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A Streamlined and Automated Procedure for Identifying No-Passing Zones Using Existing Resources Available to the Nevada Department of Transportation

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16. Abstract
Computer aided design (CAD) and geographic information systems (GIS) software should make the identification of no-passing zones possible with the click of a button. However, most highways were built before the use of CAD and GIS software was standard practice in highway design. As a result, the identification of highway segments that require no-passing zone markings is often achieved by transportation agencies using the two-vehicle method field procedure. The two-vehicle method is inherently labor intensive and time-consuming, thus the need for streamlined procedures that can be adopted by transportation agencies. The Nevada DOT (NDOT) continuously conducts asset inventory surveys along highways using an instrumented data collection vehicle. An indirect result of the process includes an accurate dataset that describes the path followed by the data collection vehicle. Software that relies on the vehicle path dataset as input to create a model of the corresponding highway geometry was developed. Using the model, the software automates the identification of theoretical line of sight obstructions based on input from the user. Therefore, the software developed provides NDOT with a decision support system that allows identifying highway segments that are candidates for no-passing zones without the need for dedicated and labor-intensive field surveys.

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The project reported herein was performed under Project P638-16-803 from the Nevada Department of Transportation by the Traffic Operations and Safety Laboratory of the Civil and Environmental Engineering Department at the University of Wisconsin-Madison (UW-Madison). The Board of Regents of the University of Wisconsin System on behalf of UW-Madison was the contractor for the project. The project team was composed of Dr. David A. Noyce, project principal investigator, Dr. Madhav Chitturi, project co-principal investigator, and Dr. Kelvin R. Santiago, project technical lead. The project team would like to acknowledge the collaboration received from the Nevada Department of Transportation staff to make the completion of the project possible. In particular, the help and support received from Mark Wooster (NDOT Project Manager), Chris Wright, Lawrence Black, and Robert Madewell.

ABSTRACT

Computer aided design (CAD) and geographic information systems (GIS) software should make the identification of no-passing zones possible with the click of a button. However, most highways were built before the use of CAD and GIS software was standard practice in highway design. As a result, the identification of highway segments that require no-passing zone markings is often achieved by transportation agencies using the two-vehicle method field procedure. The two-vehicle method is inherently labor intensive and time-consuming, thus the need for streamlined procedures that can be adopted by transportation agencies.

The Nevada DOT (NDOT) continuously conducts asset inventory surveys along highways using an instrumented data collection vehicle. An indirect result of the process includes an accurate dataset that describes the path followed by the data collection vehicle. Software that relies on the vehicle path dataset as input to create a model of the corresponding highway geometry was developed. Using the model, the software automates the identification of theoretical line of sight obstructions based on input from the user. Therefore, the software developed provides NDOT with a decision support system that allows identifying highway segments that are candidates for no-passing zones without the need for dedicated and labor-intensive field surveys.

EXECUTIVE SUMMARY

No-passing zones markings on a highway segment communicate to drivers that there is not enough clear sight distance available to safely complete a passing maneuver that requires entering the opposing lane of traffic, overtaking a leading vehicle, and rejoining the initial lane without aggressively cutting off the passed vehicle. Computer aided design (CAD) and geographic information systems (GIS) software should make the identification of no-passing zones possible with the click of a button. However, most highways part of the existing transportation network were built before the use of CAD and GIS software in highway design was standard practice. As a result, detailed geometric data about existing highways is not always readily available to allow automating the identification of segments that warrant a no-passing zone.

As a result of the limited data available, a standard practice used to identify highway segments that need a no-passing zone still involves the use of field-based procedures that are labor-intensive in nature. A common procedure used, known as the two-vehicle method, requires two vehicles to be driven along a highway separated by a required sight distance determined by the design speed of the segment under analysis. If at a location along the segment the trailing vehicle driver is unable to see the leading vehicle, the implication is that not enough sight distance exists at the location of the trailing vehicle and that no-passing zone markings are required until the location when the leading vehicle becomes visible again. The methodology that is the foundation of the two-vehicle method can be automated if accurate data about the path followed by a vehicle (latitude, longitude, and elevation) is available.

As part of the internal business processes of the Nevada DOT, highway asset inventory surveys are continuously conducted using an instrumented data collection vehicle. An indirect result of the process includes an accurate dataset that describes the path followed by the data collection vehicle. A software tool that relies on vehicle path dataset as input to create a model of the corresponding highway geometry was developed. Using the underlying model, the software tool enables automating the identification of theoretical line of sight obstructions based on input from the end user. The software tool developed provides Nevada DOT with a decision support system that allows identifying highway segments that are candidates for no-passing zones without the need for dedicated labor-intensive field surveys. Therefore, the software tool maximizes the use of Nevada DOT resources by leveraging the power of existing datasets to eliminate the field visits associated with a legacy process. As a result, the process of identifying potential safety issues caused by limited line of sight availability due to existing highway geometry, due to changes to the alignment, or due to changes in posted speed has been streamlined as a result of the project described in this report.

CHAPTER 1. BACKGROUND AND INTRODUCTION

No-passing zones along a highway are typically marked with a double and solid yellow line as shown in Figure 1-1. As the name suggests, a vehicle traveling on a no-passing zone is not allowed by law to pass a leading vehicle while traveling along the no-passing zone. The passing restriction on a segment is caused by a limitation in the sight distance that is available to a driver during the passing maneuver due to a combination of the geometric characteristics and the design speed of the segment.

Sight distance is defined by Garber & Hoel as "the length of the highway a driver can see ahead at any particular time" [1]. Therefore, a limited sight distance scenario for a passing maneuver occurs when a passing vehicle traveling along a segment is unable to see a clear distance ahead on the opposing lane of traffic that is sufficiently long to safely initiate and complete a passing maneuver. A passing maneuver involves entering the opposing lane of traffic, overtaking the leading vehicle, and re-joining the travel lane without cutting off the passed vehicle.

Figure 1-1. Example of No-Passing Zone in Nevada

In Nevada, the topographic characteristics of the state make the existence of highway segments that warrant a no-passing zone, due to limitations in the available sight distance, a common feature of two-lane highways such as the one shown in Figure 1-1. The determination on whether or not sufficient passing sight distance exists on a highway station is based on the measured sight distance available and the design speed of the highway. Across the country, these determinations are often made based on agency-specific policy derived from national guidelines. Determining highway segments that warrant a no-passing zone is key to improving the safety of the transportation network. NDOT guidelines require marking a no-passing zone if the required passing sight distance shown in Table 1-1 is not available for highway segments with the corresponding speed. Available passing sight distance requirements are based on the 85th percentile speed of the highway.

Table 1-1. Minimum Sight Distance Requirements as a Function of 85th Percentile Speed

85th Percentile Speed	**Minimum Passing Sight Distance**	**85th Percentile Speed**	**Minimum Passing Sight Distance**
30 MPH	500 ft	55 MPH	900 ft
35 MPH	550 ft	60 MPH	1000 ft
40 MPH	600 ft	65 MPH	1100 ft
45 MPH	700 ft	70 MPH	1200 ft
50 MPH	800 ft	75 MPH	1300 ft

1.1 THE NEED FOR A STREAMLINED SIGHT DISTANCE MONITORING PROCEDURE

In the past, the policy of the Nevada Department of Transportation (NDOT) called for the use of the two-vehicle [2] method to locate segments along a highway that should be marked as a no-passing zone. The two-vehicle method requires two vehicles to be driven along a highway separated by a known distance determined by the design speed of the highway. If at a location along the highway the trailing vehicle is unable to see the leading vehicle, the implication is that not enough sight distance exists at the location of the trailing vehicle and that a no-passing zone is required at that point.

While standard practice, the two-vehicle method can be time-consuming and labor-intensive, especially since NDOT relies on a 3-person crew to perform the field work. The complexities and requirements associated with the two-vehicle method led NDOT to implement a technology-based solution that streamlined field-procedures associated with the two-vehicle method. However, equipment required by the solution adopted by NDOT is no longer sold/supported by the vendor. As a result, NDOT needs a new system that can streamline the process of locating no-passing zones.

With the advances in computer aided design (CAD) and geographic information systems (GIS), an argument can be made that identifying no-passing zones is something that should be possible with the "click of a button" and that field-based and labor-intensive procedures are unnecessary. However, the reality is that most highways part of existing transportation networks were built before the use of CAD and GIS in highway design was standard practice. Therefore, obtaining the detailed geometric characteristics of highways built before CAD and GIS were standard tools is still not possible without some form of field-based dedicated data collection effort. Furthermore, even when the foundations for establishing no-passing zones policies have not changed since 1948 [3] changes in posted speeds often trigger a need for labor-intensive reviews of the alignment characteristics. For example, changes in parts of a highway vertical profile due to resurfacing projects could also trigger the need for a review of available sight distance for highway segments. As a result, tools to streamline the sight distance analysis procedures are still needed.

1.2 PREVIOUS RESEARCH

The need for these streamlined tools or procedures has prompted research throughout the years aimed at making the measurement of available sight distances and understanding the characteristics of existing highway alignments in general a simpler, more accurate, and faster process. Research efforts range from early-stage efforts to simply streamline the process to newer computer-based procedures that take advantage of data from global positioning system (GPS) sensors.

1.2.1 Early-Stage Computational Efforts

In 1989 work by Berg et al. [4] in Wisconsin introduced software capable of using Photolog data to locate horizontal curves and “provide estimates of the radius, length, superelevation, and maximum recommended speed”. The program identified “the location of segments with either stopping or passing sight distance restrictions due to horizontal and vertical alignment” [4]. As an early stage solution, Berg’s et al. program had limited success but demonstrated the feasibility of using similar data to conduct highway safety evaluations.

Regardless of the limitations, Berg et al. procedures remain valid and when modified can work with newer datasets. In fact, Drakopoulos and Örnek [5] relied on Wisconsin DOT photolog data to show that a more advanced algorithm can be used to obtain highway design information; a key factor in the automatic identification of available sight distance. Wisconsin efforts towards the use of existing data sources to evaluate highway alignments continue to this date. For example, Li et al. [6] used a centerline shapefile data to automatically finding curve radii across Wisconsin while Santiago et al. [7] used photolog data to find line of sight obstructions caused by vertical alignment geometry, a procedure further improved as part of the work documented in this report.

1.2.2 Automated Methodologies

In theory, if a dataset that represents the centerline and elevation of a highway alignment is available, the automation of sight distance evaluations is straightforward. However, in practice a high-quality dataset is rarely available thus forcing engineers to rely on field-based studies to determine available sight distance values. Independent of standard practices and limitations, researchers have proposed solutions and techniques to automate the available sight distance evaluation process. Proposed solutions often rely on the use of consumer-grade GPS devices to collect and analyze highway alignments [2], [8], [9].

Consumer grade GPS sensors generate data that is not sufficiently accurate and consistent to represent the characteristics of the highway geometry. The limitation is illustrated in Figure 1-2 which shows GPS sensor data obtained from the highly-accurate sensors typically found in a dedicated data collection/asset inventory vehicle and data from a consumer grade GPS sensor such as those found in cellphones. As the figure shows, data from the data collection vehicle is evenly and consistently spaced along the route with limited deviation from a clear path. On the other hand, data points from the consumer grade sensors have a higher degree of deviation from a clearly defined path and are not evenly spaced along a surveyed route thus introducing the challenges discussed ahead into the analysis process.

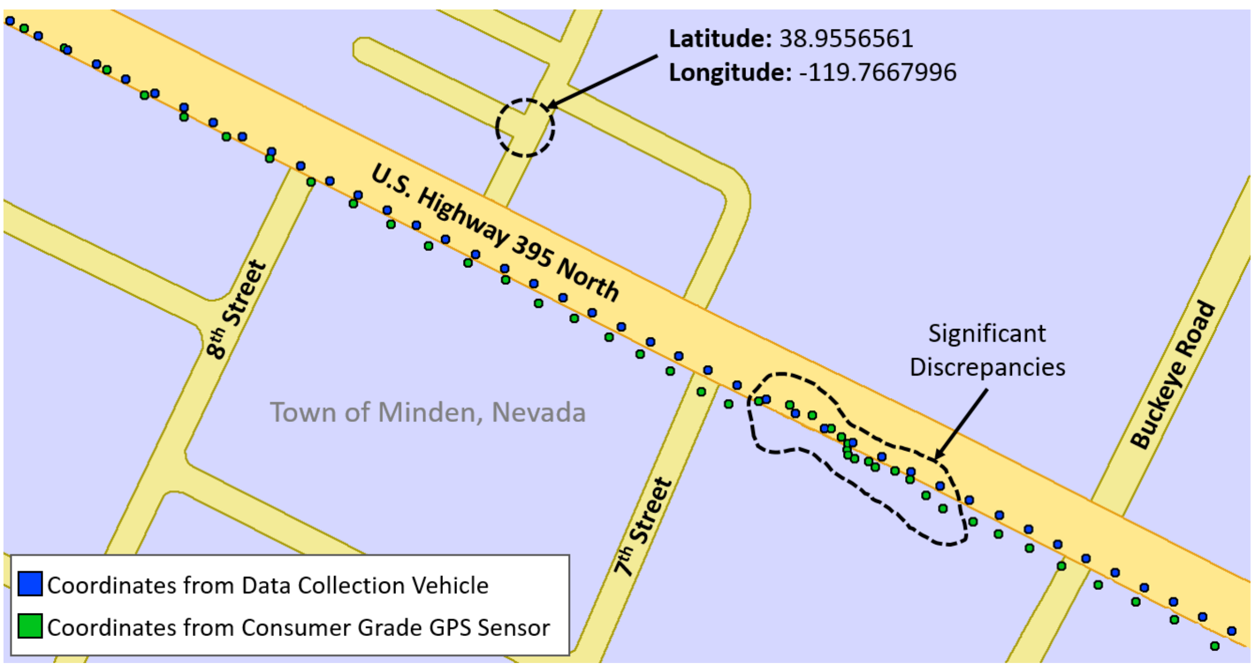


Figure 1-2. Visualization of Data from Different GPS Sensors

Challenges with existing procedures include coordinate transformations, removal of outliers, and data smoothing. Smoothing needs are usually triggered by the use of consumer-grade GPS devices. In fact, Williams [9] created an analysis algorithm for sight distance evaluation and mentioned GPS data quality as a concern. Therefore, better GPS data, such as the one from an NDOT data collection vehicle, is key to creating an accurate highway alignment model. Even with data quality limitations, the literature is full of examples where GPS data has been used successfully to evaluate highway geometry. Nehate and Rys [10] combined GPS and design information (lane width and clear zone) to find stopping sight distance values by considering line of sight obstructions of vertical and horizontal nature. Nehate and Rys [10] work was an expansion of work by Lovell in 1999 [11] who proposed evaluating sight distance by considering only obstructions of horizontal nature and without the use of GPS data.

And while research continuously shows the feasibility of streamlining/automating sight distance computations, practices across DOTs have not caught up. DOTs appear not to be willing to sacrifice a certain degree of practicality in their existing processes. As a result, labor-intensive methods such as cone, eyeball, walking, and spotting remain the standard practice used to locate no-passing zones [8].

1.3 THE POTENTIAL OF EXISTING DATASETS

Previous research on streamlining/automating the process of identifying line of sight obstructions, a key component of the no-passing zone identification process, has been focused on establishing mathematical procedures and on small-scale field tests. However, no work has created end-user-focused software capable of conducting a statewide level evaluation of line of sight obstructions that can be used to identify highway segments that should have no-passing zone markings. Fortunately, technology and data analysis procedures have evolved in such a way that datasets commonly owned by transportation agencies across the country can be used to identify locations along a highway with available sight distance values that warrant a no-passing-zone designation based on the design speed. These datasets eliminate the accuracy concerns associated with some of the procedures that rely on data obtained from consumer-grade GPS sensors.

One of these available datasets is the path followed by data collection vehicles used by transportation agencies for pavement performance monitoring and the inventory of highway assets. In fact, a by-product of the highway asset inventory process currently used by NDOT are data files for each highway route surveyed that contains the cumulative distance, elevation, and geographic position (longitude and latitude) followed by the data collection vehicle. These files, which contain observations spaced every 26.4 feet, can be used to create an accurate model that describes the vertical and horizontal alignment characteristics of each highway route surveyed during the asset inventory process. Throughout the report, the term highway route (or simply route) refers to a dataset representing vehicle positions on a highway along the direction of travel. Except for one-way highways, each highway is typically surveyed once per direction thus resulting in two route datasets.

1.4 OBJECTIVES

The Traffic Operations and Safety (TOPS) Laboratory from the University of Wisconsin-Madison was selected by NDOT to create a software tool capable of analyzing data generated by the asset inventory vehicle used by NDOT and streamlining the available sight distance analysis process. Therefore, the objective of the work presented was the development of the software tool. The development process involved expanding previous work by members of the TOPS Laboratory to make possible the identification of theoretical line of sight obstructions due to vertical and horizontal alignment characteristics.

1.4.1 Evolution of Software Architecture Decisions

During initial discussions between the TOPS Laboratory and NDOT staff at the beginning of the project, the idea of creating an analysis tool that was web-based was explored. However, one of the challenges identified with a web-based tool was the availability of resources for the immediate and long-term support of the required server. And while a web-based system would have provided simple access to the system to anyone within the department, the potential support challenges steered the project team away from the initial idea.

As a result, and in order to balance the initially-identified need for an easy to access interface and a tool with low IT support requirements, a decision was made to focus development on a stand-alone desktop application that does not require any special permissions or a formal installation to run. The stand-alone tool created by the TOPS Laboratory is contained within a directory that can be placed on any directory of the end-user computer to which the user has write privileges. Alternatively, the end-user can keep the directory containing the tool executables and supporting files inside a flash drive and run the software directly from the flash drive once connected to a computer.

1.5 REPORT STRUCTURE

Chapter 2 of this report describes the programming languages used to create the sight distance analysis tool, the data required for the operation, and the underlying theory that makes the data analysis procedures implemented possible. Chapter 3 describes the typical results from the software tool along with some of the limitations of the procedures. Chapter 4 provides an overview of the interface and a description of the configuration files that govern the analysis executed by the software. Finally, Chapter 5 presents conclusions and the recommended implementation approach.

CHAPTER 2. SOFTWARE TECHNICAL DETAILS

As mentioned in Chapter 1, a software tool that relies on data collected using the asset inventory vehicle owned by NDOT was created as part of this project to visualize the data and perform line of sight obstruction evaluations. A screenshot of the main screen of the software is shown in Figure 2-1. As the figure shows, the software allows users to "virtually navigate" a highway. In addition to the virtual navigation, tools within the software allow the user to identify segments with potential line of sight obstructions based on the route data and user-defined analysis parameters.

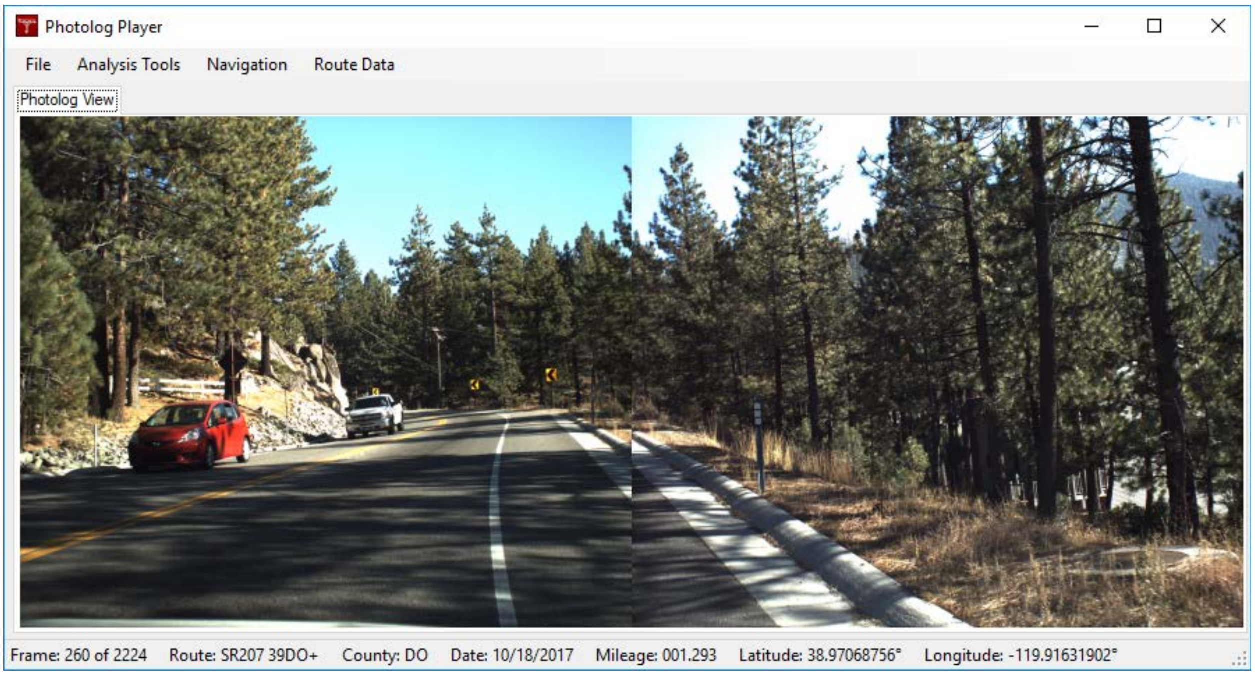


Figure 2-1. Screenshot of Software Displaying Highway Route

The software was designed to run without the need of installation thus making it easier to deploy by end users. The sections ahead describe some of the technical characteristics of the software, including the programming languages used, input files required, and nature of computational procedures. The goal of the sections ahead is not to provide instructions on how to use the software but to describe the underlying technical details. A summary of the software interface that acts as a user manual is presented in Chapter 4.

2.1 PROGRAMMING LANGUAGES USED AND CODE DELIVERY METHOD

Two languages were used in the development of the software. The first language was Visual Basic™ .Net (Vb.Net) and the second was JavaScript™. Vb.Net was used to create most of the software while JavaScript™ was used to create the web interface that displays the route data on a map. The web interface relies on the *OpenLayers Map Viewer Library* [12] and requires internet connectivity to display the *OpenStreetMap* [13] data. The software also uses the *DotSpatial* [14] project by loading it as a dynamic-link library (DLL) to enable the projection of latitude and longitude into X and Y coordinates.

2.1.1 Compatibility and Operating System Requirements

The software should run on computers that have Microsoft Windows™ and the .Net 4.5.2 framework installed. These requirements are typically satisfied by most computers that are kept up to date at transportation agencies across the country. Testing conducted on March 29, 2018 confirmed that the software was able to run on an NDOT computer running Microsoft Windows™ 7. No installation is required thus allowing anyone with a copy of the software executables, along with associated support files, to run the software on their computer thus reducing the IT support required to implement the deliverables of this project.

All the code associated with the software, including the executable files, were delivered to the NDOT project manager. The code consists of a Microsoft™ Visual Studio™ project in the Vb.Net programming language. The project was created using Microsoft™ Visual Studio™ 2015 Community Edition. Additional resources were created as part of the project (e.g., images used by the software). These resources, and associated source files have also been included as supplemental digital project files delivered to the NDOT project manager.

2.2 ROUTE DATA REQUIRED TO ENABLE THE SOFTWARE FUNCTIONALITY

To enable the software operation, the only requirement is the GPS file for a highway route produced after the data collection process followed by the NDOT Roadway Systems division is complete. However, to improve the user experience and to simplify the process of visualizing the results, photos obtained by the data collection vehicle for the front and right side of the highway should also be used as input for the software. Figure 2-2 shows a screenshot of a typical directory (or “folder”) that contains the recommended data that should be used as input by the software. The *Front* and *Right* folders contain photos associated with the vehicle positions contained in the GPS file. The two folders can be in the same directory as the GPS file. Alternatively, both directories can be inside a directory named according to the route id (e.g., 6DO_-) that is in the same directory as the GPS file as shown in Figure 2-2. For simplicity in the illustration, other files that are typically included in the same directory as the GPS file are not show in the screenshot since the extra files are not required by the software.

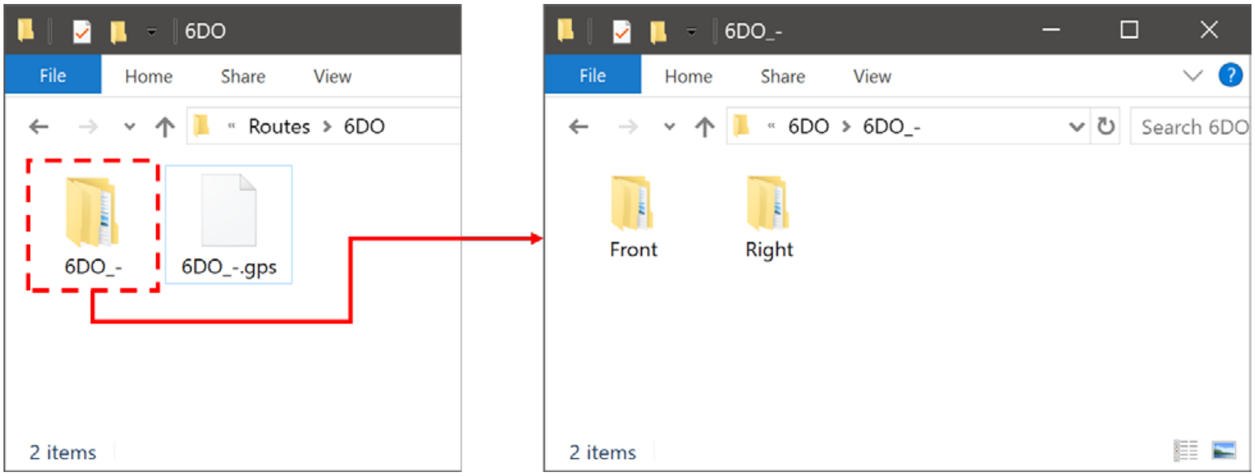


Figure 2-2. Structure of Sample Folder Containing Route Data

2.2.1 Nature of Data in the GPS File

The GPS file shown in Figure 2-2 is a binary file containing "rows" of data for different positions along a highway. Each row is associated with information reported by the data collection vehicle instruments. Viewing the content of GPS files requires the use of a "hex editor" software as shown in Figure 2-3. Hex editors allow users to modify/view the binary data that define a file by displaying the hexadecimal representation of every byte in the file, something not possible with traditional text editors which only display the ASCII-based representation of data.

Offset	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F	10	11	12	13	14	15	16	17	18
000000	01	33	2A	66	40	F0	B8	C1	50	EE	0D	F0	41	0D	63	2F	91	60	66	6E	40	44	42	43	4F
000025	FC	A0	3A	C0	5D	D5	84	62	A0	CA	E7	40	94	A2	A6	CD	E1	3E	0F	00	00	00	01	00	00
000050	00	00	00	00	00	00	43	2F	AF	FA	01	33	2A	66	40	F0	B8	C7	27	DA	5F	E0	41	0D	63
000075	6F	A5	60	81	61	40	44	42	40	F5	16	42	3A	C0	5D	D5	84	45	A5	92	BE	40	94	A3	DC
000100	EF	66	E7	02	00	00	00	02	00	00	00	00	00	00	00	00	43	2F	B9	67	01	33	2A	66	40
000125	F0	B8	CD	02	C9	22	48	41	0D	63	AF	CD	0D	A6	E7	40	44	42	3E	99	8D	A4	68	C0	5D
000150	D5	84	28	A9	F6	04	40	94	A5	33	15	B1	32	27	00	00	00	03	00	00	00	00	00	00	00
000175	00	43	2F	B0	29	01	33	2A	66	40	F0	B8	D2	E1	D1	6C	50	41	0D	63	EF	FF	72	CF	44
000200	40	44	42	3C	3D	C6	E6	70	C0	5D	D5	84	0B	32	1D	03	40	94	A6	A8	08	60	70	C1	00
000225	00	00	04	00	00	00	00	00	00	00	00	43	2F	AE	C2	01	33	2A	66	40	F0	B8	D8	C0	DA
000250	71	C0	41	0D	64	30	01	AF	91	BC	40	44	42	39	E3	E1	37	6E	C0	5D	D5	83	ED	33	0D
000275	73	40	94	A8	27	8E	36	42	57	00	00	00	05	00	00	00	00	00	00	00	00	43	2F	A5	91
000300	01	33	2A	66	40	F0	B8	DE	A8	14	E1	D8	41	0D	64	70	28	AC	4F	FB	40	44	42	37	88
000325	D0	BA	0E	C0	5D	D5	83	CE	51	1D	6C	40	94	A9	BF	F5	20	F4	29	00	00	00	06	00	00
000350	00	00	00	00	00	00	43	2F	84	35	01	33	2A	66	40	F0	B8	E4	93	AC	2C	A0	41	0D	64

Figure 2-3. View of the Content of a GPS File Using a Hex Editor

In Figure 2-3, rows of data contained in the GPS file are highlighted. As the figure shows, each row of data is made out of 60 bytes easily identifiable because of the similar sequence of hexadecimal number values ("01 33 2A 66") at the start of each row. The software tool described in this report is able to process the structure of the file and extract values that are key for the line of sight analysis procedures introduced.

A list of the key values used by the software in the analysis procedures are shown in Table 2-1. Using the values, it is possible to describe the vertical profile of a highway as shown in Figure 2-4.

Table 2-1. Key Values in GPS File

Name	Description
Distance	Cumulative distance along the highway as measured by the vehicle instruments.
Latitude	Latitude value at the corresponding distance.
Longitude	Longitude value at the corresponding distance.
Elevation	Elevation of the GPS antenna at the corresponding distance.

In Figure 2-4, the elevation and cumulative distance values are plotted on a Cartesian-style plane thus enabling the visualization of the vertical profile of a highway segment. While not shown, a similar figure can be created that shows the horizontal characteristics of the highway segment by plotting longitude values on the X-axis and latitude values on the Y-axis. The lines connecting the points in Figure 2-4 should be treated as supporting the visualization since in the GPS file no data exists between the points. Therefore, the GPS file should be treated as containing a discrete model of the highway alignment in terms of position and elevation. Because the distance between the points (D_P) is sufficiently small, the discrete model can be treated as accurately representing the continuous nature of a highway.

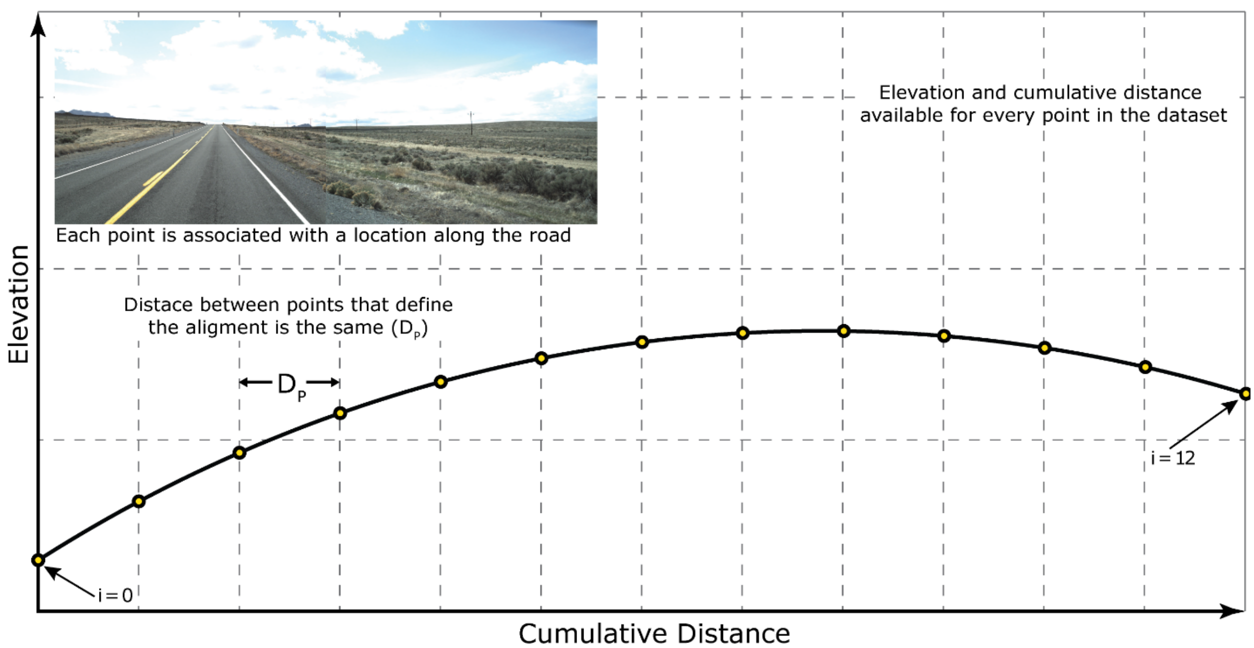


Figure 2-4. Illustration of Highway Vertical Profile Available for Analysis

It should be noted that the elevation values reported in the GPS file are for the antenna of the GPS sensor. Therefore, as will me mentioned ahead, an assumption is made that due to the constant and small offset between the highway surface and the antenna, an elevation-distance model created from the path followed by the antenna is equivalent to that of the highway surface. The sections ahead describe the steps that are involved in determining if a theoretical line of sight obstructions exists between a point i and a point downstream of the highway that is at least a distance $\mathrm{T_D}$ from the point i. Individual steps are presented for finding obstructions due to the vertical profile of the highway and for obstruction due to the horizontal alignment. The software presented in this report executes the procedures described, including the iterations mentioned ahead, on every point part of the GPS file to generate results describing if sufficient sight distance exists at a given point or, if not, how much sight distance is available.

2.3 DEFINITION OF KEY NOTATION

Steps for the sight distance analysis procedures outlined in the sections ahead require the definition of a specific notation to facilitate the explanation. Table 2-2 shows the notation used along with a description of what the notation represents. A key item that is important in the notation is the use of an index value to represent a row of data, i.e., a vehicle position, contained in the GPS file as a photolog frame and associated with the information shown in Table 2-1. In a highway route for which 5000 photolog frames were collected, the first frame is represented by index 0 while the last frame is represented by index 4999.

Table 2-2. Important Notation to Describe Nature of Vertical Line of Sight Obstructions

Notation	**Description**
$\mathrm{D_P}$	The distance between points that define a vehicle position in the GPS file. For the NDOT data collection vehicle, the distance equals 26.4 ft (8.05 meters). The distance is measured along the surface of the highway.
i	An index representing a point in the photolog dataset for which measurements from the instruments of the data collection vehicle can be found.
$\mathrm{A_H}$	Height of the GPS antenna above the surface of the highway. Assumed to be constant through the data collection associated with a route.
$\mathrm{T_D}$	The available sight distance for which a test is to be conducted.
O_H	The theoretical height of an object used in the line of sight calculations. For example, for passing sight distance a theoretical height of 3.5 ft is often used.
E_H	The theoretical height of the driver eye used in line of sight calculations. For example, 3.5 ft in most available sight distance guidance.
$\mathrm{A_E^i}$	Elevation of the GPS antenna reported by the instruments of the data collection vehicle for index i.
$\mathrm{R_E^i}$	Elevation of the highway surface for index i.

Notation	Description
C_D^i	Cumulative distance reported by the instruments of the data collection vehicle for index *i*.
O_E^i	Elevation of a theoretical obstruction on the highway at index *i* used in the line of sight calculations.
E_E^i	Elevation of a theoretical driver eye on the highway at index *i* used for the line of sight calculations.

As previously mentioned, the procedures described in the sections ahead are executed for every point/observation in a GPS file, represented by an index i and associated with the route of interest. The steps are also executed for a test sight distance (T_D) value and rely on analysis parameters such as the object height (O_H) value dictate by the NDOT policy as input. And while the focus of the software is on the calculation of passing sight distance requirements, if the input values are modified, stopping sight distance requirements can also be evaluated thus the use of the generic term T_D that represents a test sight distance.

2.4 OBSTRUCTIONS DUE TO THE VERTICAL PROFILE CHARACTERISTICS

To determine if for a given point on the highway represented by an index i a sufficiently large T_D value is available the following assumptions and steps are followed. For every point on the highway, an assumption is made that R_E^i = A_E^i. For index/point i, a corresponding index, $i + n$, needs to be identified. The relationship between i and $i + n$ needs to be one that causes the condition ahead to be satisfied.

$$C_D^{i+n} - C_D^i \geq T_D$$

The offset n can be calculated using the equation below. The $\lfloor \, \rfloor$ notation is used to represent a function, commonly known as the floor function, that truncates the decimal places out of a number.

$$n = \left\lfloor {}^{T_D}/_{D_P} \right\rfloor + 1$$

For both points, i and $i + n$, the corresponding theoretical elevation of the driver eye and a target object are then computed using the following equations.

$$E_E^i = R_E^i + E_H$$

$$O_E^{i+n} = R_E^i + O_H$$

Using C_D^i and C_D^{i+n} as the X coordinates and E_E^i and O_E^{i+n} as the corresponding Y coordinates, two points that define the theoretical position of the driver eye (C_D^i, E_E^i) and the position of a theoretical object (C_D^{i+n}, O_E^{i+n}) can be established. These two points can be used to compute the slope (m) and intercept (b) parameters of a line as follows. In the equation defined, x represents a cumulative distance value along the highway, between points i and $i + n$, and y represents the expected elevation of the theoretical line of sight at the cumulative distance represented by x.

$$m_i^{i+n} = \frac{O_E^{i+n} - E_E^i}{C_D^{i+n} - C_D^i}$$

$$b_i^{i+n} = E_E^i$$

$$y = x * m_i^{i+n} + b_i^{i+n}$$

Using the linear equation defined, the expected line of sight elevations for a set of positions along the highway defined by the range [C_D^{i+1}, C_D^{i+n-1}] are calculated. If none of the calculated elevation values in the set is lower than the corresponding highway elevation (R_E^i), i.e., no obstructions are found, it is determined that at point i there is at least an available sight distance value equal to T_D. In Figure 2-5 an example of a theoretical line of sight obstructed by the highway vertical profile is shown while Figure 2-6 shows an example in which there is no obstruction for the line of sight.

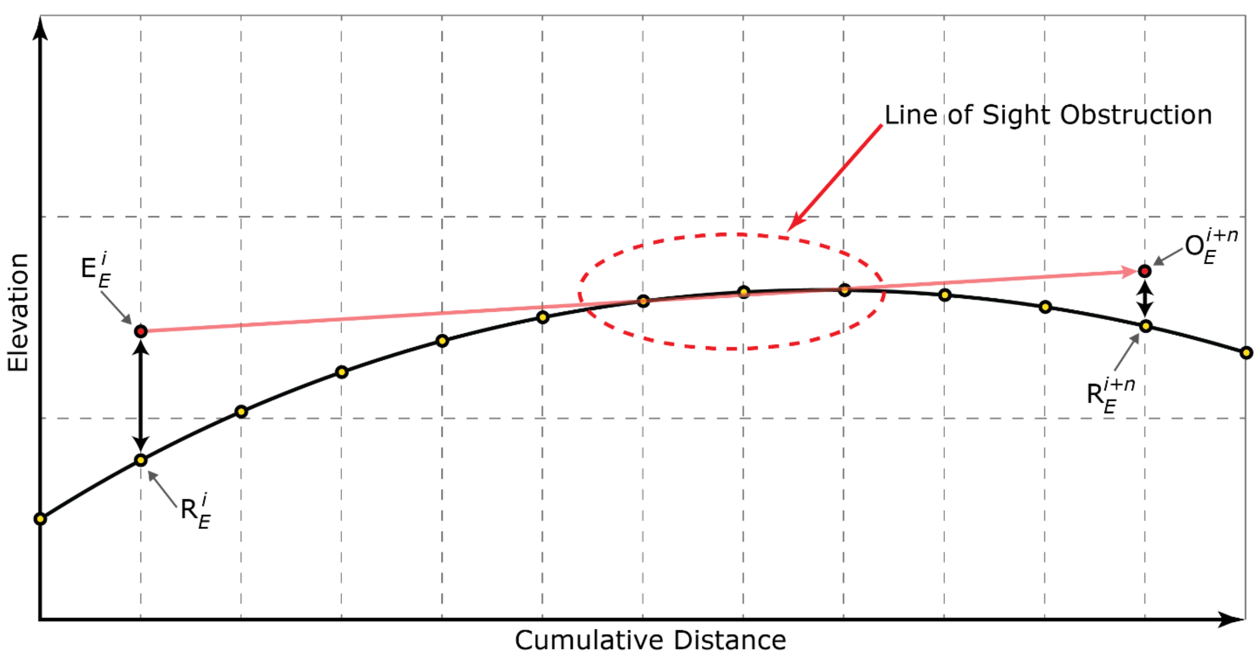


Figure 2-5. Line of Sight Obstruction Example

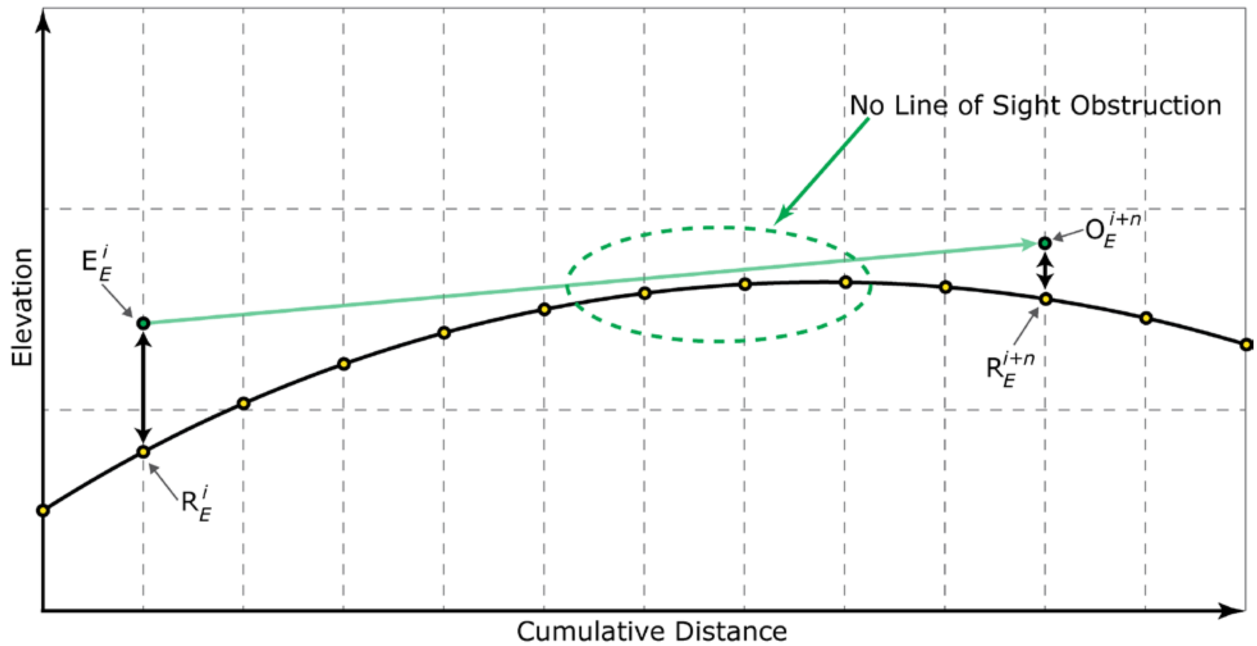


Figure 2-6. No Line of Sight Obstruction Example

2.4.1.1 Iterative Process if an Obstruction is Found Between Points i and $i + n$

If an obstruction is found, a new value of n, referred to as n' and equal to $\mathrm{n} - 1$, is used to determine if a line of sight obstructions exists. Determining obstructions by using n' means that the line of sight obstructions analysis is conducted for a new $\mathrm{T_D}$ value referred to as $\mathrm{T'_D}$ and equal to $\mathrm{D_p} * \mathrm{n}'$. Iterations that use a lower n' continue until a corresponding $\mathrm{T'_D}$ is found for which no line of sight obstructions exist. The value of $\mathrm{T'_D}$ is then reported as the available sight distance value for point i.

2.5 OBSTRUCTIONS DUE TO THE HORIZONTAL ALIGNMENT CHARACTERISTICS

Like the previously described process for analyzing the vertical profile of the highway, computing the sight distance available at a point i along the highway due to the characteristics of the horizontal alignment requires the identification of the corresponding theoretical line of sight obstructions. The identification of theoretical line of sight obstructions due to the characteristics of the horizontal alignment is based on the concept that limited assumptions can be made about the amount of a roadside distance that can be assumed as clear. For example, due to vegetation, farming, and other land developments an argument can be made that assuming the existence of a clear distance beyond the edge of the shoulder is not a safe assumption from the perspective of highway safety management. Therefore, for a clear line of sight to exist between a point i on the highway and another point $\mathrm{i} + \mathrm{n}$ (with the offset n calculated as shown in section 2.5.1), a straight line connecting the points must always stay inside the clear boundaries of the highway.

Figure 2-7 illustrates the condition described. In the figure, the dashed lines represent the path of a vehicle described by the data in the GPS file. For analysis purposes, in the scenario shown, a vehicle would travel in the i to $\mathrm{i}+\mathrm{n}$ direction. The solid lines represent the boundaries of what can be considered an unobstructed highway surface from the perspective of horizontal geometry. Point $\mathrm{P_A}$ represents a position along the vehicle path described by the GPS file while point $\mathrm{P_C}$ represents the coordinate of the intersection of the line (perpendicular to the theoretical line of sight) that connects $\mathrm{P_A}$ with the rightmost edge of the unobstructed highway surface. Point $\mathrm{P_B}$ represents the coordinate of where the intersection between the mentioned perpendicular line and the theoretical line of sight takes place. In the figure, $\mathrm{P_C}$ is located on the rightmost edge given the travel direction and the right curve illustrated, Section 2.5.1.1 discusses how to approach scenarios concerning both right and left curves.

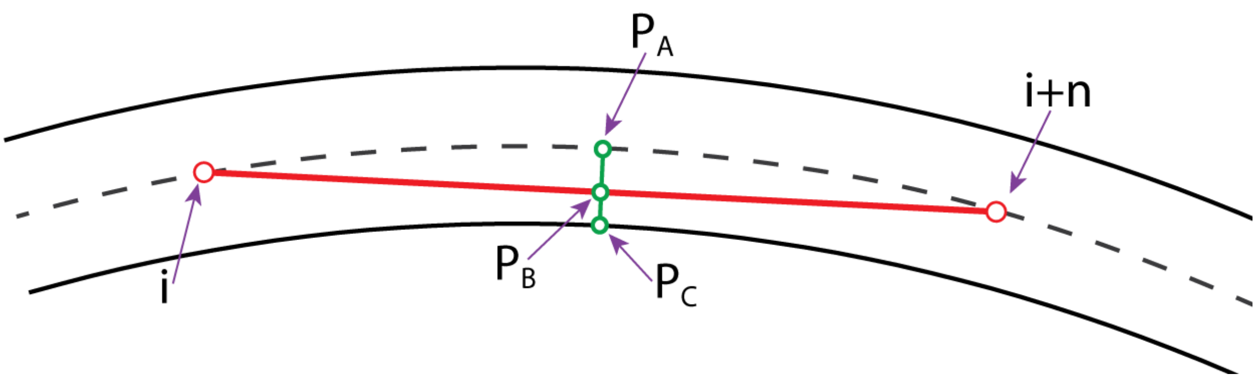


Figure 2-7. Description of Theoretical Concept of Horizontal Line of Sight Obstructions

In Figure 2-7 no theoretical line of sight obstructions exists between i and $\mathrm{i}+\mathrm{n}$ because the distance between $\mathrm{P_B}$ and $\mathrm{P_A}$ is lower than the distance between $\mathrm{P_C}$ and $\mathrm{P_A}$. In other words, no theoretical line of sight obstruction exists because the line of sight between i and $\mathrm{i}+\mathrm{n}$ is inside the boundaries of the unobstructed highway surface. The sections ahead describe the mathematical steps involved in implementing the analysis procedure described.

2.5.1 Mathematical Definition of Procedures

The parameters that define a theoretical line of sight, such as that connecting points i and $\mathrm{i}+\mathrm{n}$ in Figure 2-7 (i.e., the slope, m, and intercept, b) can be obtained using the familiar equation ahead. In the equation, the x and y coordinates are the projected coordinates of the latitude and longitude values that define points in the path followed by the data collection vehicle and contained in the GPS file. In the equation, the subscript i indicates the point along the highway for which the evaluation is conducted. Accordingly, superscript $\mathrm{i}+\mathrm{n}$ indicates that the slope computed is for a line connecting position i with position $\mathrm{i}+\mathrm{n}$. The n value represents the previously described frame offset.

$$m_i^{i+n} = \frac{y_{i+n} - y_i}{x_{i+n} - x_i}$$

$$b_i^{i+n} = y_{i+n} - m_i^{i+n} * x_{i+n}$$

Based on the slope ($\mathrm{m_i^{i+n}}$) and intercept ($\mathrm{b_i^{i+n}}$) parameters, the form in which the typical equation of the line is written can be changed from the $\mathrm{y = mx + b}$ form into the $\mathrm{ax + by + c}$ form using the following values for the parameters.

$$\mathrm{a = m_i^{i+n}}$$

$$\mathrm{b = -1}$$

$$\mathrm{c = -b_i^{i+n}}$$

Using the a, b, and c parameters, the following equation can be defined and used to compute the perpendicular distance from a point to a line. In the equation, the index j refers to points in the dataset found between the $\mathrm{[i, i + n]}$ range. In other words, j represents the index of a point between the highway points i and $\mathrm{i + n}$ defining the theoretical line of sight analyzed. The value of $\mathrm{d_\perp}$ is also the distance between $\mathrm{P_B}$ and $\mathrm{P_A}$.

$$\mathrm{d_\perp = \frac{|ax_j + by_j + c|}{\sqrt{a^2 + b^2}}}$$

As part of the analysis process, a $\mathrm{d_\perp}$ value is calculated for every point found in the $\mathrm{[i, i + n]}$ range. If any of the values is found to meet the condition shown ahead then an obstruction is said to exist between points i and $\mathrm{i + n}$. In the condition shown, $\mathrm{T_\perp}$ represents the clear width shown in Figure 2-7 as the distance between $\mathrm{P_C}$ and $\mathrm{P_A}$. As will be discussed further ahead in the report, when implementing the analysis procedures, the user of the software will be required to enter two different types of $\mathrm{T_\perp}$ values, one that will be used as a comparison threshold for left curves and one for right curves.

$$\mathrm{d_\perp > T_\perp}$$

As in the case for the identification of line of sight obstructions caused by the vertical profile of the highway, if an obstruction is found, then an iterative process in which the above condition is tested for smaller values of $\mathrm{i + n}$ is followed until a point is found that does not satisfies the above condition. Once that happens, at point i, an available sight distance value equal to at least $\mathrm{T_D}$ (i.e., $\mathrm{T_D'}$) is said to exist.

2.5.1.1 *Selecting T_D Value Based on Nature of Curvature*

The mathematical procedure introduced in Section 2.5.1 is agnostic to the curvature type (left or right) that connects the theoretical locations of the driver eye (at position i) and a hypothetical object (at position $\mathrm{i} + \mathrm{n}$). The reason for the agnostic nature of the process is because the process of identifying obstructions involves, as a first step, calculating the perpendicular distance values between the theoretical line that connects the eye and object and the vehicle path points location between position i and position $\mathrm{i} + \mathrm{n}$. As previously shown, the perpendicular distance calculation is independent of the curvature.

As a second step in the analysis process, the perpendicular distances calculated are compared with a threshold value, previously introduced as $\mathrm{T}_{\perp}$, to determine if an obstruction exists. The $\mathrm{T}_{\perp}$ value represents the available distance to the left or right of the vehicle path that for analysis purposes is expected to be clear. Figure 2-8 shows a scenario in which the theoretical line of sight is obstructed because the maximum perpendicular distance between the line of sight and the vehicle path is greater than the corresponding available clear distance to the right of the path. Similarly, Figure 2-9 shows the same scenario described but for the case of a left curve.

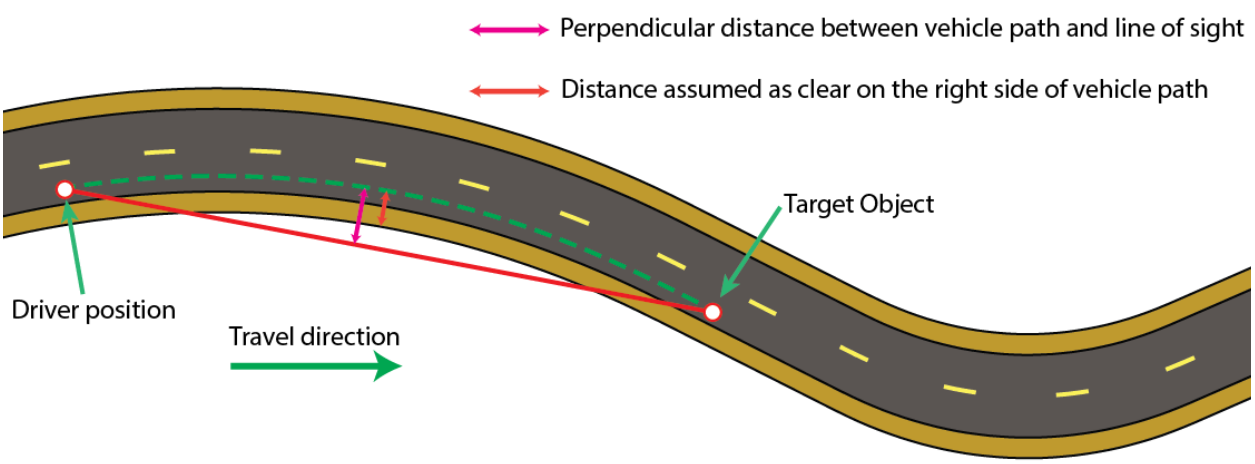


Figure 2-8. Theoretical Line of Sight Obstruction on Right Curve

As previously suggested, the $\mathrm{T}_{\perp}$ value is treated as input in the sight distance analysis process focused on obstructions due to the horizontal alignment characteristics of the highway. Theoretically, the $\mathrm{T}_{\perp}$ value can be considered as infinite under a flat terrain situation with no development or vegetation outside the highway boundaries. Such an assumption is not realistic. In fact, a challenge faced by transportation agencies is controlling what happens outside the highway boundaries created by the outer shoulder edges. As a result, for purposes of identifying line of sight obstructions caused by the horizontal characteristics of the highway, an assumption is often made that there is no guaranteed clear distance beyond the outer edge of highway shoulders. Therefore, if an assumption is made that the vehicle path data represents the middle of the rightmost lane of the highway, then the $T_{\perp}$ value for the right curve can be considered to be half a lane width plus the combined paved and unpaved shoulder width of the adjacent shoulder. The same convention suggests a $T_{\perp}$ value of 1.5 times a lane width plus the combined paved and unpaved width of the corresponding shoulder.

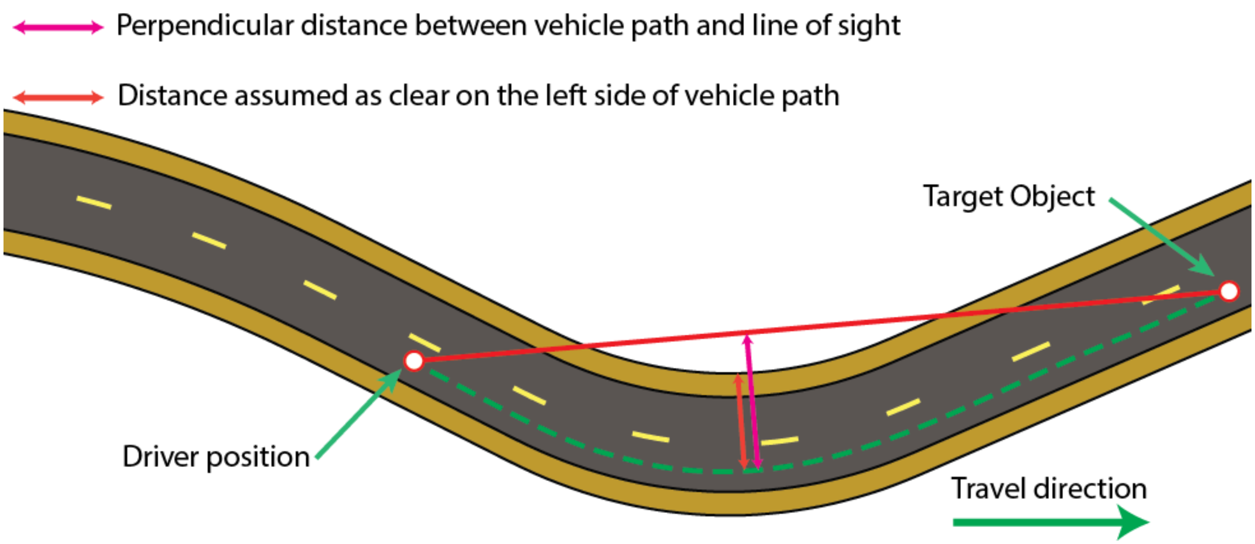


Figure 2-9. Theoretical Line of Sight Obstruction on Left Curve

As will be shown in Chapter 4, the T_D value will be an input to the software tool described in this report. Therefore, selecting a corresponding T_D value requires engineering judgment, knowledge about the typical design policies that would have been followed at the highway route analyzed, or actual information about the characteristics of the highway. The end user of the software tool introduced should keep in mind that the procedures presented are the foundation of a decision-support system that relies on existing data to model the roadway geometry. Therefore, the final decision about how obstructions are identified should be made by the user.

CHAPTER 3. STRUCTURE OF RESULTS AND LIMITATIONS

The software developed as part of the project presented in this report relies on the datasets and analysis procedures described in Chapter 2. As with any other tools, there are limitations associated with the operation of the software as well as limitations associated with the underlying analysis methodologies implemented by the software. A summary of the results produced by the software is shown in the section ahead and the limitations associated with the results are shown in the subsequent sections.

3.1 RESULTS GENERATED BY THE SOFTWARE

Two types of output files containing the results of the analysis process can be generated by the software. The first file is a Keyhole Markup Language (KML) file and the second is a Comma Separated Value (CSV) file. The KML file can be opened with software such as Google™ Earth to show a visual representation of the locations along a route where theoretical obstructions to the line of sight were identified by the software based on the route data and user-defined analysis parameters. While typically opened using Google™ Earth, KML files are plain text files with a well-defined structure that can be interpreted by other programs to show location-based datasets. A screenshot of the KML file visualization is shown in Figure 3-1. In the figure, highway segments identified as not complying with the minimum passing sight distance requirements for 75 MPH are marked and information about the segment is available.

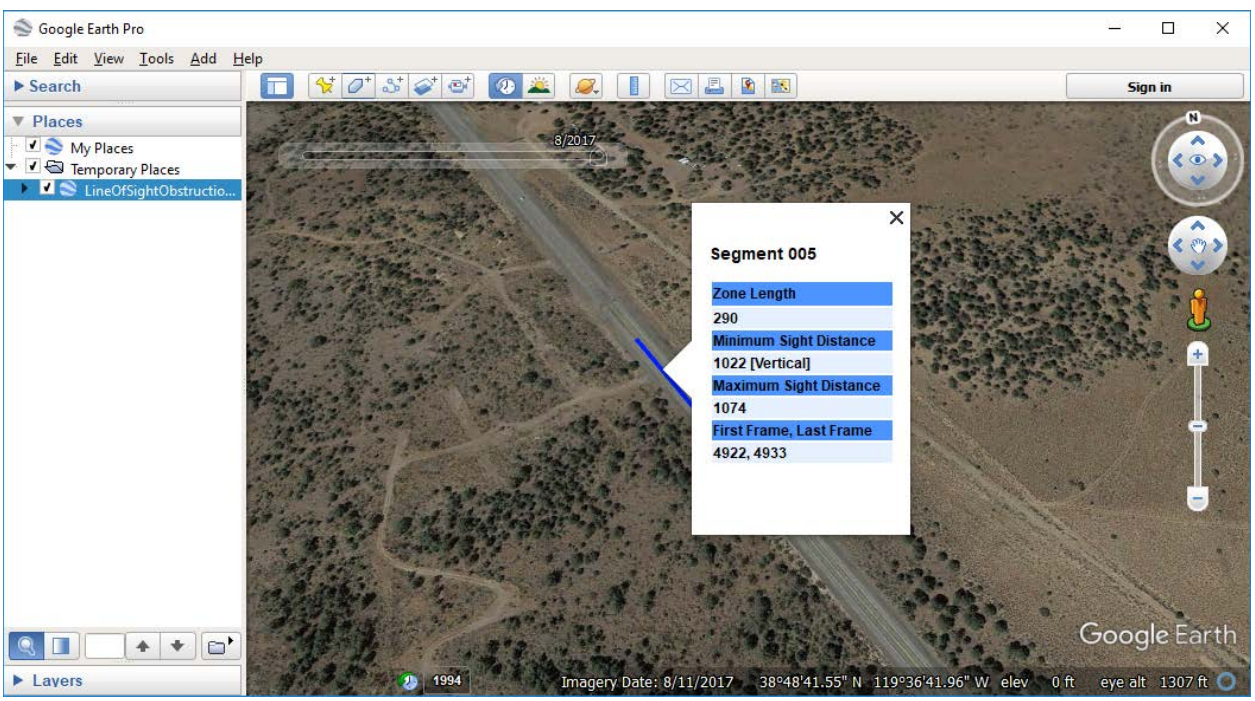
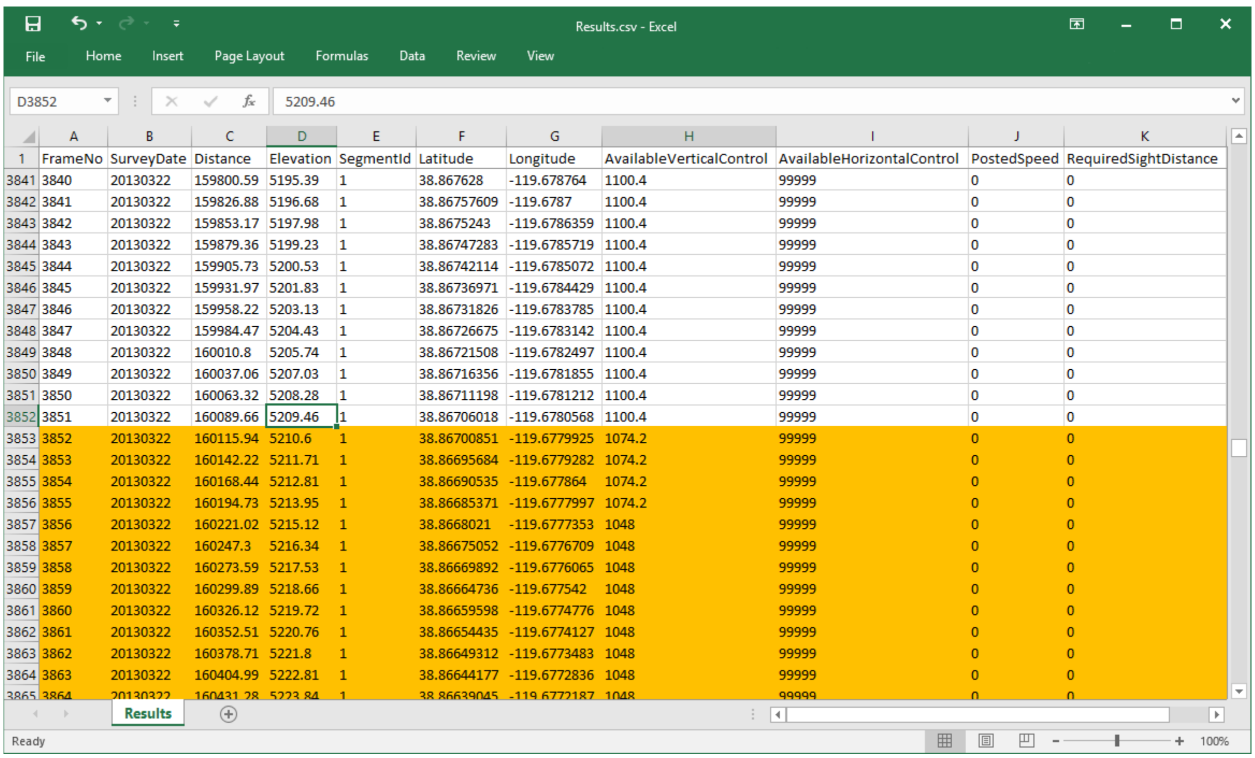


Figure 3-1. Sample KML File Visualized Using Google™ Earth

The second type of a file produced by the software, the CSV file, contains the geographic position information associated with every single position and photo logged by the NDOT data collection vehicle. Along with the position information, column 8 shows the available sight distance due to the vertical profile of the highway while column 9 shows the available sight distance due to the horizontal geometry of the highway. Available sight distance values reported are never higher than the sight distance used as input for the analysis process. The maximum value reported as available sight distance is a design decision made to make the computational process faster. Therefore, when interested in using the software to calculate available sight distance values for each vehicle position, a speed value higher than any analysis speed along the highway segments should be used as input for the software. Further details about the inputs for the software are discussed in Chapter 4.



	A	B	C	D	E	F	G	H	I	J	K
1	FrameNo	SurveyDate	Distance	Elevation	SegmentId	Latitude	Longitude	AvailableVerticalControl	AvailableHorizontalControl	PostedSpeed	RequiredSightDistance
3841	3840	20130322	159800.59	5195.39	1	38.867628	-119.678764	1100.4	99999	0	0
3842	3841	20130322	159826.88	5196.68	1	38.86757609	-119.6787	1100.4	99999	0	0
3843	3842	20130322	159853.17	5197.98	1	38.8675243	-119.6786359	1100.4	99999	0	0
3844	3843	20130322	159879.36	5199.23	1	38.86747283	-119.6785719	1100.4	99999	0	0
3845	3844	20130322	159905.73	5200.53	1	38.86742114	-119.6785072	1100.4	99999	0	0
3846	3845	20130322	159931.97	5201.83	1	38.86736971	-119.6784429	1100.4	99999	0	0
3847	3846	20130322	159958.22	5203.13	1	38.86731826	-119.6783785	1100.4	99999	0	0
3848	3847	20130322	159984.47	5204.43	1	38.86726675	-119.6783142	1100.4	99999	0	0
3849	3848	20130322	160010.8	5205.74	1	38.86721508	-119.6782497	1100.4	99999	0	0
3850	3849	20130322	160037.06	5207.03	1	38.86716356	-119.6781855	1100.4	99999	0	0
3851	3850	20130322	160063.32	5208.28	1	38.86711198	-119.6781212	1100.4	99999	0	0
3852	3851	20130322	160089.66	5209.46	1	38.86706018	-119.6780568	1100.4	99999	0	0
3853	3852	20130322	160115.94	5210.6	1	38.86700851	-119.6779925	1074.2	99999	0	0
3854	3853	20130322	160142.22	5211.71	1	38.86695684	-119.6779282	1074.2	99999	0	0
3855	3854	20130322	160168.44	5212.81	1	38.86690535	-119.677864	1074.2	99999	0	0
3856	3855	20130322	160194.73	5213.95	1	38.86685371	-119.6777997	1074.2	99999	0	0
3857	3856	20130322	160221.02	5215.12	1	38.8668021	-119.6777353	1048	99999	0	0
3858	3857	20130322	160247.3	5216.34	1	38.86675052	-119.6776709	1048	99999	0	0
3859	3858	20130322	160273.59	5217.53	1	38.86669892	-119.6776065	1048	99999	0	0
3860	3859	20130322	160299.89	5218.66	1	38.86664736	-119.677542	1048	99999	0	0
3861	3860	20130322	160326.12	5219.72	1	38.86659598	-119.6774776	1048	99999	0	0
3862	3861	20130322	160352.51	5220.76	1	38.86654435	-119.6774127	1048	99999	0	0
3863	3862	20130322	160378.71	5221.8	1	38.86649312	-119.6773483	1048	99999	0	0
3864	3863	20130322	160404.99	5222.81	1	38.86644177	-119.6772836	1048	99999	0	0
3865	3864	20130322	160431.28	5223.84	1	38.86639045	-119.6772187	1048	99999	0	0

Figure 3-2. Sample CSV Style Output Generated by the Analysis Tool

3.2 LIMITATIONS OF ASSOCIATED WITH DIRECTION OF TRAVEL

The analysis procedures mathematically defined in Chapter 2 assume the availability of vehicle path data contained in a GPS file. Vehicle path datasets, which are an indirect result of the highway assets inventory process, are associated with a specific direction of travel along the highway. In fact, the highway asset inventory process traditionally involves the data collection vehicle traveling once per direction along the highway. Therefore, when interpreting the results from the analysis procedures, the end user must keep in mind that theoretical line of sight obstruction results identified should be treated as being tied to the direction of travel represented by the dataset. Having theoretical line of sight obstructions tied to a single direction of travel along the highway have implications for results that can be better explained using the illustration shown in Figure 3-3.

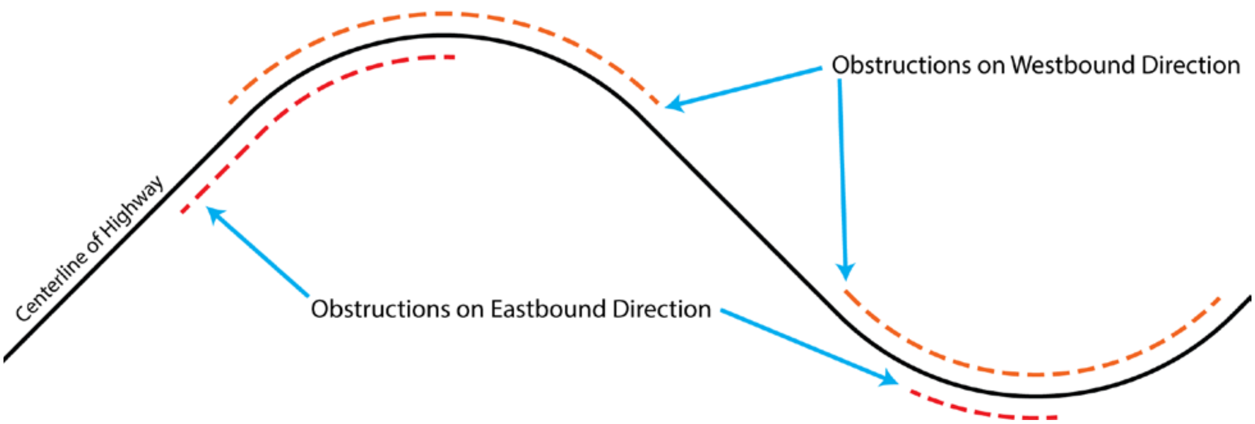


Figure 3-3. Illustration of Line of Sight Obstructions by Direction of Travel

The goal of Figure 3-3 is to illustrate that analyzing two vehicle path datasets from a highway, one per direction of travel, can result in the identification of highway segments with theoretical line of sight obstructions that are different and associated with a direction of travel. Therefore, when interpreting obstruction results such as the one shown in Figure 3-3 that are produced by the software, the user should analyze the combined results from both directions of travel. These combined results can be used to determine where potential obstructions exist on a specific direction of travel and where potential obstructions are independent of the direction of travel.

3.3 LIMITATIONS RESULTING FROM VEHICLE PATH DATASET ACCURACY

Just like in their physical reality, highway alignments during the design process are modeled as been continuous. However, the data used to model the geometry of a highway alignment by the software tool is discrete in nature. In other words, elevation and position values for the path followed by the data collection vehicle are only known for points spaced at a constant distance interval determined by the configuration of the data collection vehicle. Therefore, end users relying on the implementation of the procedures introduced in Chapter 2 by the software need to be aware that results produced are only as good as the model that can be established from the vehicle path dataset. In fact, the accuracy of the model used to identify theoretical line of sight obstructions is correlated to the spacing between consecutive points that define a vehicle path dataset. In general, a shorter space between the points results in a more accurate model while a longer space results in a lower accuracy model. The two sections ahead discuss the aforementioned correlation in more detail from the perspective of the horizontal and vertical geometry of a highway alignment.

3.3.1 Horizontal Geometry Perspective

Latitude and longitude values part of the vehicle path dataset, in their projected form, are treated by the software tool developed as accurately representing the horizontal characteristics of a highway alignment. Therefore, the underlying assumption of the software is that the distance (i.e. space) between points is short enough to treat the data as accurately representing the curvature of the highway. Figure 3-4 illustrates how model accuracy is correlated to the distance between points part of the vehicle path dataset. A good quantifiable indicator of how accurate a collection of points is at representing a curve is the area between the lines connecting the points and the smooth and continuous line that defines the curve. As shown in the figure, longer distances between points result in an increased area and reduced model accuracy.

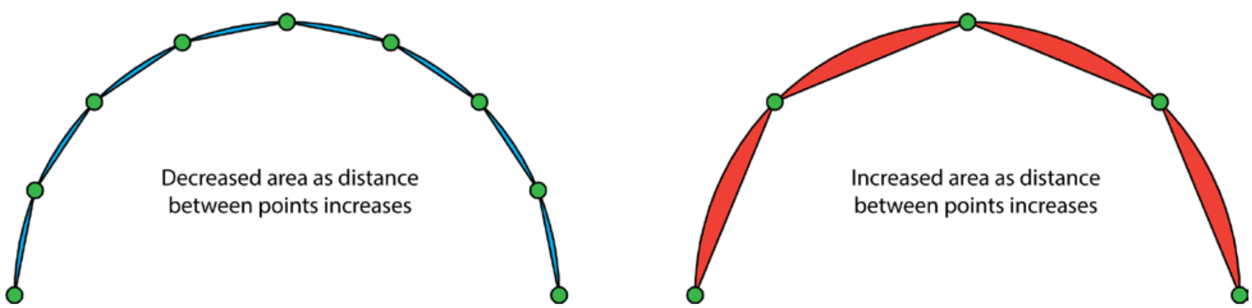


Figure 3-4. Illustration of How Distance Between Points Decreases the Accuracy of a Model

From a results interpretation perspective, the implications of the discussed model accuracy considerations are that false obstructions could be identified due to the limitations of the underlying vehicle path dataset. Based on the 26.4 feet of spacing between points produced by the NDOT data collection vehicle that define the vehicle path dataset, the concern for misidentified obstructions should be minimal in most circumstances and easily manageable. However, if there are concerns about the quality of the results produced by the software due to the quality of the vehicle path data, alternatives exist. Under such a scenario, the line of sight analysis procedures should be executed with a higher threshold for identifying an obstruction due to horizontal geometry and the results compared side-by-side to see if a small increase in the threshold value causes a potential obstruction been removed from the results. As will be shown in Chapter 4, the software tool provides an interface to change the aforementioned threshold value. And since software results are available in map form, performing the side-by-side comparison is a simple task.

One special case that should be mentioned regarding how the vehicle path dataset could lead to incorrectly identified obstructions is related to intersections. From an alignment modeling perspective, a vehicle path is assumed to represent a continuous road with curves that do not require stopping or slowing down before changing the direction of travel. As a result, theoretical line of sight obstructions identified by the software and which are found at the location of an intersection (where the highway changes direction) should be highlighted as in need of further review and analysis of the situation.

3.3.2 Vertical Geometry Perspective

The analysis procedures introduced in Chapter 2 rely on the cumulative distance and elevation values associated with each point in a vehicle path dataset. Therefore, as in the case of the horizontal geometry there are limitations that should be considered when interpreting the location of theoretical line of sight obstructions identified by the software as caused by the vertical profile of the highway. As in the case of the horizontal geometry, under most circumstances, the 26.4 feet spacing between the points that define a vehicle path dataset is short enough to accurately represent the vertical profile characteristics of a highway. Still, the same correlation between model accuracy and distance between points, previously shown in Figure 3-4, exists and should be understood by users of the software.

In the case of the model limitations associated with vertical geometry, these limitations could result in false negatives as opposed to the false positives mentioned in the case of horizontal geometry. From the line of sight analysis perspective, a false negative represents a highway segment that should have been flagged as having a theoretical line of sight obstruction but was reported as providing sufficient sight distance. As previously discussed, the potential for false negatives is not something that should be expected as the norm but instead an exception caused by uncommon vertical alignment characteristics. Uncommon characteristics that could cause the underlying highway model used in detecting theoretical line of sight obstructions to be significantly inaccurate include sudden pavement bumps and sharp changes in the vertical slope of the highway alignment. These two are highway features/defects that would not be captured when modeling the vertical profile of a highway by assuming that a smooth curvature can be used to connect the vehicle path points defined by cumulative distance and elevation values.

If the user suspects that potential false negatives exist on the results produced by the software, then the line of sight analysis procedure could be executed with different parameters values to account for the potential model inaccuracies that results from the use of the vehicle path data. From the perspective of vertical geometry, theoretical line of sight obstructions are detected using eye and object height as input parameters and false negatives are produced when an obstruction on the highway can't be properly modeled using the vehicle path data. As a result, the eye height and object height parameters should be equally reduced by an amount based on the expected errors that the model is suspected of not capturing. The negative offset on parameter value should be site-specific and rely on engineering judgment and knowledge of site conditions.

3.4 LIMITATIONS ASSOCIATED WITH THE END OF A ROUTE

When determining if sufficient sight distance exists at a point along the highway, the procedure used involves identifying a point downstream of the test location (specifically at a distance equal to T_D) and determining if the line of sight that connects the two points is obstructed. As previously shown, the determination about the existence of an obstruction is made based on the scenario analyzed (i.e. horizontal or vertical) and on the analysis parameters. If no obstruction to the line is found, then the analysis procedure reports that for the point analyzed at least the distance to the downstream point is said to exist as the available sight distance. Given the nature of the analysis procedure, when evaluating the availability of sight distance at locations represented by points on the vehicle path dataset that are near the end of the highway route, there are limitations that must be understood prior to interpreting the results.

The cutoff point that determines points along the highway that are near the end of the route and that should be evaluated in more detail are those found to be at a distance less than T_D from the end of the highway route. If the available sight distance reported by the software for a point along the highway route, and within the aforementioned cutoff, is equal to the remaining distance along the highway route then that point should be treated as potentially having an available sight distance higher than reported. Further evaluation of the mentioned points includes the use of available sight distance values on the opposite direction of travel and the use of additional data sources. The use of available sight distance values on the opposite direction of travel can be of value if the highway geometry is symmetrical along the center line of the highway and the direction of travel.

CHAPTER 4. INTERFACE SUMMARY AND CONFIGURATION

The sections ahead discuss the interface of the software that implements the procedures described in Chapter 2 and that produces the results summarized in Section 3.1. As will be shown ahead, concepts presented include the operation of the software as a route visualization tool and the use of the software to generate the results showing the location of theoretical line of sight obstructions that can be used to streamline the no-passing zone identification process. Finally, a summary of the software configuration parameters is introduced.

4.1 LAUNCHING THE SOFTWARE AND FOLDER STRUCTURE

Launching the software requires opening the *SightDistanceTool.exe* file located in the folder that contains the files and folders required for the operation of the software and that are shown in Figure 4-1. The contents of the folder, which is a project deliverable, should be placed in a local folder where the user has writing rights. Additional content in Figure 4-1 that is required for the proper operation of the tool includes the posted speed database which is located inside the *data* folder and further described in Section 4.4. The *img* folder contains the images that are displayed by the software and which can be modified by the user as needed to change the appearance and supplemental information shown by the software. The *config* folder contains files that allow customizing analysis parameters used in the analysis interface and other files that are required to make the operation of the software possible. More information about key components of the *config* folder is presented in Section 4.6. The *DotSpatial.Projections.dll* is required by the software to convert latitude and longitude values into projected coordinates.

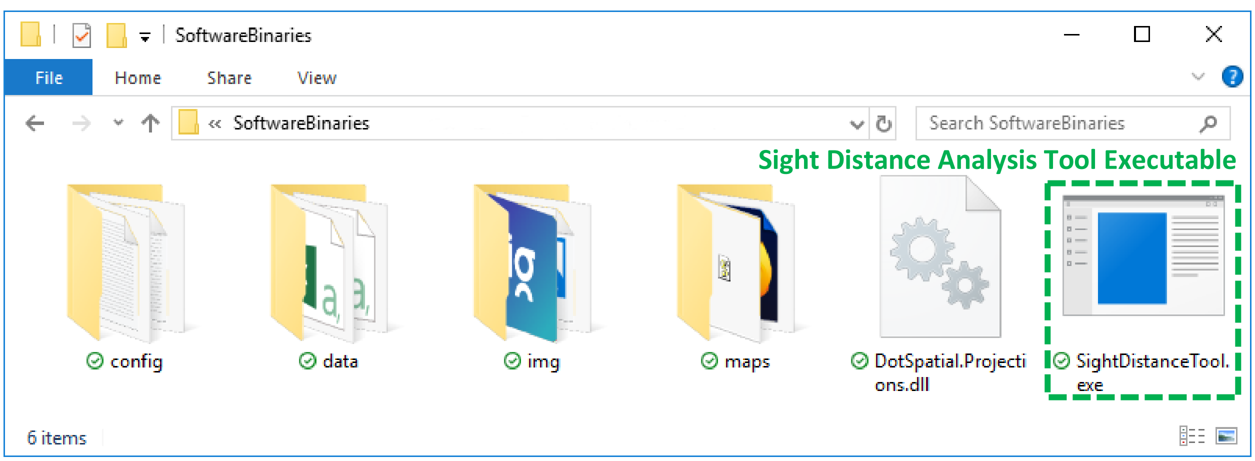


Figure 4-1. Location of Tool

The *maps* folder contains files that make the operation of the map interface possible. The contents of this folder should be treated as an individual application that is loaded by the software and that is created using HTML and JavaScript™. Modifications to the content of the *maps* folder are possible but should be treated as changing the code of the application. If not done properly, the changes can render the mapping functionality of the software inoperable.

4.2 OPENING A ROUTE FOR ANALYSIS OR VISUALIZATION

The analysis process implemented by the software requires opening a vehicle path dataset contained in a GPS file. To open the dataset, the *Open Route* menu must be accessed as shown in Figure 4-2. The GPS file that is opened by the software is the type of file that is produced by the asset inventory process and that makes visualization of a highway route possible. The content of the GPS file is considered to be in "binary format" which means the content can't be easily viewed using a text editor due to the specific encoding used to store the data. The structure of the file has been previously shown in Figure 2-3 and discussed in Section 2.2.

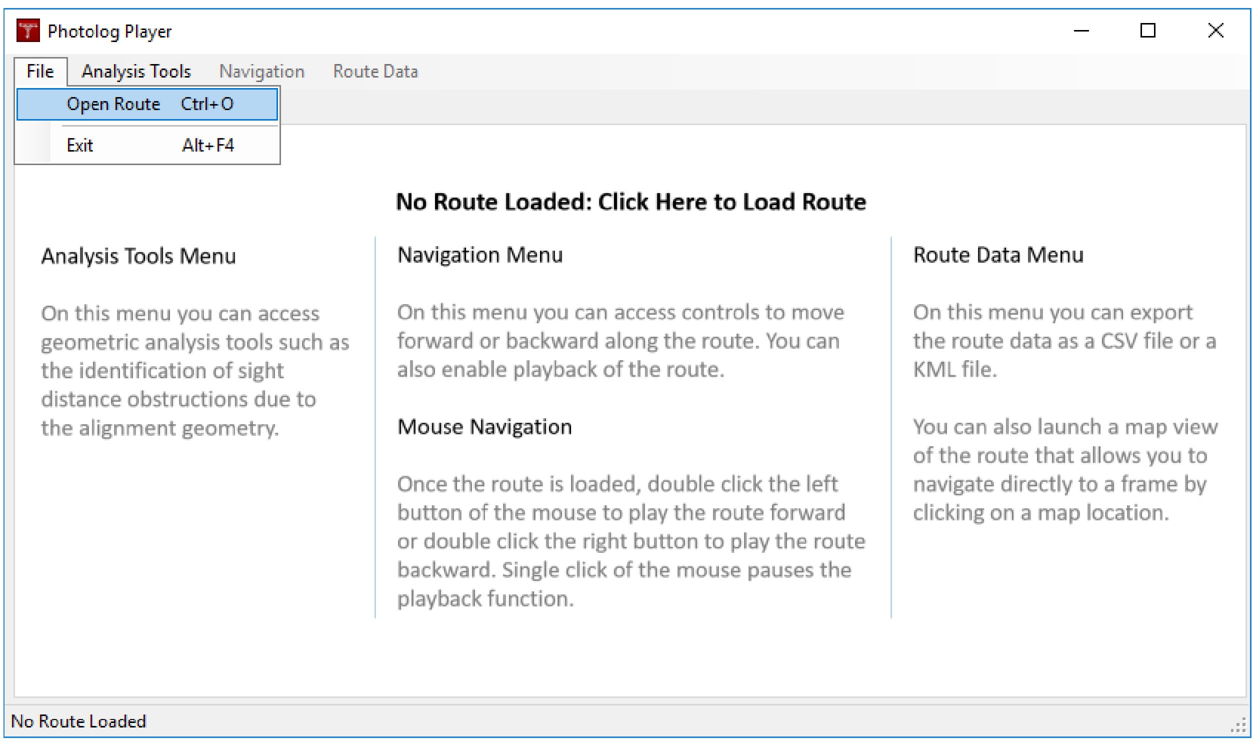


Figure 4-2. Screenshot: Load Route Interface

After the GPS file is opened, the interface of the software will change from the one shown in Figure 4-2 to the one shown in Figure 4-3 and that contains photographs associated with the highway route defined in the GPS file. As previously mentioned, the only requirement to operate the software is the presence of the GPS file. The highway photos shown in the figure will only be visible if the necessary folder structure, previously shown in Figure 2-2, is in place. Otherwise, the photo area of the software will be replaced with an error message indicating that no photos are available for the route.

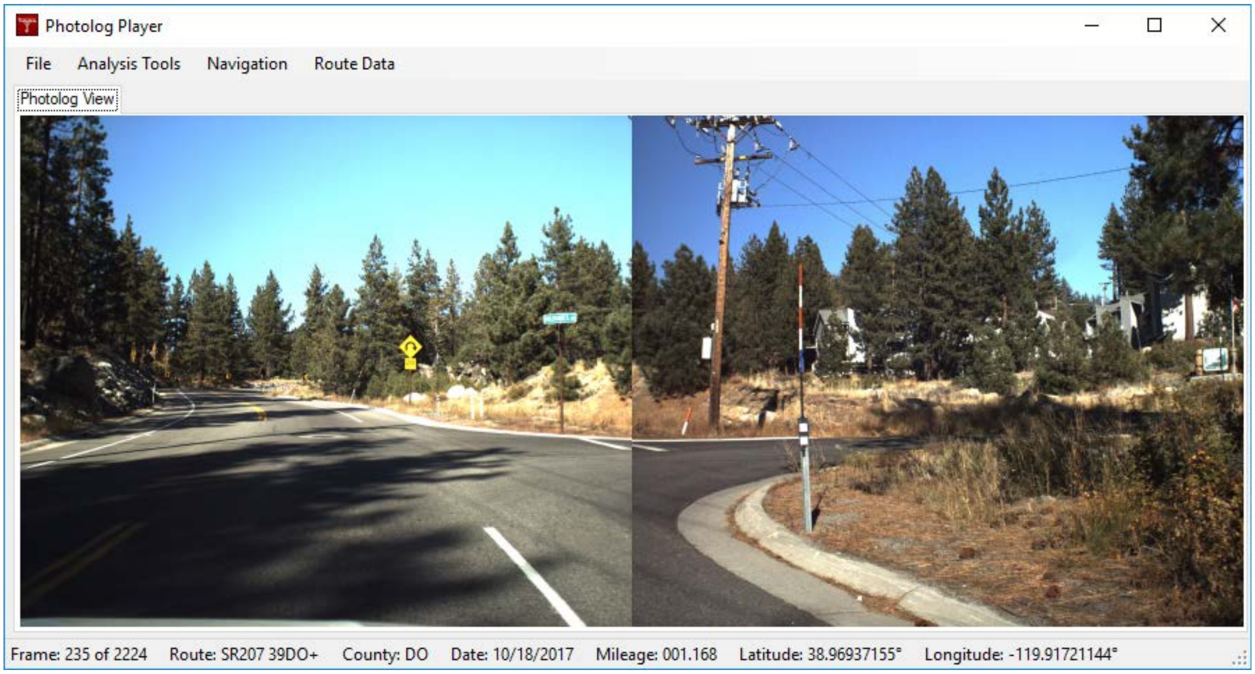


Figure 4-3. Screenshot: Route Loaded

If the corresponding photographic data is available, then the software can be used as a visualization tool to navigate to a location along the highway route and export associated route data. The section ahead discusses the use of the software as a highway route visualization tool.

4.3 USING THE SOFTWARE AS A VISUALIZATION TOOL

To use the software shown in the figures as a highway route visualization tool there are two primary approaches that can be used. The first approach involves the use of a navigation menu that allows specific frame (a point part of the GPS file) data to be displayed on the screen. As will be discussed, frame-by-frame navigation is also possible using the mouse and a set of keyboard shortcuts. The second approach involves the use of a map interface to display the entire vehicle path contained in the GPS file and which also allows selecting a location along the map that will be displayed on the software.

4.3.1 Navigating to a Specific Frame on a Route

Once the GPS file is loaded, the *Navigation* menu shown in Figure 4-4 allows users to move forward and backward along the route using the buttons shown on the screen. The *Navigation* menu includes the ability to enter a "playback mode" which causes the software to automatically move forward and backward along the route without the need for any additional user input. As shown in Figure 4-4, next to each navigation command there is a corresponding keyboard shortcut that can be used to operate the navigation interface without the need for directly accessing the menus.

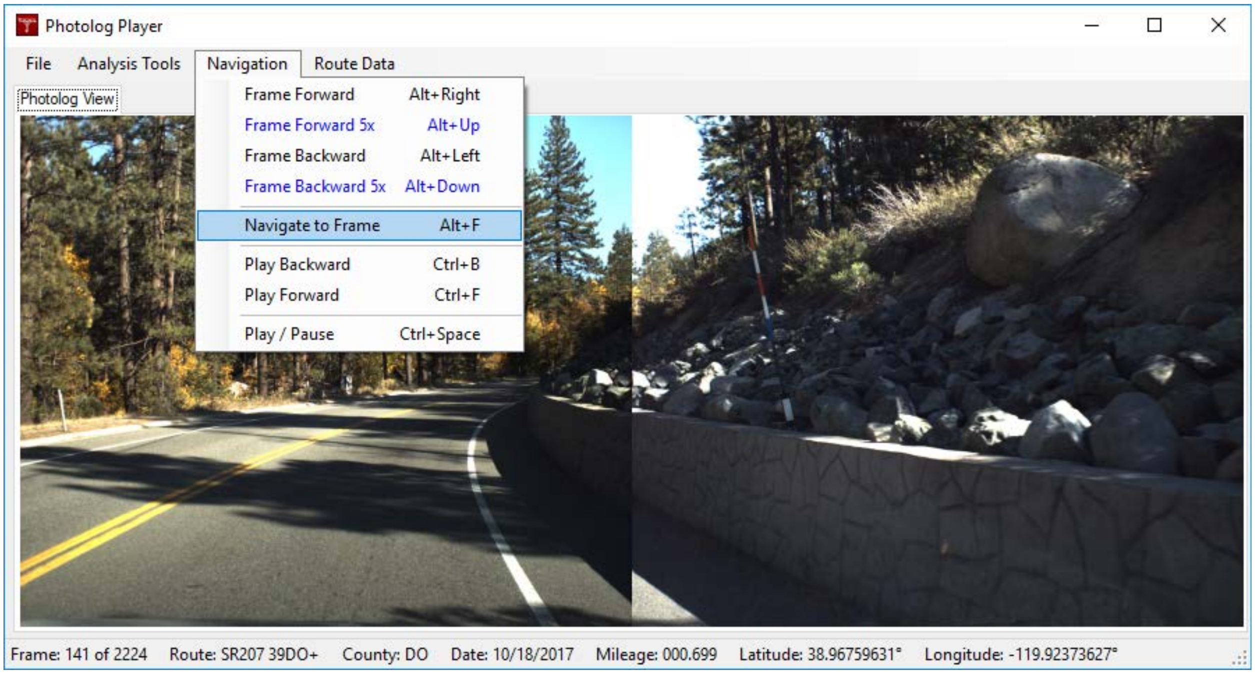


Figure 4-4. Screenshot: Navigating to Specific Frame

As the user virtually navigates the route, information about the highway location shown on the photograph is displayed on the "status bar" of the software. Information displayed includes the current frame number, route name, county information (if available), date the photograph shown was taken, a cumulative mileage value, and the corresponding latitude and longitude values. Each time the frame displayed by the software changes, the "status bar" information is updated with the corresponding information.

4.3.1.1 Navigation Control Using the Mouse

An alternative to use the *Navigation* menu to change frame positions is to use the scroll wheel typically found in a computer mouse to navigate along the route. Scrolling in the positive direction moves forward while scrolling in the negative direction moves backward on the route. Double-clicking with the left mouse button on the highway photo causes the route automatic playback to start moving on the forward direction while double-clicking with the right button causes the route playback to start moving in the backward direction. While playback is active, a single click of any mouse button pauses the playback.

When the automatic route playback is paused, a single click of the left mouse button causes the route position to move forward by one frame while a single click of the right mouse button causes the route position to move backward by one frame.

4.3.2 Navigating to a Specific Location on a Map

The *Route Data* menu allows access to the *Show Map View* action. When launched, a map interface like the one shown in Figure 4-5 is launched. The map interface displays the entire route contained in the GPS file as a green line on the map and allows navigating to a specific location on the route by clicking the desired location on the map. If the click is outside the boundaries of the route, the route location closest to the click will be the one displayed. The highway location shown on the photo, (i.e., the position for which the "status bar" displays data) is shown as a red marker on the map Window.

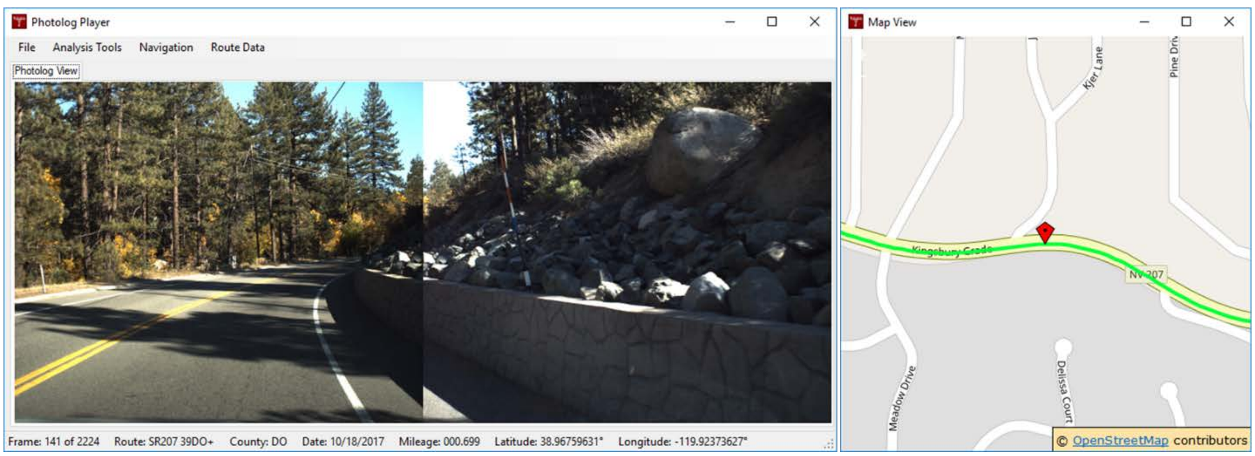


Figure 4-5. Screenshot: Navigating to Specific Location on Map

As previously mentioned in Section 2.1, the software relies on *OpenStreetMap* [13] data to display the map interface and requires internet connectivity to appropriately display the map tiles. Therefore, the names and locations of the highways shown in the map are not controlled by the user since *OpenStreetMap* is a crowdsourced online mapping system. For major highways, such as the ones contained in the GPS files analyzed by the software, the mapping data provided by *OpenStreetMap* should be adequate both in terms of quality and content.

4.3.3 Exporting Route Data as CSV File

In addition of the route navigation and visualization capabilities of the software, the software can also be used to convert the vehicle path data contained in the GPS file into a CSV file. The version of the CSV file produced by the software contains not only information such as latitude and longitude values that are part of the GPS but also projected coordinate values that are not part of the GPS file. To convert the vehicle path data into CSV, the *Export Route Data* action part of the *Route Data* menu must be selected. When selected, the user will be asked to select where will the data be saved. The ability to export route data into a CSV file can be useful when creating visualizations of the alignment of a route using tools such as spreadsheet computer programs.

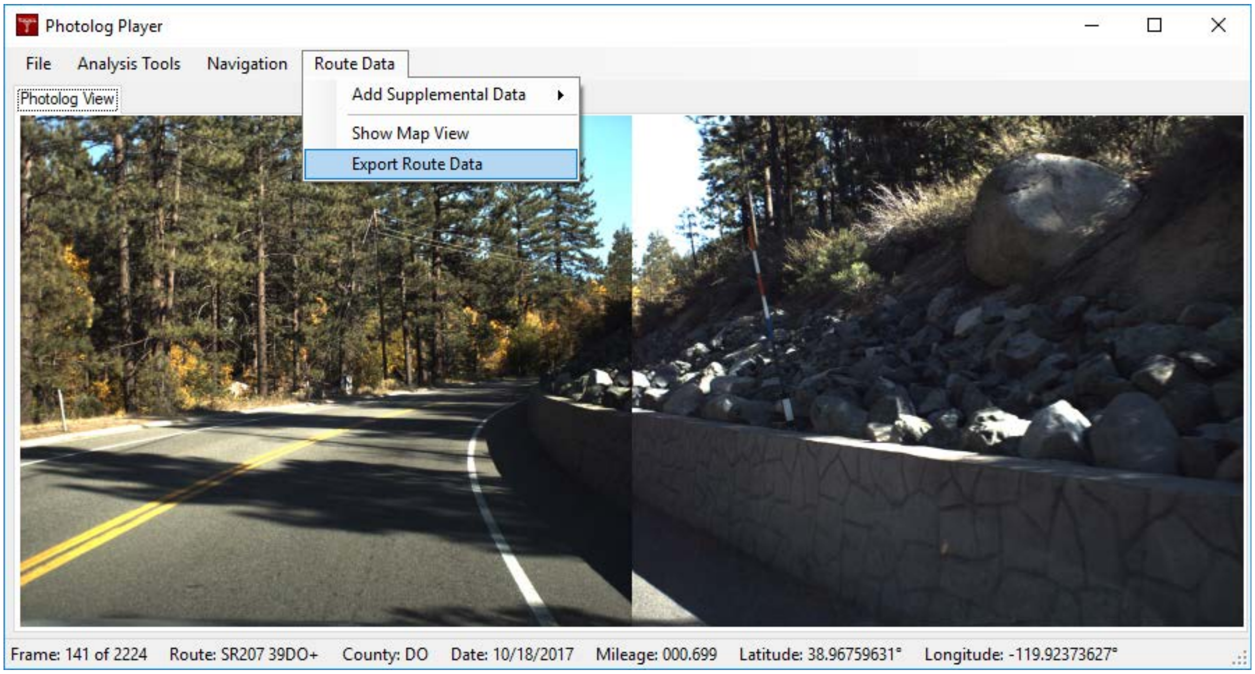
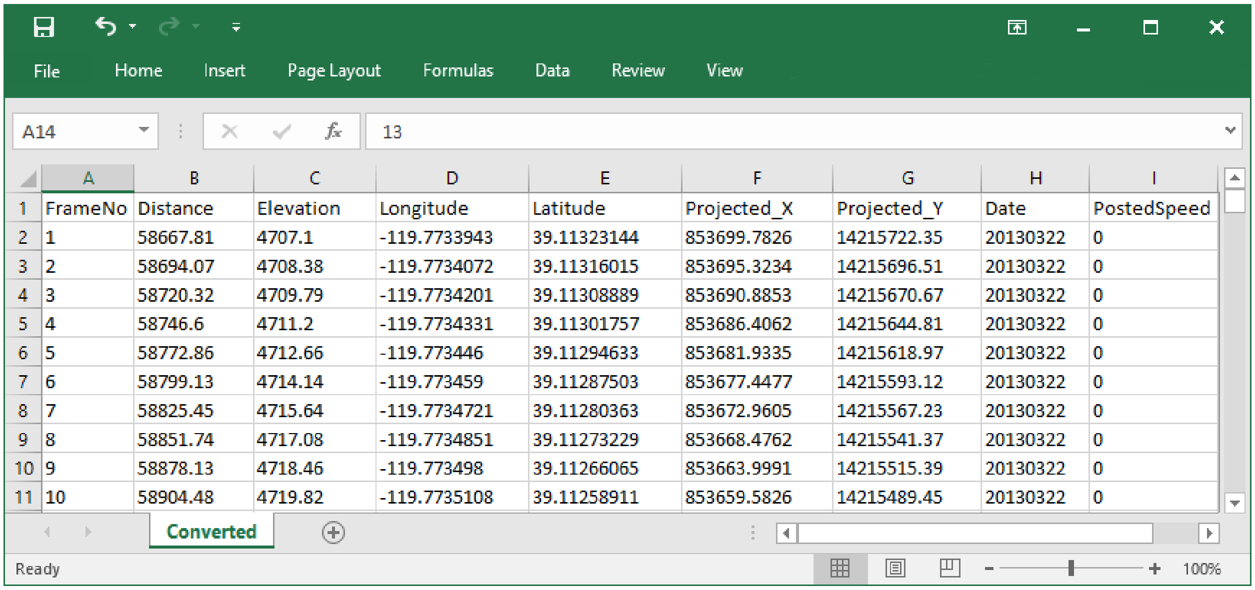


Figure 4-6. Screenshot: Exporting Route Data as CSV File

The structure of the CSV file produced is shown in Figure 4-7 in the form of a screenshot. As the figure shows, information contained in the CSV file columns include frame number, cumulative distance, elevation, longitude, latitude, projected X coordinate, projected Y coordinate, date of data collection, and posted speed. The posted speed column is an optional field that is only populated if the necessary data is loaded into the software as will be shown in Section 4.4. Finally, while the data contained in the GPS files is in metric units (i.e., meters) the CSV file maintains the convention used throughout the entire software interface and contains vehicle path information in feet.



FrameNo	Distance	Elevation	Longitude	Latitude	Projected_X	Projected_Y	Date	PostedSpeed
1	58667.81	4707.1	-119.7733943	39.11323144	853699.7826	14215722.35	20130322	0
2	58694.07	4708.38	-119.7734072	39.11316015	853695.3234	14215696.51	20130322	0
3	58720.32	4709.79	-119.7734201	39.11308889	853690.8853	14215670.67	20130322	0
4	58746.6	4711.2	-119.7734331	39.11301757	853686.4062	14215644.81	20130322	0
5	58772.86	4712.66	-119.773446	39.11294633	853681.9335	14215618.97	20130322	0
6	58799.13	4714.14	-119.773459	39.11287503	853677.4477	14215593.12	20130322	0
7	58825.45	4715.64	-119.7734721	39.11280363	853672.9605	14215567.23	20130322	0
8	58851.74	4717.08	-119.7734851	39.11273229	853668.4762	14215541.37	20130322	0
9	58878.13	4718.46	-119.773498	39.11266065	853663.9991	14215515.39	20130322	0
10	58904.48	4719.82	-119.7735108	39.11258911	853659.5826	14215489.45	20130322	0

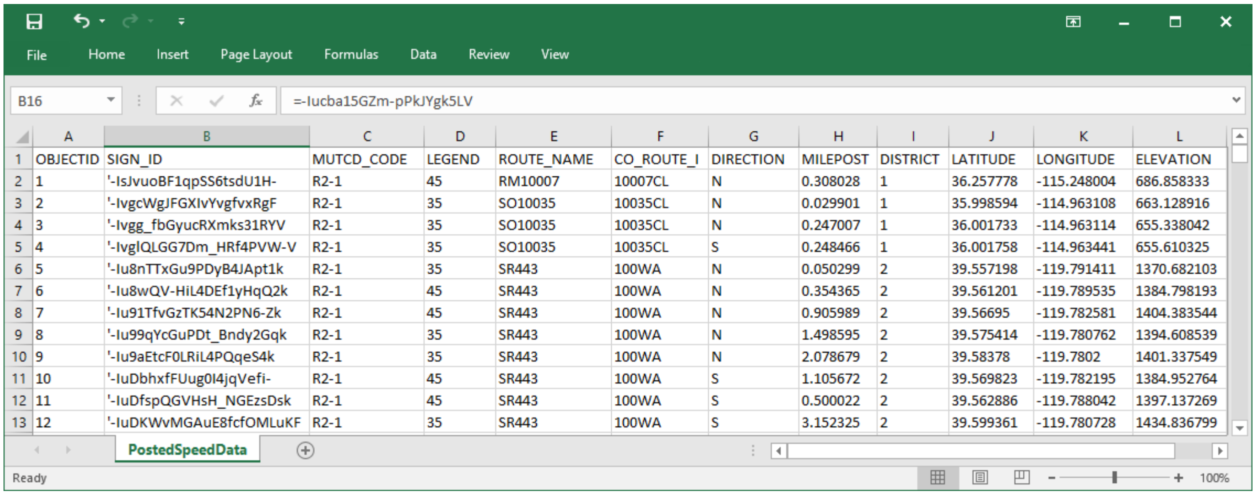
Figure 4-7. Screenshot: Results of Route Data Export to CSV File

The projected coordinate values included in the exported CSV file are based on the assumption that the vehicle path data contained in the GPS file was collected in WGS84 coordinate reference system and that the target projection is the based on the *NAD_1983_UTM_Zone_11N* parameters. As will be shown in Section 4.6, these are configuration parameters for the software that can be changed based on the needs and analysis goal of the user.

4.4 ADDING SUPPLEMENTAL SPEED DATA (OPTIONAL)

An optional feature of the software shown in the previous figures is the ability to load a posted speed database provided to the project team by NDOT. The purpose of the database is to assign a posted speed value (if available) to each point defined in the GPS file. This posted speed database is what would make it possible for the CSV file shown in Figure 4-7 to display a posted speed value in Column 9. Figure 4-8 shows a screenshot of the CSV file that defines the database that is available to the software. As shown in the figure, the database is a collection of posted speed sign locations along with the corresponding speed limit and other information such as the name of the highway route.

For the software to use the database, the user needs to manually load the database through the menu interface shown in Figure 4-9 by accessing the corresponding action available under the *Add Supplemental Data* menu item. As with other menu interfaces, loading a GPS file into the software is what enables the interface. Once posted speed data is loaded, the software will assign a posted speed to each point contained in the loaded GPS file if matching data, based on the route name, is found in the database.



OBJECTID	SIGN_ID	MUTCD_CODE	LEGEND	ROUTE_NAME	CO_ROUTE_I	DIRECTION	MILEPOST	DISTRICT	LATITUDE	LONGITUDE	ELEVATION
1	'-IsJvuoBF1qpSS6tsdU1H-	R2-1	45	RM10007	10007CL	N	0.308028	1	36.257778	-115.248004	686.858333
2	'-IvgcWgJFGXIvYvgfvxRgF	R2-1	35	SO10035	10035CL	N	0.029901	1	35.998594	-114.963108	663.128916
3	'-Ivgg_fbGyucRXmks31RYV	R2-1	35	SO10035	10035CL	N	0.247007	1	36.001733	-114.963114	655.338042
4	'-IvglQLGG7Dm_HRf4PVW-V	R2-1	35	SO10035	10035CL	S	0.248466	1	36.001758	-114.963441	655.610325
5	'-Iu8nTTxGu9PDyB4JApt1k	R2-1	35	SR443	100WA	N	0.050299	2	39.557198	-119.791411	1370.682103
6	'-Iu8wQV-HiL4DEf1yHqQ2k	R2-1	45	SR443	100WA	N	0.354365	2	39.561201	-119.789535	1384.798193
7	'-Iu91TfvGzTK54N2PN6-Zk	R2-1	45	SR443	100WA	N	0.905989	2	39.56695	-119.782581	1404.383544
8	'-Iu99qYcGuPDt_Bndy2Gqk	R2-1	35	SR443	100WA	N	1.498595	2	39.575414	-119.780762	1394.608539
9	'-Iu9aEtcF0LRiL4PQqeS4k	R2-1	35	SR443	100WA	N	2.078679	2	39.58378	-119.7802	1401.337549
10	'-IuDbhxfFUug0I4jqVefi-	R2-1	45	SR443	100WA	S	1.105672	2	39.569823	-119.782195	1384.952764
11	'-IuDfspQGVHsH_NGEzsDsk	R2-1	45	SR443	100WA	S	0.500022	2	39.562886	-119.788042	1397.137269
12	'-IuDKWvMGAuE8fcfOMLuKF	R2-1	35	SR443	100WA	S	3.152325	2	39.599361	-119.780728	1434.836799

Figure 4-8. Screenshot: Posted Speed Data

If posted speed data is loaded, the implication is that during the analysis process that will be discussed in Section 4.5 an automatic required sight distance value is used based on the posted speed data identified. While this can provide flexibility into the analysis process, the flexibility is only provided if accurate data is contained in the database. Since the database is manually generated through a dedicated data collection effort, the end user must take into account the possibility of errors in the analysis process due to incorrect posted speed values.

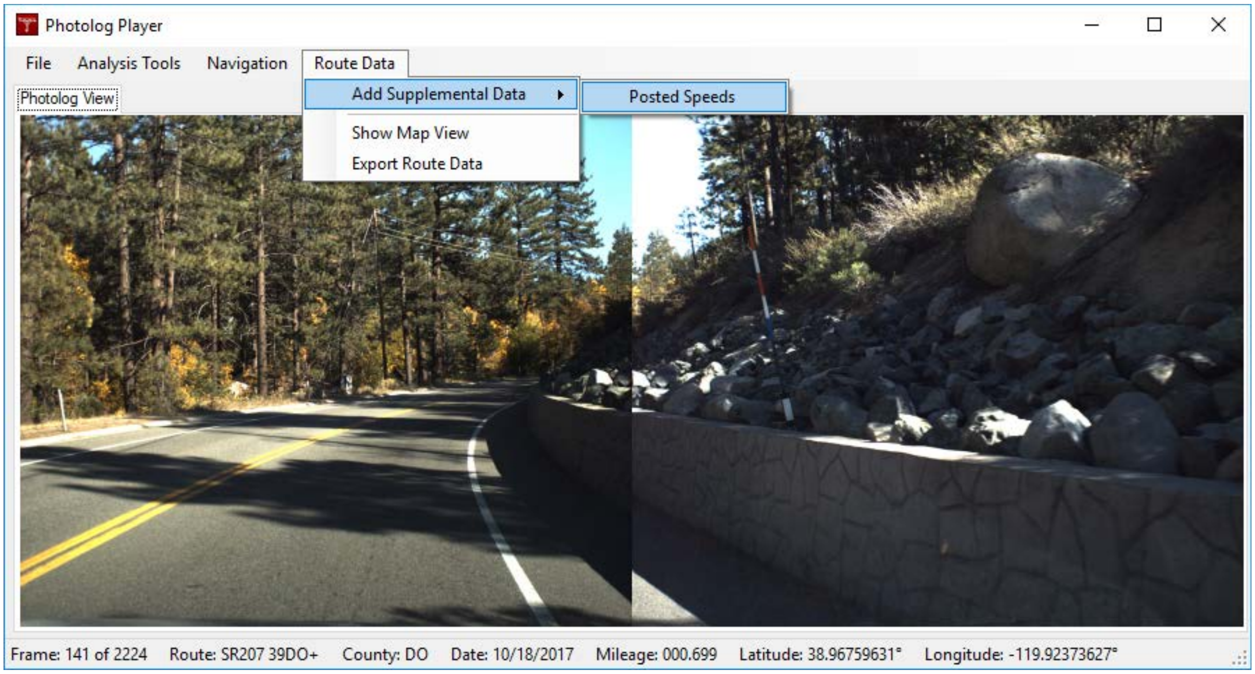


Figure 4-9. Screenshot: Procedure to Load the Posted Speeds Database

4.5 ANALYSIS INTERFACE FOR LINE OF SIGHT OBSTRUCTIONS

Figure 4-10 shows the software interface used to identify theoretical line of sight obstructions. To launch the interface, a GPS file must first be loaded into the software as shown in Section 4.2. Once loaded, the analysis interface can be accessed by selecting *Line of Sight Obstructions* action from the *Analysis Tools* menu. As the figure shows, the analysis interface consists of a collection of input parameters that makes the identification of theoretical line of sight obstructions possible.

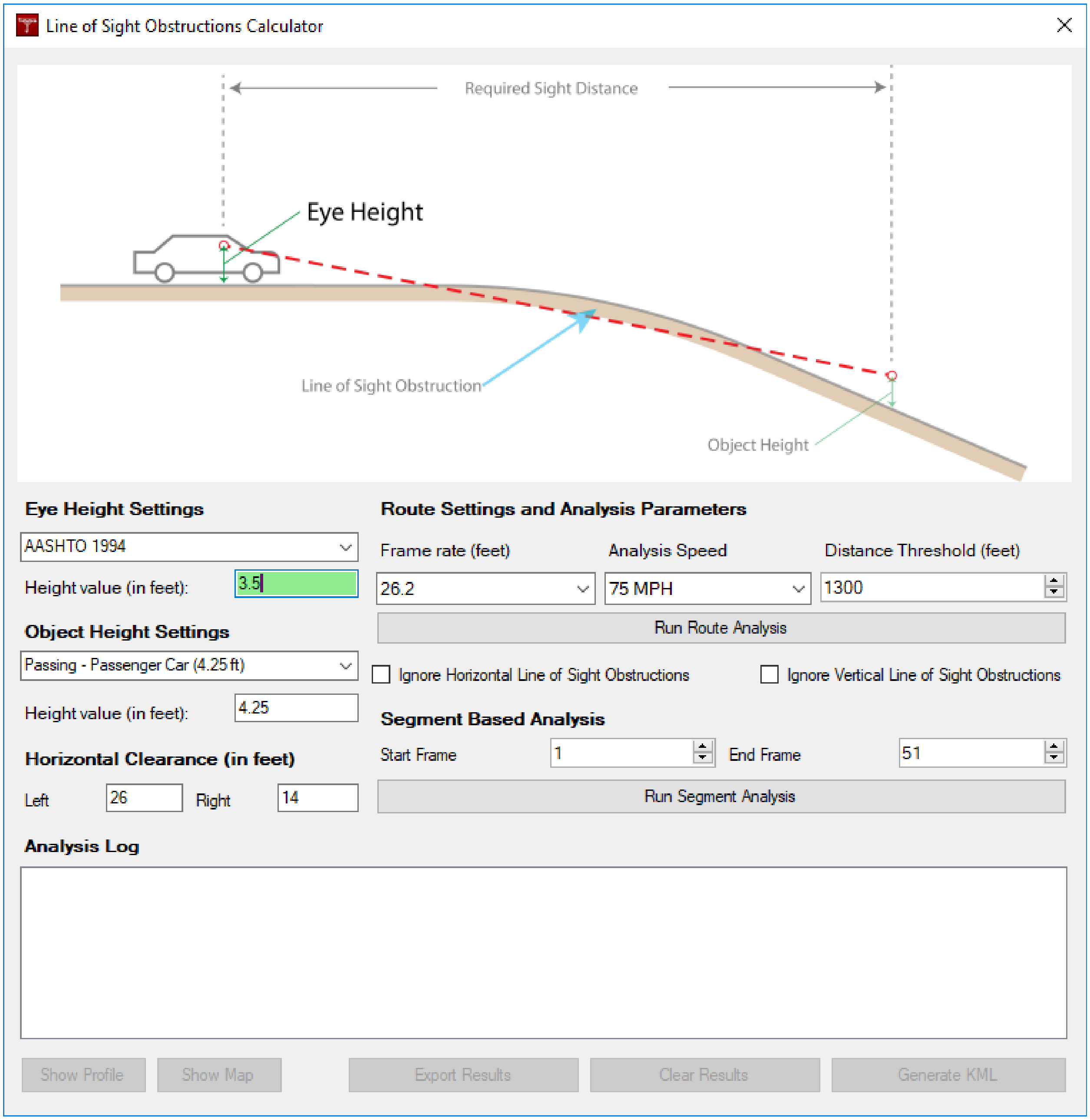


Figure 4-10. Screenshot: Line of Sight Analysis Interface

4.5.1 Selecting Analysis Parameters

Prior to identifying theoretical line of sight obstructions, the parameter values that will be used by the analysis procedure must be selected/entered in the software. By default, the software will have a set of values for eye height, object height, left/right horizontal clearance, frame rate, and distance threshold (required sight distance) in feet assigned. However, all these values can be changed by the user based on the desired analysis parameters. In addition to the ability to enter parameter values manually, the interface provides for drop-down boxes that allow access to other pre-defined values. For example, when the selected item on the analysis speed dropdown box is changed, the corresponding required distance threshold is changed.

To support the user, the interface of the software has been designed to display information (or a graphic) about the active parameter. For example, when a parameter field becomes active the field is highlighted in green and support information is displayed. In the case shown in Figure 4-10, the active field is the eye height one and as a result the corresponding support image displayed on the upper portion of the analysis interface explains the meaning of the parameter. Therefore, the best explanation for each of the analysis parameters provided by the interface is available directly through the analysis interface. As an additional example, when the focus is on the analysis speed drop-down box, the interface displayed changes accordingly as shown in Figure 4-11.

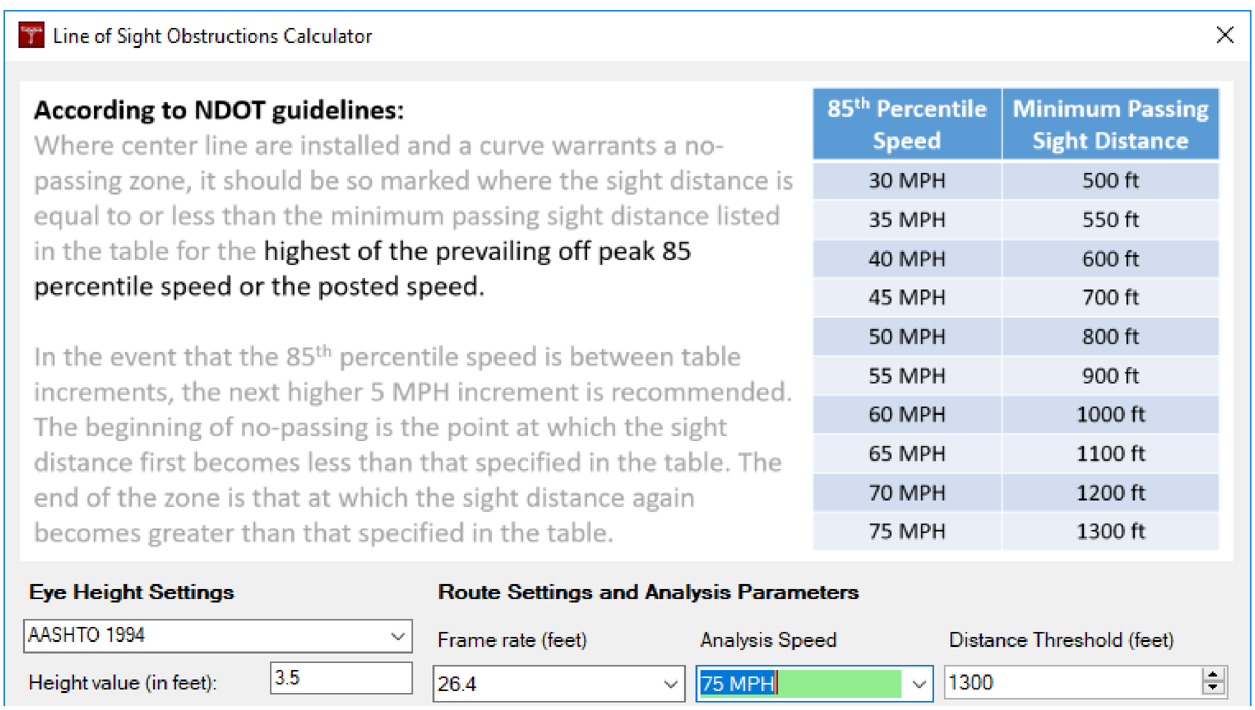


Figure 4-11. Screenshot: Example of Support Information for Analysis Speed Options

4.5.1.1 Frame Rate Parameter

While listed as a parameter that can be changed, for analysis that rely on data from the NDOT data collection vehicle the value of 26.4 should be treated as a constant. The ability to change the value has been introduced in the case that the data collection procedures change in the future and a different distance between points in a GPS file is needed as part of the analysis procedures.

4.5.2 Details About Other Parameters

In addition to the information about each of the parameters that is significant for the analysis procedures, and that is displayed through the interface as previously shown in Figure 4-11, the mathematical implication of each parameter can also be found on this report. Chapter 2 provides details about the meaning of each parameter for the analysis process.

4.5.3 Selecting an Analysis Speed

If the speed database is loaded by using the procedure discussed in Section 4.4, specifying an analysis speed is redundant as the known posted speed for a point will be used to determine the required sight distance at a location on the highway and if a theoretical line of sight obstruction exists. However, if no posted speed information is loaded (a recommended approach to avoid errors caused by a potentially incorrect data source) then a recommended approach is to select an analysis speed that is higher than any of the speeds along the highway.

By selecting a higher analysis speed, if an obstruction is found on a segment the available sight distance is also reported. Using the reported sight distance available the user can then decide, based on the known speed for the segment where the obstruction is located, if the available sight distance reported is sufficient for the known speed conditions.

4.5.4 Executing the Analysis for an Entire Highway Route or for a Highway Segment

By pressing the *Run Route Analysis* button, theoretical line of sight obstructions are identified based on the specified analysis parameters (including the required sight distance) along the entire highway route. Obstruction calculations are performed by analyzing both the horizontal and vertical alignment characteristics of the modeled highway alignment. As an alternative to analyzing an entire highway route, a start and end frame can be selected for analysis, thus limiting the results produced by the software to the segment specified using the frame values. When the keyboard/mouse focuses on the start or end frame box (e.g., while changing the value) the highway photo shown on the main screen will switch to the corresponding location to support the process of narrowing the analysis to the specified segment.

4.5.5 Focusing on Vertical or Horizontal Obstructions

By default, the analysis executed when the *Run Route Analysis* or *Run Segment Analysis* buttons are pressed involves taking into account the horizontal and vertical characteristics of the highway alignment. If the user prefers to only analyze obstructions one condition at a time, the interface provides for the corresponding option. For example, if the *Ignore Horizontal Line of Sight Obstructions* is checked, then the results produced by the software will only take into account the vertical profile characteristics of the highway alignment. Similarly, if the *Ignore Vertical Line of Sight Obstructions* is checked then only the horizontal alignment characteristics are considered. This functionality is useful when generating maps, as will be shown in the next section, since individual maps for obstructions can be overlaid together to see where each type of obstruction exists on the alignment.

4.5.6 Exporting the Results

Once the analysis for an entire highway route or segment is executed, the list of individual obstructions is displayed on the analysis interface as shown in Figure 4-12. As the list shows, the theoretical line of sight obstructions are identified by the start and end frame as well as by the controlling highway alignment characteristic that triggered the identification of a theoretical line of sight obstruction (vertical or horizontal). The purpose of having each individual obstruction will be explained in the next section. However, exporting the entire results as a KML file or as a CSV file can be achieved by pressing the corresponding button. The *Export Results* button produces a CSV file, that the user gets to select where it is saved, and the *Generate KML* button produces a KML file with a save location also specified by the user. Examples of the results generated have been previously introduced in Section 3.1.

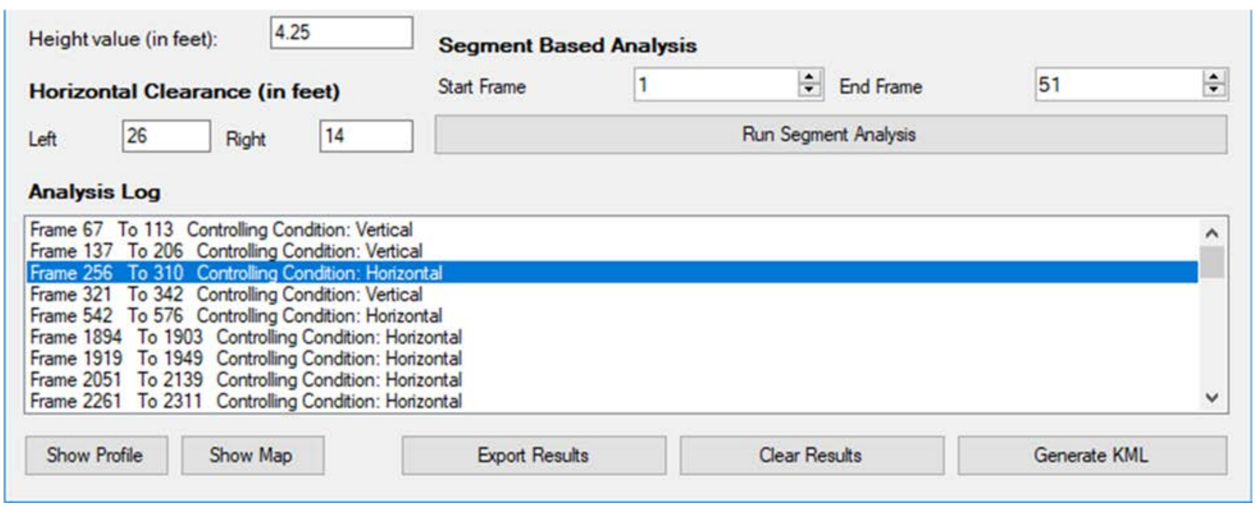


Figure 4-12. Screenshot: List of Individual Obstructions

Selecting an individual obstruction from the list automatically changes the highway photo displayed on the software interface (i.e., the photo and coordinates) associated with the first frame of the obstruction selected. This functionality allows users to navigate to a highway location and visually confirm (if photos are available) the geometric conditions of the highway. To clear the results displayed, and stored in memory, the *Clear Results* button can be used. The results displayed are also cleared if an analysis is executed again.

4.5.6.1 Generating Results for Multiple Conditions

If the user is interested in conducting multiple analysis to compare the results, once an analysis is executed the individual results should be saved by using *Export Results* or *Generate KML* buttons. Multiple analysis of the same route with different parameters can be conducted to create maps that show obstructions identified not only under different analysis speeds but also under different horizontal clearance values. For example, as previously mentioned in the report, if concerns exist about horizontal obstructions caused by selecting a horizontal clearance threshold that does not necessarily represents reality, then an analysis focused only on obstructions due to horizontal characteristics can be executed for a range of horizontal clearance values. The results can then be compared side-by-side to see if small changes in clearance values result in obstructions removed from the list of results.

4.5.7 Examining Individual Obstructions

Once an individual obstruction is selected from the list, the *Show Profile* button can be pressed to view the vertical profile characteristics (elevation and cumulative distance) associated with the obstructions as shown in Figure 4-13. The blue line represents the vertical profile of the portion of the road with the reported obstruction. The yellow line represents the vertical profile of a portion of a road that is immediately downstream of the segment with the reported obstruction.

For analysis purposes, the profile analysis tool shown in Figure 4-13 is significant for obstructions in which the vertical alignment of the highway is the factor causing the line of sight obstruction. However, the tool is available for any type of obstruction. When the tool is launched, only the blue and yellow lines are shown. However, clicking on the profile causes the red dashed line on the figure to appear. The red dash line represents the required line of sight that was used to identify obstructions and when the figure is clicked the line appears at the closest location to the click that represents a point part of the vehicle path dataset and also part of the segment with obstructions. The profile analysis tool acts as a tool to visualize the severity of the vertical obstructions identified since the user can see the location along the highway where the theoretical line of sight is blocked.

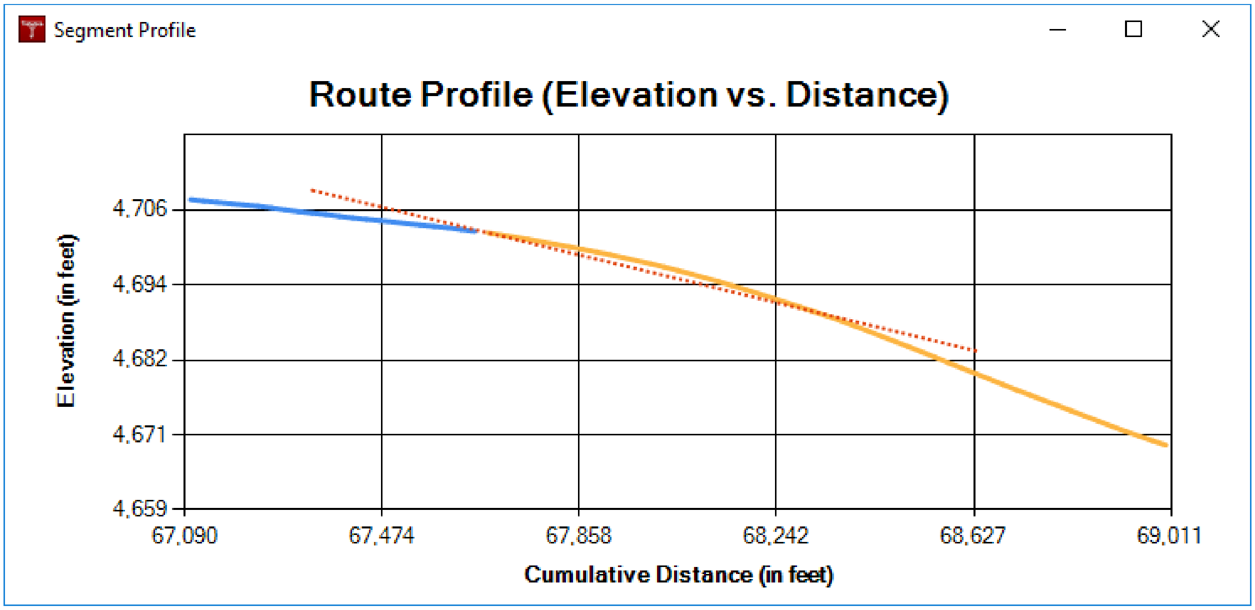


Figure 4-13. Screenshot: Vertical Profile of Individual Obstruction

Selecting one or more individual obstructions shown on the list and pressing the *Show Map* button launches the map visualization tool shown in Figure 4-14. In the map, individual obstruction segments are shown in red. The map interface can be controlled with the middle scroll wheel of the mouse by pressing and holding to pan and by scrolling to zoom in/out.

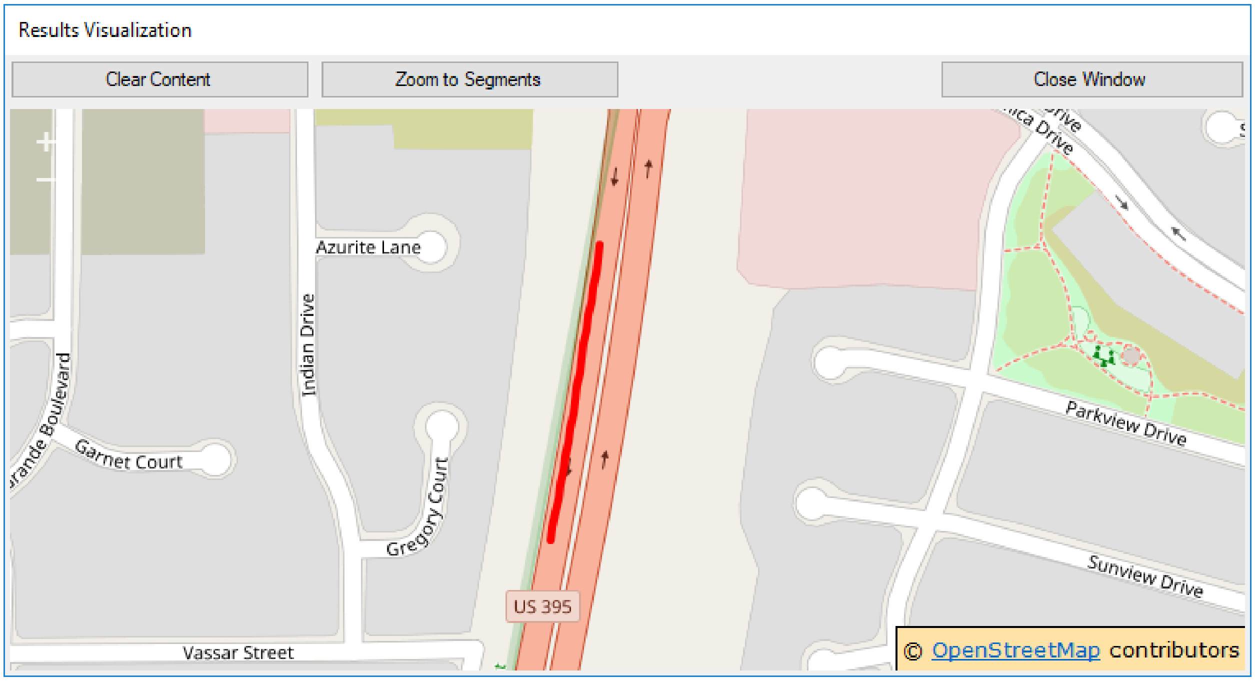


Figure 4-14. Screenshot: Map Interface Showing the Location of Individual Obstructions Selected

4.6 CONFIGURING PRE-DEFINED PARAMETER VALUES

Throughout the software development process, the goal was providing a flexible interface that can be configured by the users without the need for changes to the code. As a result, text configuration files that define the parameters and operation of the software are included inside the *config* folder located in the same the directory that contains the software executable files. The location of the *config* folder relative to the other software files is shown in Figure 4-15.

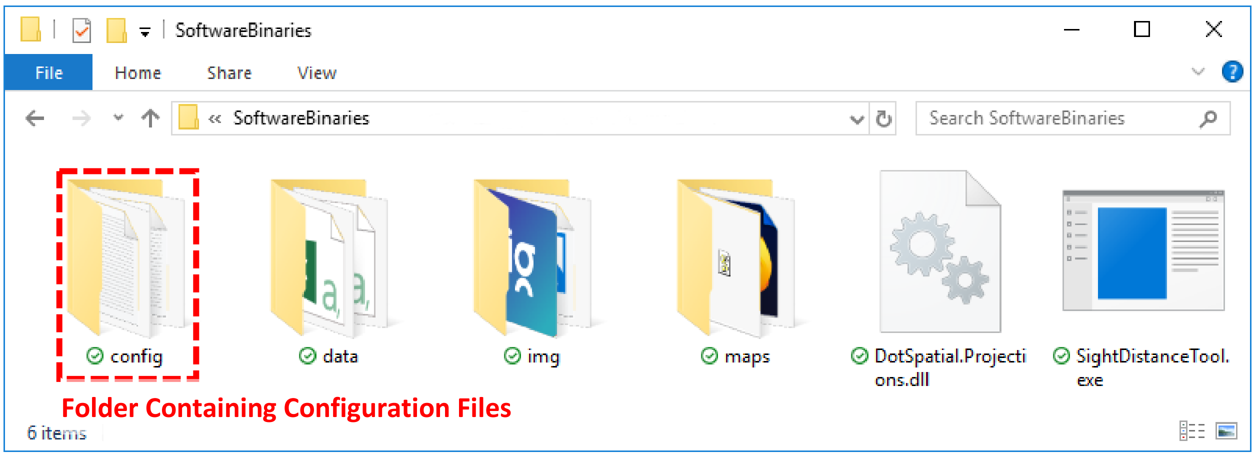


Figure 4-15. Screenshot: Location of Folder Containing Configuration Files

Figure 4-16 highlights key analysis interface parameters that are configurable by the user. Each of the configurable parameters is associated with drop-down boxes that cause the corresponding value fields to change. A description of how each of the key configurable options shown can be customized by the user is presented in the sections ahead. As will be shown, changing the configuration parameters involves modifying the content of text files and can be achieved with a simple text editor.

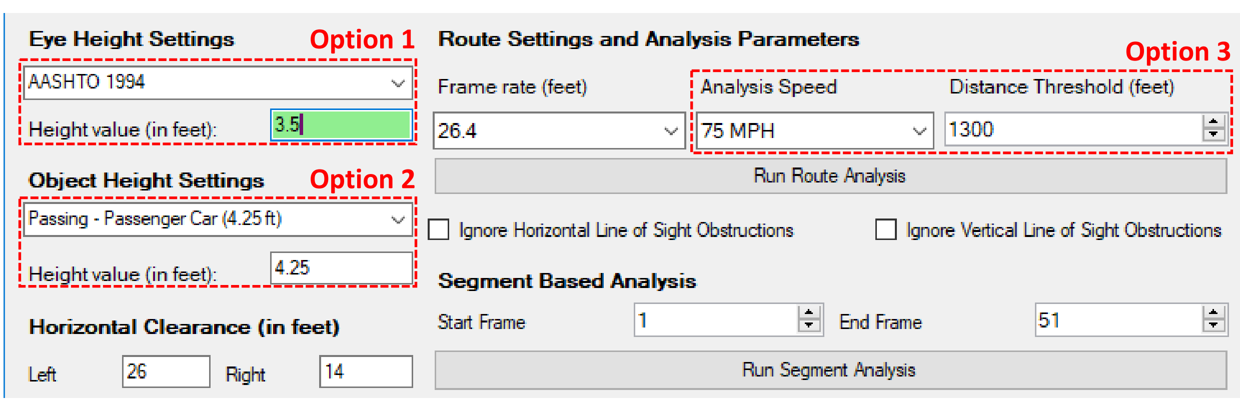


Figure 4-16. Key Analysis Values Configurable by User

4.6.1 Analysis Parameters: Object Height by Analysis Type [Option 1]

The values that are readily available as object height for the user to select can be configured using text files located in the *objectparams* folder part of the *config* folder. Figure 4-17 shows the default configuration files that are distributed with the software. Each file name that is inside the *objectparams* folder is displayed as an option in the drop-down box that allows users to select an object analysis height. The analysis height value associated with the corresponding file will match the content of the corresponding text file. For example, when the user selects "Passing – Passenger Car (4.25 ft)" in the software as the object analysis height, the reason that a height value of 4.25 is assigned to the text box is because 4.25 is the content of the text "Passing – Passenger Car (4.25 ft).txt" file. Configuration files placed inside the *objectparams* folder can be used to easily add options to the software that enable analyzing different object height values corresponding to sight distance analyses that are not necessarily tied to passing sight distance analysis parameters. Similarly, if the analysis parameters recommended by guidelines change, then new values can be added to the *objectparams* folder, thus avoiding the need to manually enter a value every time the software is launched.

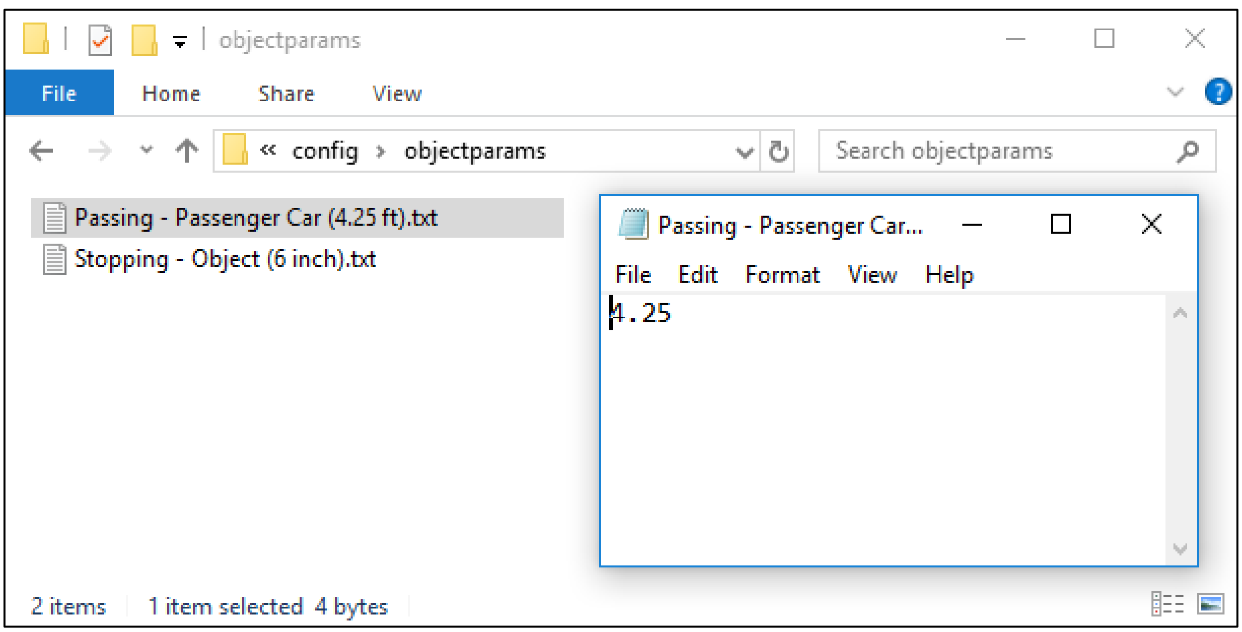


Figure 4-17. Configuration: Object Height Values

4.6.2 Analysis Parameters: Eye Height by Analysis Type [Option 2]

Values readily available as eye height for the user to select can be configured using text files located in the *eyeparams* folder part of the *config* folder. Figure 4-17 shows the default configuration file that is distributed with the software. Each file name that is inside the *eyeparams* folder is displayed as an option in the drop-down box that allows users to select an eye height for analysis. The eye height value associated with the corresponding file will match the content of the corresponding text file. For example, when the user selects "AASHTO 1994" in the software as the eye height for analysis, the reason that an eye height value of 3.5 is assigned to the text box is because 3.5 is the content of the "AASHTO 1994.txt" file. Configuration files placed inside the *eyeparams* folder can be used to easily add options to the software that enable analyzing different eye height values corresponding to sight distance analyses that are not necessarily tied to the typical passing sight distance analysis parameters. Similarly, if the analysis parameters recommended by guidelines change, then new values can be added to the *eyeparams* folder thus avoiding the need to manually type a value every time the software is launched.

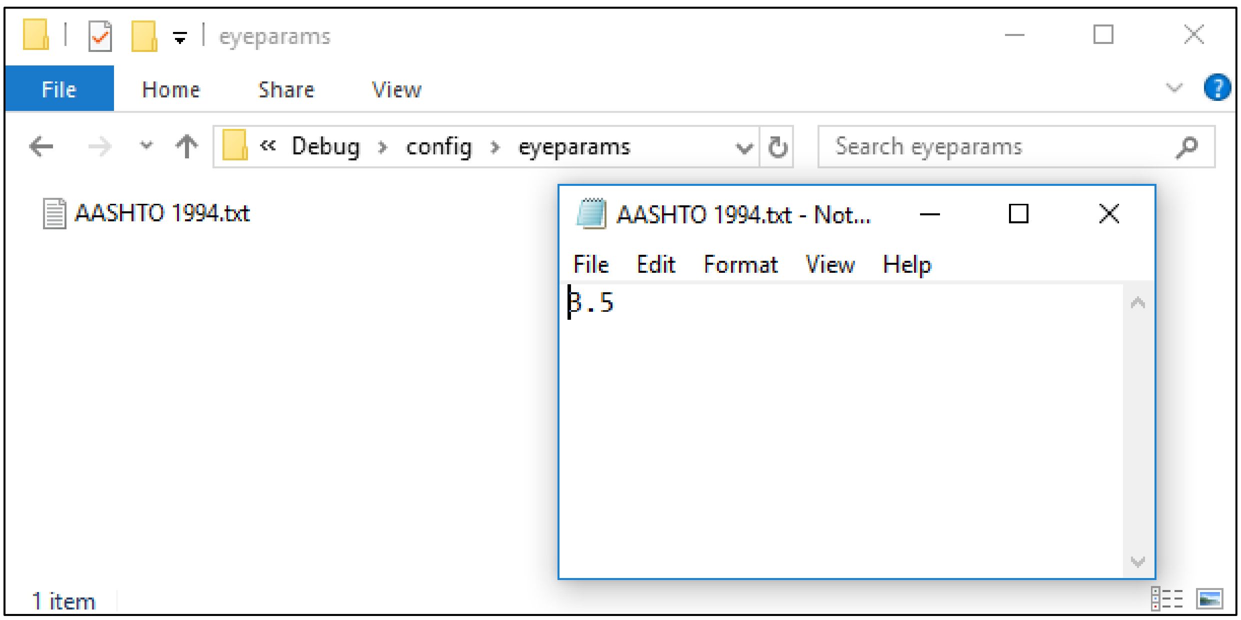


Figure 4-18. Configuration: Eye Height Values

4.6.3 Analysis Parameters: Required Sight Distance by Speed [Option 3]

Analysis speed and required sight distance values displayed by the software are based on the content of folders that are located inside the *speedparams* folder. When a user selects an object height option from the corresponding drop-down box, the software looks for a folder located inside the *speedparams* folder that matches the name of the selected option. Inside the folder, a collection of files like the one shown in Figure 4-19 is required. As the figure shows, the file names describe speed values that will be presented to the user as analysis speed options associated with the object height parameter option selected. In turn, the content of each file is the required sight distance value associated with the speed and which is automatically populated into the corresponding required distance field of the sight distance analysis tool.

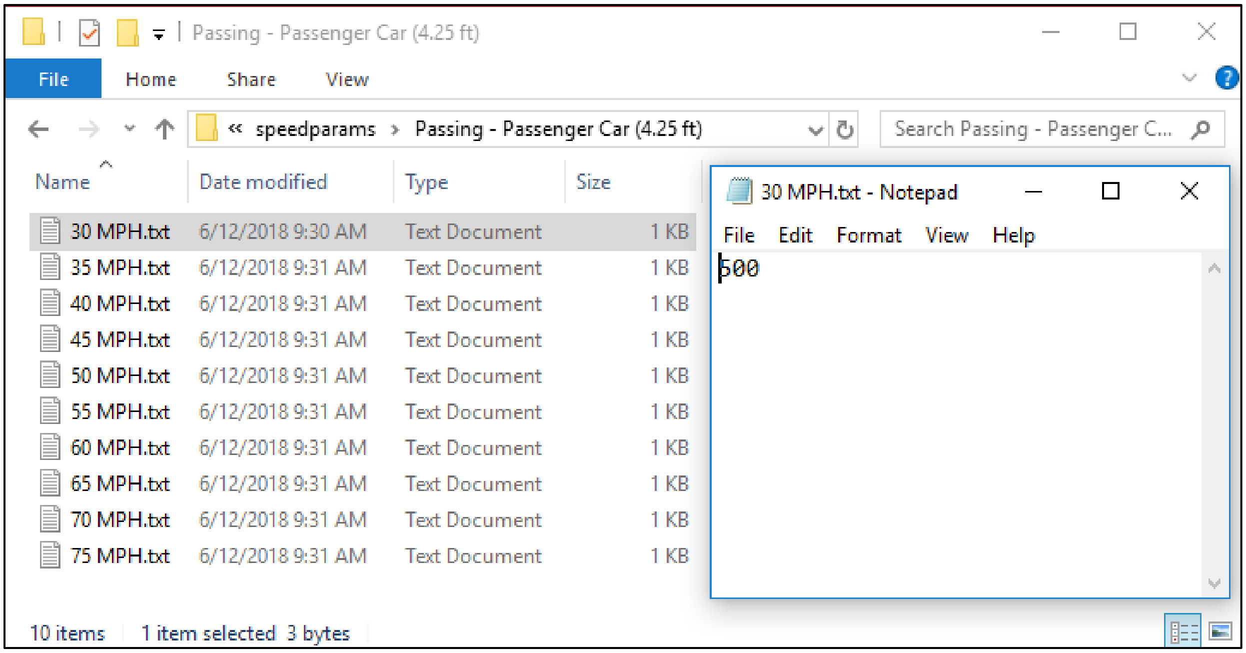


Figure 4-19. Configuration: Sight Distance Requirements by Speed

4.6.4 Additional Configuration Parameters

In addition to the configuration files introduced in the previous sections, which control key parameters of the analysis process, there are other configuration files that the user can change. These configuration files are located in the *config* folder. A list of these additional files, which are meaningful to the analysis, is shown in Table 4-1 along with a summary of the file purpose.

Table 4-1. Purpose of Additional Configuration Files

File Name	**Description**
Original.prj	File containing the technical details of the coordinate system associated with the location data included in the GPS file.
Desination.prj	File containing the technical details of the projected coordinate system to which the latitude and longitude values in the GPS file will be converted.
LeftClearance.txt	Default value used as the typical clear distance available to the left of the vehicle path (in ft).
RightClearance.txt	Default value used as the typical clear distance available to the right of the vehicle path (in ft).
FrameRate.txt	Contains a list of distance between frames that should be made available to the user. One distance between frame value (in ft) per line of the file.

CHAPTER 5. CONCLUSIONS AND IMPLEMENTATION GUIDANCE

No-passing zones markings communicate to drivers that there is not enough clear sight distance available on a marked highway segment to safely complete a passing maneuver that requires entering the opposing lane of traffic, overtaking a leading vehicle, and rejoining the initial lane without aggressively cutting off the vehicle passed. No-passing zones are typically marked using a double solid yellow line along the middle of the road. As conditions change along the highway (e.g. due to a new posted speed or changes to the geometry), the need to evaluate the new conditions for compliance with sight distance requirements is often triggered. This means that segments without a no-passing zone today may be in need of one in the future.

With the widespread use of computer aided design (CAD) and geographic information systems (GIS), identifying no-passing zones is something that arguably should be possible with the “click of a button” on a software tool. However, an existing reality is that most highways that are part of the existing transportation network were built before the use of CAD and GIS was standard practice in highway design. As a result, detailed geometric data about existing highways is not always readily available to allow automating the required available sight distance analysis. As a result of the limited data available, a standard practice used to identify highway segments that need a no-passing zone based on the highway geometry and speed still involves the use of field-based procedures that are labor-intensive in nature.

A common procedure used by transportation agencies across the United States, known as the two-vehicle method, requires two vehicles to be driven along a highway separated by a required sight distance determined by the design speed of the segment under analysis. If at a location along the segment the trailing vehicle driver is unable to see the leading vehicle, the implication is that not enough sight distance exists at the location of the trailing vehicle and that no-passing zone markings are required until the location when the leading vehicle becomes visible again.

5.1 PREVIOUS NDOT STREAMLINING EFFORTS

If the methodology that is the foundation of the two-vehicle method can be automated or streamlined the time savings associated with the identification of no-passing zones could be significant. For example, NDOT standard procedures called for the use of a 3-person crew to perform the field work associated with the identification of no-passing zones through the two-vehicle method. As a result of the complexities and requirements associated with the two-vehicle method, NDOT pursued the implementation of a technology-based solution that streamlined field-procedures associated with the two-vehicle method.

However, equipment required by the solution adopted by NDOT is no longer sold/supported by the vendor. As a result, NDOT identified the need for a new system that can streamline the process of locating no-passing zones.

5.2 DEVELOPMENT OF SOFTWARE TO STREAMLINE ANALYSIS PROCEDURES

Software that eliminates the need for field work to conduct line of sight obstruction evaluations was developed and described in this report. The software relies on vehicle path datasets generated during asset inventory surveys conducted along highways as part of existing NDOT internal business processes. These asset inventory surveys along highways are continuously conducted using an instrumented data collection vehicle and the vehicle path dataset that the software relies on is an indirect result of the process. The vehicle path dataset contains latitude, longitude, and elevation values that can be used as a surrogate to describe the geometry of the highway alignment. Using the dataset, the software creates a model of the highway that enables automating the identification of theoretical line of sight obstructions based on input parameters from the user.

The software developed provides Nevada DOT with a decision support system that allows identifying highway segments that are candidates for no-passing zones without the need for dedicated labor-intensive and field surveys. The software maximizes the use of Nevada DOT resources by leveraging the power of existing datasets to eliminate the field visits associated with a legacy process. As a result, the process of identifying potential safety issues caused by limited line of sight availability due to existing highway geometry, due to changes to the alignment, or due to changes in posted speed has been streamlined as a result of the project described in this report.

5.3 TECHNOLOGY MAINTENANCE APPROACH

During the development process of the software an effort was made to make the software a flexible tool for NDOT. As part of the project deliverables, NDOT received the source code of the software thus eliminating concerns about not having the ability to make changes to the analysis tool in the future and preventing a vendor lock-in scenario. Additionally, and as was shown in Section 4.6, the software analysis interface relies heavily on the use of configuration parameters that can be edited with a simple text editor to change how the software operates. As a result, users without computer programming skills are able to modify the analysis parameters used by the software as well as some of the interface components. By creating a flexible analysis interface that can be edited without the need for core code changes, the technical debt associated with the use of the software is reduced thus providing NDOT with a solution that is both flexible and robust.

5.4 IMPLEMENTATION GUIDANCE

As shown throughout the report, analysis procedures presented that are implemented via the software developed rely on datasets already owned, or actively collected, by NDOT. As a result, the implementation of the underlying analysis procedures made possible by the software can be achieved without significant changes to internal NDOT processes. The sections ahead provide implementation guidance on several areas that are relevant to the analysis procedures that are now possible.

5.4.1 Acquisition of Data

Implementation of the analysis procedures made possible by the software does not require changes to the existing data collection system used by NDOT to conduct assets inventory surveys along highways. As previously mentioned, the minimum data required to implement the analysis procedures is the GPS file generated once a route is surveyed and prepared for compatibility with the RoadView™ software used by NDOT as part of existing asset inventory practices. As a result, when conducting a sight distance analysis on a highway route, the first step in the process should be to locate the newest GPS file that is available for the route.

5.4.2 Integration of Results with Existing Datasets

The results of the analysis procedures implemented by the software can be saved in two different ways: as a CSV file and as a KML file. If a sight distance analysis is conducted using required sight distance values associated with speeds that are higher than the estimated/measured speeds, a recommended approach, then the CSV file produced will contain an available sight distance value for each point that defines the vehicle path in the GPS file. Since each point is associated with a latitude and longitude value, as well as a cumulative mileage value, the reported available sight distance values can be integrated with existing NDOT databases. Another integration approach possible involves storing the KML files that result from the analysis process in the same network location as the GPS file. Saving the results on the same place as the GPS file will make the sight distance analysis procedure results easily available to numerous NDOT groups without the need for directly integrating the results into existing databases.

5.4.3 Using an Existing Dataset or Collecting a New One

If the route for which a sight distance evaluation is to be conducted undergo changes after the time when the last asset inventory survey of the highway was conducted, as part of the cyclical process, then a new survey could be required. For results to be meaningful, the vehicle path data contained in a GPS file used for analysis needs to reflect the most recent alignment geometry. The decision on whether a new survey is needed to support the sight distance analysis procedures should be primarily based on two considerations. First, by considering changes made to the highway since the time of the last survey, and, second, by considering the specific goals of the available sight distance evaluation.

If geometric changes made to the route, since the time of the last survey, were significant enough that alignment improvements were made to the route it is likely that due to the use of CAD, no-passing zones were already identified as part of the design process and that appropriate markings were part of the corresponding highway improvement project deliverables. The second consideration, the specific goals of the available sight distance evaluation, is important because if only a particular segment of the entire route is of interest and that segment has not suffered changes since the last survey represented by the GPS file then the existing data could be used by limiting the analysis to the appropriate segment.

5.4.4 Training Considerations

The software developed as part of the project described in this report was designed, to the extent possible, to be intuitive and provide guidance to the user throughout the analysis process. For example, supplemental images are displayed when parameter values are changed/reviewed in the analysis interface. In addition to the built-in support tools, Chapter 4 of this report provides a user guide for the software. Additionally, supplemental guidance in the form of video was delivered to the NDOT project manager along with the software binaries and source. Therefore, prior to using the software, this report, as well as the supplemental video delivered should be treated as required training material.

In addition to the ability of users to learn the operation of the software from the training materials available, knowledge about highway design is important. Therefore, users of the software should be familiar with NDOT design policies and have a working knowledge of the type of input values used by the software. The aforementioned knowledge by the users should be treated as a key requirement since the use of inappropriate values could lead to incorrect results or to the incorrect interpretation of results.

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