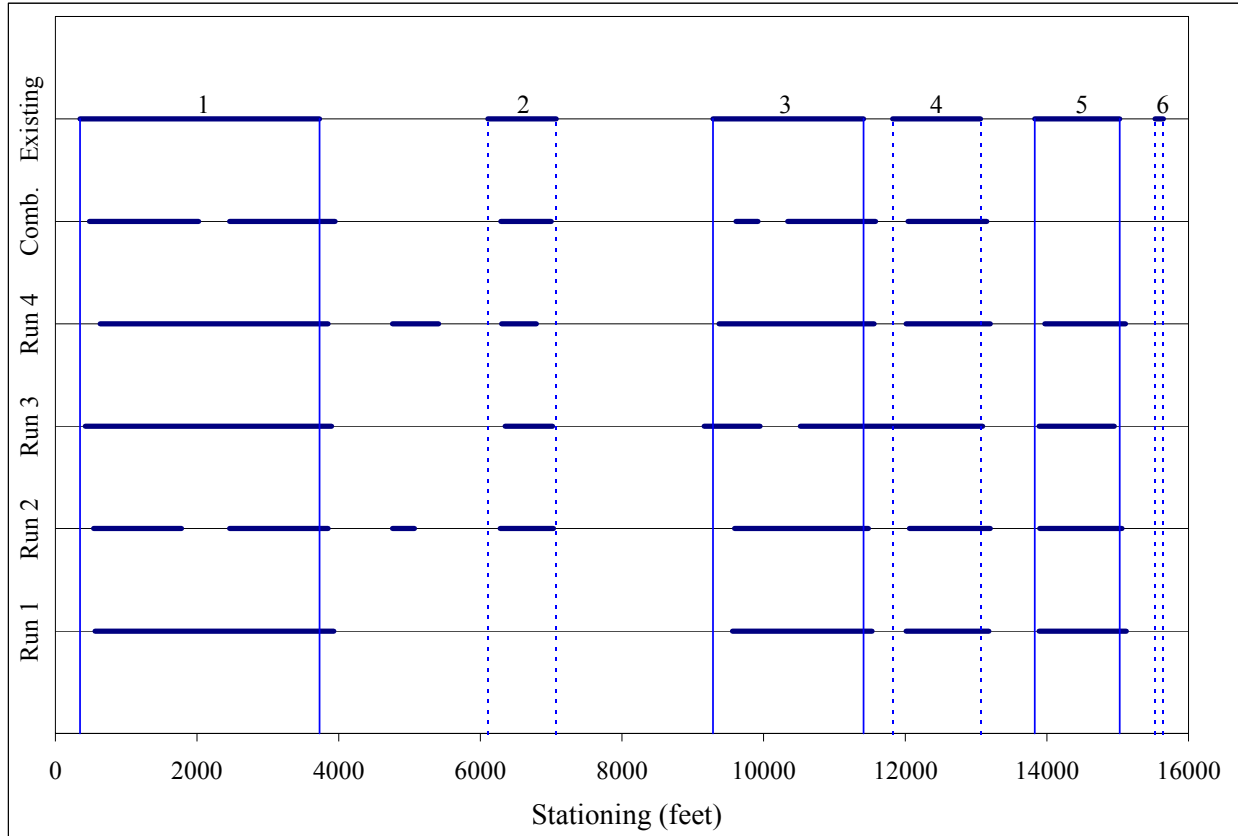
be. Additionally, the problem seen in run 2 occurring between stations 400+00 and 450+00 is almost consistent among all of the runs. The researchers reasoned that this is the cause for no-passing zones starting before the tenth no-passing zone because all of the runs either show dips in the data or excessive vertical jumps that cause the algorithm to register no-passing zones. All of the runs ended the tenth no-passing zone well before what the existing conditions show. Upon further inspection, at this location the segment is entering the town of Independence and the intersection of FM 50 with FM 390. These two characteristics call for a no-passing zone despite there being sufficient distance for a passing zone according to the MUTCD. These are circumstances that the GPS no-passing zone algorithm cannot account for, and thus the system user must identify these situations and apply good engineering judgment.

Additionally, as in the southbound direction, the researchers noted two major horizontal curves that could cause sight distance restrictions. These occurred in existing no-passing zones 4 and 10 in the northbound direction.

### **FM 912 Eastbound**

No-passing zone results for FM 912 eastbound are presented in [Figure 2-6](#). FM 912 is an extremely straight roadway segment. As such, there is no concern with no-passing zones existing due to horizontal curves. The one concern that the no-passing zone algorithm does not address is the approach of a highway intersection, as was the situation on FM 50 northbound. At the very end of the run in the eastbound direction FM 1155 intersects perpendicularly with FM 912. Researchers believed this is the cause for no-passing zone 6, along with the fact there are insufficient data at the end of the runs to identify the sixth no-passing zone. What is meant by insufficient data is that in order to obtain an accurate reading of whether there is a passing or no-passing zone at a location data are needed for the roadway ahead of the location in question for a distance equal to the minimum required passing sight distance.





**Figure 2-6. FM 912 Eastbound No-Passing Zones.**

As with FM 50, FM 912 results show some similarities, along with some errors. For example, in run 1 the most glaring difference is that existing no-passing zone 2 does not appear in the results of the no-passing analysis. When looking at the raw GPS data for run 1 in [Figure A-19](#) it is somewhat difficult to see why this occurs. The GPS data seem to show a slight vertical curve at this location; however, the curve is not as prominent as the ones seen in runs 2 or 3 or even 4. Because of this, the researchers hypothesize that the smoothing process eliminates the significance of the curve because the GPS data do not show its true effect. In response, sight restrictions at this location are not detected and a no-passing zone is not located.

Another interesting observation of run 1 is the consistency with which the no-passing zones are offset from the existing no-passing zones. No-passing zones in run 1 start 212, 277, 188, and 64 feet past the beginning of the existing no-passing zones 1, 3, 4, and 5, respectively. In addition, the no-passing zones from run 1 end 200, 121, 116, and 93 feet past the existing no-passing zones. These differences in beginning and ending points show that the no-passing zone algorithm no-passing zones have different lengths of 12, 156, 72, and 29 feet when compared to

the lengths of the existing no-passing zones. These accuracies [inaccuracies?] can be discussed in the conclusions, but the point to make here is that even though attempts were made to align the run results with the existing results, offsets in the existing and calculated no-passing zones did occur. Simply offsetting the run 1 stations back 200 feet better aligns the existing and calculated no-passing zones.

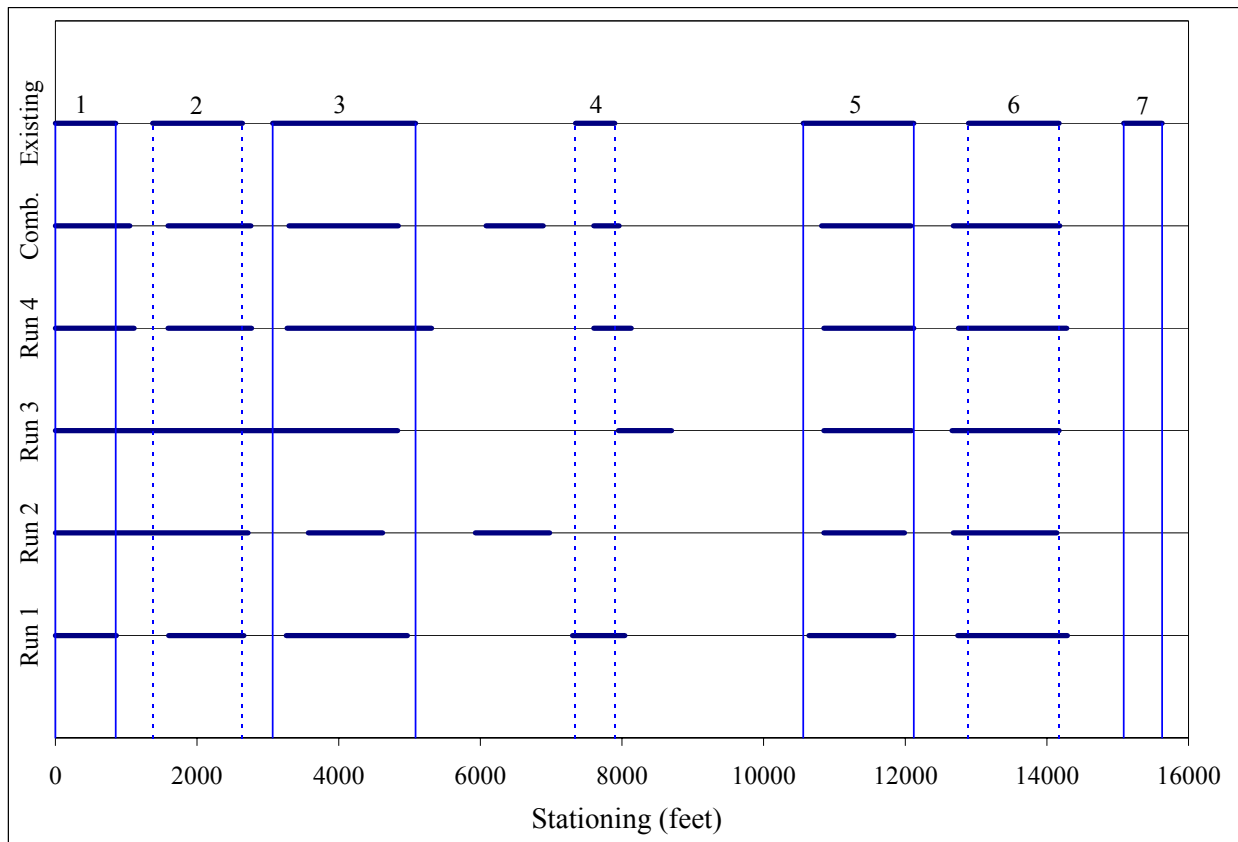
The other major differences that occur in FM 912 eastbound results are in runs 2 and 4 between the existing no-passing zones 1 and 2. When analyzing [Figures A-21](#) and [A-25](#), run 2 shows the beginning of what looks like a vertical crest curve and then an abrupt and noticeable jump downward in elevation between stations at about 56+50 and 57+50. The elevation change is about 7 feet, leading to about a 7 percent grade between the points, which is not unheard of but is very unlikely given the fact that plan sheets for FM 912 show that in this location the slope of the road does not exceed 2 percent. Whatever the case, the jump through the smoothing process causes a slight vertical curve to be modeled that is inconsistent with what the plan sheet profile dictates. Likewise, run 4 shows a jump in the vertical data between about station 55+00 and 57+50. Just like in run 2, a vertical crest curve results via the smoothing process and a no-passing zone is established, contrary to the existing markings and contrary to what the plan sheet profile indicates.

Lastly, it is important to look at run 3 results because they show a continuous no-passing zone between the third and fourth existing no-passing zones. As determined from the video data, the distance between existing no-passing zones 3 and 4 is 413 feet. The MUTCD provides guidance that if the distance between no-passing zones is less than 400 feet, no-passing zone markings should connect the two zones (3). This same philosophy was applied to the no-passing zone algorithm, which is the cause for the longer continuous no-passing zone in run 3. The distances between the two segments separating the two original segments as calculated by the no-passing zone algorithm was less than 400 feet so the algorithm combined the two segments to create the long continuous connecting segment.

### **FM 912 Westbound**

[Figure 2-7](#) shows the results from the westbound runs on FM 912. These results reiterate the importance of retrieving good GPS data. From observation, run 1 seems to conform the best of the four runs to existing conditions. This is despite what appear in [Figure A-29](#) to be some inaccurate data points around stations 22+00, 50+00, and 125+00. This speaks to the importance

of smoothing the data points. In run 2, the third no-passing zone is definitely out of place and the reason can be seen in [Figure A-31](#), where the vertical crest curve surrounding station 70+00 is much more prominent than what is seen in the other runs or even the plan sheet profile. This causes inaccurate placement of the no-passing zone. Alternatively, in the same run the vertical curves following station 80+00 are not as defined as in the other runs, resulting in existing no-passing zone 4 being left out.



**Figure 2-7. FM 912 Westbound No-Passing Zones.**

In run 3 a continuous no-passing zone extends from the beginning of the run through most of existing no-passing zone 3. The cause of this is clearly seen in [Figures A-33](#) and [A-34](#). A huge skew in the vertical curve at the location surrounds station 20+00. This is definitely in contrast to what is seen on the plan sheet profile of [Figure A-38](#). Also, as in run 2 the vertical curve just past station 80+00 is not as evident or as extreme as it should be and thus it is not caught by the no-passing zone algorithm. Additionally, at this same location, actually closer to stations 90+00 and 100+00, the data fluctuate, causing multiple sag and crest curves. These

curves result in the no-passing zone algorithm establishing a no-passing zone where it should not exist.

Run 4, as with run 1, does a good job of locating the no-passing zones as compared to the existing conditions, despite some GPS data variability as seen in [Figure A-35](#). Run 4 has some of the same problems arise in inaccurate data that the previous runs did; however, because the jumps between data points are not as great, the smoothing process enables the no-passing zone algorithm to approximately locate the existing no-passing zones. The last item to mention on FM 912 westbound is the fact that none of the runs identify the seventh existing no-passing zone. This no-passing zone occurs as FM 912 intersects into SH 105. So the seventh existing no-passing zone is a result of this intersection and the no-passing zone algorithm will not address this issue. It is something that must be identified in the field.

### **FM 1940 Southbound**

Before beginning the discussion of the results for FM 1940 it is important to note that the first four existing no-passing zones on FM 1940 exhibited vertical as well as horizontal curves. In all four instances the horizontal curves occurred near the end of the no-passing zones. It was difficult for the researchers to tell whether the existing no-passing zones were marked solely in response to the vertical curves or if they were a result of both horizontal and vertical curves.

The GPS raw data profiles for runs 1 and 2 in the southbound direction as seen in [Figures A-39](#) and [A-41](#) appear to be fairly smooth and similar in shape to the plan sheet profile in [Figure A-48](#). Other than overlaps or small gaps in the no-passing zones, only between existing no-passing zones 2 and 3 are there any unexpected irregularities. These irregularities in the no-passing zones occur between stations 80+10 and 81+30 on run 1 and stations 61+70 and 82+10 on run 2. Unlike many of the previous roadways, these locations do not seem to be plagued by bad GPS data on runs 1 and 2. So the researchers cannot account for these no-passing zones that the algorithm identified on runs 1 and 2 between no-passing zones 2 and 3.

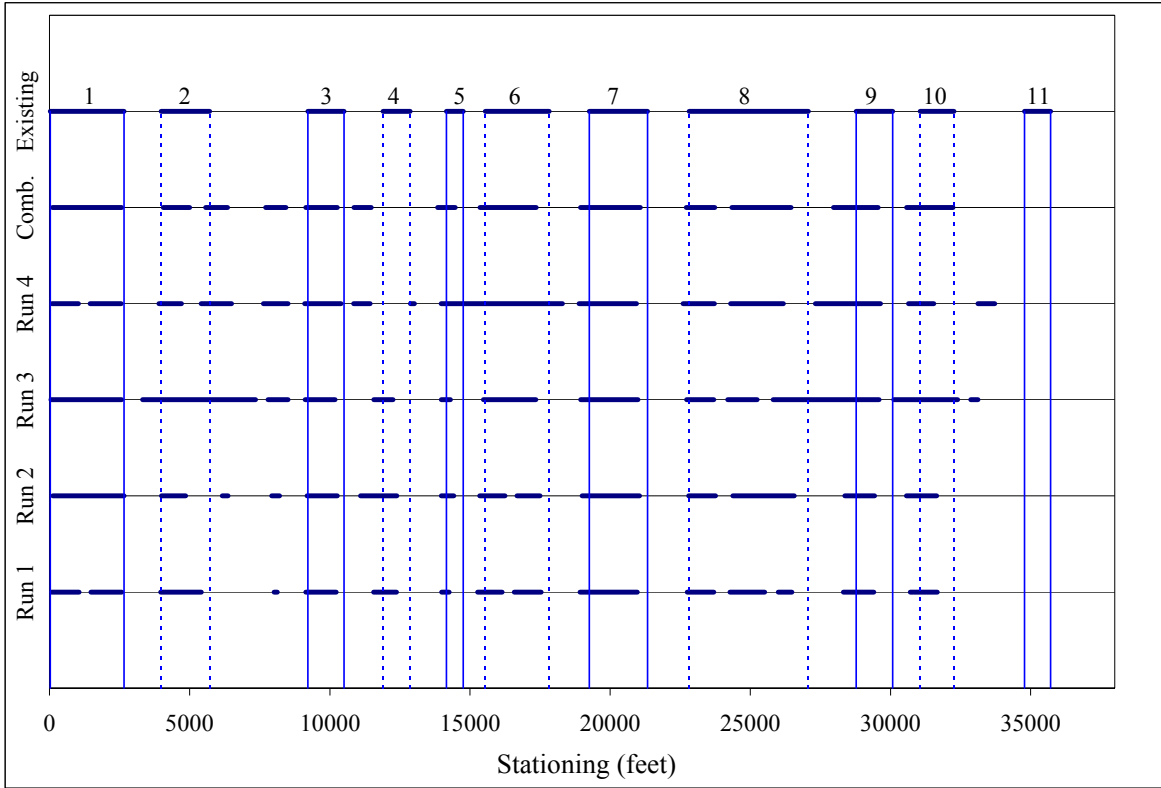
On the other side of the spectrum from runs 1 and 2, the GPS data for runs 3 and 4 are very inaccurate when compared to the plan sheet profile as seen in [Figures A-43](#) and [A-45](#). These inaccuracies are reflected in results of the no-passing zone algorithm. A few of the problems can be seen in [Figure 2-8](#) between existing no-passing zones 2 and 3. It all boils down to the fact that the GPS produced bad data on these runs, which resulted in inaccurate profiles and inaccurate no-passing zone placement.

The last item to mention on FM 1940 southbound is what appears to be the algorithm's inability to locate the existing no-passing zone 11. However, it is just a repeat case of what occurred on FM 912 in the eastbound direction. There is just not enough data at the end of the run to accurately dictate whether a no-passing zone exists. More GPS data are needed past the end of that eleventh no-passing zone. When the algorithm was run these GPS data were not present.

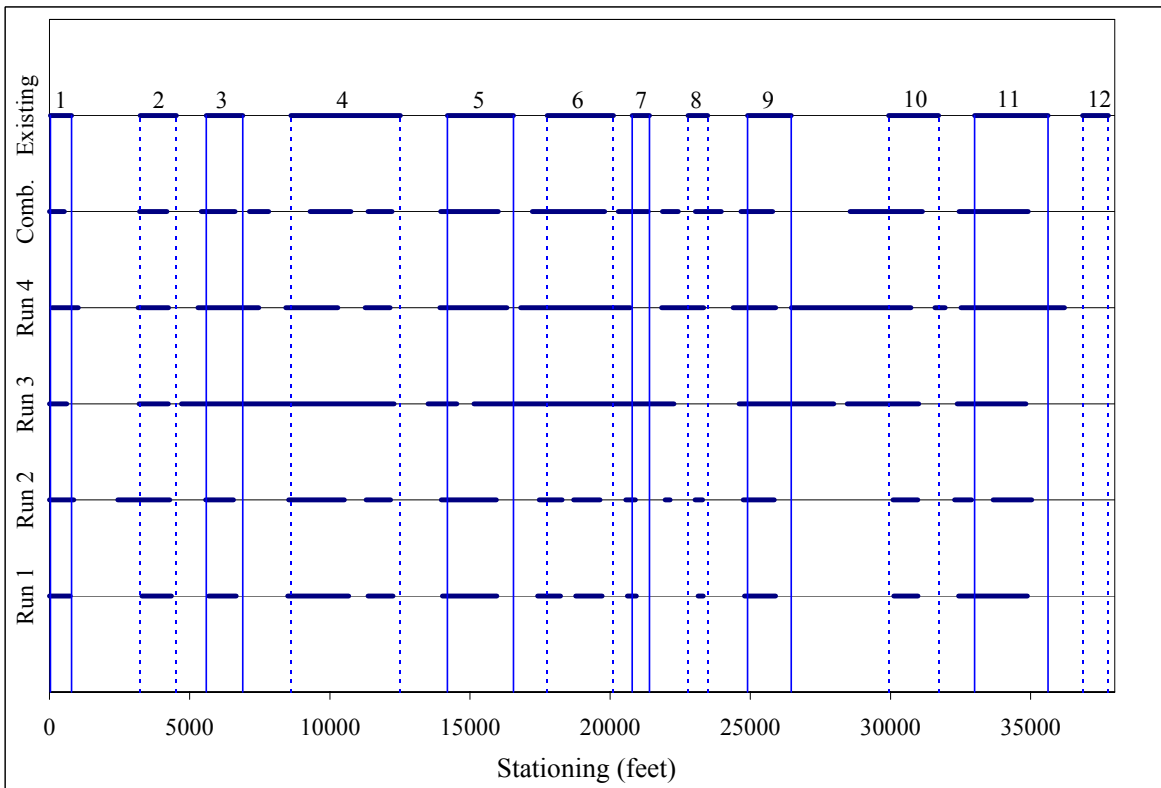
### **FM 1940 Northbound**

Like in the southbound direction of FM 1940, the northbound direction also had several no-passing zones in which vertical as well as horizontal curves occurred. These occurred in existing marked no-passing zones 8, 9, 10, 11, and 12. In no-passing zones 8, 9, 10, and 12 the horizontal curves occurred near the end of the existing no-passing zone, while the horizontal curve occurred near the middle of existing no-passing zone 11. Again, it is difficult to determine how many, if any, of the existing no-passing zones are a result of horizontal sight restrictions because the horizontal curves occur in conjunction with the vertical curves on the roadway.

In the northbound direction, the first two runs produced smooth GPS profiles, as seen in [Figures A-49](#) and [A-51](#). In contrast, the third and fourth runs in the northbound direction had very poor GPS profiles that were not smooth. The consequences can be seen in the no-passing zone algorithm results in [Figure 2-9](#). Runs 1 and 2 conform much better to the existing conditions than do runs 3 and 4. No further discussion is provided on FM 1940 northbound. Many of the same trends that held true for the previous cases hold true here.



**Figure 2-8. FM 1940 Southbound No-Passing Zones.**



**Figure 2-9. FM 1940 Northbound No-Passing Zones.**

## **DISCUSSION**

The results in the previous section showed the general proof of concept of an automated method for locating no-passing zones. In its current form the developed automated method is not ready for implementation. It has the potential to produce valid results, but it lacks consistency to produce usable and valid results on every run. The presentation of three different roads and the various runs of data collected on them was repetitive. However, the figures aided in showing how the developed processes performed on the different roadways, but more importantly the repetitive runs showed how the quality of the collected GPS data varied. The methods and equipment used to collect the GPS data did not provide the repeatability that is needed for the calculation of the no-passing zones. This problem is the key to the whole process. If the GPS data are more consistent and smoother, many of the problems that were experienced can be eliminated.

In addition to improving the quality of the GPS data, further work and analysis need to be completed on the no-passing algorithm itself. Run 1 of [Figure 2-4](#) in the southbound direction of FM 50 performed well when compared to the existing no-passing zone markings. But in that run the algorithm produced two separate no-passing zones within the sixth existing no-passing zone. This type of result was seen repeatedly throughout the runs. These problems may be due to the inconsistent GPS data, but two alternative options for improvement need to be considered as well. One is the smoothing process, which can possibly be modified to obtain better representations of the roadways. The second is the no-passing zone algorithm, which may need to be adjusted.

The no-passing zone algorithm, as described earlier, is an iterative process. Two separate and distinct intervals were described. These intervals can be adjusted to produce a more accurate model, or some sensitivity analysis can be completed in order to determine some length that is a safety factor and can be added on to the beginning and end of the determined no-passing zones. In doing so, the gaps between adjacent no-passing zones might decrease below the minimum 400 feet that is suggested as a guideline for separating no-passing zone segments.

## **FINDINGS AND RECOMMENDATIONS**

The research presented in this chapter shows a proof of concept for the use of GPS to locate no-passing zones, but it is not ready for implementation. The developed smoothing

process and no-passing zone algorithm need further refinement. Additionally and probably more essential to the success of this system is identification of what exactly causes the variability in the GPS data. The researchers need to explore further the various GPS solutions available that fit within the automated location of no-passing zone concept. In this research only one GPS system was tested; additional systems should be tested.

Furthermore, with further research the no-passing zone algorithm can be expanded to include sight restrictions due to horizontal curves. If these problems can be solved and the horizontal component of roadways included in the process, then a system capable of detecting no-passing zones using GPS will be a very useful tool for field crews to mark or check no-passing zones in a safe and efficient manner.

## REFERENCES

1. *2000 Uniform Vehicle Code: Millennium Edition*. The National Committee on Uniform Traffic Laws and Ordinances, Alexandria, Virginia, 2000.
2. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, Washington, D.C., 2004.
3. *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S. Department of Transportation, Washington, D.C., 2003.
4. Rose, E.R., H.G. Hawkins, A.J. Holick, and R.P. Bligh. *Evaluation of Traffic Control Devices: First Year Activities*. FHWA/TX-05-0-4701-1, Texas Transportation Institute, The Texas A&M University System, College Station, Texas, 2004.
5. El-Rabbany, A. *Introduction to GPS: The Global Positioning System*. Artech House, Boston, 2<sup>nd</sup> Edition, 2006.
6. Namala, S.R., and M. Rys. "Automated Calculation of Passing Sight Distance Using Global Positioning System Data." K-TRAN: KSU-03-02, Kansas State University, Manhattan, Kansas, and Kansas Department of Transportation, Topeka, Kansas, 2006.
7. Cleveland, W.S. "Visualizing Data." AT&T Bell Laboratories, Murray Hill, New Jersey, 1993.
8. Matlab Support Page: Spline Toolbox. The Mathworks, Inc., [www.mathworks.com/support/](http://www.mathworks.com/support/). Accessed September 26, 2007.



9. *Texas Centric Mapping System/Lambert Conformal*. Texas Administrative Code, Title 1: Administration, Part 10: Department of Information Resources, Chapter 201: Planning and Management of Information Resources Technologies, Rule 201.6: Geographic Information Standards.



## **CHAPTER 3: GUIDELINES FOR THE PEDESTRIAN COUNTDOWN TIMERS**

### **INTRODUCTION**

Pedestrian-related accidents are a cause of serious concern across the country. In 2005, there were a total of 4881 pedestrian fatalities involving motor vehicle crashes. Of those crashes, 1133 (23 percent) occurred at intersections (both signalized and unsignalized) (1). Seventy-two percent of all pedestrian fatalities occurred in urban areas where there are more intersections. These statistics indicate a need to improve pedestrian safety at intersections. A recent study jointly sponsored by the Transit Cooperative Research Program and the National Cooperative Highway Research Program (NCHRP) recommended engineering treatments to improve pedestrian safety at unsignalized intersections (2). Over the past few years, numerous agencies have implemented measures like pedestrian countdown timers (PCTs) to improve pedestrian safety at signalized intersections (3). However, there have not been any guidelines established for the implementation of PCTs at signalized intersections. This chapter identifies the issues involved in the installation and operation of PCTs, reviews the implementation of such devices across the country, and develops some guidelines about where they can be implemented for effectively improving pedestrian safety. The recommendations presented in this chapter are based on existing information and did not include a field evaluation of PCT effectiveness.

### **Definitions of Displays**

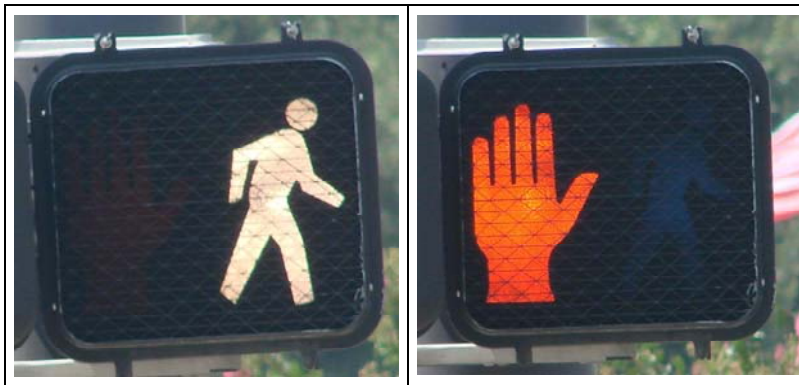
The *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) establishes the basic principles for the use of traffic control devices in Texas (4). The 2006 TMUTCD is based on the 2003 national MUTCD (5). The two MUTCDs are generally very similar, but there are some instances where additional information has been added to the TMUTCD. The meaning of pedestrian signal head indications is addressed in Section 4E.02 and the use of PCTs is addressed in Section 4E.07. The language in these sections is identical in both the Texas and national MUTCDs.

As indicated in Section 4E.02, two symbols are used to convey three messages to pedestrians: the walking pedestrian and the upright raised hand. These symbols are shown in [Figure 3-1](#). The walking pedestrian symbol is displayed only in a steady mode. The upright hand is displayed in two modes (flashing and steady) to convey two different messages. The

steady pedestrian display is referred to as the walk indication. The flashing hand is referred to as the pedestrian clearance interval, which is also called the “flashing don’t walk” (FDW). The steady hand is referred to as the “don’t walk” indication or “steady don’t walk” (SDW). The TMUTCD defines the walk interval, the pedestrian clearance interval (flashing don’t walk), and the steady don’t walk interval as follows (4).

### *Walk*

“A steady walking person symbol (symbolizing walk) indication means that a pedestrian facing the signal indication is permitted to start to cross the roadway in the direction of the signal indication, possibly in conflict with turning vehicles. The pedestrian shall yield the right-of-way to vehicles lawfully within the intersection at the time that the walking person indication is first shown.”



**Figure 3-1. Pedestrian Signal Indication Symbols.**

### *Flashing Don’t Walk*

“A flashing upraised hand (symbolizing don’t walk) means that a pedestrian shall not start to cross the roadway in the direction of the signal indication, but that any pedestrian who has already started to cross on a steady walking person (symbolizing walk) signal indication shall proceed out of the traveled way.”

### *Solid Don’t Walk*

“A steady upraised hand (symbolizing don’t walk) signal indication means that a pedestrian shall not enter the roadway in the direction of the signal indication.”

## **Understanding of the Displays**

Both vehicular and pedestrian signal displays communicate three basic messages – proceed, prepare to stop (clearance), and stop. However, where the vehicular traffic signal uses three colors to convey these messages, the pedestrian signal uses only two colors, of which one color/symbol indication is used to convey two messages. The difference between the two is that one message is associated with a flashing indication and the other with a steady indication. Research has consistently shown that pedestrians do not understand the three messages conveyed by pedestrian signals.

### *Pedestrian Understanding*

Numerous studies have indicated that pedestrians do not have a good understanding of the FDW indications (6, 7). Some pedestrians interpret that the FDW indication means they can enter the crosswalk as long as the SDW indication is not displayed (8). In addition, many elderly pedestrians return back to the sidewalk when they see the FDW indication (9). Such findings have prompted some traffic engineers to question the safety aspects of using FDW indications.

Numerous treatments to improve understanding of the FDW indications have been identified and tried at various locations. These include illuminated pushbuttons, animated eye displays, PCTs, and in-pavement lighting. This document evaluates the implementations of the PCTs across the country.

### *Measures of Effectiveness*

There are many indicators of pedestrian comprehension of pedestrian signal indications. Surveys have been conducted to evaluate signal indication comprehension. Many of these surveys have been followed by studies of pedestrian behavior to confirm the findings of the surveys. Studies have identified numerous pedestrian behavior indicators to evaluate pedestrian understanding of pedestrian signals. These indicators include the following:

- pedestrian running,
- pedestrian balking (aborting crossing),
- pedestrian beginning to walk during the steady walk,
- pedestrian beginning to cross during the flashing don't walk,
- pedestrian completing their crossing during the solid don't walk,

- average walking speed,
- pedestrian remaining in the crosswalk at the release of opposing vehicular traffic, and
- pedestrian-vehicle conflicts.

### **PEDESTRIAN COUNTDOWN TIMERS**

The intent of pedestrian countdown signals is to increase pedestrian understanding of the FDW interval by informing the pedestrians of the number of seconds remaining in the pedestrian change interval. The Texas MUTCD states that the PCT may be added to inform the pedestrian of the number of seconds remaining in the pedestrian clearance interval (4). The displays in a PCT are illustrated in Figure 3-2. The MUTCD also states that countdown displays shall not be used during the walk interval or during the yellow change interval of a concurrent vehicular phase.

A survey of the literature indicated that majority of the agencies count down the PCT from the onset of the pedestrian clearance. However, some engineers feel that PCTs may have a negative impact on motorists (10). Since drivers are able to see the countdown timers, some may be encouraged to speed through the intersection, thereby entering the intersection late in the yellow interval and/or after the onset of the red light, thus increasing red light violation rates at intersections equipped with countdown signals.



**Figure 3-2. Displays in a Pedestrian Countdown Timer.**

## **Functionality**

A PCT is a very simple device that monitors the time allocated to each element of the pedestrian phase (walk and FDW times) and emulates the operation subsequently, i.e., during the first cycle after the device is installed, the PCT monitors the pedestrian phase operation and records the duration of the walk and the FDW durations. During the first cycle, the PCT does not display the countdown timer. From the subsequent cycles, the countdown timer operates normally by counting down the walk and the FDW indications. TxDOT should configure the PCT to only monitor, emulate, and display the countdown indication only during the FDW interval to comply with the Texas MUTCD (4). If the signal operator modifies the pedestrian phase parameters, the PCT will monitor the new parameters the first time they are used and then the PCT starts displaying the countdown displays from the subsequent cycles.

## **Past Implementation Experience**

There are numerous implementations of PCTs across the United States. Many of these implementations have been evaluated and documented either in reports or in papers presented at the meetings of the Transportation Research Board or the Institute of Transportation Engineers. The following list summarizes the known documented evaluations of PCTs. As part of this effort, researchers reviewed the findings of these evaluations to document the effectiveness and implications of using PCTs and to make recommendations for the installation of PCTs by TxDOT districts.

- 14 intersections in Washington D.C., 2006 (3);
- 14 intersections in San Francisco, CA, 2006 (11);
- 5 intersections in Peoria, IL, 2006 (10);
- 11 intersections in Berkeley, CA, 2005 (12);
- 10 intersections in Las Vegas, NV, 2004 (13);
- 3 intersections in Boston, MA, 2004 (14);
- 5 intersections in Montgomery County, MD, 2002 (15);
- 4 intersections in San Jose, CA, 2002 (16);
- 2 intersections in Lake Buena Vista, FL, 2000 (17);
- 5 intersections in the Twin Cities metropolitan area, MN, 2000 (18);
- 2 intersections in Orlando, FL, 1998 (19); and

- 1 intersection in Hampton, VA, 1997 (20).

### **Significant Observations**

PCTs have been evaluated at various locations over the years. However, the findings of these evaluations show varied success. Furthermore, these evaluations identified numerous questions related to PCT implementation, which one document summarized as indicated below (16):

- Could the public incorrectly interpret the countdown display to mean that it is permitted to leave the curb as long as it is possible to complete the crossing before the countdown reaches zero?
- Would erratic behavior of pedestrians, such as running, hesitating, or turning around in the crosswalk increase?
- Would the incidence of motorists entering the intersection on yellow or red increase?

The success of a PCT implementation relies upon the “*pedestrian’s ability to judge the time necessary to cross the street*” (16). Hence, it is also essential to gain an understanding of the pedestrian’s ability to judge how long it would take to clear the crosswalk. These issues can be evaluated by observing the following parameters at intersections.

#### *Pedestrians Waiting for Solid Walk to Cross*

This parameter measures the number of pedestrians that have arrived at the intersection during the FDW or the SDW indications and have waited until the solid walk indication appears to enter the crosswalk. This measure gives an idea of the pedestrian’s understanding of each of the pedestrian signal indications.

One of the most recent evaluations in Washington, D.C., found that the number of pedestrians starting to cross during FDW decreased marginally, though statistically insignificantly (3). However, many other studies have observed an increase in the number of pedestrians entering the crosswalk during the FDW indications (8, 11, 16). In these studies, however, the number of pedestrians still in the crosswalk appears to decrease, indicating that the pedestrians are adapting their behavior by increasing their walking speed in response to the countdown timer display. Hence, it can be concluded from the studies that the countdown signal



may cause people to enter the intersection during FDW when the countdown signal still displays a high number that pedestrians believe is adequate to cross the intersection.

#### *Pedestrians Entering and Exiting during Walk, FDW, and SDW Displays*

The San Jose study that evaluated pedestrians entering and exiting the crosswalk indicated that while the number of pedestrians entering the crosswalk during the FDW indication increased slightly, the number of pedestrians entering during the SDW decreased slightly (16). These changes, while statistically not significant, were consistent at most locations. Similarly, the study also found that the number of pedestrians exiting the crosswalk during the FDW increased slightly and the number of pedestrians exiting during the SDW decreased slightly.

These observations illustrate that pedestrians are probably using the remaining time before the onset of the SDW to begin a crossing maneuver after the start of the FDW indication. The pedestrians are likely increasing their walking speed and exiting before the onset of the SDW indication. This conclusion indicates that the pedestrians are violating the law by entering the crosswalk after the onset of FDW. However, they are exiting the crosswalk before the onset of the SDW and are potentially in a safer situation compared to having no PCTs. Hence, the violation of the law by pedestrians is balanced by a more critical objective of getting the pedestrians off the street before the onset of a conflicting vehicular phase.

#### *Unusual Pedestrian Behavior*

Various studies indicated that pedestrian understanding of the traditional FDW indication is not well understood. Pedestrians do not know how much time is left in the FDW interval before the onset of the SDW. Hence, at the onset of FDW, some pedestrians turn back and return to the curb or run to the end of the crosswalk. These can be described as unusual pedestrian behaviors. Some pedestrians may step off the curb after the onset of FDW, possibly resulting in pedestrians still in the crosswalk at the onset of a conflicting vehicular phase. This can cause the pedestrians and the vehicles to abruptly stop or proceed around each other. This behavior can also be termed unusual behavior. The objective of the PCT is to reduce the number of unusual pedestrian behaviors. However studies in San Jose (16), Berkeley (12), and Washington, D.C. (3), have not indicated any statistically significant reduction in unusual pedestrian behavior. A study in Lake Buena Vista, Florida, however, observed that while the number of pedestrians in the crosswalks at the onset of SDW increased slightly when a PCT was

used, the number of pedestrians running in the crosswalk decreased, illustrating the mixed benefits of PCT (17).

### *Pedestrian Walking Speeds*

As mentioned earlier, pedestrians do not know the time remaining in the pedestrian clearance interval at an intersection with traditional pedestrian signals. However when PCTs are used, pedestrians know how much time is remaining and hence can walk faster if necessary. Therefore, the expectation was that the walking speeds would increase at locations with PCTs. However, in a majority of studies no statistically significant changes in walking speeds were observed (3, 12, 16, 17).

### *Pedestrian Surveys*

Many studies evaluating PCT implementation also conducted pedestrian surveys. The objective of the surveys was to correlate the pedestrian responses in the survey with pedestrian behavior at the pedestrian crossing. Specifically, the surveys targeted the following issues:

- understanding of the pedestrian signal displays,
- perception about the safety of using PCT signals,
- impact of PCT on pedestrian decision-making process, and
- perception of the time required to cross the street.

The surveys in Washington, D.C. (3), San Francisco (11), and San Jose (16) generally indicate the following findings:

- Pedestrians understand that the time remaining shown in PCTs indicates the time remaining before the onset of SDW indication.
- Pedestrians strongly perceive the PCT to be a safer display for pedestrian clearance interval.
- More pedestrians think that it is permissible to enter the crosswalk after the start of FDW because they know the time available to cross.
- Pedestrians do not have a very good sense of the time necessary to cross the intersection and may be unable to distinguish between the time required for wider streets and that required for narrower streets.

- In a PCT, pedestrians are provided more information about crossing the intersection and use this information to decide whether to start crossing the intersection. This can result in pedestrians perceiving that they have adequate time to cross the intersection in the available time and they step onto the crosswalk during the pedestrian clearance interval. This is a violation of the law and the PCT appears to encourage such behavior.

### *Motorists' Behavior*

Many studies investigated the impact of PCT on motorists' behavior. An undesirable effect of the PCT can be motorists observing the countdown timer and speeding up and potentially entering the intersection after the onset of red. No such behavior was observed in any study. Some of the studies also looked at crash rates and found that either there was no increase in crash rates or there were insufficient data to reach a conclusion.

## **FUTURE IMPLEMENTATION**

Based on the analysis of implementations of PCT across the country, lessons can be learned about the expectations of such implementations in the future. While most of these studies have looked at implementations of PCTs at signalized intersections, some studies have included sites at mid-block pedestrian crossings (16). Some studies have also investigated the impact of age and gender on PCT compliance and did not find any statistically significant differences between the various age groups (15, 21). Hence, future evaluations need to consider the positive and potentially negative implications of PCT installations to ensure appropriate expectations. Such an understanding will also influence identifying the locations where the installation of PCTs can improve pedestrian safety. Discussion of the following issues can assist in making engineering and policy decisions about implementing PCTs.

### **Pedestrian Signal Understanding**

One of the challenges associated with traditional pedestrian signals is the fact that pedestrians are sometimes confused by the use of two symbols to convey three messages. As mentioned, pedestrians do not always recognize the difference between the flashing and steady upraised hand symbol. The countdown timer has the potential to improve pedestrian understanding.

### *Traditional Display*

It is well known that a majority of pedestrians do not understand the traditional FDW display in pedestrian signals. This lack of understanding can result in unusual pedestrian behavior, which may be sometimes unsafe for pedestrians. The underlying problems are:

- Many pedestrians do not know that they should not step off the curb after the onset of FDW.
- If pedestrians are in the crosswalk when FDW starts, they do not know if they have adequate time to cross the street before the conflicting traffic movement starts.

### *Pedestrian Countdown Display*

Preliminary surveys of pedestrians have indicated that they feel PCTs are safer than traditional FDW displays. However, a deeper analysis illustrates the following:

- Pedestrians tend to ignore the FDW symbol and only concentrate on the countdown timer. This has reduced the understanding of the FDW display.
- Pedestrians know how much time they have to cross, and thus an underlying assumption is that they make better decisions to cross the street.
- However, pedestrians do not have a very good sense of the time necessary to cross the intersection and may be unable to distinguish between the crossing time required for wider streets and that required for narrower streets.

### *Summary of Findings*

Based on the findings of the activities, the researchers concluded the following:

- While pedestrians perceive the PCT to be safer, their understanding of the display has declined.
- Pedestrians are using the countdown timer and are disregarding the FDW symbol.
- More pedestrians are using the pedestrian clearance interval to step off the curb.
- However, pedestrians are unable to judge the time required to get across the street.

### **Pedestrian Signal Compliance**

Beyond comprehension, pedestrian compliance with pedestrian traffic signals is also an issue of importance for the following reasons.

- A significant number of pedestrians do not understand the traditional FDW display.

- Many pedestrians do not comply with the pedestrian signal; they start walking after the onset of the FDW.
- A majority of pedestrians perceive PCT to be a safer pedestrian signal.
- However, more pedestrians are not complying with the PCT signal than with the traditional FDW signal. Pedestrians are judging that time remaining in the PCT is adequate to cross the street and decide to start crossing the street.
- This raises the issue of implementing a traffic control device that, while a majority of users perceive it to be a safer device, has nonetheless illustrated a decrease in the compliance of the same device.

### **Impact on Pedestrian Safety**

Earlier topics illustrated pedestrian understanding and compliance with the PCT compared to traditional FDW indications in a pedestrian signal. Studies have indicated that while understanding of the pedestrian clearance interval and compliance has deteriorated for the PCT, a majority of pedestrians perceive the PCT to be safer than traditional pedestrian signals. When pedestrian behavior is observed, it was also noticed in many of the studies that fewer pedestrians are in the crosswalk at the onset of SDW when compared to traditional pedestrian signals. This is an indication of improved safety. This was the case when pedestrians enter the crosswalk in the early portion ( $\leq 5$  seconds) of the FDW indications. Pedestrians entering the crosswalk in the later portion ( $> 5$  seconds) after the onset of FDW appear to still be in the crosswalk at the onset of SDW. However, in many of the cases, the onset of SDW coincided with the onset of the yellow for the associated vehicle phase. Hence, even in many of these cases pedestrians had time to get off the crosswalk before the start of the conflicting vehicle phase. Therefore, it appears that there is an improvement in pedestrian safety due to the use of PCTs.

This improvement in pedestrian safety is illustrated by fewer pedestrians at the onset of SDW and the onset of a conflicting vehicular phase. This observation can be attributed to pedestrians using the additional information about time available and increasing their walking speed. Studies that specifically recorded pedestrian speeds did not find any increase that was statistically significant. However, there appears to be no other explanation for the improvement in pedestrian safety in spite of more pedestrians stepping off the curb after the onset of FDW.

Some studies also looked at pedestrian characteristics (age and gender) and found some general trends.

- More male pedestrians tend to not comply with pedestrian signals than female pedestrians. This trend is reflected in a larger proportion of males involved in accidents.
- Older pedestrians tend to be more conservative than younger pedestrians. Older pedestrians and children also consistently exhibit slower pedestrian speeds.

These trends can have an impact on decisions about where PCTs can be deployed. A Pedestrian and Bicycle Safety Toolbox used by the Metropolitan Transportation Commission provides some recommendations about the use of PCTs (22). According to the toolbox, PCTs can benefit pedestrians with mobility limitations. However, as stated earlier, pedestrians' comprehension of the FDW indication worsens after installation of the PCT, resulting in more pedestrians starting to cross after the onset of FDW, and the pedestrian's judgment of the time required to cross the street is poor. Hence, the installation of a PCT at locations having a high proportion of elderly and handicapped pedestrians should be done with a lot of care.

### Cost

The PCT can be implemented by changing the lens of the pedestrian signal. Most of the existing conventional pedestrian signals can be retrofitted with no additional wiring. A typical pedestrian lens is illustrated in Figure 3-3. The cost of retrofitting an existing pedestrian signal with a new PCT lens ranges from \$300 to \$800 (22). Enquiries in Texas have found that a new lens can be purchased for approximately \$250. Since the remaining infrastructure does not change for a PCT when compared to a traditional pedestrian signal, the cost of implementing PCT at a new traffic signal does not have significant financial impact.



**Figure 3-3. Pedestrian Countdown Lens.**

### Controller Operations

The type of signal controller operations has an impact on pedestrian signal operations. At intersections operating in a fully actuated mode, pedestrian signals are also usually fully actuated, i.e., they only display WALK when a pedestrian presses the pedestrian button. Frequently during such operations, the WALK indication is displayed for the programmed

duration, followed by the FDW indication, which is followed by the SDW indication. However, if the vehicular phase has more demand or if there is no demand on the minor movements, the onset of SDW occurs before the onset of yellow in the traffic signal, as illustrated in [Figure 3-4](#). Such an operation is not desirable, as it may give the impression to the pedestrian that it is safe to cross the intersection. However, the vehicle phase can terminate at any time, causing the pedestrian to be in an unsafe situation.

An ideal pedestrian signal operation is one in which the onset of the SDW and the yellow indication in the traffic signal happen at the same time, as illustrated in [Figure 3-5](#). Such an operation will not give any displays that will cause confusion in the pedestrian about opportunities to cross the intersection.



**Figure 3-4. Illustrating the Onset of SDW before the Onset of Yellow.**



**Figure 3-5. Illustrating the Onset of SDW at the Onset of Yellow.**

Pedestrian signal indications illustrated in [Figure 3-5](#) can be achieved by selecting the appropriate feature in the controller based on the mode of signal operation. For intersections operating in a fully actuated mode, a controller feature called Rest-in-Walk (RIW) enables the simultaneous onset of SDW and the yellow indication in the traffic signal. This is achieved by the traffic signal controller causing the pedestrian signal to dwell in WALK indication until the

controller receives a request to service a conflicting vehicular or pedestrian movement. The FDW display starts after detecting a conflicting call and results in the onset of SDW at the onset of yellow. This is possible for all phases operating in a fully actuated manner. If the RIW feature is used, it will result in a delay to the conflicting call, as the WALK indication will have to change to a FDW, followed by the vehicle clearance interval, before the green indication can be displayed to the traffic making the conflicting call. Users should consider the impacts of the additional delay before electing to utilize the RIW feature.

Traffic signal controllers operating in a coordinated manner, however, have some coordination modes or features which can be selected to achieve the desired pedestrian signal operation. Selection of coordination modes differs based on the controller equipment used. The objective is to use the coordination mode in which the controller dwells in the WALK indication for the coordination phases. Recommendations about the selection of the appropriate coordination modes are documented in TxDOT Project Report 0-4657-1 (23).

## **RECOMMENDATIONS**

Based on the review of the implementation of PCTs across the country, the following recommendations can be made about implementing pedestrian countdown timers by TxDOT districts.

### **Where to Implement**

Pedestrians perceive PCT to be a safer pedestrian signal than traditional pedestrian signals. Fewer pedestrians are present in the crosswalk at the onset of SDW when PCTs are used. This is an indication of improvement in pedestrian safety. However, implementation of PCT at intersections having a high proportion of elderly has shown mixed results. While the review of past studies has not resulted in any numerical criteria, the following recommendations should be considered with respect to the use of PCTs at new signal installations.

- Use PCTs except at intersections where elderly pedestrians are high in number.
- Observe the safety record of PCTs and their impact on any elderly pedestrians.
- Implement PCTs at intersections with high proportion of elderly pedestrians if no safety concerns are observed.
- Select intersections according to the following priority list to retrofit existing pedestrian signals with PCTs.



1. intersections with known history of safety problems,
2. intersections with high proportion of unfamiliar pedestrians (convention centers),
3. intersections with high pedestrian volumes, and
4. intersections with wide pedestrian crosswalks.

### **How to Implement**

PCTs shall be installed as follows to be consistent with the Texas MUTCD (4).

- The countdown timer shall display only during the pedestrian clearance interval and not during the WALK interval.
- The countdown timer shall not display during the associated vehicle clearance interval (yellow indication).
- The onset of the SDW indications should coincide with the onset of yellow indication in the associated traffic signal.
- To improve pedestrian understanding of the PCT operation, the R10-3e sign, as shown in [Figure 3-6](#), shall be installed beside the pedestrian push button. Design details for this sign are presented in the 2007 *Standard Highway Sign Designs for Texas* (24).
- Before implementation of PCTs, a strong public education campaign should be conducted to reiterate the meanings of individual displays to encourage compliance with the pedestrian signals.

A further explanation of these implementation guidelines can be obtained from [Figure 3-7](#), which illustrates the timelines of PCT with respect to traffic signal indications for the various scenarios. As mentioned earlier, PCT can be configured to ensure that the countdown display is only displayed during the pedestrian clearance interval. Similarly, signal controller features can be selected to ensure that the countdown is not displayed during the vehicle clearance interval.

The desired PCT operation of simultaneous onset of the SDW and the yellow indication depends on the mode of intersection operations. The following operational strategy should be considered for intersections operating in fully actuated mode.

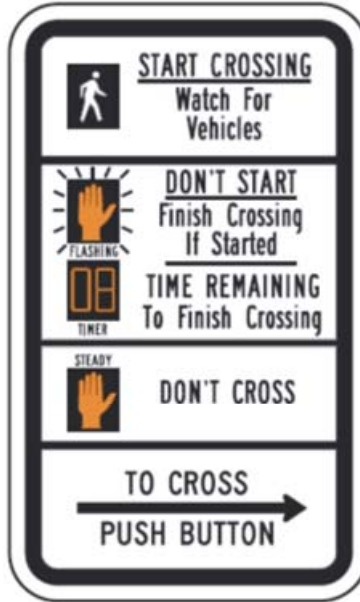


Figure 3-6. Countdown Pedestrian Traffic Signal Sign.

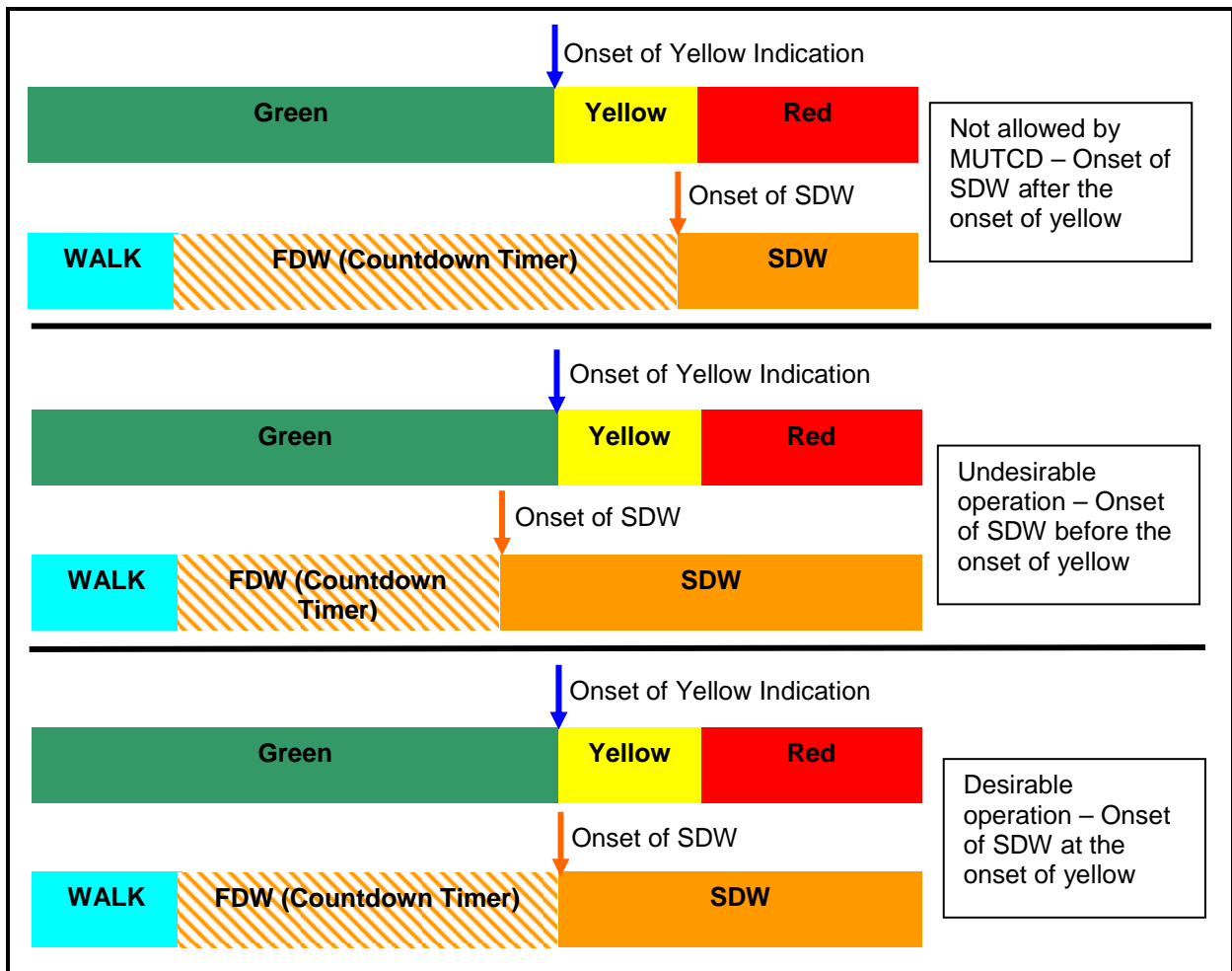


Figure 3-7. Timelines of PCTs with Traffic Signal Indication.

- Operate pedestrian phases in a fully actuated mode and do not have any pedestrian phases in recall.
- Use Rest-In-Walk feature for actuated traffic movements if delay to side street traffic placing a call will be acceptable.

The following operational strategy should be considered for intersections operating in actuated-coordinated mode.

- Use the coordination mode or feature appropriate for controller manufacturer (23) for the coordinated phases.
- Actuated phases should use Rest-In-Walk feature if delay to side street traffic placing a call will be acceptable.

## **PROPOSED CHANGES TO NATIONAL MUTCD**

On January 2, 2008, the FHWA published a Notice of Proposed Amendments (NPA) for the national MUTCD (25). This rulemaking effort includes over 500 significant proposed changes to the 2003 national MUTCD. Among those changes are several in Section 4E.08 that relate to PCTs. The proposed changes will result in the changes listed below with regard to the use of PCTs, if the proposed language remains the same in the final rule and is then retained in the Texas MUTCD which is based on the final rule. The FHWA expects the final rule on the NPA to be issued in late 2009.

- Pedestrian change interval countdown displays (the new term used in the NPA) shall be required for all new pedestrian signal heads unless the crosswalk is so short that the pedestrian change interval is 3 seconds or less.
- A pedestrian change interval countdown display shall be added to all existing pedestrian signal heads within 10 years unless the crosswalk is so short that the pedestrian change interval is 3 seconds or less.
- The display of the number of seconds shall begin with the beginning of the FDW (flashing upraised hand indication) (proposed text edited for clarity).
- The countdown display shall end (0 display) at the end of the FDW (flashing upraised hand indication) (proposed text edited for clarity).
- Countdown displays shall not be used during the walk interval or during the yellow change interval for concurrent vehicular phase (proposed text edited for clarity).

- If the concurrent vehicle green indication continues to be displayed after the display of the FDW has terminated, the countdown pedestrian signal shall be dark during the additional green time.

These changes, if adopted into a future Texas MUTCD by TxDOT, will require TxDOT to implement PCT on a widespread basis in the future. However, it is not known at this time whether the proposed MUTCD text will be adopted in the final rule. The FHWA will review and consider all docket comments and before determining whether to make a change in the proposed language.

## REFERENCES

1. *Fatality Facts 2005 – Pedestrians*. Insurance Institute for Highway Safety. [http://www.iihs.org/research/fatality\\_facts/pedestrians.html](http://www.iihs.org/research/fatality_facts/pedestrians.html). Accessed May 16, 2007.
2. Fitzpatrick, K. et al. *Improving Pedestrian Safety at Unsignalized Crossings*. National Cooperative Highway Research Program Report 562, Transportation Research Board, Washington, D.C., 2006.
3. *Evaluation of Countdown Pedestrian Signals in the District of Columbia*. Final Report, District Department of Transportation, Washington D.C., August 2006.
4. *Texas Manual on Uniform Traffic Control Devices*. Texas Department of Transportation, Austin, Texas, 2006. [www.dot.state.tx.us/publications/traffic/2006part4.pdf](http://www.dot.state.tx.us/publications/traffic/2006part4.pdf). Accessed May 16, 2007.
5. *Manual on Uniform Traffic Control Devices*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2006. [mutcd.fhwa.dot.gov/HTM/2003r1/part4/part4e.htm](http://mutcd.fhwa.dot.gov/HTM/2003r1/part4/part4e.htm). Accessed May 16, 2007.
6. Zegeer, C.V., K.S. Opiela, and M.J. Cynecki. *Pedestrian Signalization Alternatives*. Report FHWA-RD-83-102, Federal Highway Administration, Washington, D.C., July 1985.
7. Robertson, H.D., and E.C. Carter. The Safety, Operational and Cost Impacts of Pedestrian Indications at Signalized Intersections. *Transportation Research Record 959*, Transportation Research Board, Washington, D.C., 1984.

8. Huang, H., and C. Zegeer. *An Evaluation of Pedestrian Countdown Signals*. A Report Prepared by The University of North Carolina at Chapel Hill Highway Safety Research Center for the Federal Highway Administration, February 1999.
9. Leonard, J., M. Juckes, and B. Clement. *Safety & Behavior: Behavioral Evaluation of Pedestrians and Motorists Towards Pedestrian Countdown Signals*. Prepared by Dessau-Soprin Inc. for the City of Monterrey, California, March 1999.
10. Schattler, K.L., and T.K. Datta. "Assessment of Pedestrian and Driver Behavior at Signalized Intersections with Countdown Pedestrian Signals." *Institute of Transportation Engineers 2006 Spring Conference Compendium of Technical Papers CD-ROM*, San Antonio, Texas, March 2006.
11. Markowitz, F., S. Sciortino, J.L. Fleck, and B.M. Yee. Pedestrian Countdown Signals: Experience with an Extensive Pilot Installation. *ITE Journal*, Institute of Transportation Engineers, Washington, D.C., January 2006.
12. PHA Transportation Consultants. *Pedestrian Countdown Signal Evaluation*. City of Berkeley, California, July 2005.
13. Pulugurtha, S.S., and S.S. Nambisan. *Effectiveness of Pedestrian Countdown Timers to Enhance Safety in Las Vegas*. Institute of Transportation Engineers District Annual Meeting, Orlando, Florida, August 2004.
14. Petraglia, K. An Evaluation of Countdown Pedestrian Signals. *New England Chronicle*, May 2004.
15. Singer, J.P., and N.D. Lerner. *Countdown Pedestrian Signals: A Comparison of Alternative Pedestrian Change Interval Displays*. WESTAT, Rockville, Maryland, 2005.
16. Botha, J.L., A.A. Zabyshny, J.E. Day, R.L. Northouse, J.O. Rodriguez, and T.L. Nix. *Pedestrian Countdown Signals: An Experimental Evaluation – Volume 1*. City of San Jose Department of Transportation, San Jose, California, May 2002.  
[www.sanjoseca.gov/transportation/forms/report\\_pedcountdown.pdf](http://www.sanjoseca.gov/transportation/forms/report_pedcountdown.pdf). Accessed August 16, 2007.
17. Huang, H., and C. Zegeer. *The Effects of Pedestrian Countdown Signals in Lake Buena Vista*. [www.dot.state.fl.us/Safety/ped\\_bike/handbooks\\_and\\_research/research/CNT-REPT.pdf](http://www.dot.state.fl.us/Safety/ped_bike/handbooks_and_research/research/CNT-REPT.pdf). Accessed August 14, 2007.

18. Farraher, B.A.B. Pedestrian Countdown Indication – Market Research and Evaluation. *Annual Meeting Compendium of Technical Papers*, Institute of Transportation Engineers, Washington, D.C., 2000.  
[www.dot.state.mn.us/metro/trafficeng/signals/files/compendium.pdf](http://www.dot.state.mn.us/metro/trafficeng/signals/files/compendium.pdf). Accessed May 16, 2007.
19. Chester, D.C., and M. Hammond. Evaluation of Pedestrian Understanding of Pedestrian Countdown Signals. *Annual Meeting Compendium of Technical Papers*, Institute of Transportation Engineers, Washington, D.C., 1998.
20. Allsbrook, L. *Pedestrian Signal Countdown Device*. Traffic Engineering and Operations, Department of Public Works, City of Hampton, Virginia, 1997.
21. Mahach, K., A.J. Nedzesky, L. Atwater, and R. Saunders. A Comparison of Pedestrian Signal Heads. *Annual Meeting Compendium of Technical Papers*, Institute of Transportation Engineers, Washington, D.C., 2002.
22. Metropolitan Transportation Commission, Pedestrian & Bicyclist Safety Toolbox – Countdown Signals, Oakland, California.  
[www.mtc.ca.gov/planning/bicyclespedestrians/tools/countdownSignal/index.htm](http://www.mtc.ca.gov/planning/bicyclespedestrians/tools/countdownSignal/index.htm). Accessed July 7, 2007.
23. Sunkari, S.R., R.J. Engelbrecht, and K.N. Balke. *Evaluation of Advance Coordination Features in Traffic Signal Controllers*. Research Report 0-4657-1, Texas Transportation Institute, College Station, Texas, September 2004.
24. *2007 Standard Highway Sign Designs for Texas Book*. Texas Department of Transportation, Austin, Texas, 2007. [www.dot.state.tx.us/publications/traffic.htm](http://www.dot.state.tx.us/publications/traffic.htm). Accessed January 28, 2008.
25. National Standards for Traffic Control Devices; the Manual on Uniform Traffic Control Devices for Streets and Highways; Revision; Proposed Rule. Docket No. FHWA-2007-28977, *Federal Register*, Volume 73, Number 1, pages 267-334, January 2, 2008.

## **CHAPTER 4: EVALUATION OF LEAD-FREE THERMOPLASTIC PAVEMENT MARKING MATERIAL**

The TxDOT departmental material standard (DMS) for thermoplastic pavement marking material is DMS-8220, Hot Applied Thermoplastic. This specification indicates that the pigment should be “*a heat-resistant, double-encapsulated medium chrome yellow or other approved heat-resistant pigment*” that is 5-10 percent by weight of the total material (1). The chrome yellow pigment contains lead, but the lead is considered safe because it is encapsulated. Even so, Texas is in the minority of state transportation agencies that use a leaded pigment in the marking material specification. There are numerous reasons supporting the use of leaded pigments in yellow markings; the most significant is the concern that organic pigments do not provide sufficient yellow color to be perceived by drivers as yellow in all conditions. The concern over the color performance of yellow pavement markings has led to a research project sponsored by the National Cooperative Highway Research Program (NCHRP). NCHRP Project 5-18, Color Effectiveness of Yellow Pavement Marking Materials, is evaluating many different aspects of yellow markings, including human factors’ evaluations of driver recognition of various yellow pavement markings, field evaluations of yellow pavement marking materials, and developing recommendations for yellow pavement marking color coordinates (2).

In the summer of 2007, TxDOT began experimenting with the use of lead-free thermoplastic pavement markings. In July 2007, TxDOT requested that Texas Transportation Institute (TTI) researchers assist in the evaluation of field applications of lead-free thermoplastic markings. Accordingly, TTI researchers observed the installation of lead-free markings at the two sites listed below.

1. US 79 in Franklin, Texas, new surface treatment (seal coat) surface, and
2. SH 21 just east of the Brazos River, new surface treatment (seal coat) surface.

The US 79 site included both lead-free and standard yellow thermoplastic materials that were installed on consecutive days in a two-way left-turn lane in the city. The SH 21 site consisted only of lead-free thermoplastic installed as the left edge line on a divided highway, transitioning to a double solid centerline on an undivided highway. For both sites, the initial evaluations were conducted as the first element of an evaluation which will continue into the fifth year of the project. At each site, researchers measured retroreflectivity and color. The

initial measurements were made at the time of installation, with future measurements planned at approximately 3 months, 6 months, and 12 months.

## MEASUREMENTS

Researchers measured three attributes of the yellow markings at each site. These attributes and the instruments used to measure the attributes are 30 meter retroreflectivity, 30 meter nighttime color, and 45°/0° daytime and nighttime color. [Table 4-1](#) summarizes key elements of these measurements.

**Table 4-1. Lead-Free Yellow Marking Measurements.**

Attribute	Measurement Geometry	Instrument	Description
Retro-reflectivity	30 meter	LTL 200Y	A measure of the amount of light retroreflected to the driver from the pavement marking.
Nighttime Color	30 meter	LTL 200Y	A measure of the nighttime color of the pavement marking as viewed by the driver.
	45°/0°	BYK Gardner Color Guide	A measure of color using Illuminant A and the standard color measurement geometry. The measurement was made on a section of markings where there were no beads.
Daytime Color	45°/0°	BYK Gardner Color Guide	A measure of color using Illuminant D65 and the standard color measurement geometry. The measurement was made on a section of markings where there were no beads.

The measurements were then compared to minimum retroreflectivity levels and color boxes where appropriate. The minimum retroreflectivity level of 175 mcd/m<sup>2</sup>/lx for yellow markings is contained in Special Specification 6110, Reflectorized Pavement Markings with Retroreflective Requirements (3). Several different color boxes exist for pavement markings. The TxDOT color box for yellow markings is contained in DMS-8220, Hot Applied Thermoplastic (1), and is based on a D65 illuminant and standard observer of 10°. This is the color box that would apply to the sample measured with the BYK Gardner Color Guide. The appropriate yellow color box for the 30 meter color measurements is contained in the July 31, 2002, Final Rule by the FHWA, which established daytime (45°/0°) and nighttime (30 meter)



color boxes for traffic materials (4). [Table B-1](#) provides the specific x and y values for these color boxes.

## RESULTS

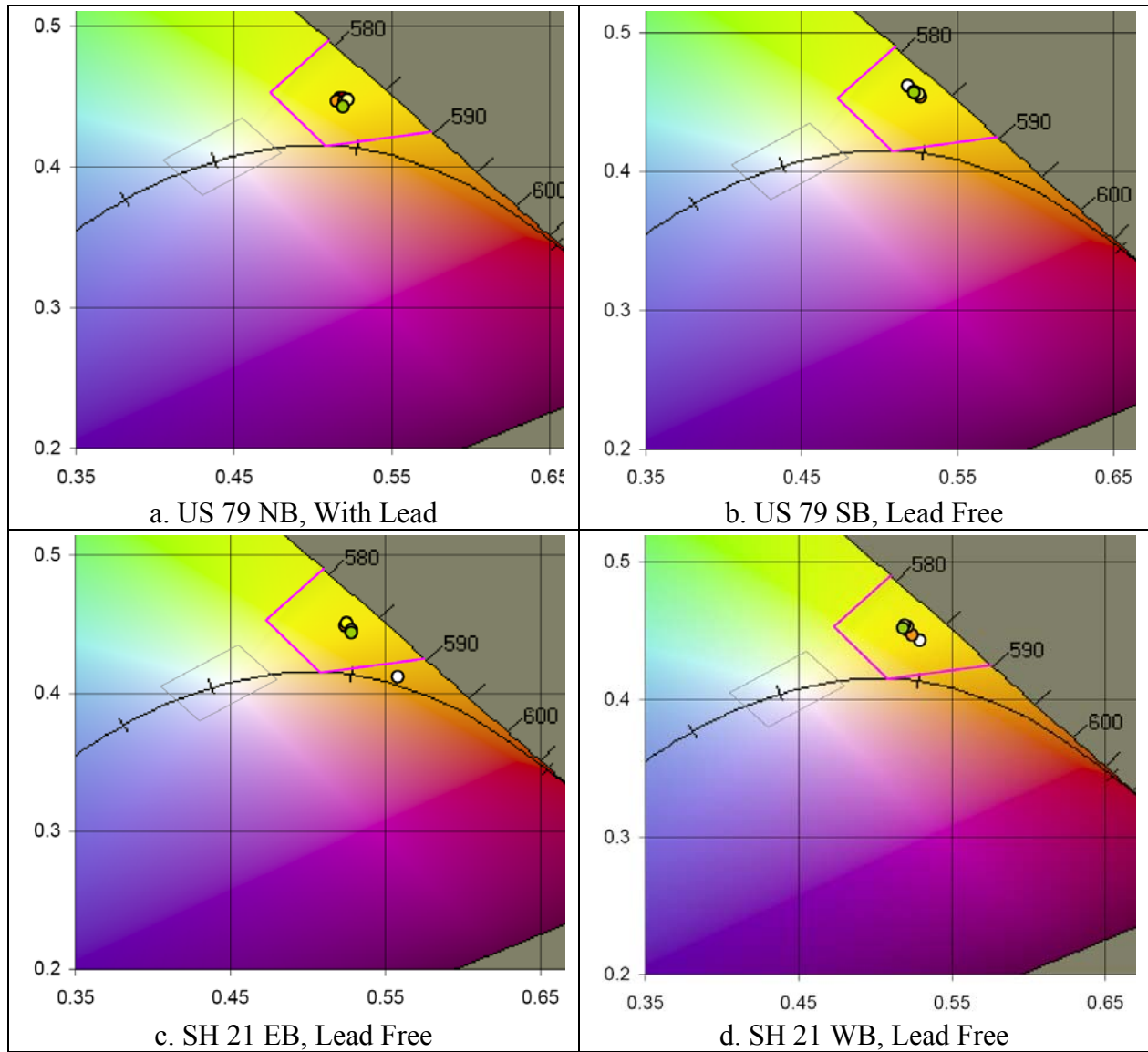
The actual retroreflectivity and color measurements are given in [Appendix B](#). The significance of these initial findings is summarized below.

### Retroreflectivity

The retroreflectivity ( $R_L$ ) measurement results are indicated in [Table B-2](#). Measurements were made with the LTL 2000Y retroreflectometer. The average  $R_L$  values were 225 for the marking using a leaded pigment on US 79, and 268, 200, and 187 for the lead-free material used on US 79, SH 21 WB, and SH 21 EB, respectively. There is a statistically significant difference in the retroreflectivity values of the leaded and lead-free markings on US 79. All of the measurements are above the  $175 \text{ mcd/m}^2/\text{lx}$  minimum level required in TxDOT specification. There was no installation of a new yellow marking with leaded pigment at the SH 21 site. It is worth noting that the markings measured on the pavement were applied to surface treatment (seal coat). This surface represents a very rough pavement surface, which may have an impact on the measured retroreflectivity. However, there were not application sites included in the initial evaluation where the lead-free marking material was applied to a smoother pavement surface.

### Color – 30 Meter

The 30 meter color measurements are indicated in [Table B-3](#). The individual color values were plotted against the x-y points defining the color box from the FHWA final rule on marking color. This color box is based on Illuminant A and a viewing geometry that is the same as the 30 meter retroreflectivity geometry. [Figure 4-1](#) illustrates the plot of the color points for the various color measurements with the LTL 2000Y. All of the measurements are within the FHWA color box. It is worth noting that the markings measured on the pavement were applied to surface treatment (seal coat). As with the retroreflectivity measurement, this surface represents a very rough pavement surface, which may have an impact on the measured color. However, there were not application sites included in the initial evaluation where the lead-free marking material was applied to a smoother pavement surface.

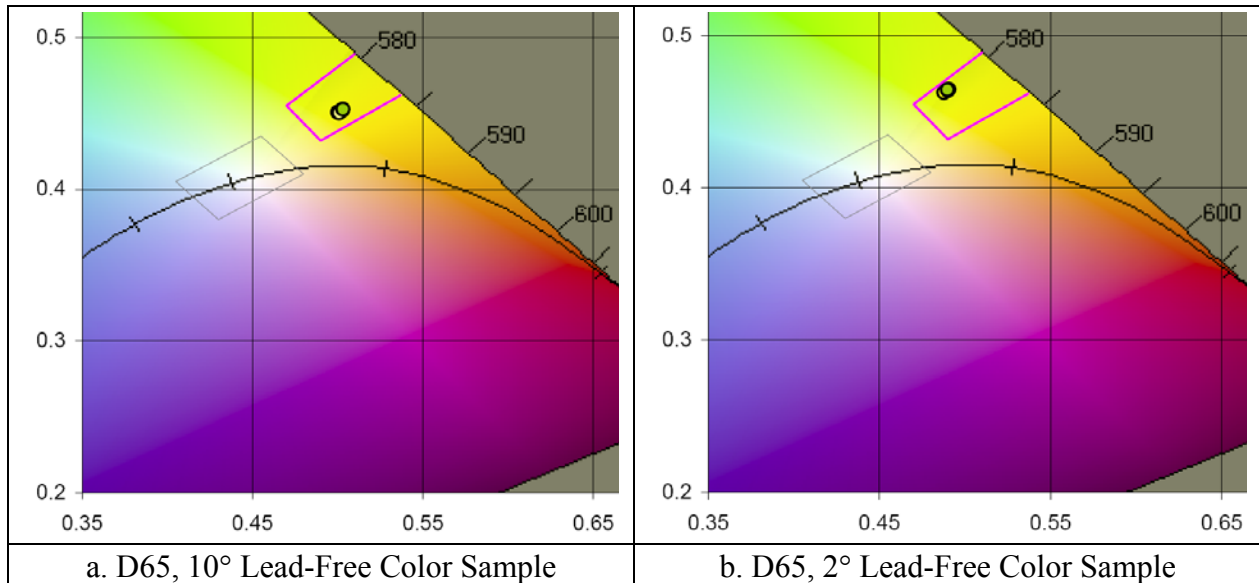


**Figure 4-1. Color Findings for 30 Meter Geometry Measurements.**

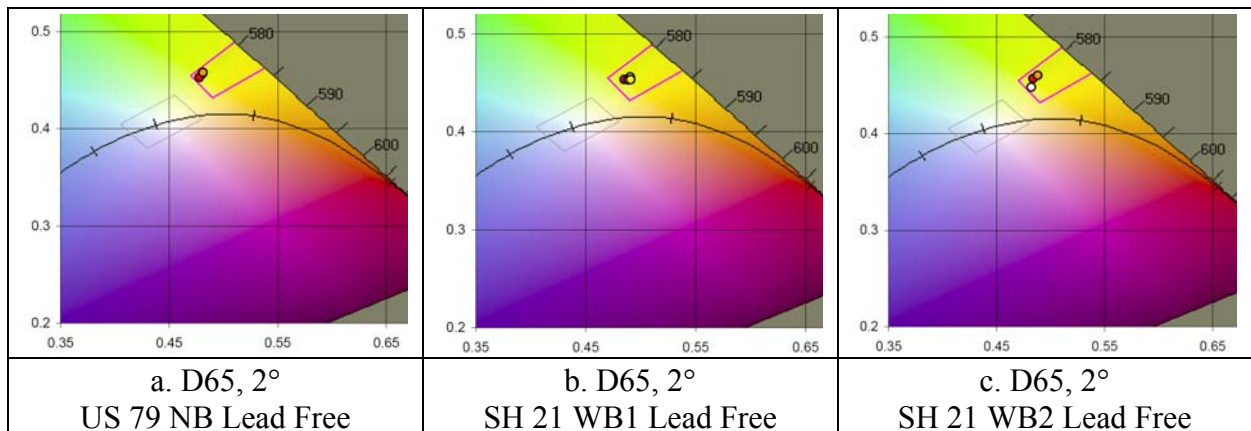
**Color – 45°/0°**

The researchers also measured the color of marking materials containing no beads using a range of illuminants and standard observers at a 45° illumination geometry and a 0° observation geometry. The 45°/0° color measurements are indicated in [Table B-4](#). Several of these x-y color points were plotted to determine whether they are within the color box. The TxDOT color box from DMS 8220 was used for the D65 measurements (for both the 2° and 10° standard

observers). The researchers did not identify a 45°/0° color box for illuminant A. Figure 4-2 illustrates the plot of the color points for the color measurements with the BYK Gardner Color Guide on the single color sample that was collected on an aluminum plate. All of the measurements are within the TxDOT color box for both standard observers. The 10° standard observer is the TxDOT standard for measurements of a color sample. Figure 4-3 shows similar plots of the D65, 2° measurements using the TxDOT DMS 8220 color box. All of these measurements are also within the box.



**Figure 4-2. Color Findings for 45°/0° Geometry Measurements – D65, 10°.**



**Figure 4-3. Color Findings for 45°/0° Geometry Measurements – D65, 2°.**

## FINDINGS

Based on the results presented above, the researchers offer the following preliminary findings regarding retroreflectivity and color of the lead-free marking material at installation. It is worth noting that further evaluation will be conducted during the final year of the study to assess the long-term implications of using lead-free yellow thermoplastic material.

- Retroreflectivity
  - ♦ The retroreflectivities of the lead-free applications are above the minimum level specified by TxDOT. At the location that provided the ability to measure leaded and lead-free materials on the same pavement surface, the lead-free material had a higher retroreflectivity level. The initial retroreflectivity of the lead-free material appears to be acceptable.
  - ♦ Retroreflectivity values can vary significantly from one location to another. A few of the factors that can cause variation in measured retroreflectivity include: marking pigment; difference in pavement surface smoothness; type, density, and embedment of the beads; and marking thickness. Differences in retroreflectivity between the leaded and lead-free marking samples may be due to factors other than the pigment.
- 30 Meter Color
  - ♦ The retroreflective color measurements (at 30 meter geometry) for both the leaded and lead-free materials are located in the center of the FHWA color box for 30 meter yellow marking materials. The initial 30 meter color of the lead-free marking material appears to be acceptable.
- 45°/0° Color
  - ♦ The standard color measurements of lead-free material with no beads was found to be within the TxDOT color box for yellow markings. The initial 45°/0° color of the lead-free marking material appears to be acceptable.

## REFERENCES

1. *DMS-8220, Hot Applied Thermoplastic*. Texas Department of Transportation, Austin, Texas, September 2007.

2. National Cooperative Highway Research Program Project 5-18, Color Effectiveness of Yellow Pavement Marking Materials. Transportation Research Board, Washington, D.C. <http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=877>. Accessed August 31, 2007.
3. *Special Specification 6110, Reflectorized Pavement Markings with Retroreflective Requirements*. Texas Department of Transportation, Austin, Texas, March 2005. <ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/spec/ss6110.pdf>. Accessed August 31, 2007.
4. Traffic Control Devices on Federal-Aid and Other Streets and Highways; Color Specifications for Retroreflective Traffic Signs and Pavement Marking Materials. *Federal Register*, Vol 67, No. 147, Docket FHWA-99-6190, U.S. Government Printing Office, Washington, D.C., July 31, 2002, pages 49569-49575.



## **CHAPTER 5: ADDITIONAL WORK ACTIVITIES**

### **INTRODUCTION**

There were two fourth-year activities that are different from previous years' activities in that the results cannot be described as a chapter in the annual research report. In both cases, these activities will result in a separate product that does not fit into the confines of a chapter report. The two activities in the fourth year addressed the following topics: traffic signal accessibility issues and impacts of work zones.

### **TRAFFIC SIGNAL ACCESSIBILITY ISSUES**

This activity is consolidating information from a variety of sources related to meeting state and national accessibility guidelines at signalized intersections. The result of the activity is a set of guidelines that was produced as a separate product.

### **WORK ZONE IMPACTS HANDBOOK**

In September 2004, the Federal Highway Administration (FHWA) published a final rule establishing new procedures related to assessing the safety and mobility impacts of work zones on the traveling public. The rule applies to all state and local governments who receive federal-aid funding for highway projects. The rule requires work zone impacts to be identified and addressed as part of a transportation management plan that begins at project development and proceeds through construction, including an after implementation review and assessment element. The transportation management plan for a given project is expected to address temporary traffic control, transportation operations, and public information aspects for the project. The overall goal of the rule is to improve work zone safety and mobility by creating a mechanism to establish good policy and practices that consider the broader safety and mobility impacts of work zones. The compliance deadline for the new rule is October 12, 2007.

Overall, implementing the new rule is both a challenge and an opportunity. As written, the work zone assessment process is a multifaceted procedure that must identify impacts, address those limitations, examine resources and costs, perform periodic evaluations, and address implementation and training needs. To assist TxDOT in implementing the work zone impacts

rule, researchers are developing a *Work Zone Impacts Handbook* that will provide the information needed to understand and implement the rule at the project level. The handbook will provide detail and explanation on all the components of the rule, identify relevant TxDOT policies, and contain an index of strategies that are applicable to work zone impact mitigation. The overall goal of the *Work Zone Impacts Handbook* is to provide the guidance and knowledge for TxDOT personnel to create the transportation management plans required by the rule. The handbook is intended to be an explanatory reference, not an encyclopedia of all work zone knowledge.

During the fourth year of this project, the research team continued the development activities that were initiated in the third year. They met with a panel of TxDOT work zone experts on several occasions to review drafts of the handbook and continued to refine the handbook based on the panel's comments. This effort will continue into the fifth year of the project, during which researchers will finalize the handbook.



## **APPENDIX A: GPS PAVEMENT PROFILE RESULTS**

### **Texas Centric Mapping System**

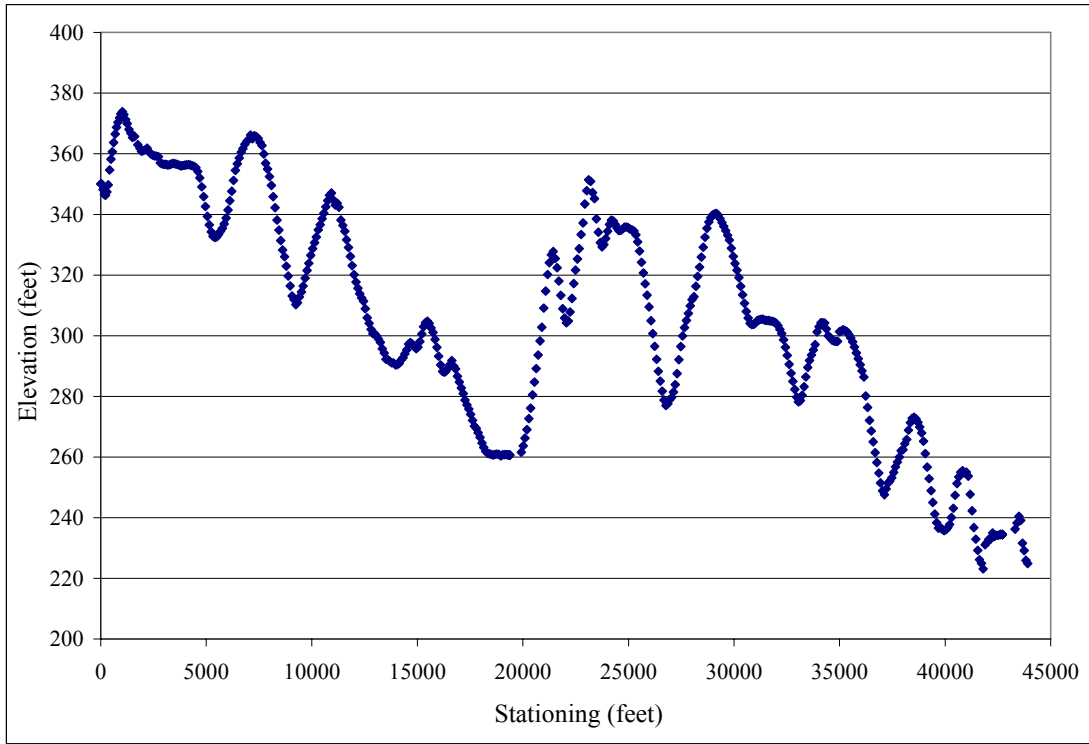
(5) Statewide mapping system.

(A) Usage. No existing mapping system has been generally recognized as a standard for minimum-distortion mapping of the entire State of Texas. This section defines such a mapping system, in both a conformal and an equal area version. Either version of this mapping system may be employed for a single geospatial dataset that covers all of, or a large portion of, the State of Texas. Usage of this mapping system is not required. Existing standard mapping systems such as Universal Transverse Mercator and State Plane Coordinate System may be more appropriate for geospatial datasets that cover smaller regions of the State.

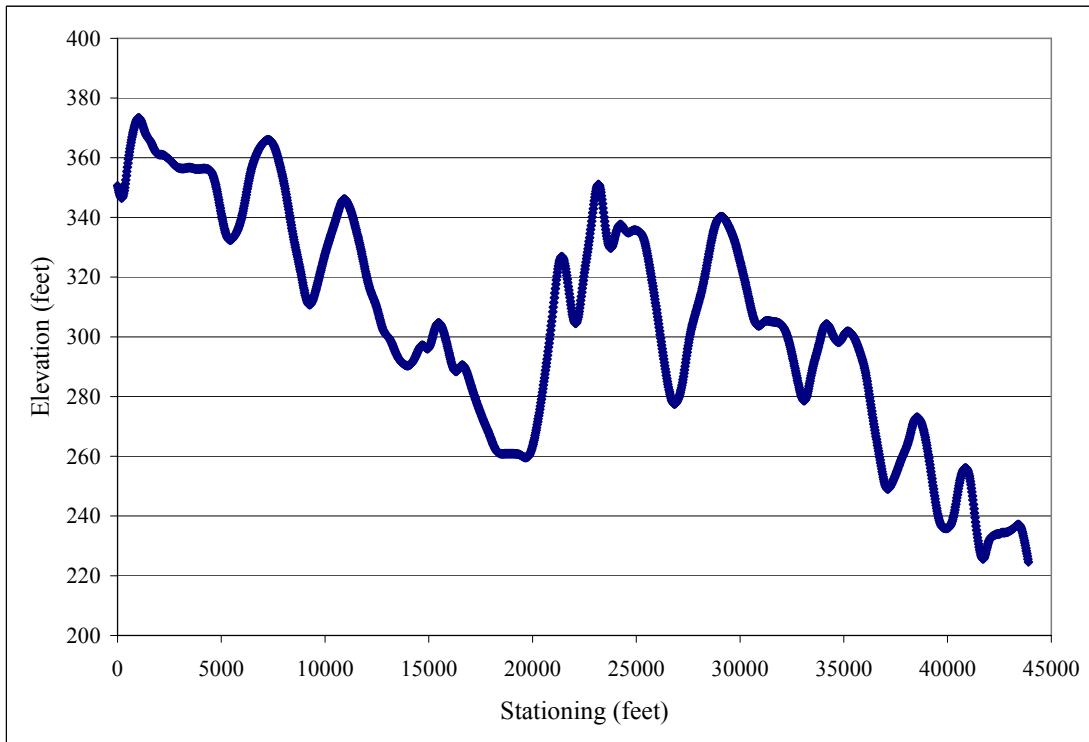
(B) Conformal version. A mapping system named “Texas Centric Mapping System/Lambert Conformal” is hereby defined, and the terms “Texas Centric Mapping System/Lambert Conformal” and its abbreviated form “TCMS/LC” shall be used only in strict accord with this definition:

- (i) Mapping System Name: Texas Centric Mapping System/Lambert Conformal
- (ii) Abbreviation: TCMS/LC
- (iii) Projection: Lambert Conformal Conic
- (iv) Longitude of Origin: 100 degrees West (-100)
- (v) Latitude of Origin: 18 degrees North (18)
- (vi) Lower Standard Parallel: 27 degrees, 30 minutes (27.5)
- (vii) Upper Standard Parallel: 35 degrees (35.0)
- (viii) False Easting: 1,500,000 meters
- (ix) False Northing: 5,000,000 meters
- (x) Datum: North American Datum of 1983 (NAD83)
- (xi) Unit of Measure: meter

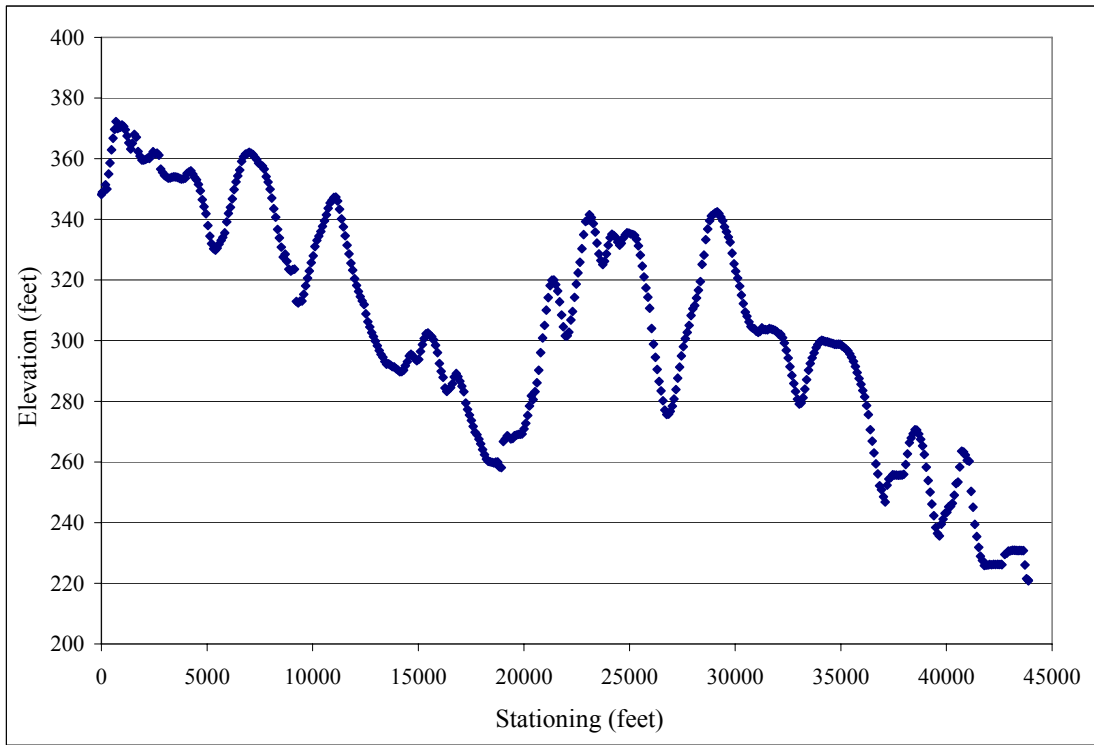
# FM 50 Southbound



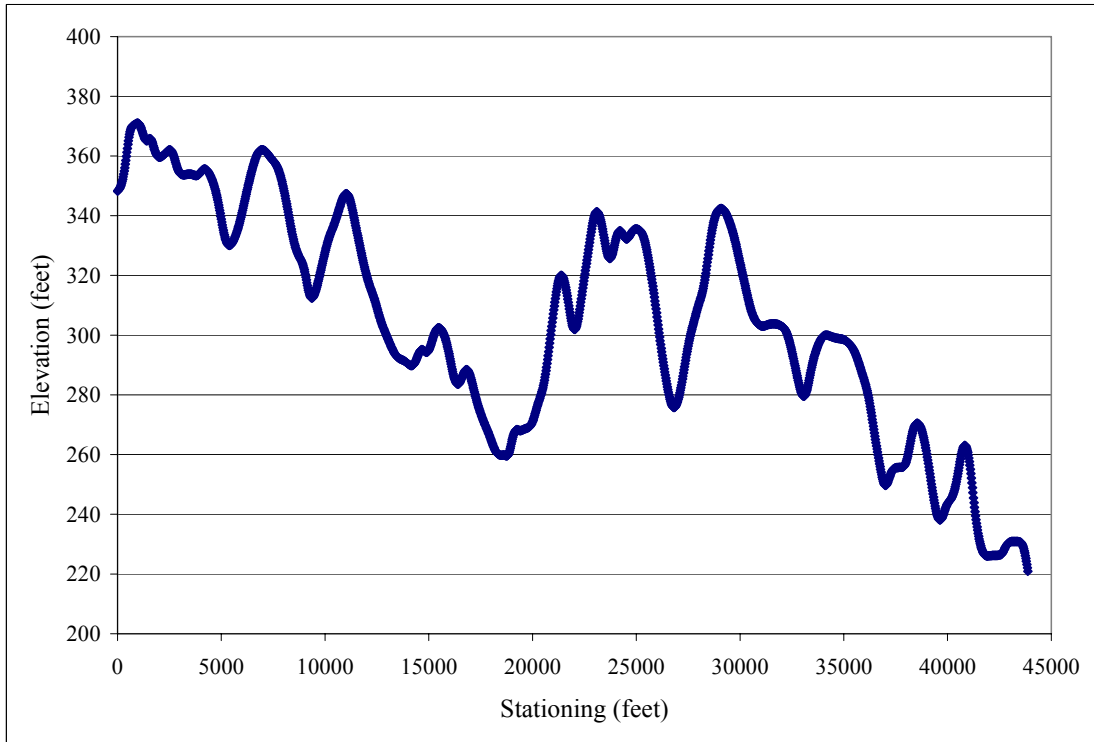
**Figure A-1. FM 50 Southbound Run 2 Raw Data.**



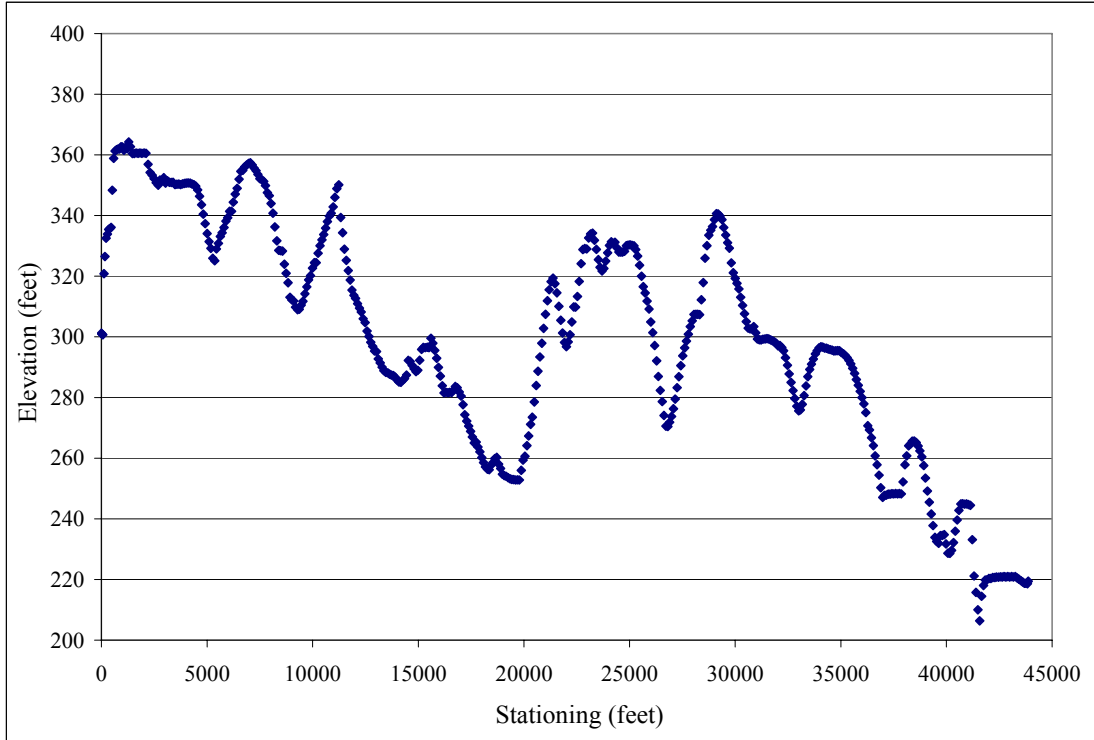
**Figure A-2. FM 50 Southbound Run 2 Smoothed Data.**



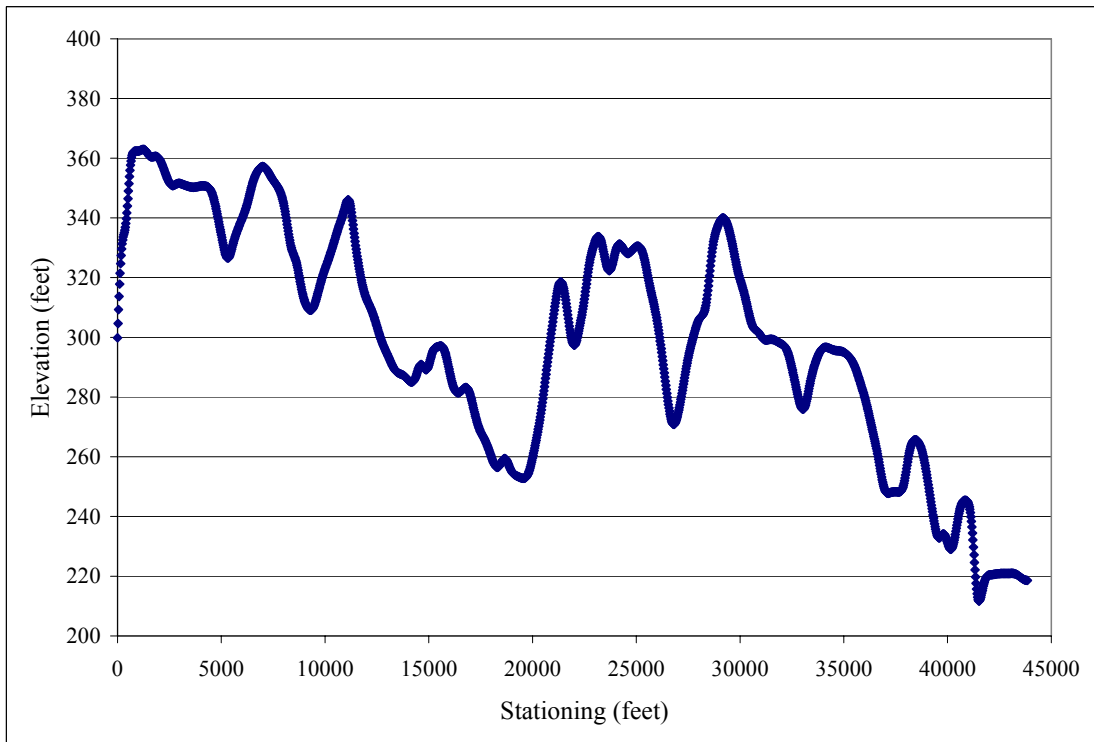
**Figure A-3. FM 50 Southbound Run 3 Raw Data.**



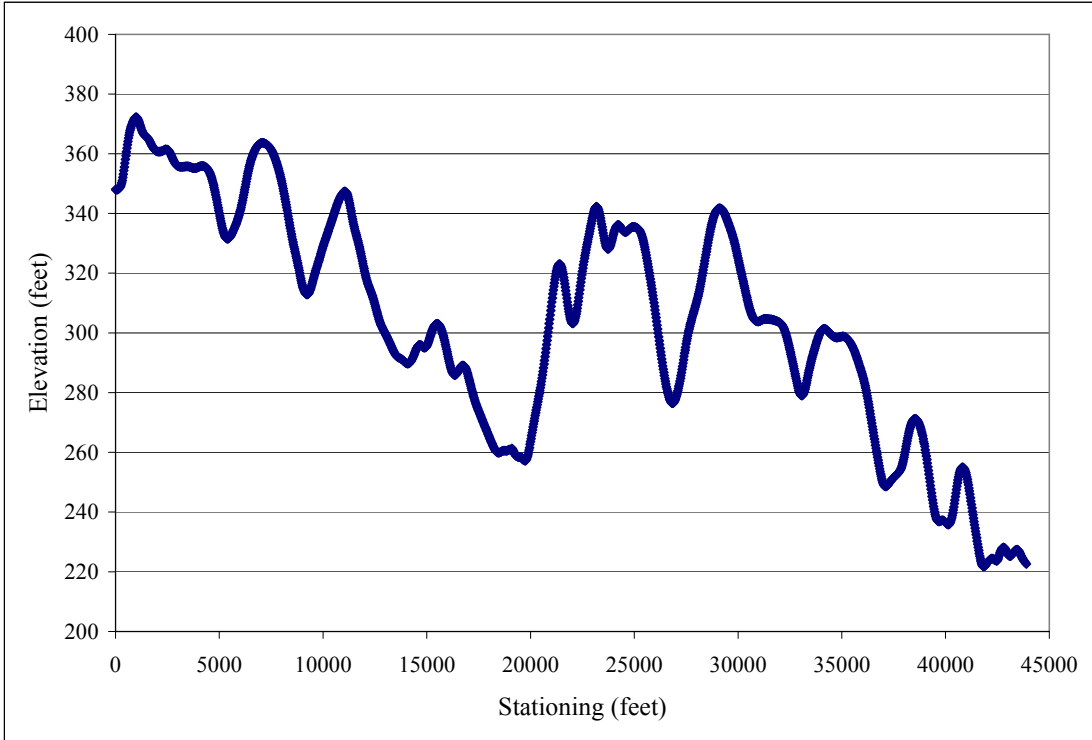
**Figure A-4. FM 50 Southbound Run 3 Smoothed Data.**



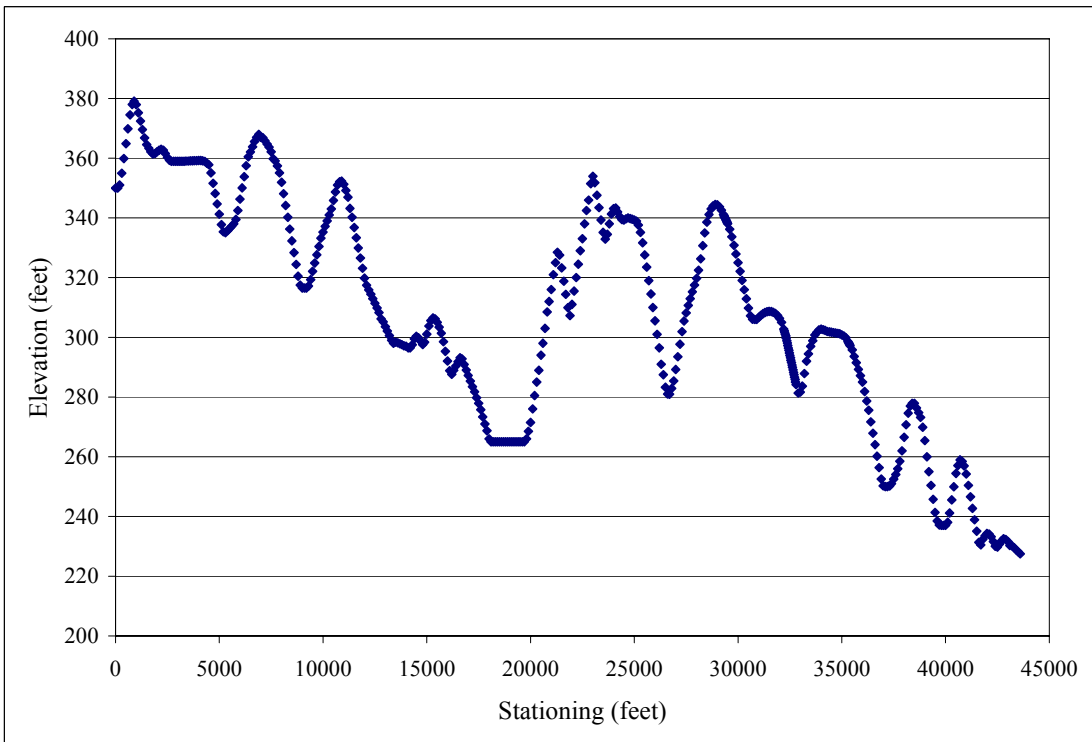
**Figure A-5. FM 50 Southbound Run 4 Raw Data.**



**Figure A-6. FM 50 Southbound Run 4 Smoothed Data.**

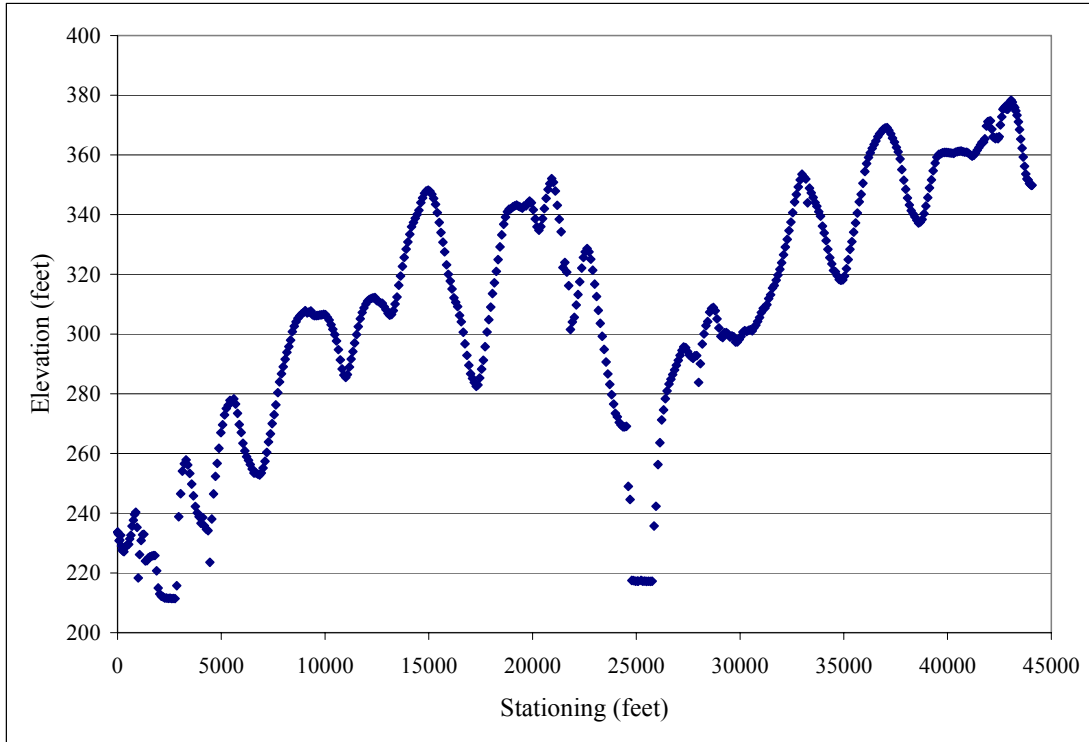


**Figure A-7. FM 50 Southbound Combined Smoothed Data.**

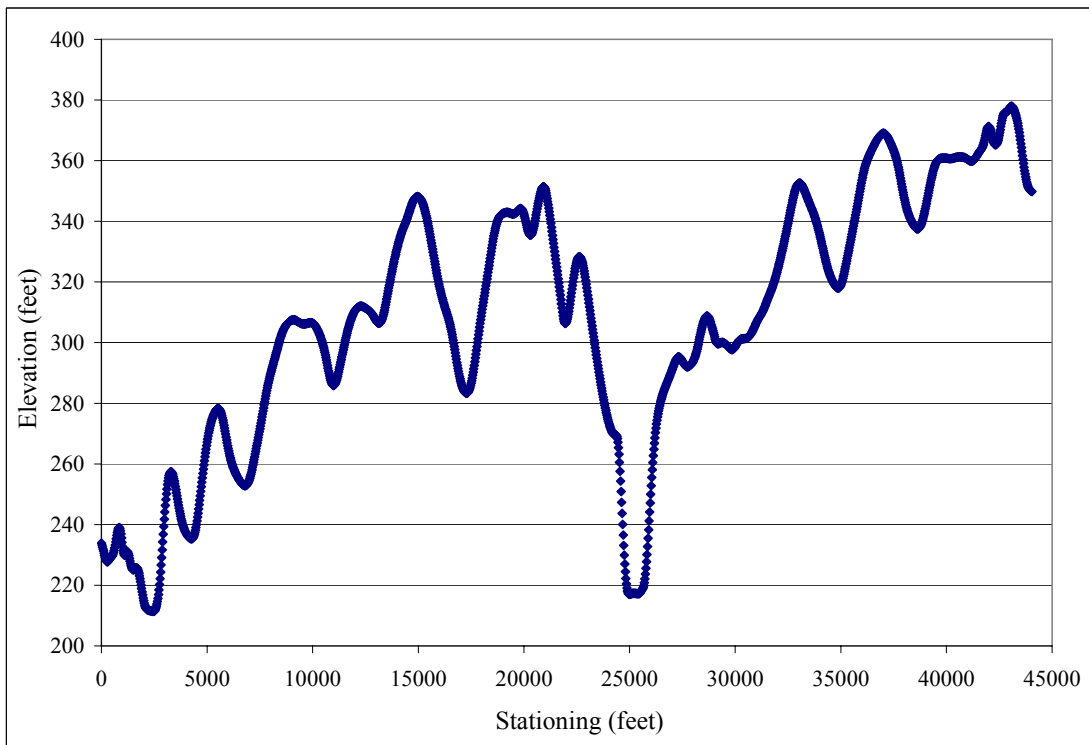


**Figure A-8. FM 50 Southbound Plan Sheet Data.**

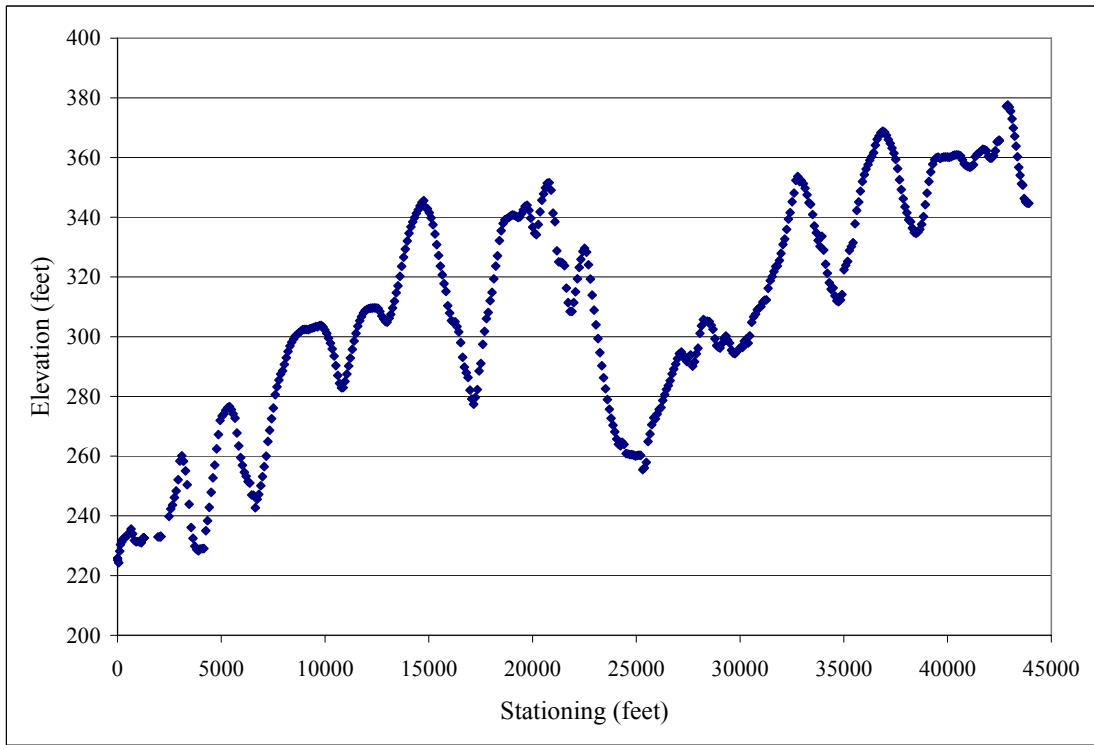
# FM 50 Northbound



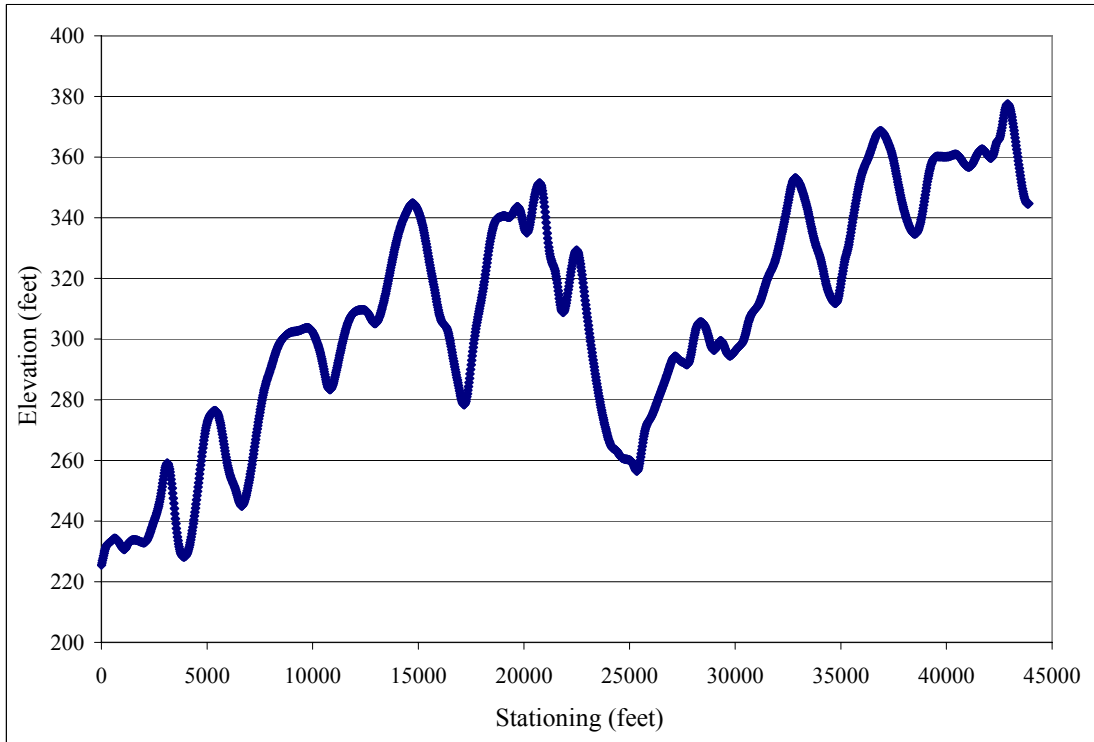
**Figure A-9. FM 50 Northbound Run 1 Raw GPS Data.**



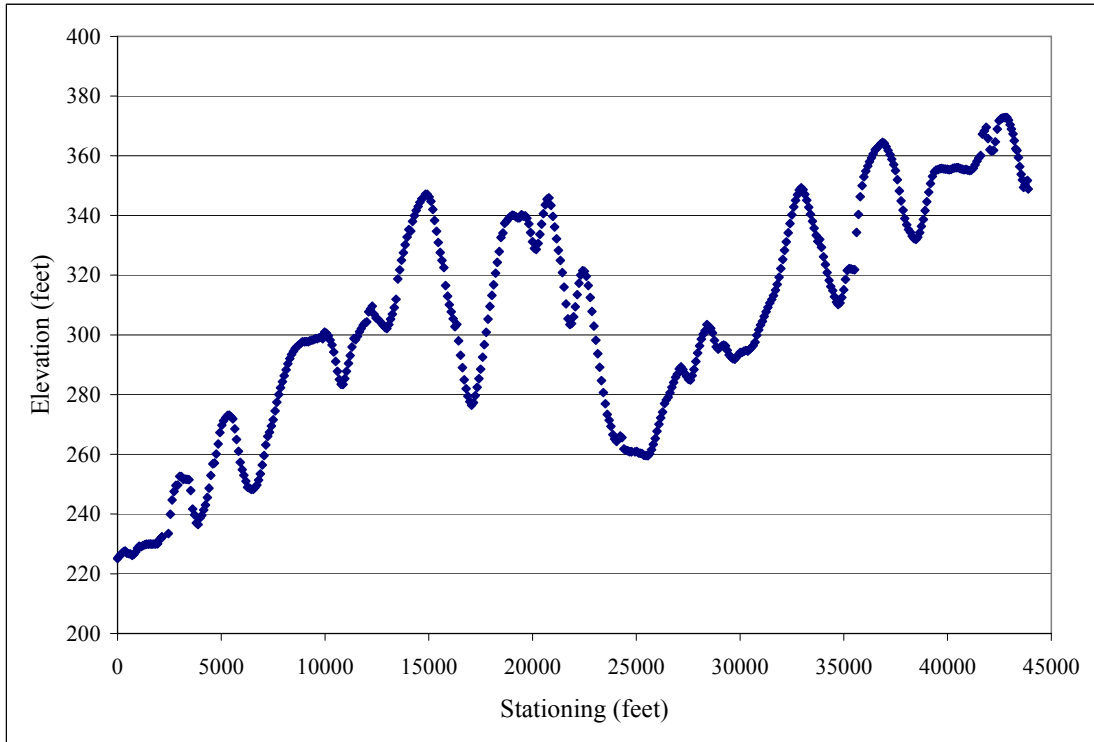
**Figure A-10. FM 50 Northbound Run 1 Smoothed Data.**



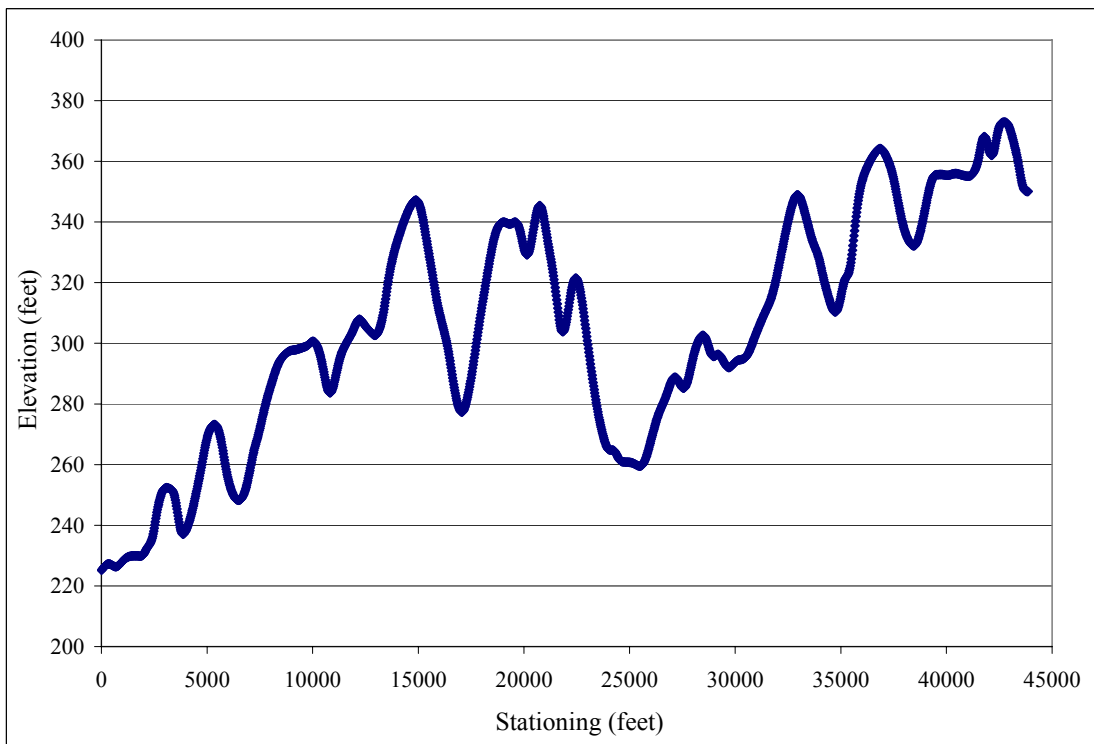
**Figure A-11. FM 50 Northbound Run 2 Raw Data.**



**Figure A-12. FM 50 Northbound Run 2 Smoothed Data.**

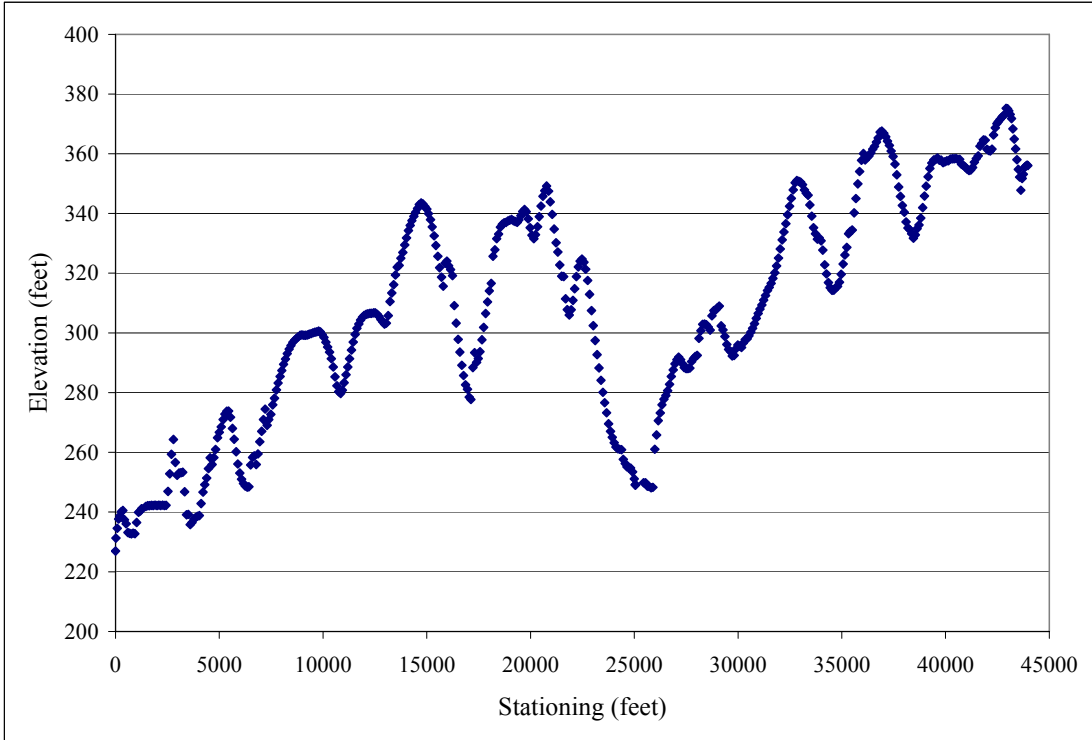


**Figure A-13. FM 50 Northbound Run 3 Raw Data.**

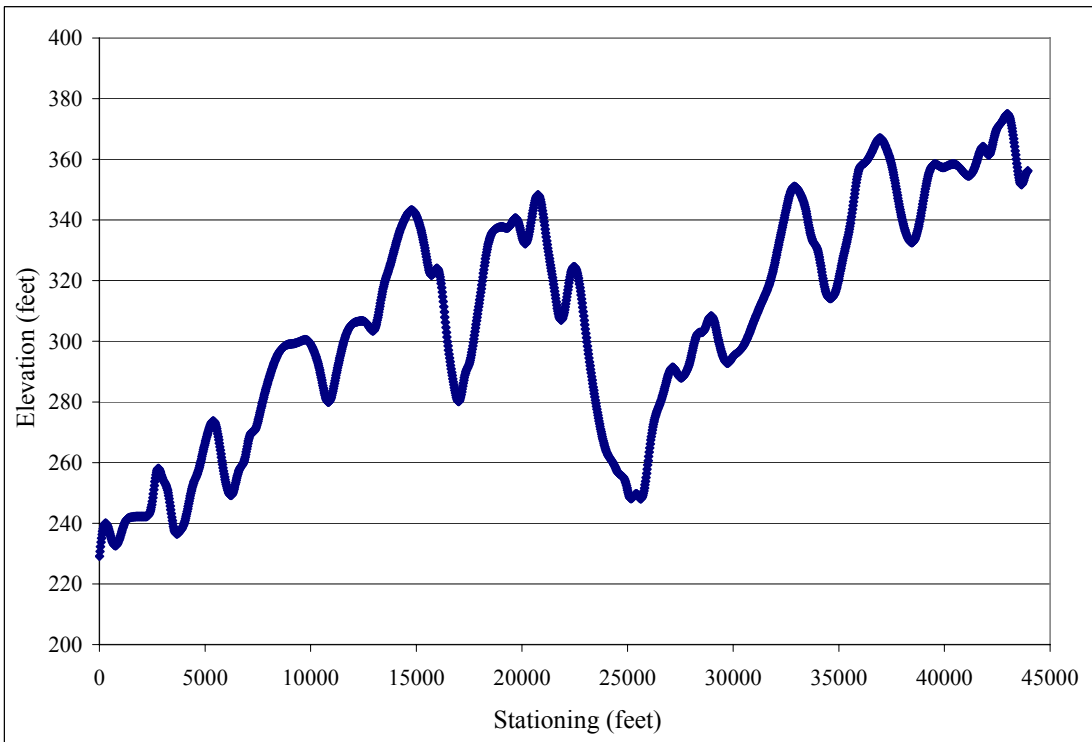


**Figure A-14. FM 50 Northbound Run 3 Smoothed Data.**

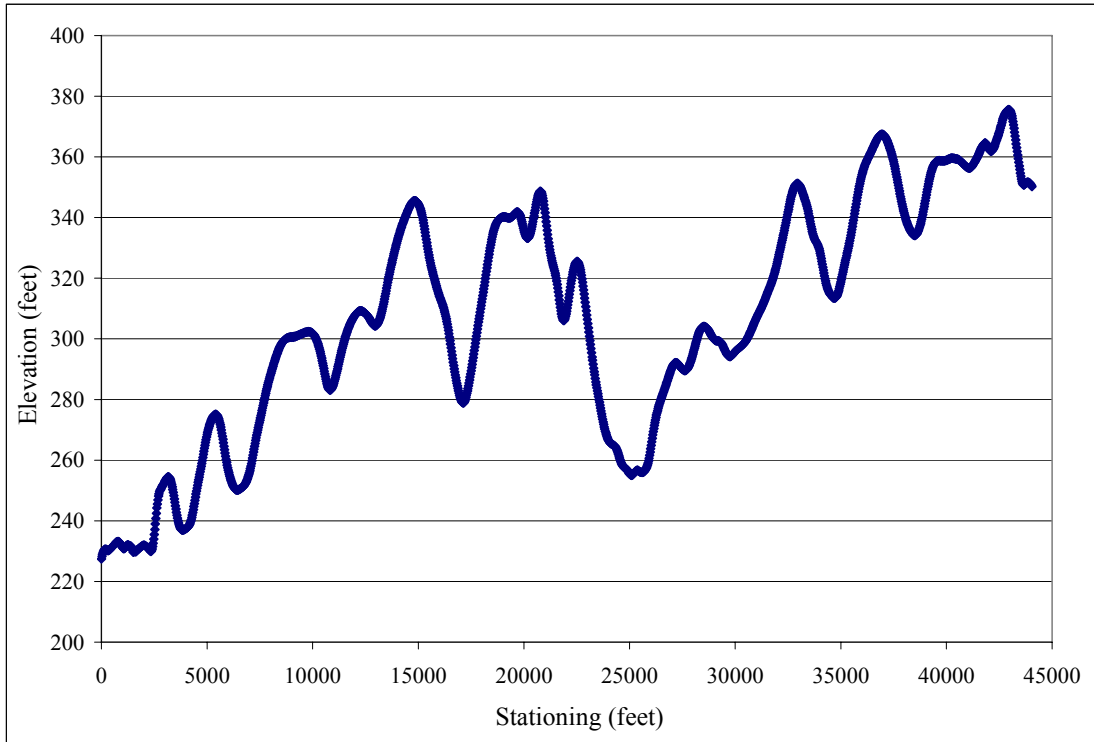




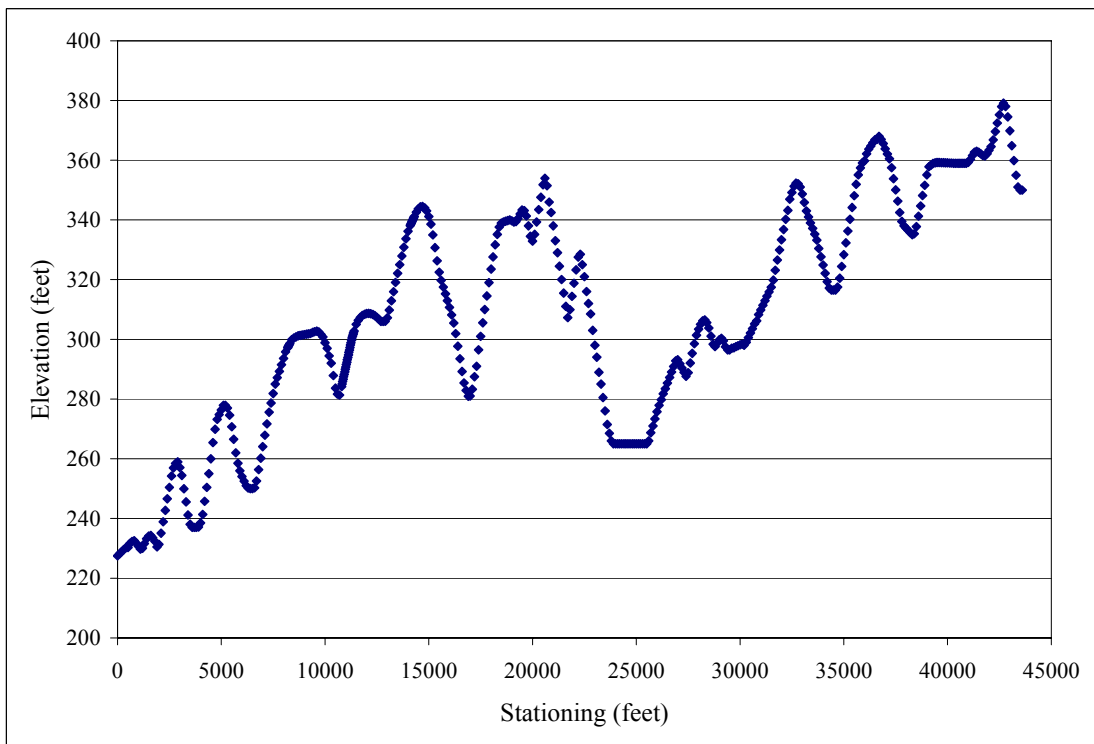
**Figure A-15. FM 50 Northbound Run 4 Raw Data.**



**Figure A-16. FM 50 Northbound Run 4 Smoothed Data.**

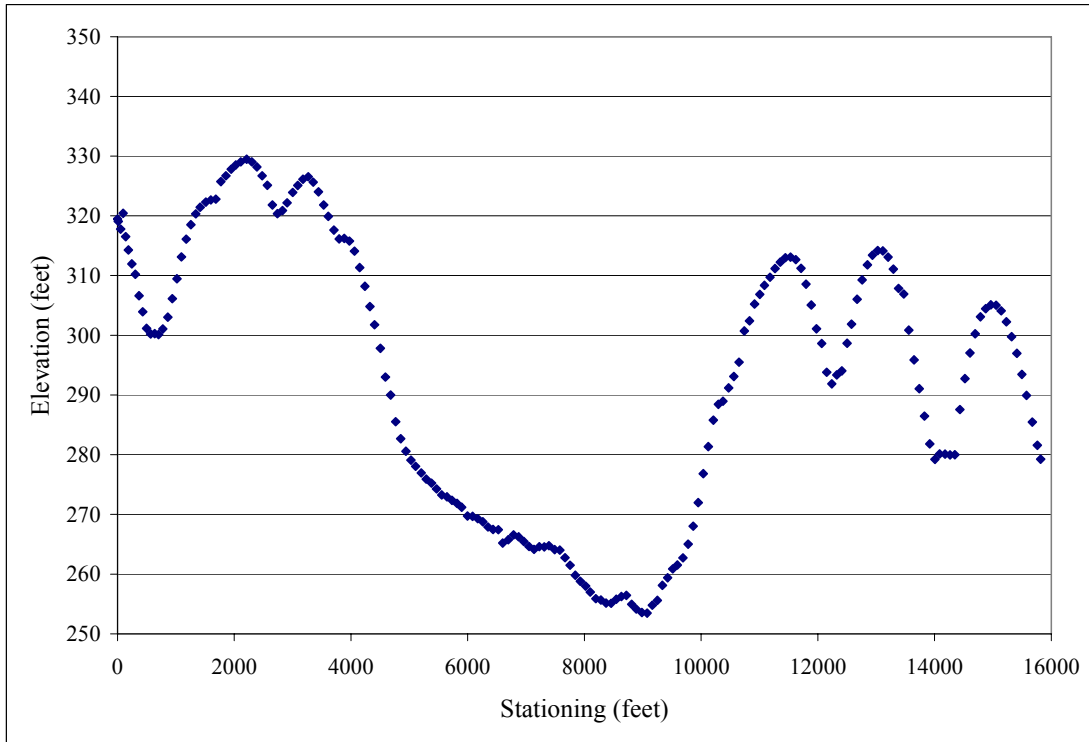


**Figure A-17. FM 50 Northbound Combined Smoothed Data.**

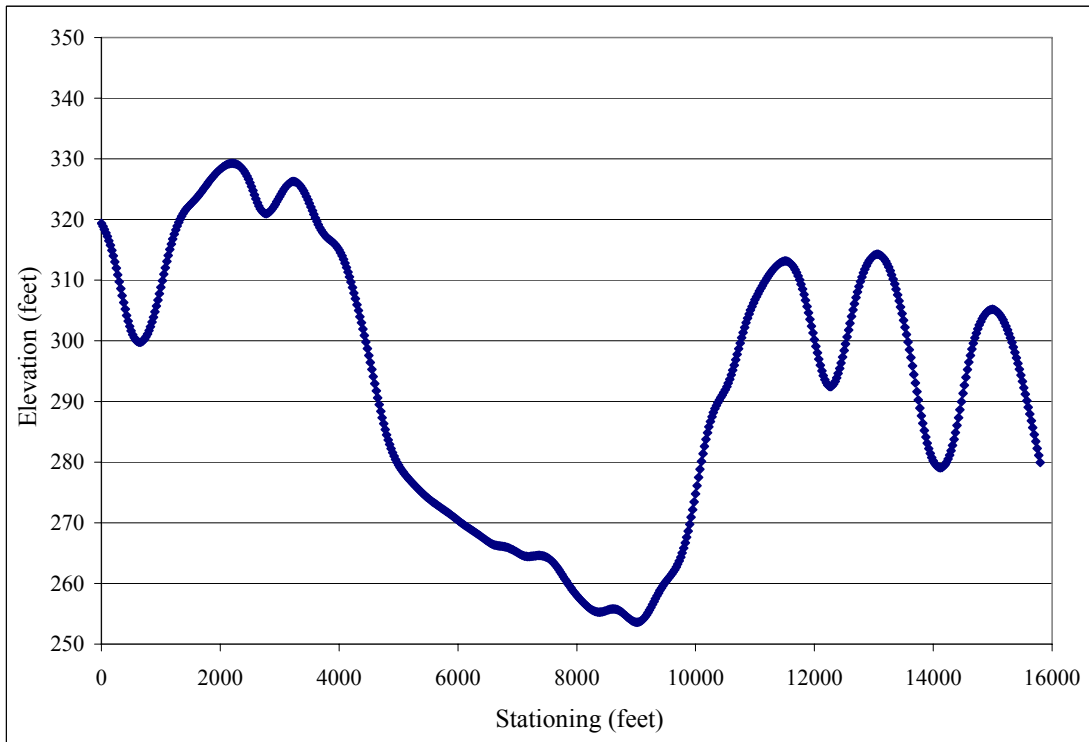


**Figure A-18. FM 50 Northbound Plan Sheet Data.**

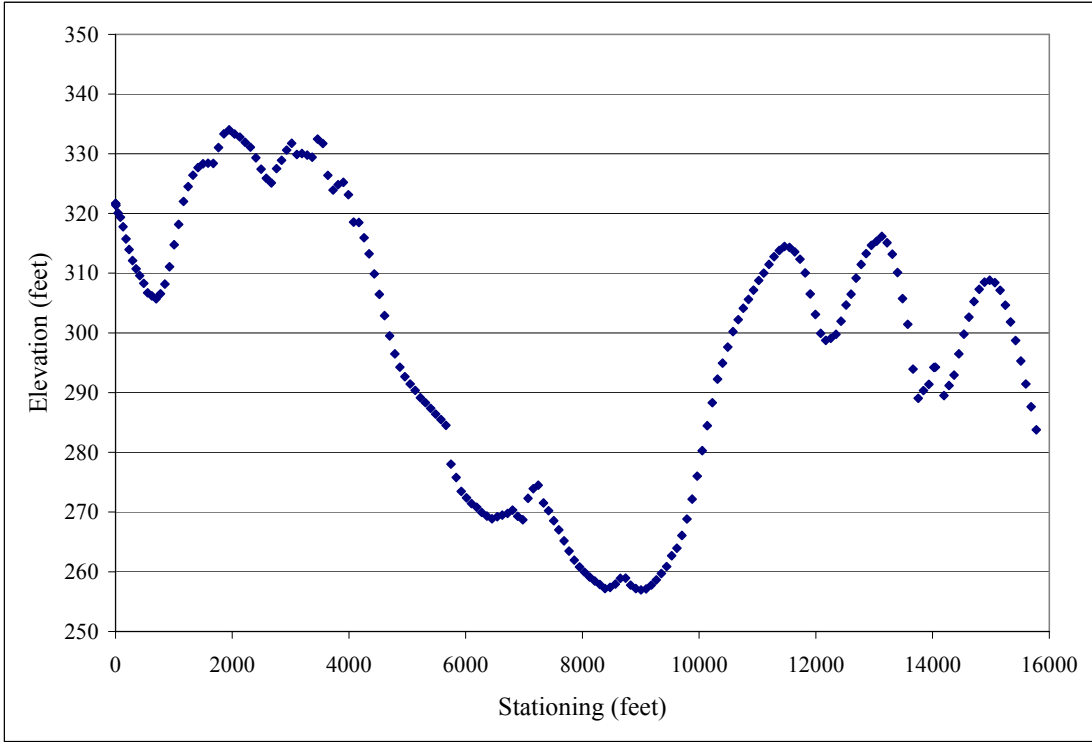
## FM 912 Eastbound



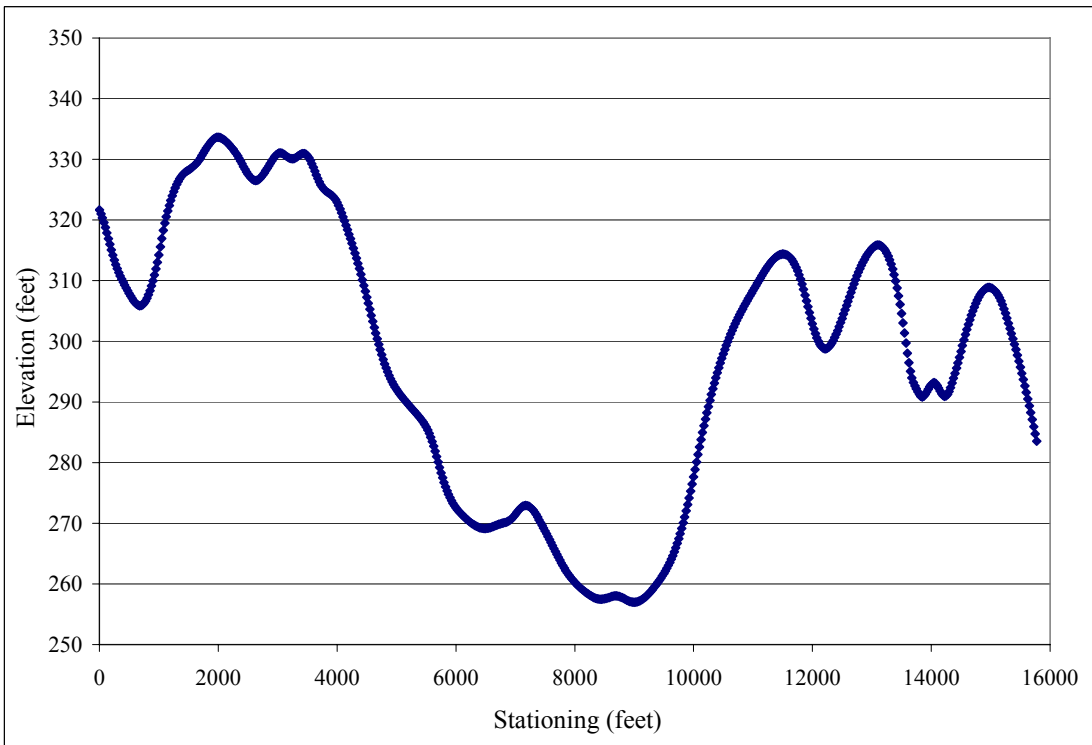
**Figure A-19. FM 912 Eastbound Run 1 Raw GPS Data.**



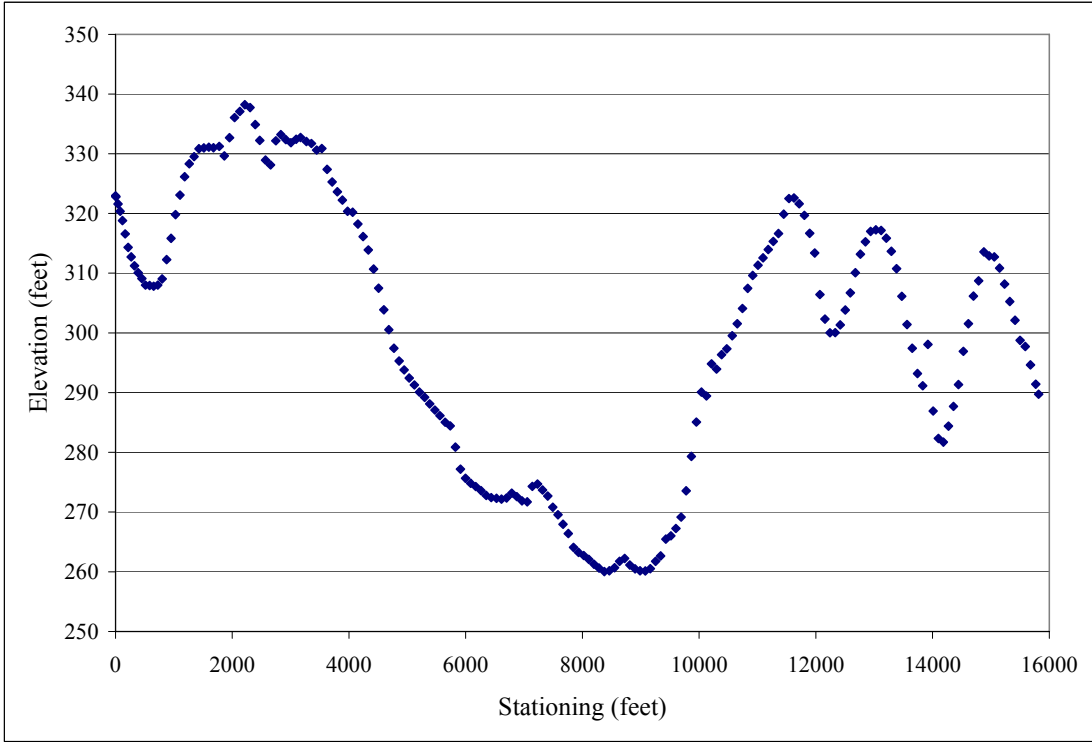
**Figure A-20. FM 912 Eastbound Run 1 Smoothed Data.**



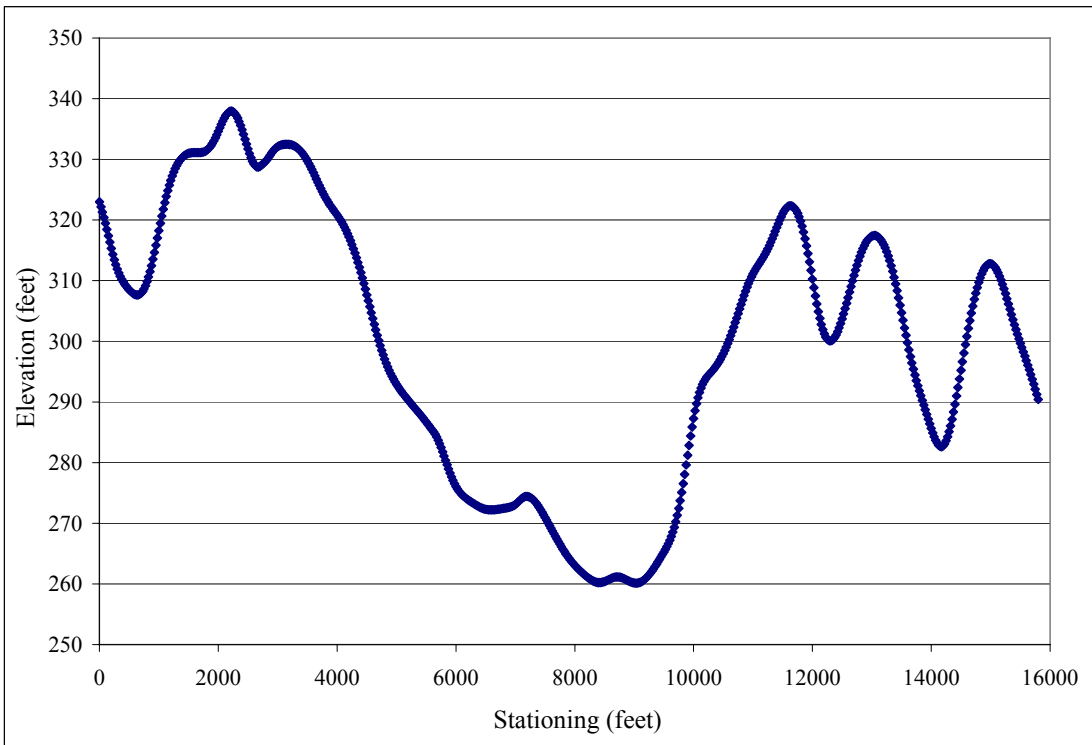
**Figure A-21. FM 912 Eastbound Run 2 Raw Data.**



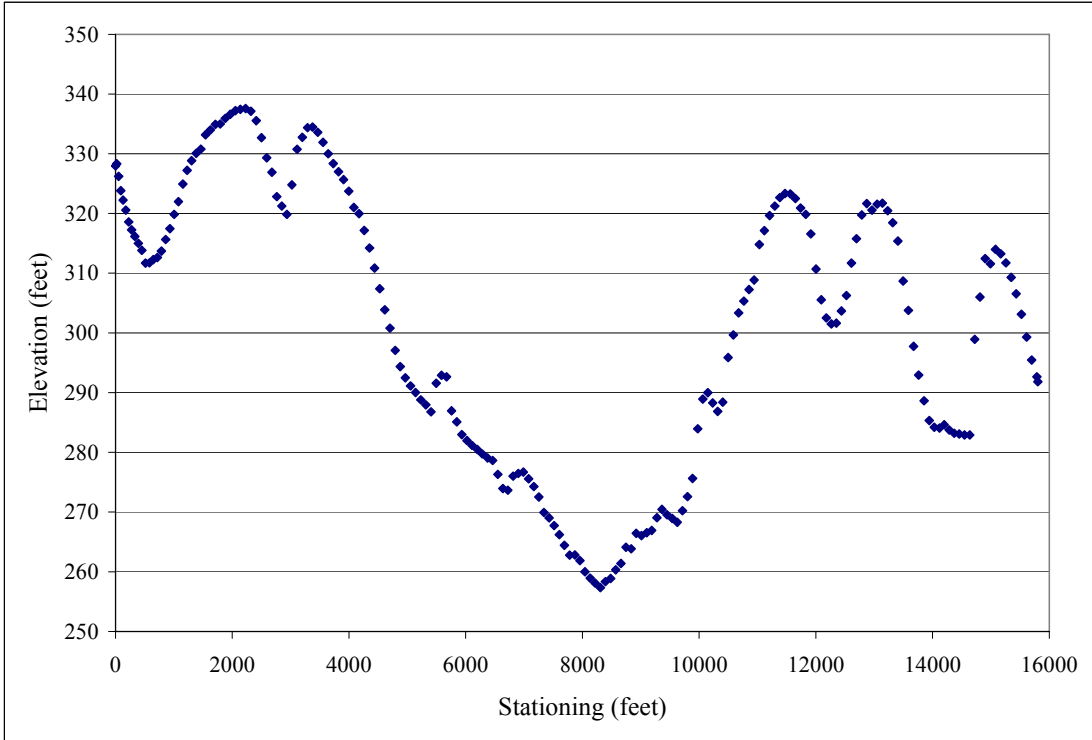
**Figure A-22. FM 912 Eastbound Run 2 Smoothed Data.**



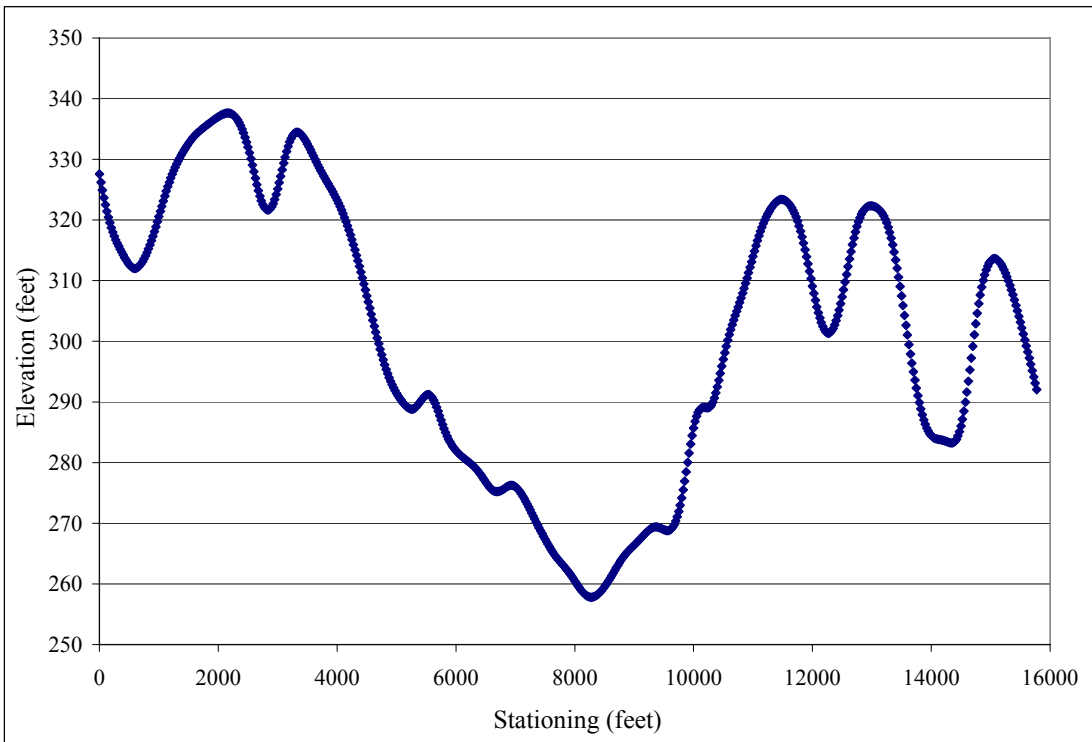
**Figure A-23. FM 912 Eastbound Run 3 Raw Data.**



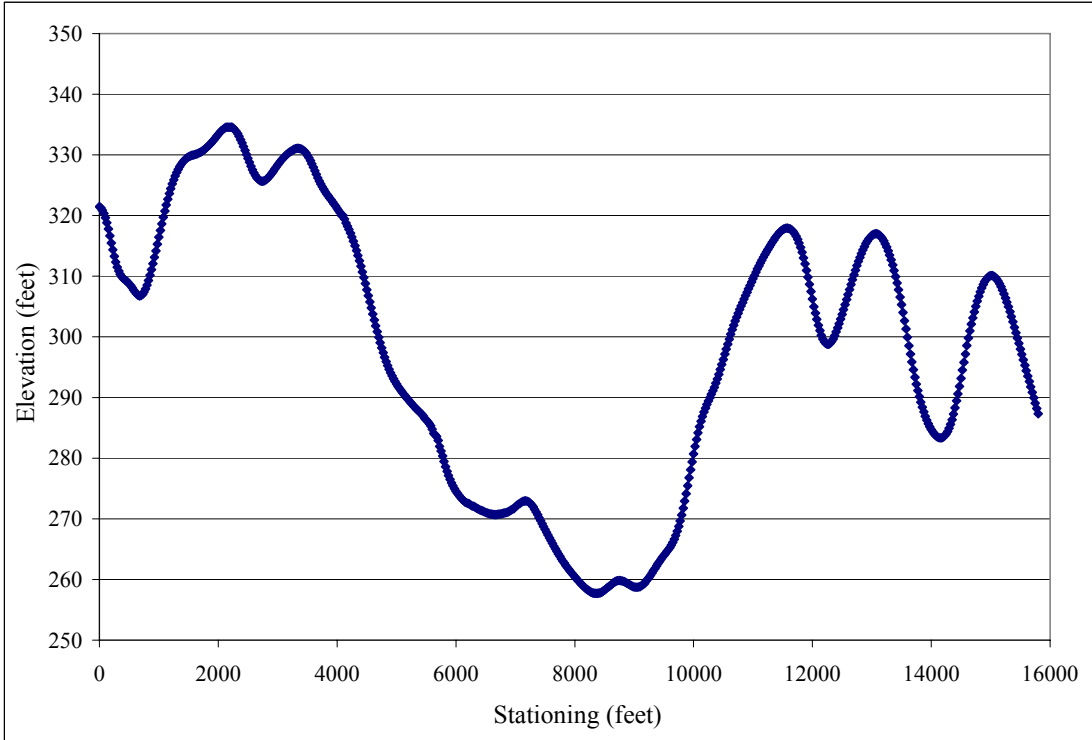
**Figure A-24. FM 912 Eastbound Run 3 Smoothed Data.**



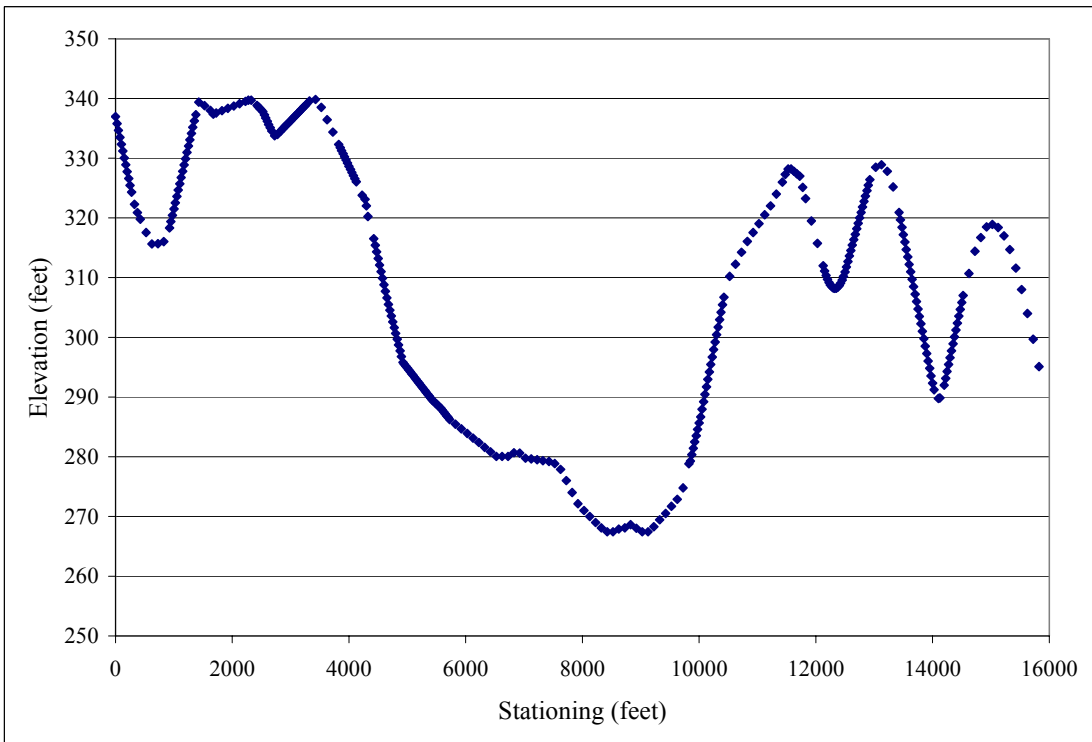
**Figure A-25. FM 912 Eastbound Run 4 Raw Data.**



**Figure A-26. FM 912 Eastbound Run 4 Smoothed Data.**

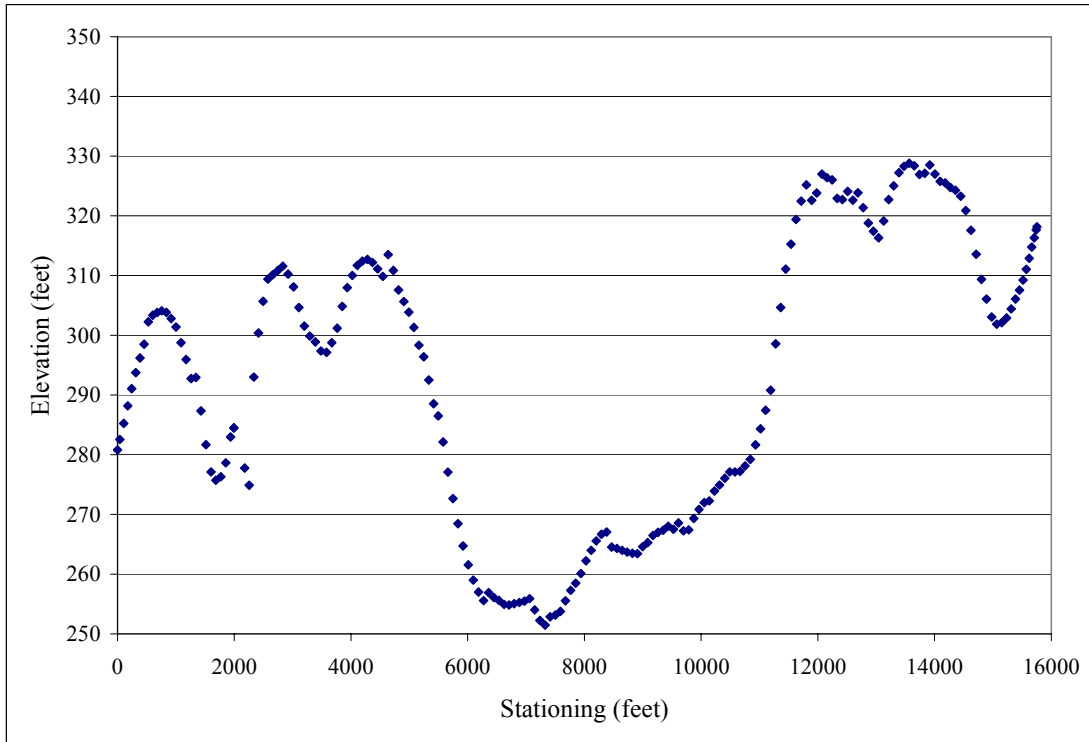


**Figure A-27. FM 912 Eastbound Combined Smoothed Data.**

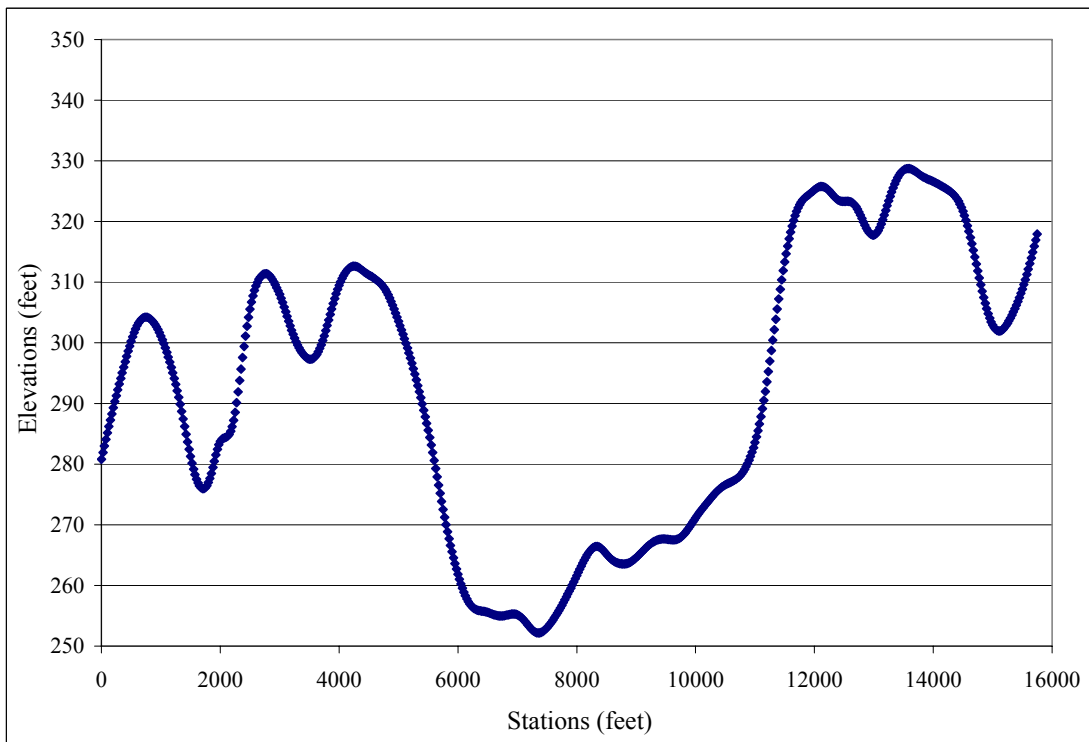


**Figure A-28. FM 912 Eastbound Plan Sheet Data.**

## FM 912 Westbound

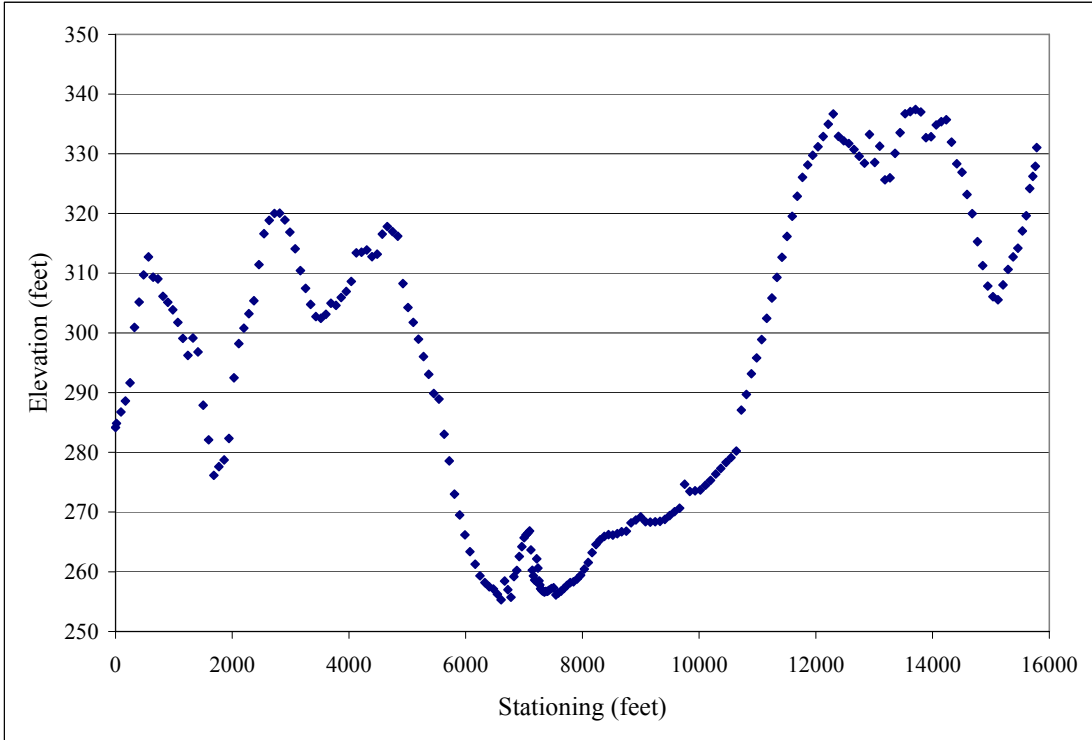


**Figure A-29. FM 912 Westbound Run 1 Raw GPS Data.**

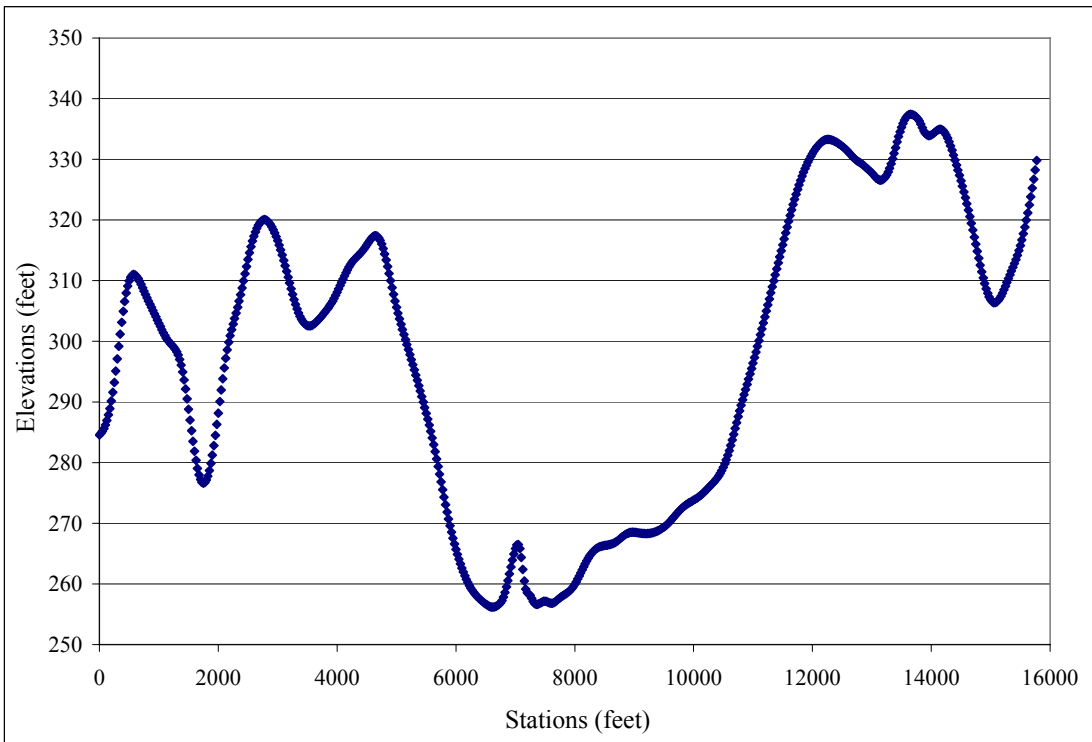


**Figure A-30. FM 912 Westbound Run 1 Smoothed Data.**

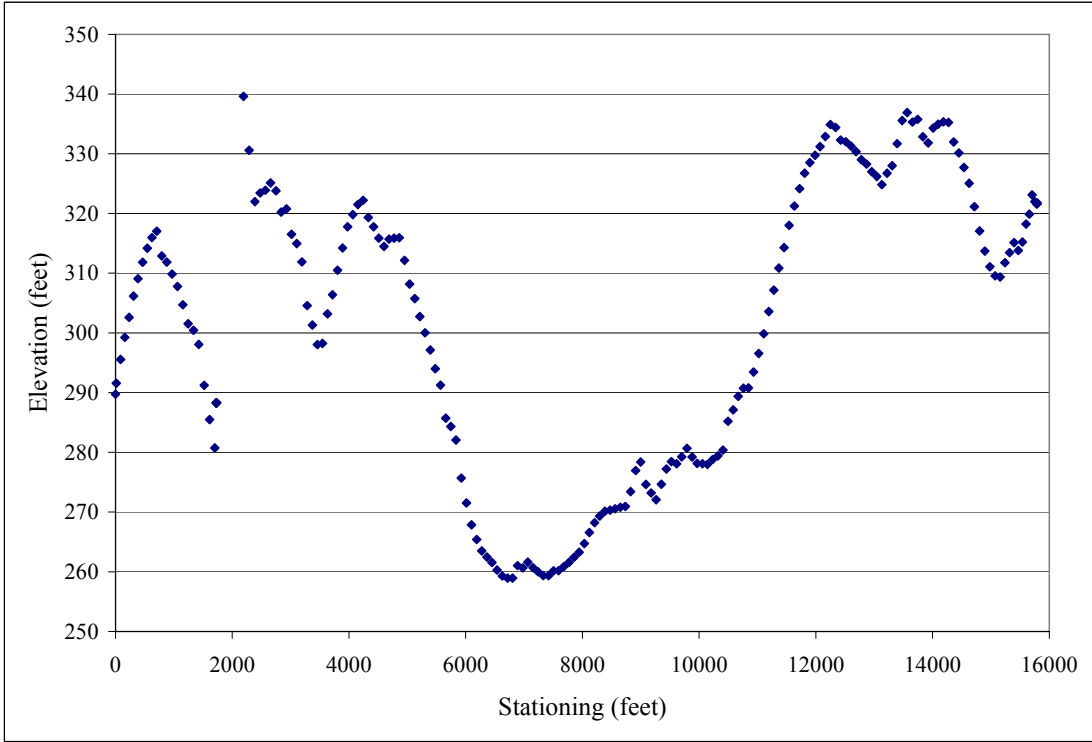




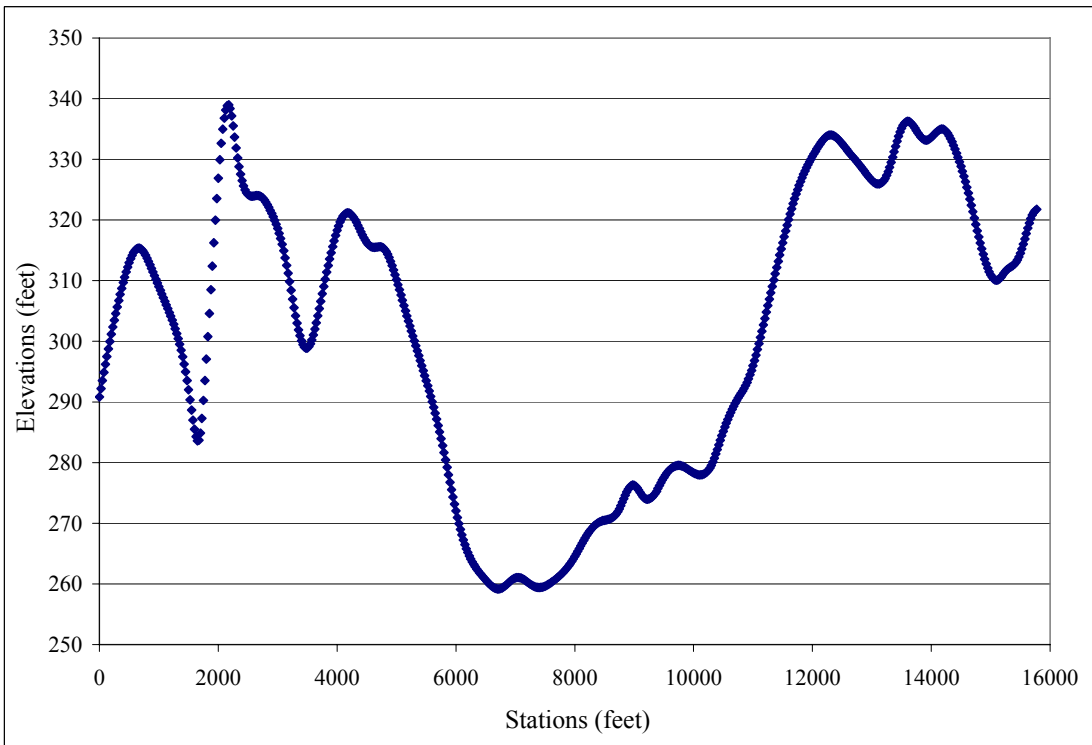
**Figure A-31. FM 912 Westbound Run 2 Raw Data.**



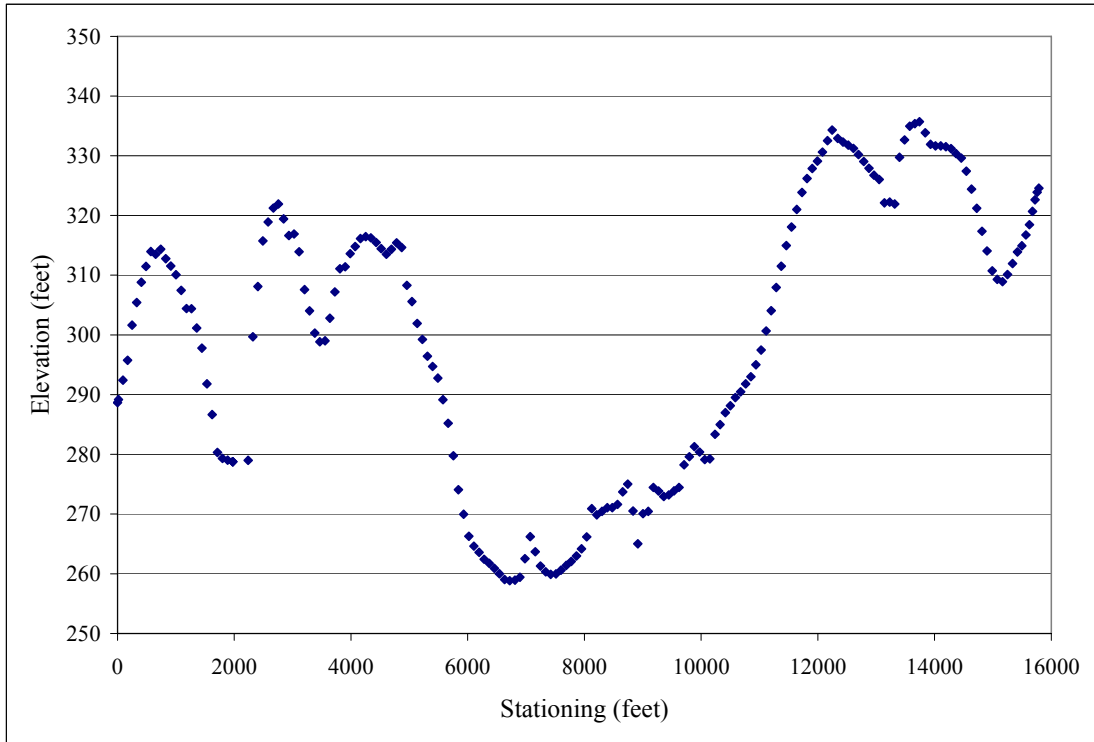
**Figure A-32. FM 912 Westbound Run 2 Smoothed Data.**



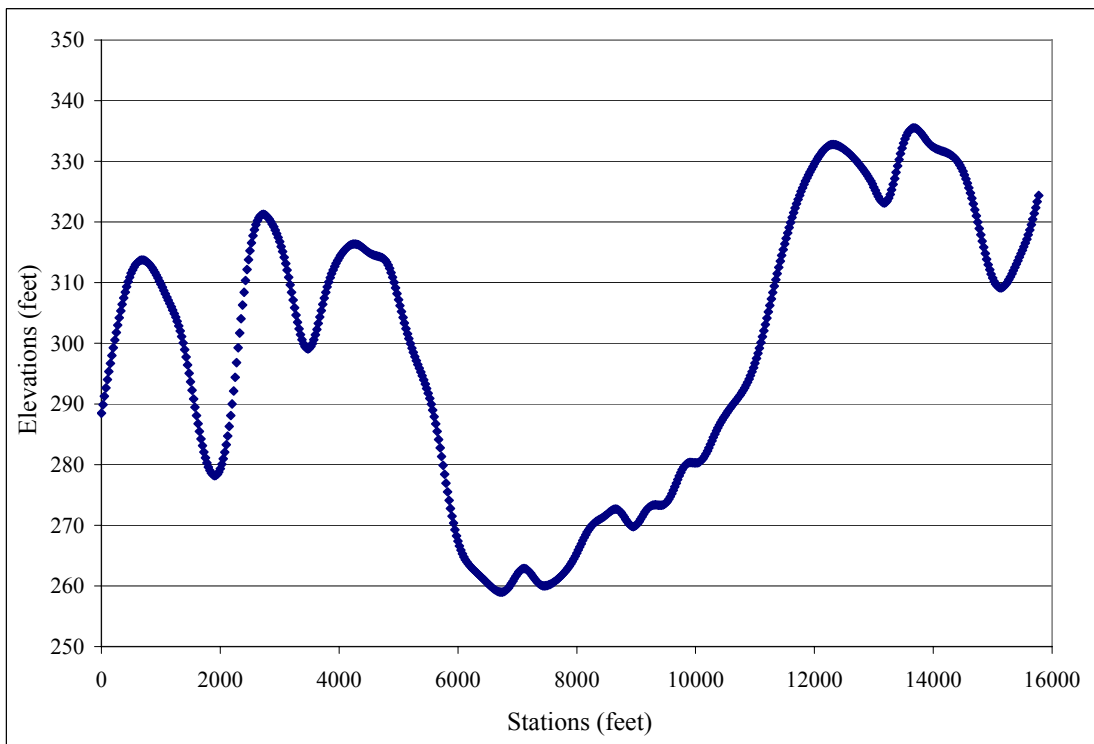
**Figure A-33. FM 912 Westbound Run 3 Raw Data.**



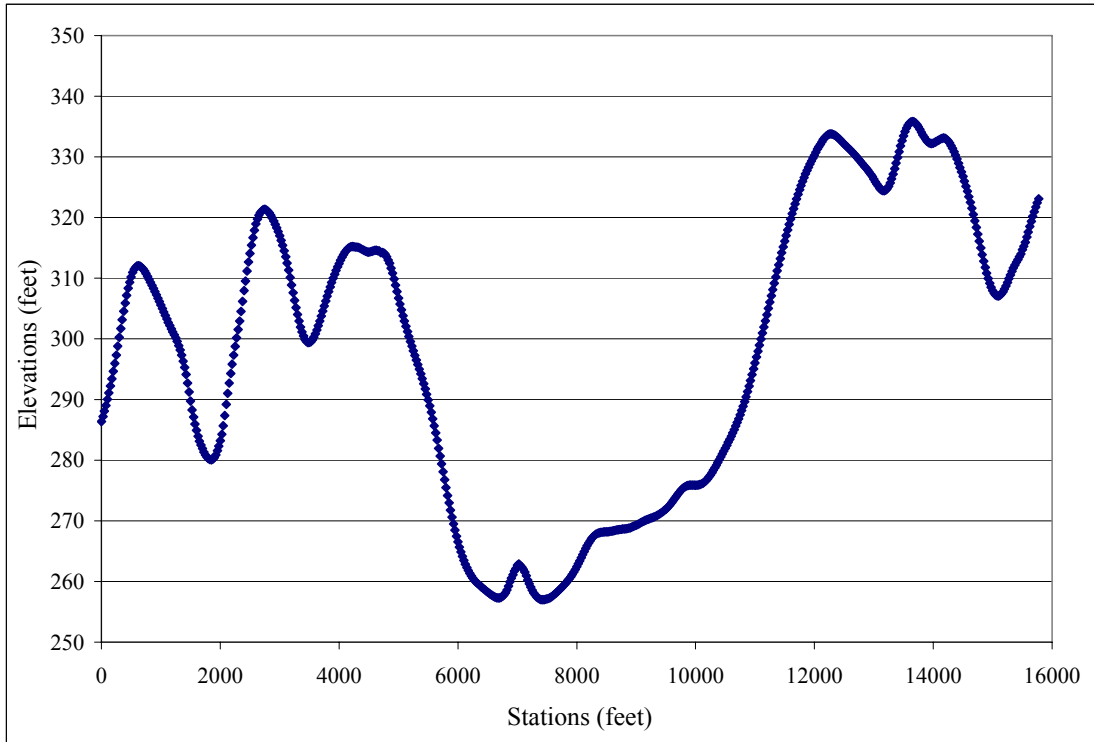
**Figure A-34. FM 912 Westbound Run 3 Smoothed Data.**



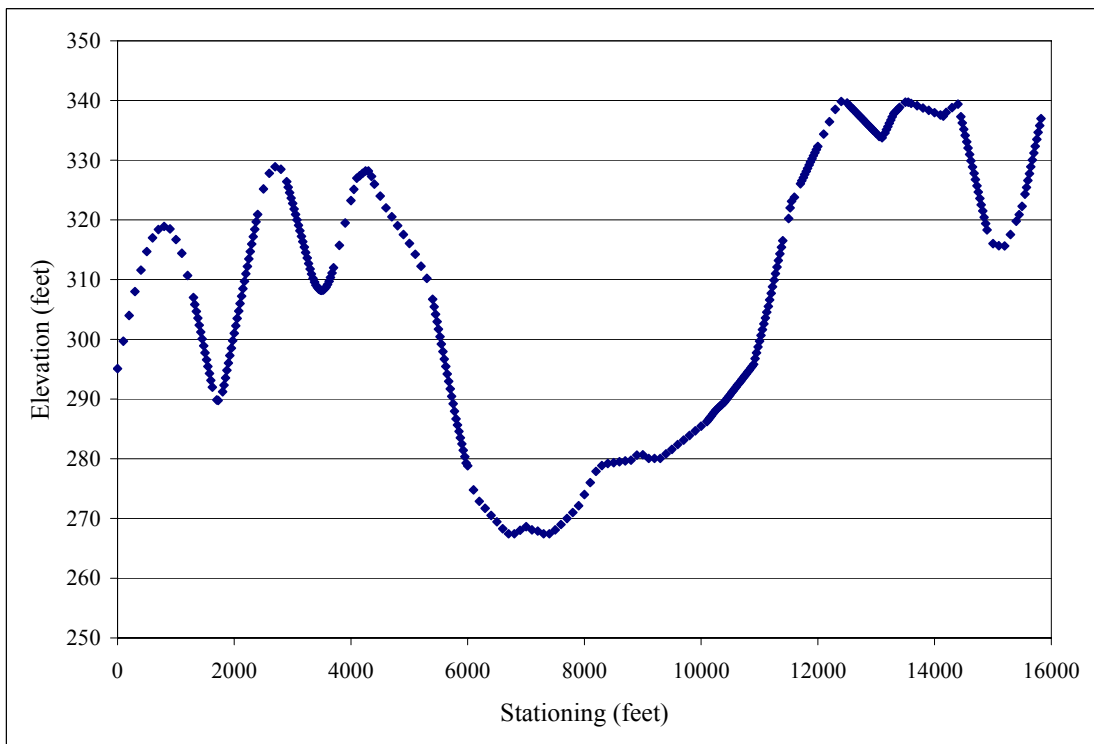
**Figure A-35. FM 912 Westbound Run 4 Raw Data.**



**Figure A-36. FM 912 Westbound Run 4 Smoothed Data.**

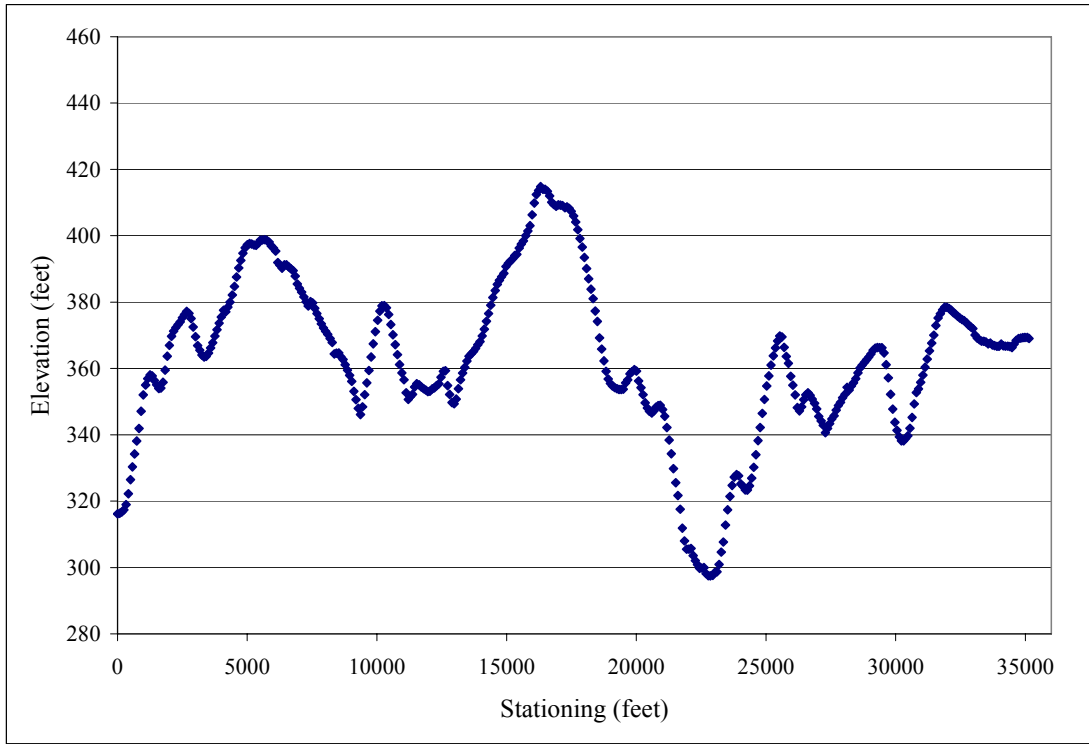


**Figure A-37. FM 912 Westbound Combined Smoothed Data.**

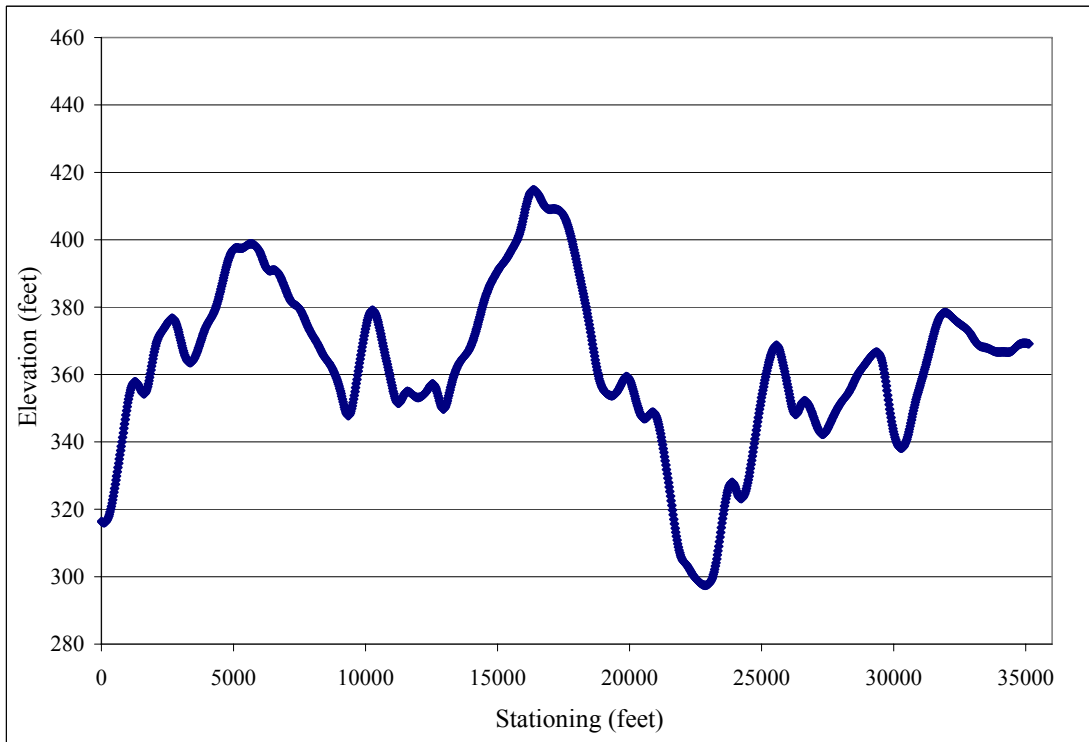


**Figure A-38. FM 912 Westbound Plan Sheet Data.**

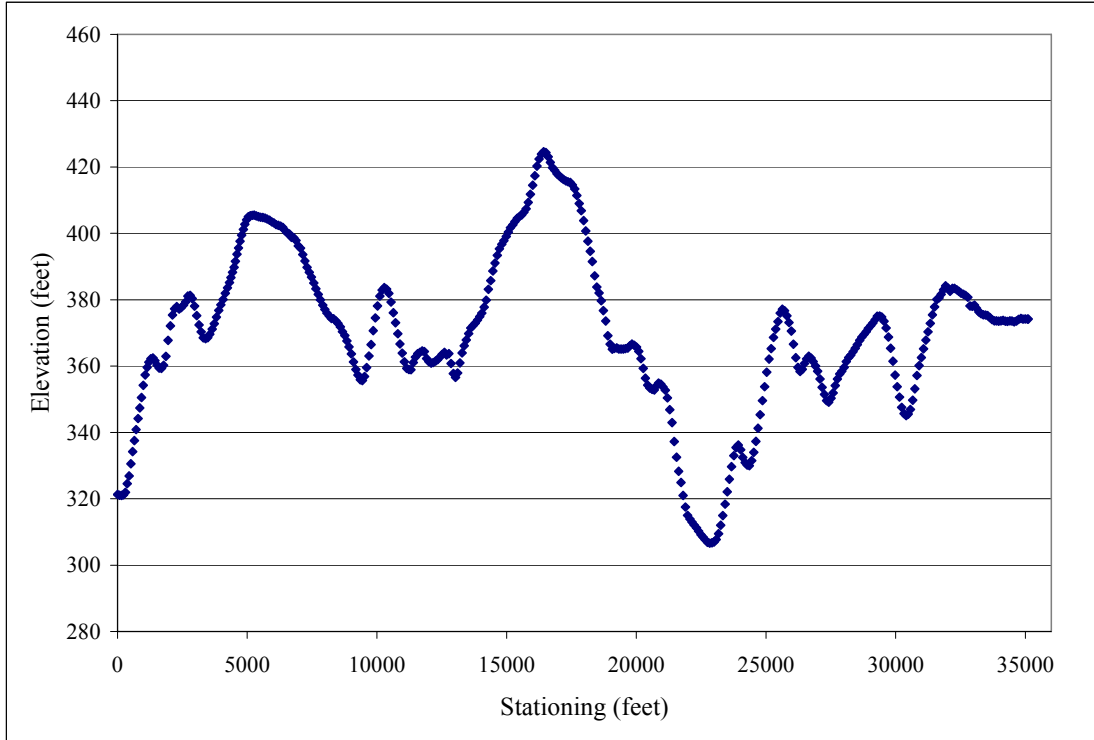
**FM 1940 Southbound**



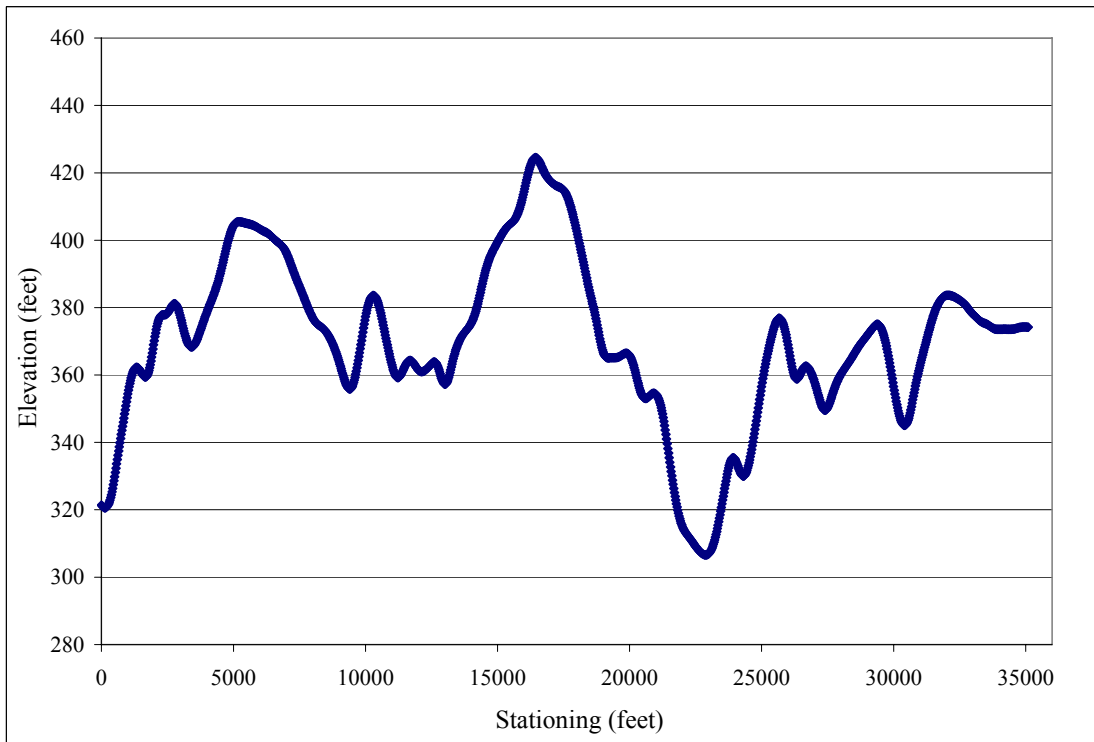
**Figure A-39. FM 1940 Southbound Run 1 Raw Data.**



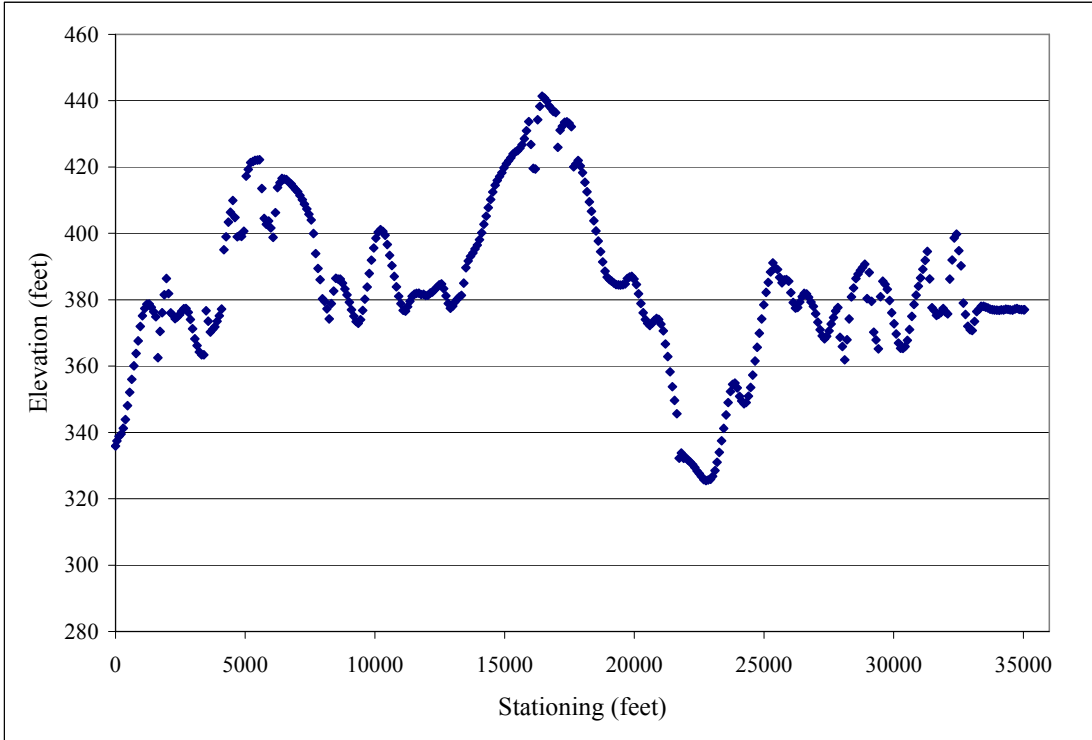
**Figure A-40. FM 1940 Southbound Run 1 Smoothed Data.**



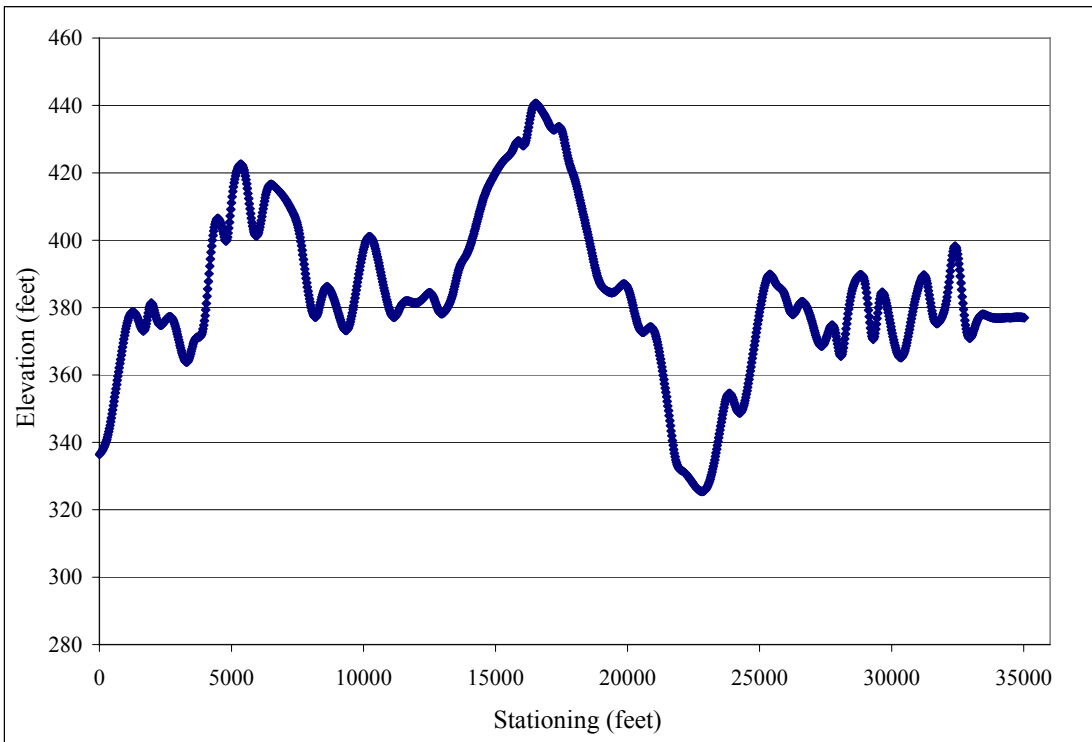
**Figure A-41. FM 1940 Southbound Run 2 Raw Data.**



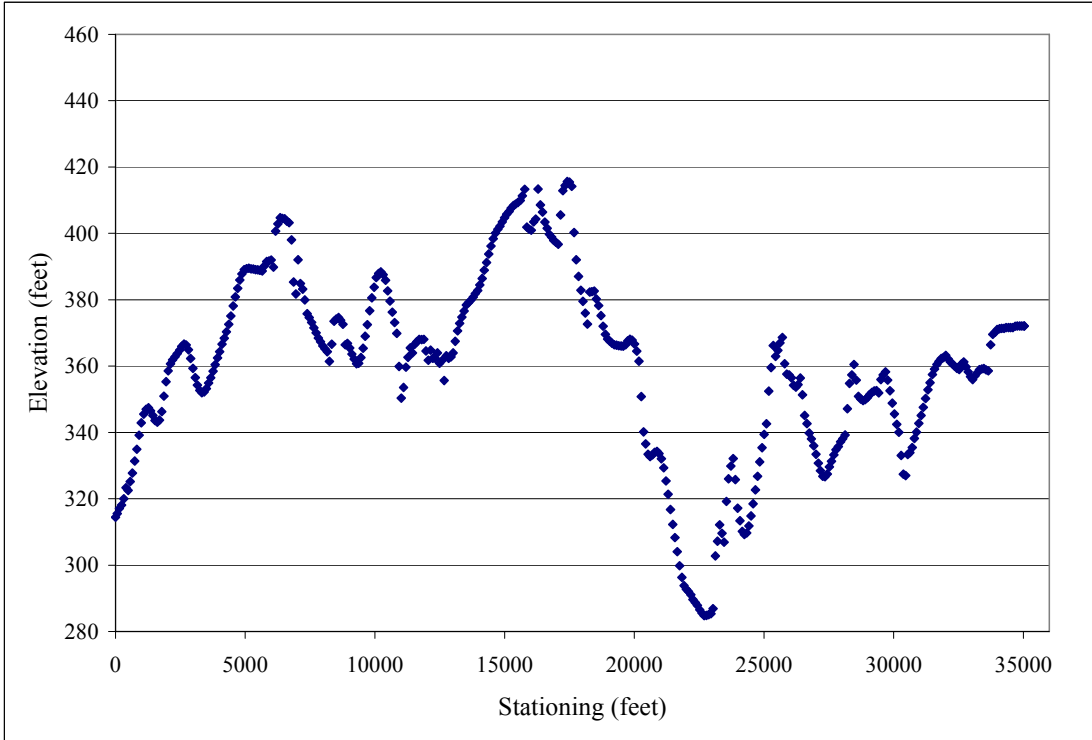
**Figure A-42. FM 1940 Southbound Run 2 Smoothed Data.**



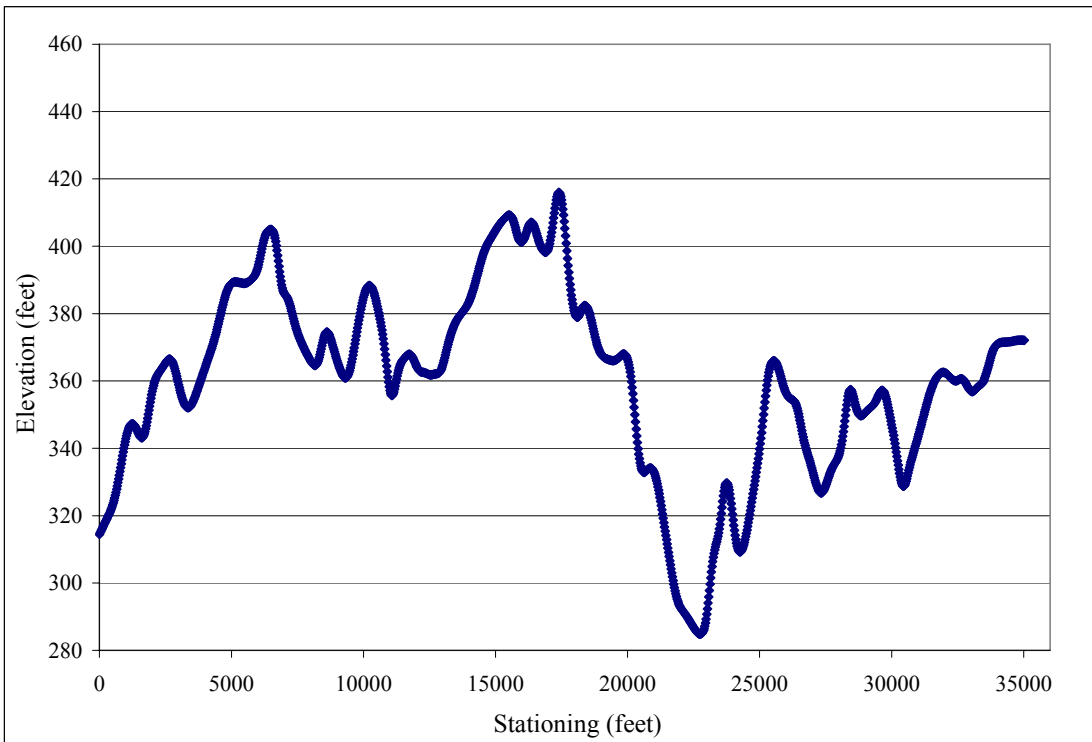
**Figure A-43. FM 1940 Southbound Run 3 Raw Data.**



**Figure A-44. FM 1940 Southbound Run 3 Smoothed Data.**

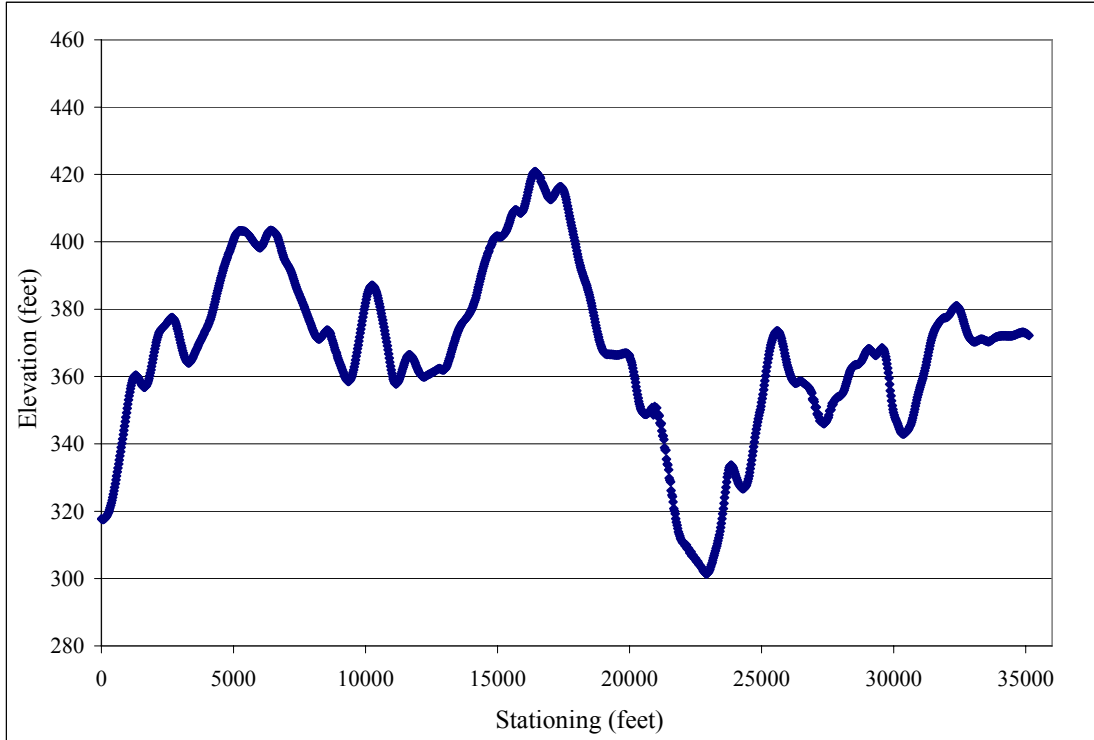


**Figure A-45. FM 1940 Southbound Run 4 Raw Data.**

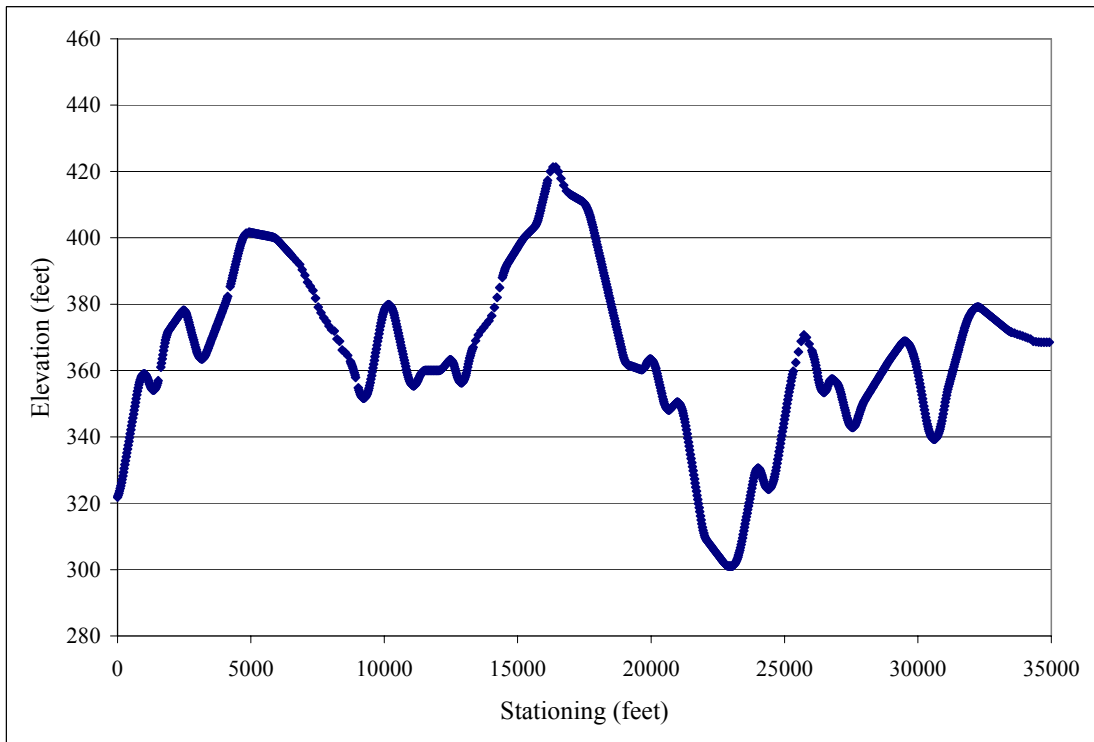


**Figure A-46. FM 1940 Southbound Run 4 Smoothed Data.**



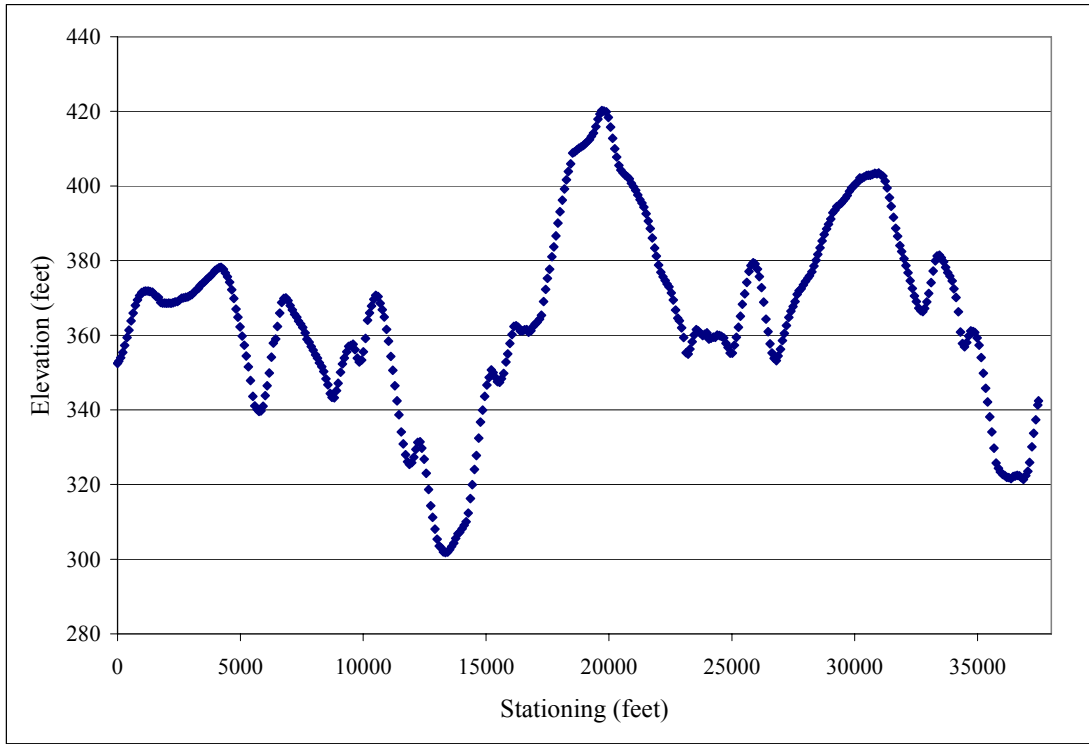


**Figure A-47. FM 1940 Southbound Combined Smoothed Data.**

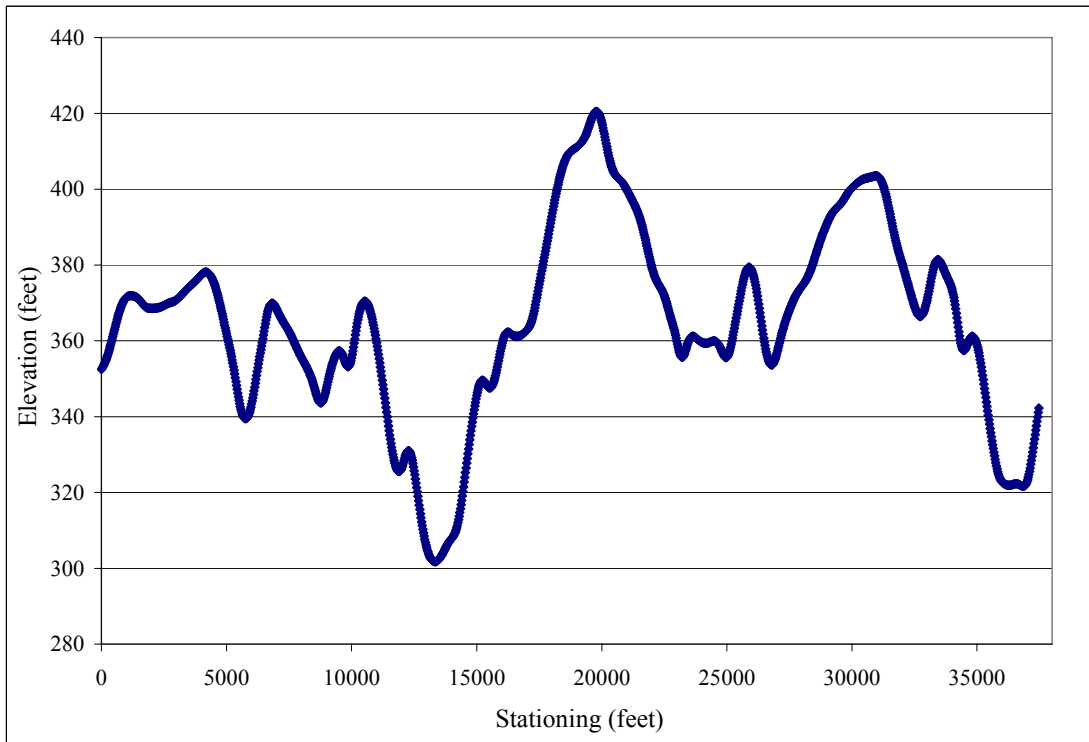


**Figure A-48. FM 1940 Southbound Plan Sheet Data.**

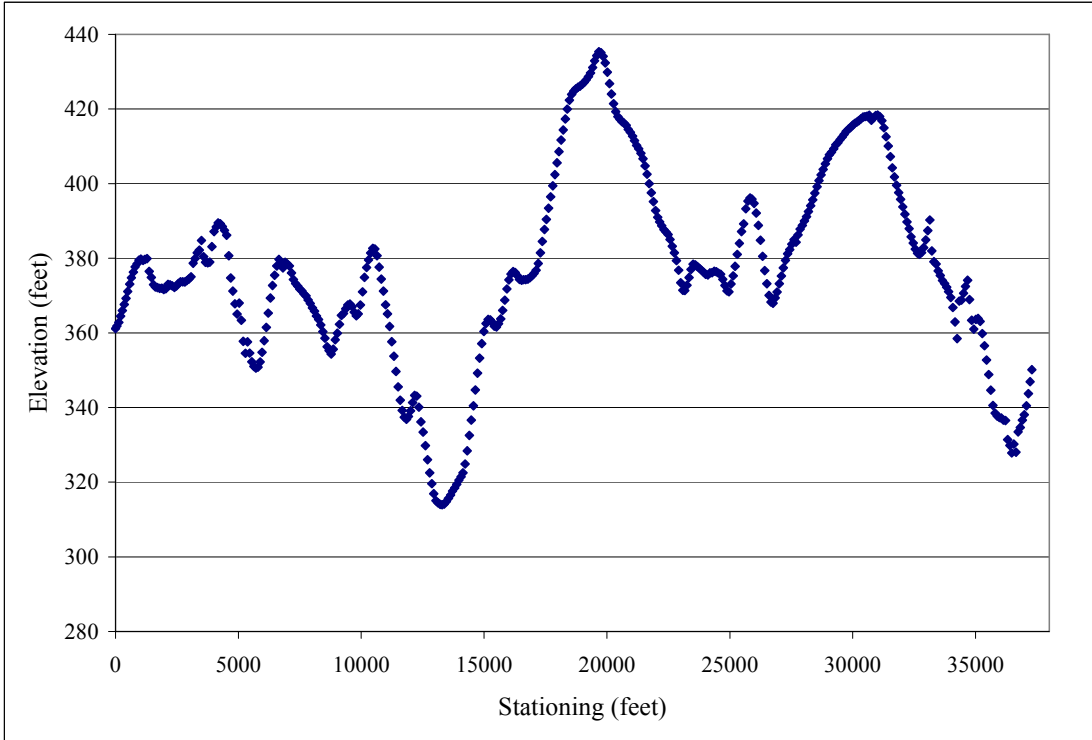
### FM 1940 Northbound



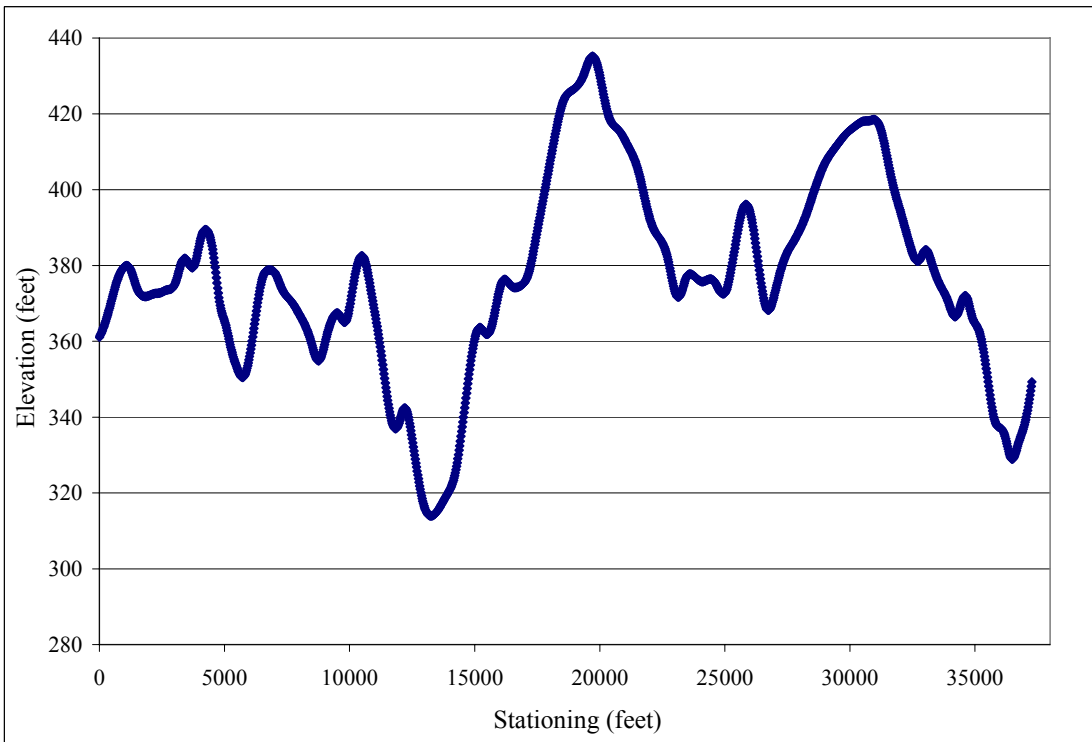
**Figure A-49. FM 1940 Northbound Run 1 Raw Data.**



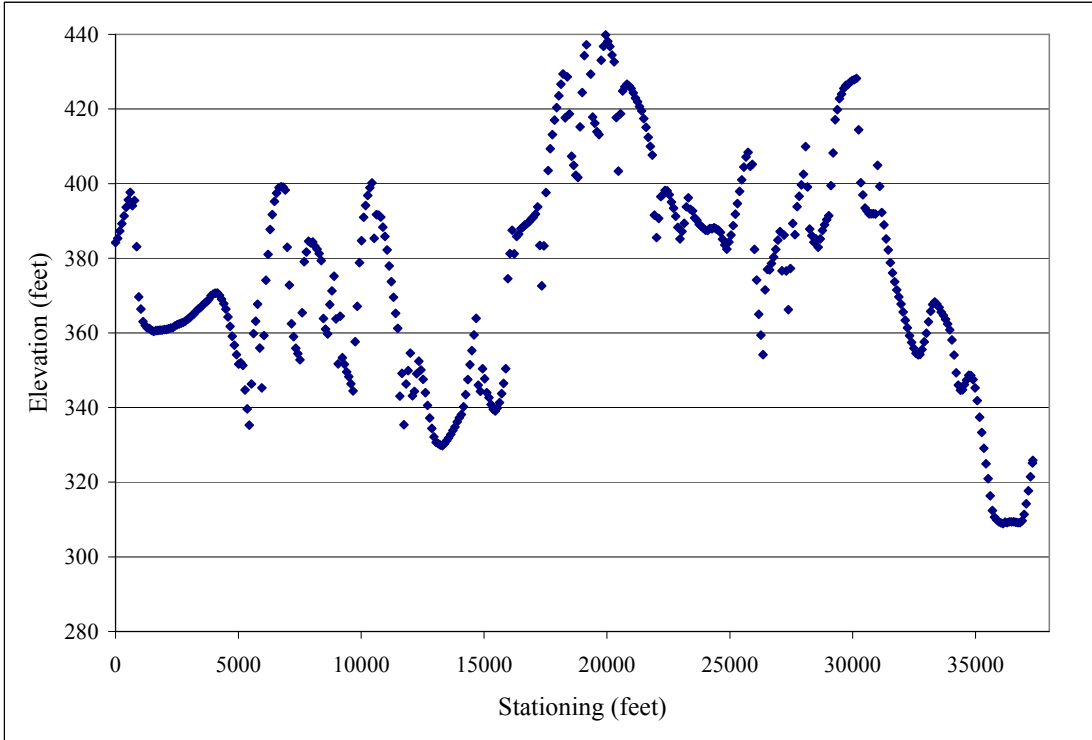
**Figure A-50. FM 1940 Northbound Run 1 Smoothed Data.**



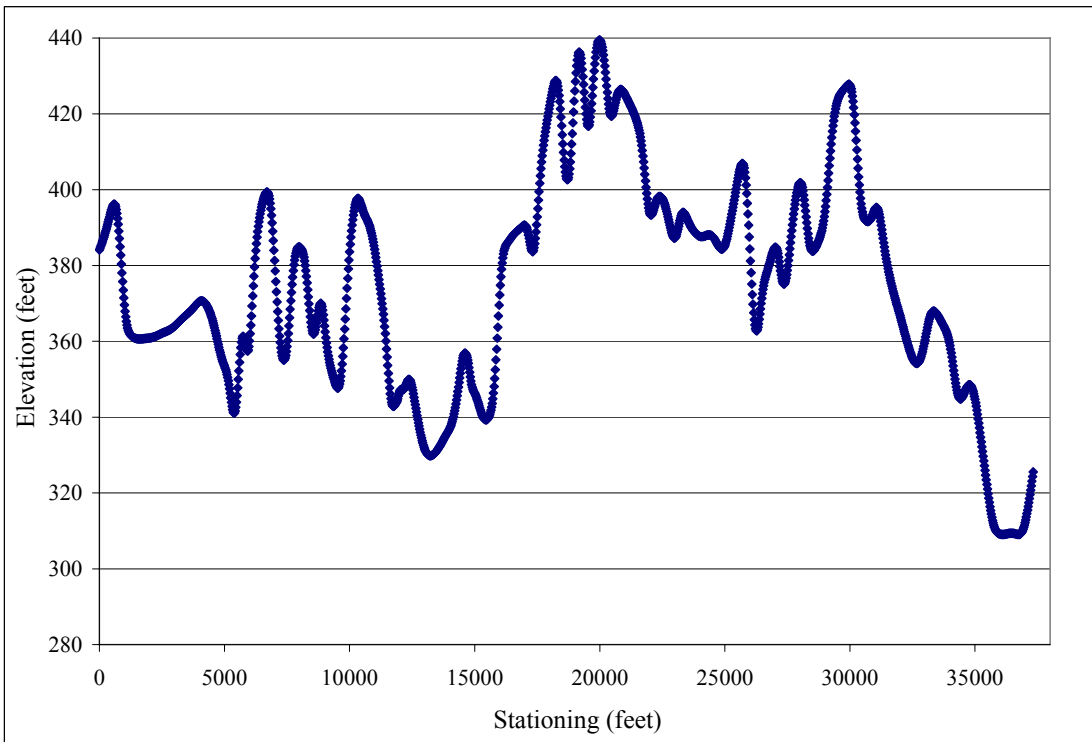
**Figure A-51. FM 1940 Northbound Run 2 Raw Data.**



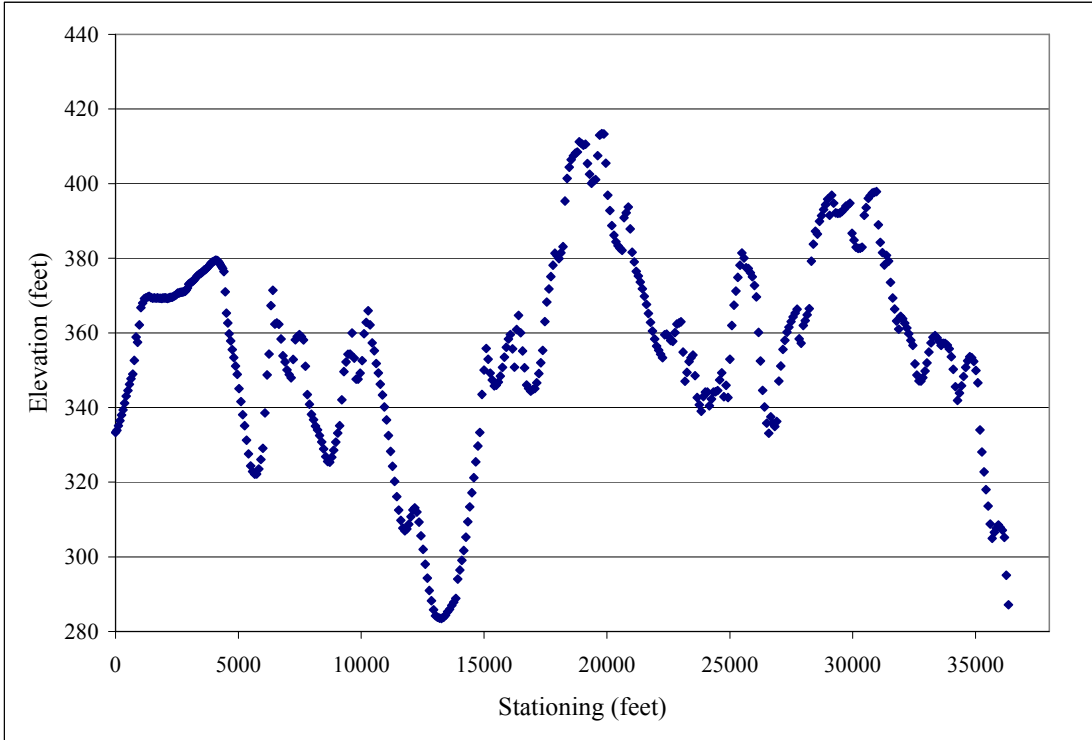
**Figure A-52. FM 1940 Northbound Run 2 Smoothed Data.**



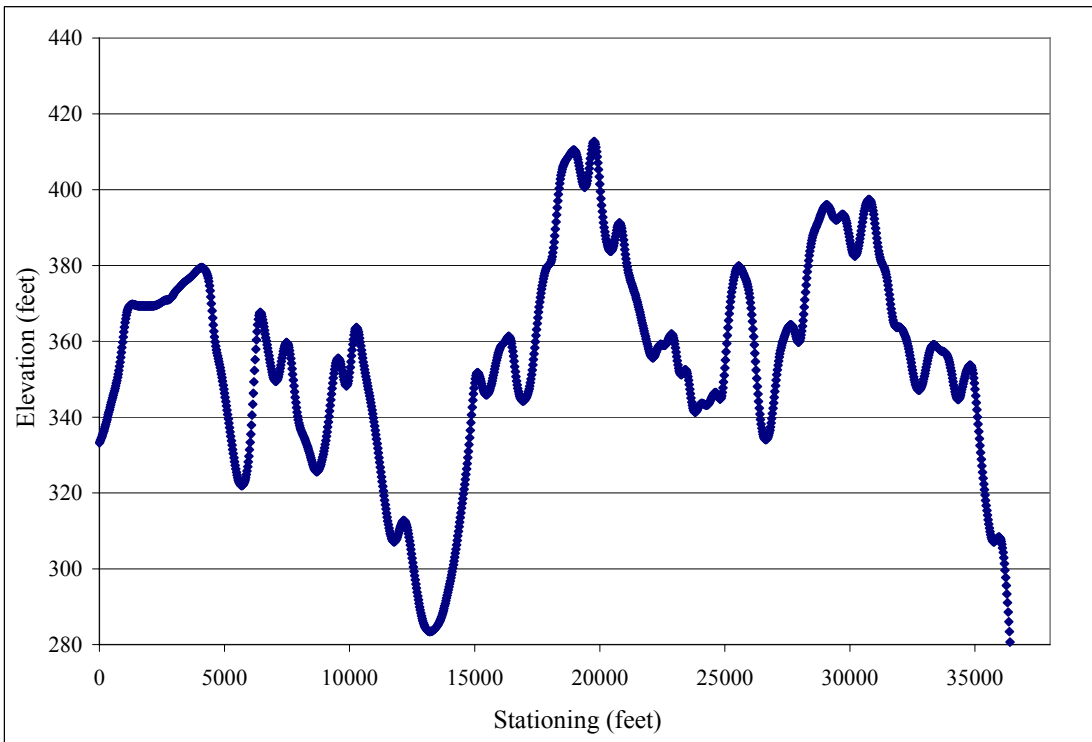
**Figure A-53. FM 1940 Northbound Run 3 Raw Data.**



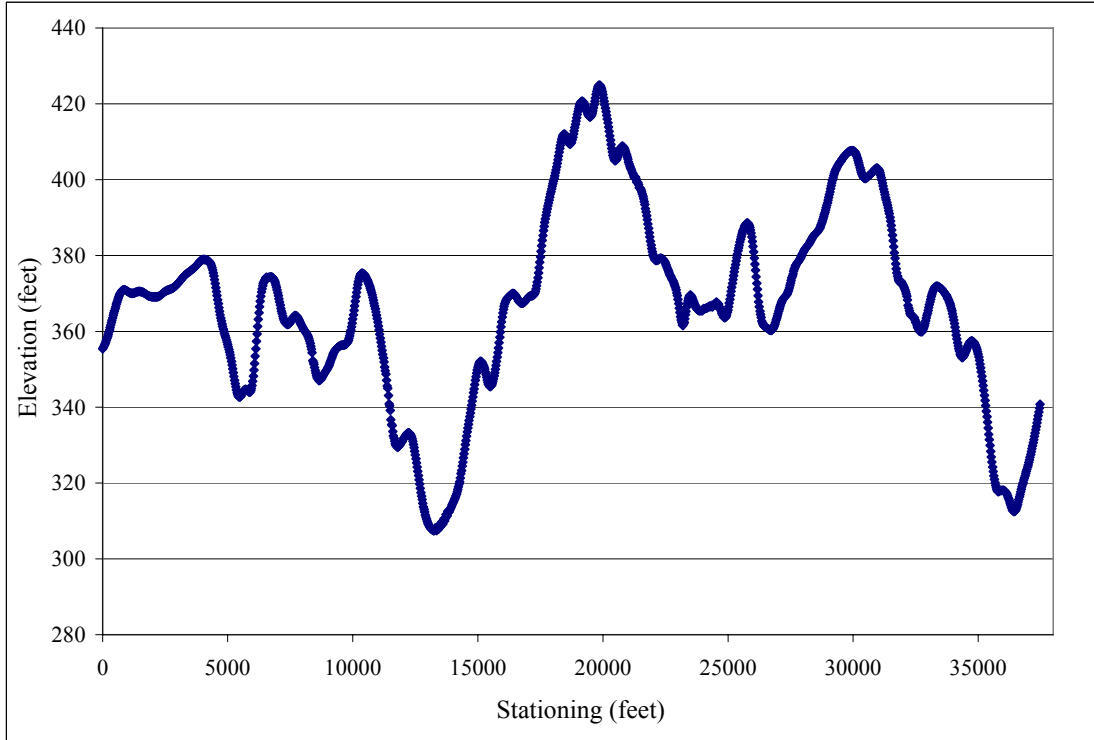
**Figure A-54. FM 1940 Northbound Run 3 Smoothed Data.**



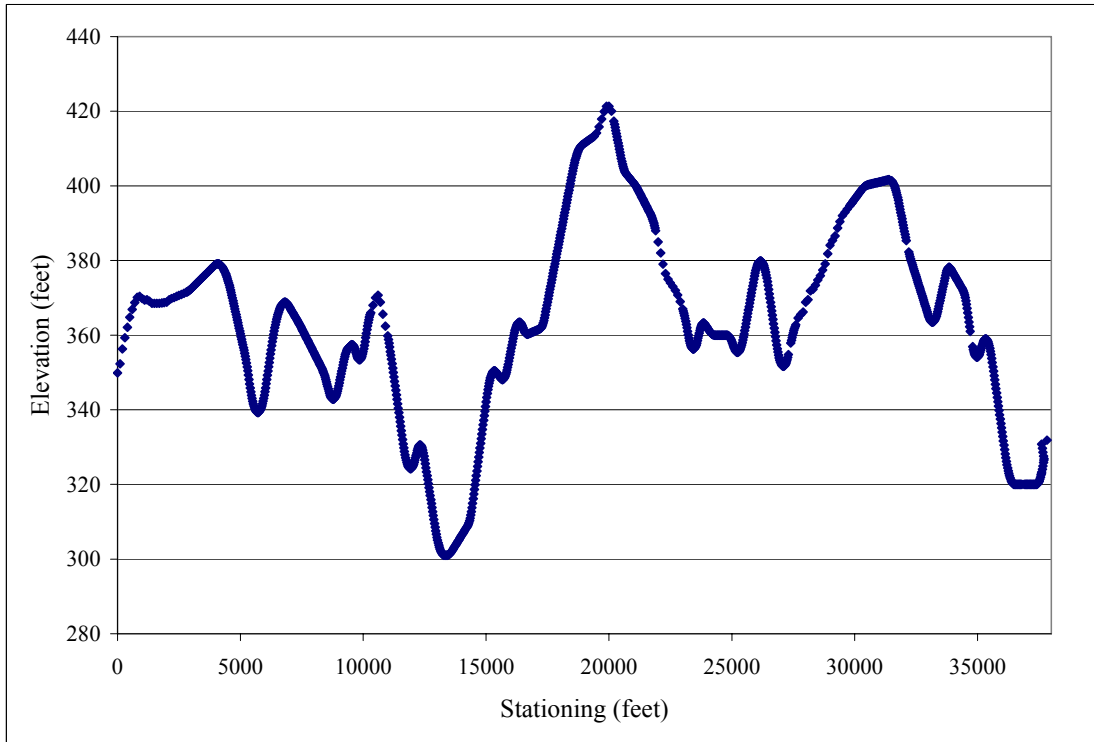
**Figure A-55. FM 1940 Northbound Run 4 Raw Data.**



**Figure A-56. FM 1940 Northbound Run 4 Smoothed Data.**



**Figure A-57. FM 1940 Northbound Combined Smoothed Data.**



**Figure A-58. FM 1940 Northbound Plan Sheet Data.**

**APPENDIX B:  
LEAD-FREE PAVEMENT MARKING MEASUREMENTS**

The tables in this appendix give the detailed results of the color and retroreflectivity measurements for the yellow thermoplastic markings with and without lead.

**Table B-1. Color Specifications for Yellow Pavement Markings.**

Agency	Specification	1		2		3		4	
		x	y	x	y	x	y	x	y
TxDOT	DMS-8220	0.470	0.455	0.510	0.489	0.490	0.432	0.537	0.462
FHWA	Nighttime 30 meter	0.473	0.453	0.510	0.490	0.508	0.415	0.575	0.425
FHWA	Daytime 45°/0°	0.498	0.412	0.557	0.442	0.479	0.520	0.438	0.472

**Table B-2. Results of Retroreflectivity Measurements.**

Site	Material	Measurements	Average
US 79 NB	Lead-free	319 235 257 276 270 249	268
US 79 SB	With lead	197 237 223 243 240 207	225
US 79 SB	Pavement	10 9	10
SH 21 EB	Lead-free	164 179 184 193 207 198	187
SH 21 WB	Lead-free	193 194 206 180 210 220	200

US 79 Leaded application measured day after

US 79 Lead-free application measured 15 minutes after application

SH 21 EB mostly type III beads

SH 21 WB mostly type II beads

SH 21 measured 30 minutes after application

**Table B-3. Results of 30 Meter Color Measurements.**

Site	Material	Measurements	
		x	y
US 79 NB	With lead	0.517	0.449
		0.519	0.449
		0.515	0.447
		0.520	0.447
		0.522	0.448
		0.519	0.443
US 79 SB	Lead-free	0.518	0.462
		0.523	0.457
		0.526	0.454
		0.522	0.458
		0.525	0.456
		0.522	0.457
US 79 SB	Pavement	0.499	0.419
		0.489	0.420
SH 21 EB	Lead-free	0.558	0.412
		0.527	0.447
		0.524	0.449
		0.525	0.451
		0.528	0.446
		0.528	0.444
SH 21 WB	Lead-free	0.529	0.443
		0.520	0.451
		0.524	0.447
		0.521	0.453
		0.519	0.454
		0.518	0.452

Measured with LTL 2000Y



**Table B-4. Results of 45°/0° Color Measurements.**

Site	Material	Illuminant/ Observer	Measurement		
			x	y	Y
US 79 NB	Lead-free	D65, 2°	0.4808	0.4570	46.4
			0.4779	0.4531	45.66
			0.4812	0.4583	44.81
		A, 2°	0.5484	0.4359	54.13
			0.5455	0.4345	54.20
			0.5500	0.4328	51.62
			0.5422	0.4365	53.73
SH 21 WB-1	Lead-free	D65, 2°	0.4904	0.4561	45.51
			0.4850	0.4536	45.72
			0.4886	0.4532	41.84
			0.4908	0.4534	44.46
		A, 2°	0.5521	0.4301	49.91
			0.5456	0.4334	54.04
			0.5502	0.4315	52.01
SH 21 WB-2	Lead-free	D65, 2°	0.4820	0.4482	45.89
			0.4836	0.4570	45.68
			0.4888	0.4605	45.35
		A, 2°	0.5444	0.4342	54.64
			0.5501	0.4323	52.99
			0.5480	0.4330	53.08
Color Sample on metal plate No Beads	Lead-free	D65, 2°	0.4906	0.4648	45.99
			0.4903	0.4645	45.72
			0.4900	0.4644	46.27
			0.4878	0.4627	46.62
			0.4900	0.4641	46.15
			0.4898	0.4646	44.99
		D65, 10°	0.5001	0.4507	43.31
			0.5028	0.4518	42.89
			0.5025	0.4521	43.23
			0.5024	0.4522	43.07
			0.5009	0.4503	42.86
		A, 2°	0.5031	0.4527	42.91
			0.5494	0.4368	53.08
			0.5495	0.4367	53.29
			0.5492	0.4366	52.62
			0.5490	0.4366	52.62
0.5494	0.4359	52.04			
0.5486	0.4365	51.92			

SH 21 WB site 1 was on the WB edge line approximately halfway between the Brazos River and FM 50  
 SH 21 WB site 2 was on the WB edge line just west of the intersection with FM 50

Measurements on no bead only due to inaccurate color rendition with beads, so no measurement on leaded marking, as beads were on the pavement from previous installation the day before.

