Procedure for Establishing No Passing Zones

by

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Graduate Research Assistant

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Assistant Professor

FINAL REPORT

for

RESEARCH PROJECT 23241-95-4

Center for Transportation Engineering Studies
Department of Civil Engineering
North Carolina State University

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/NC/95-007		

4. Title and Subtitle	5. Report Date
Procedure for Establishing No Passing Zones	February 1996
	6. Performing Organization Code
7. Author(s) R. L. Brown and J. E. Hummer, Ph.D., P.E.	8. Performing Organization Report No.
9. Performing Organization Name and Address Center for Transportation Engineering Studies North Carolina State University Box 7908 Raleigh, NC 27695	10. Work Unit No. (TRAIS) 11. Contract or Grant No. 23241-95-4
12. Sponsoring Agency Name and Address North Carolina Department of Transportation P. O. Box 25201 Raleigh, NC 27611	13. Type of Report and Period Covered Final Report July 1, 1994-June 30, 1995 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Highway agencies establish no passing zones on two-lane highways where there is less than a specified minimum passing sight distance available to drivers. Many agencies measure passing sight distance using a "two-vehicle" method, which is labor-intensive and may result in overly-conservative estimates. The purpose of this project was to determine whether there was another method of measuring passing sight distance that would produce estimates as accurate or more accurate than the two-vehicle method with less labor. The project team developed and investigated three promising new methods--using radar, lasers, and optical rangefinders--and also investigated a "one-vehicle" method in use in three divisions of the North Carolina Department of Transportation. The team conducted an experiment comparing the accuracy of the three new methods, the one-vehicle method, and the two-vehicle method at 40 curve and hill crest sites in the Piedmont and Mountain regions of North Carolina. Based on the results of the experiment, the labor required by each candidate method, and other important parameters such as equipment cost and training requirements, the team recommends the one-vehicle method as the best method for measuring passing sight distance.

17. Key Words	18. Distribution Statement
Passing, sight distance, study, measurement, two-lane highway, curve, crest	One hundred copies of this document were printed at a cost of $2.31 per copy.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

The authors express their sincere appreciation to the North Carolina Department of Transportation (NCDOT) for funding this research.

The authors thank Hap Crowe, Jr., P.E., the Chairman of the Technical Advisory Committee, and Ken Putnam, P.E., both of whom provided great insight and assistance throughout the project. The authors also thank Pat Strong, P.E., Mike Stanley, P.E., and Lori Cove, P.E., the other members of the Committee. The project would not have been possible without assistance from people in several divisions of the North Carolina Department of Transportation. We therefore thank Roger Hawkins and John Farrow from Division 3; Tom Gould and Cary Woody from Division 5; Ray Goff and Franklin Bullock from Division 6; Will Garner, Jr., P.E. and Rusty Thompson from Division 8; and Gene Allman from Division 13. Finally, we thank Bart Nichols and Dave Wilhoite of Kustom Signals, Inc. for use of the laser equipment.

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INTRODUCTION

The accurate placement of no-passing zones on two-lane highways is critical for motorist safety and to protect departments of transportation from lawsuits after accidents. Also, providing no-passing zones that are not longer than required maintains the efficiency of the roadway. Agencies, including the North Carolina Department of Transportation (NCDOT), establish no-passing zones where the measured passing sight distance falls below the passing sight distance required in the *Manual on Uniform Traffic Control Devices* (FHWA, 1988).

The standard method of measuring passing sight distance used by most divisions of NCDOT and most highway agencies nationwide employs a crew of two persons (a process called "pulling sight distance" by NCDOT pre-striping crews). A new method at least as accurate and efficient as the standard method and requiring only one employee and one vehicle would greatly benefit NCDOT and other agencies. However, one-vehicle methods, whether currently in use by some agency or created during this project, would need evaluating for accuracy and other parameters.

The goal of this project was to develop a new method to measure passing sight distance on highways with a crew of one vehicle and employee. The specific objectives of the project included:

1) To build and calibrate one or two promising prototype one-person methods or devices;

2) To prove that one or both prototype methods are superior to the current basic method in personpower, equipment cost, and accuracy; and

3) To provide specifications for the recommended method and training in how the method works.

The scope of this project limited findings to a method for passing sight distance only, even if the method could possibly be used for determining stopping, decision, or intersection sight distances. The primary focus was on two-lane highways, and specifically rural highways. The researchers also limited their use of devices to off-the-shelf technology. Time and money constraints led to this stipulation. The researchers also wanted to find a method requiring minimal employee training. Lastly, the scope of this project involved data collection in North Carolina only.

STATE-OF-THE-ART REVIEW

Literature

The *MUTCD* presents the concept of passing sight distance and the standards for marking two-lane roads for no-passing. The *MUTCD* accomplished this by explaining how minimum passing sight distances are computed and by providing a table, Table 1 in this report, for minimum passing sight distance based on the 85th percentile speed of a section of highway in question.

Two methods for determining passing sight distance are currently presented in the literature on traffic studies (FHWA, 1991). The two-vehicle

Table 1: Minimum Passing Sight Distance Requirements

85 Percentile Speed (MPH)	Minimum Passing Sight Distance (Feet)
30	500
40	600
50	800
60	1000
70	1200

Source: FHWA, 1988

method is the predominant method with the walking method only being used at sites when more accuracy is needed. The walking method was the main method used in North Carolina until the two-vehicle method came into use.

The two-vehicle method employs two trucks equipped with two-way communication, distance measuring instruments (DMIs), and a paint sprayer operated from within the truck. The DMIs measure odometer readings to the nearest 0.3 m (1 ft.). Upon starting, one truck moves ahead of the other the required passing sight distance. After each truck resets its DMI to 0.0, they both begin to drive through the stretch of road to be pulled for sight distance. The drivers try to maintain the required separation by use of two-way communication. When the rear driver of the team loses sight of a point 1.0668 m (3.5 feet) above the ground on the lead vehicle (an *MUTCD* standard), he or she administers a short paint mark which indicates the start of the no-passing zone. A paint mark is also placed on the pavement when the lead truck comes back into view to designate the end of the no-passing zone and the start of the passing zone. Some field teams use a series of mirrors to augment the rear driver's eye height to 1.0668 m (3.5 ft). Other teams assume that the driver eye height of the truck is sufficient as is.

The walking method involves two employees walking through a site (curve or hill) separated by a rope or chain equal in length to the required passing sight distance according to the *MUTCD* (Weber, 1978). Each employee holds a range pole at one end of the rope or chain. Each range pole is marked at the assumed vehicle eye height according to the *MUTCD* (currently 1.0668 m or 3.5 ft.) These aid the crew members in simulating an actual driver's point of view. This rope or chain set-up is the only equipment needed for this method other than a means of marking the pavement. When walking through a site, the rear crew member stops at the point at which the lead range pole marker disappears and a mark is made for the start of the no-passing zone. The end of the no-passing zone occurs when the lead range pole marker comes back into view. The research team adopted the walking method as the control or reference method against which to compare other methods, since it is routinely viewed as the most accurate method that field crews employ in a reasonable time.

A literature review revealed no past or present research concerning the development of a one-vehicle, one-employee method. Searches of on-line catalogs of the North Carolina State University (NCSU) library and of the Transportation Research Information Service (TRIS) yielded only one reference to a one-vehicle method. A "cone method" once used in New Jersey required one vehicle but two employees to set up cones at 30.48 meters (100 ft) intervals at the proximity of a curve or hill (Waldorf, 1977). These cones were used to estimate passing sight distances along the curves and hills while driving a stretch of highway. In effect, the cones acted as an approximation for the location of an imaginary lead vehicle for the two-vehicle method described above. This method failed to meet the one-employee criterion and required extensive setup time for each curve or hill; consequently, the researchers dismissed it as a possible new method.

Professional Contacts

In addition to the literature review, the research team contacted leading state DOTs, divisions within NCDOT, manufacturers and vendors, and other potentially helpful professionals. The objective of this activity was determining if any past or ongoing research existed relating to a one-vehicle, one-person method for determining no-passing zones. The researchers also asked about current methods.

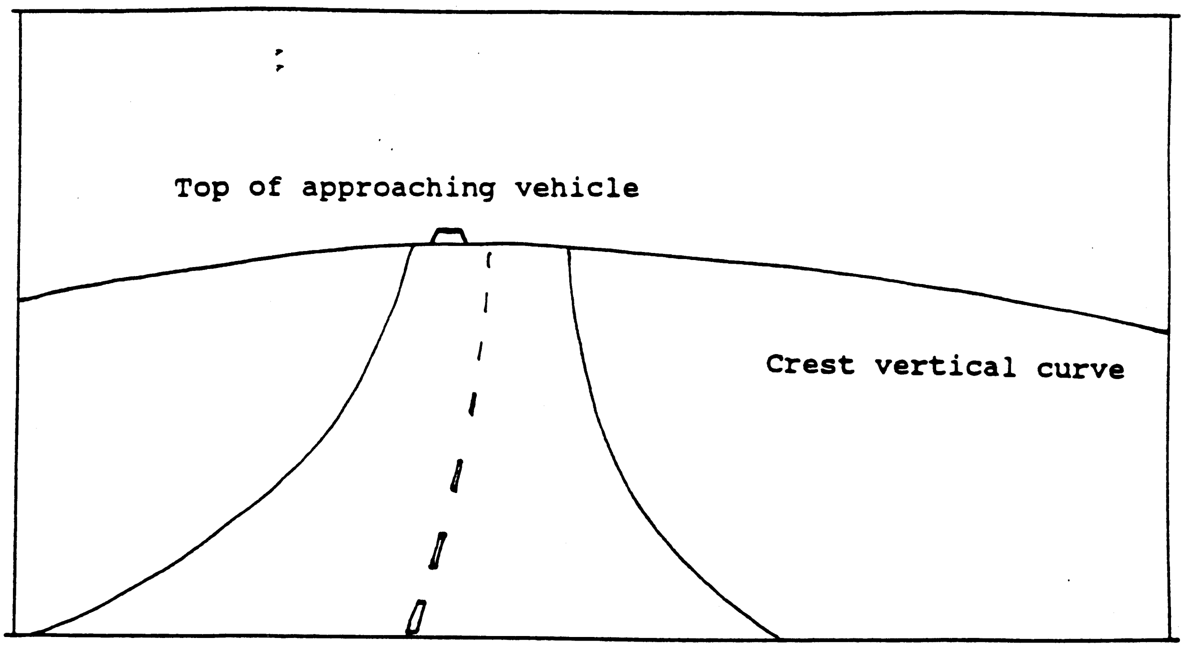
The study team contacted thirteen of the nation's leading DOTs for ideas and advice concerning a one-vehicle, one-person method for measuring sight distance. The Pennsylvania, New Jersey, Texas, Michigan, California, and Colorado DOTs reported using the two-vehicle method to measure passing sight distances. Kentucky reported that some of its divisions use the two-vehicle method, while some use a one-vehicle "eye-balling" method, one that would later turn up as a method currently in use in North Carolina in some divisions. Iowa reported using the two-person walking method.

The Virginia, Wisconsin, Arizona, and New York DOTs reported using videologs (Virginia used it in only certain areas), while Connecticut reported using a photolog system. In all cases, the videolog or photolog system was part of a highly specialized data collection vehicle. This work was contracted in some cases; in other cases, a vehicle was actually purchased by the state.

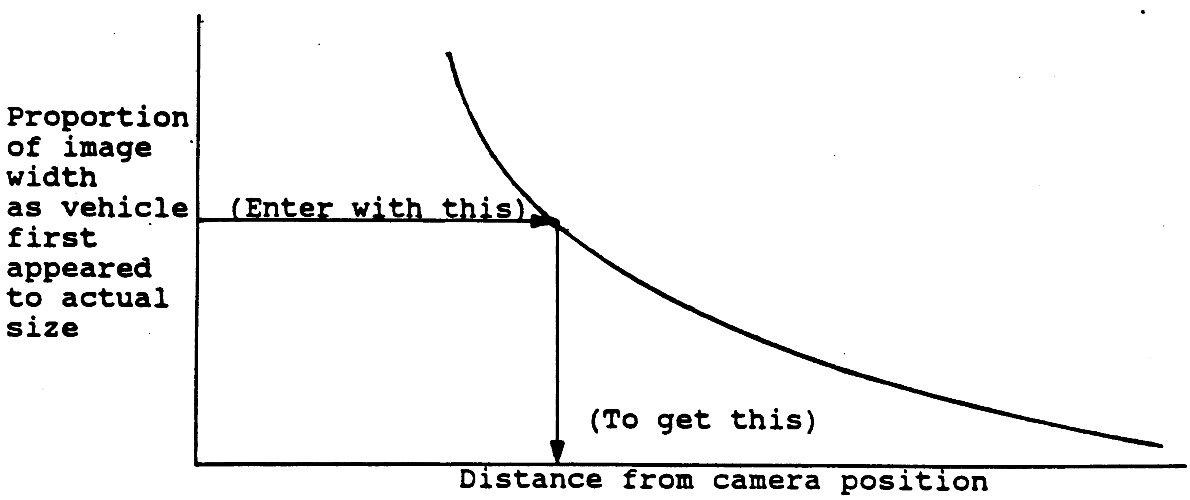
Mandli Communications, Inc. and Roadware Corporation are the two major companies in this line of work. Roadware makes the ARAN, which is more familiar to pavement management officials. Both companies provide services on a per mile or per day basis. While these systems would determine passing sight distance with a high degree of accuracy, along with other valuable highway and pavement data, they do not come at a low cost. Vehicle costs range from $50,000 to $1.2 million and service rates are about $17 per mile or $2000 per day (Vander Deem, 1994).

The project team came up with two possibilities for new methods early in the project. One possibility dealt with the apparent size of an approaching vehicle. With the knowledge that objects approaching a viewer appear to get larger according to a hyperbolic function, the size of an image of a vehicle when first seen rounding a curve or cresting a hill could be used to estimate passing sight distance (Figure 1). The second possibility involved using the fact that distance equals speed multiplied by time. Passing sight distance could be estimated by somehow recording an oncoming vehicle's average speed and the time required to travel from point of first visibility to the observer's position.

With these two possibilities in mind, the team contacted video and speed detection device vendors and manufacturers for their recommendations. Upon explaining the preliminary ideas for the speed estimation method, vendors tried to recommend radar and video equipment models that would adequately do the job at minimal costs. Vendors of video equipment suggested that on-screen measurements of the apparent size of an oncoming vehicle with standard



Sample image of approaching vehicle as it first appears from technician's position.



Sample conversion of image and actual width to distance using hyperbolic function.

Figure 1: Video Method

equipment would not produce accurate sight distance estimations. They suggested that equipment similar to that used by Roadware and Mandli would be needed, resulting in very high costs.

At this stage, the project team formulated two additional possible methods. One was the use of a rangefinder to directly measure passing sight distance as the distance from the observer to an oncoming vehicle just appearing over a hill or around a curve. Vendors were contacted, and recommended various models that determined this distance directly. These devices ranged from simple optical devices to advanced laser rangefinders costing several thousand dollars. Many of the same devices could estimate vehicle speed, for use with that method, or could measure distance directly. The second additional method involved the use of a remote-control (RC) vehicle in which the vehicle could be stopped just as it disappears from the viewer and the distance to the vehicle directly measured. Table 2 shows various rangefinders and speed detectors which vendors suggested for use in these methods.

Table 3 shows a summary of the telephone survey of the fourteen NCDOT divisions the researchers conducted. The researchers talked primarily to division traffic engineers and their staffs. The major finding from the survey was that Divisions Three, Five, and Six use a one-vehicle, one-person method for all measuring of passing sight distance. Divisions Eleven and Fourteen reported the two-vehicle as their primary method, but that they use the one-vehicle method on occasion based on manpower availability. Divisions Three and Five cited the source of this one-vehicle method as Division Six. The researchers later

Table 2: Distance and Speed Detector Features

product	type	range	magnif.	weight	dimens.	tripod use	focus req.	bearing	incline	power	retailer	price
Distance Detectors												
1000 Rangematic	Optical binocular	50-1000 yds	6 X	22 oz.	10.75" X 2" X 2.5"	No	Yes	No	No	None required	Ranging/ V.I.T.	?
1000 Rangematic	Optical binocular	50-1000 yds	6 X	22 oz.	10.75" X 2" X 2.5"	No	Yes	No	No	None required	Bass Pro Shops	$99.00
Leica Geovid	Laser binocular	24-1000 m	7 X 42	?	?	Yes	No	Yes	No	?	U. S. Cavalry	$4,495.95
Leica Geovid	Laser binocular	24-1000 m	7 X 42	?	?	Yes	No	Yes	No	?	Leica	$5,844.00
KVH Datascope	Optical monocular	unlimited	5 X 30	11.5 oz.	4.5" X 1.7" X 2.4"	No	No	Yes	No	3V lithium batt. (3)	Edmund Scientific	$445.00 discounted
KVH Datascope	Optical monocular	unlimited	5 X 30	11.5 oz.	4.5" X 1.7" X 2.4"	No	No	Yes	No	3V lithium batt. (3)	U. S. Cavalry	$444.95
Prosurvey 1000	Laser	5-2500 ft.	n/a	4.25 lbs.	10" X 3.3" X 11"	Yes	No	No	No	2.3Ah rech. battery	Laser Atlanta	$5,495.00
Prosurvey 1000	Laser	5-2500 ft.	n/a	4.25 lbs.	10" X 3.3" X 11"	Yes	No	Yes	No	2.3Ah rech. battery	Laser Atlanta	$6,495.00
Prosurvey 1000	Laser	5-2500 ft.	n/a	4.25 lbs.	10" X 3.3" X 11"	Yes	No	No	Yes	2.3Ah rech. battery	Laser Atlanta	$5,995.00
Prosurvey 1000	Laser	5-2500 ft.	n/a	4.25 lbs.	10" X 3.3" X 11"	Yes	No	Yes	Yes	2.3Ah rech. battery	Laser Atlanta	$6,995.00
ProLaser II	Laser	20-2000 ft.	n/a	4.25 lbs.	10" X 3.3" X 11"	Yes	No	No	No	battery pack	Kustom Signals, Inc.	$4,590.00
Speed Detectors												
ProLaser II	Laser	20-2000 ft.	n/a	4.25 lbs.	10" X 3.3" X 11"	Yes	No	No	No	battery pack	Kustom Signals, Inc.	$4,590.00
Falcon	Radar	20-2000 ft.	n/a	5 lbs.	?	No	No	No	No	battery pack	Kustom Signals, Inc.	$1,435.00
HR-12	Radar	20-2000 ft.	n/a	5 lbs.	?	*vehicle mounted	No	No	No	battery pack	Kustom Signals, Inc.	$1,885.00
Vascar	passive	visibility limited	n/a	n/a	box-6.75"X3.275" X4.125" odometer-1.25"X1"X3.5"	*vehicle mounted	No	No	No	car battery	Traffic Safety Systems	$1,250.00

Table 3: NCDOT Division Survey Summary

DIVISION	CONTACT	METHOD
1	Steve Yetman	Two-V
2	Steve Hamilton	Two-V
3	Roger Hawkins	One-V
4	Sid Tomlinson	Two-V
5	Tom Gould	One-V
6	Franklin Bullock	One-V
7	Vance Barham	Two-V
8	Rusty Thompson	Two-V
9	David Moore	Two-V
10	Thomas Thrower	Two-V
11	Perry McCutchin	Two-V/One-V
12	Bob Jenkins	Two-V
13	Ken Putnam	Two-V
14	Roger Stewman	Two-V/One-V

observed the method in action in all three of these divisions.

To summarize briefly the history of determining sight distance in North Carolina according to the contacts with the divisions, all divisions in North Carolina once used the manual walking method. Some divisions later began using a vehicle to pull the rope or chain used with the walking method. When FHWA documented a two-vehicle method, all divisions began using this approach. Later still, Division Six developed or learned of a one-vehicle method. They believed this method to be reliable and began using it on a regular basis. Divisions Three and Five later became interested in learning this procedure, and subsequently began using it. Divisions Eleven and Fourteen also learned of this procedure and began using it in some cases. To this point, these are the only divisions in North Carolina currently using this method. Other divisions knew of this method but chose to use the two-vehicle method, being somewhat skeptical of the one-vehicle method and wanting to use a federally-documented method.

The one-vehicle method currently in use in three NCDOT divisions requires just one employee. To mark a curve or hill for passing sight distance, the employee drives slowly through it. When the employee reaches the point at which the vista opens up and the employee is sure there is a stretch of road ahead sufficient for safe passing, he or she stops the vehicle and places a paint mark on the right side of the highway. Drivers usually sight down the ditch-line as an aid to finding this point when measuring curves for sight distance. This point is the end of the no-passing zone in the direction of travel. The point where the vista opens is usually much easier to locate accurately than the point where the sight distance decreases below the minimum while coming into a curve or hill. The driver then resets the DMI to 0.0, travels the required passing sight distance, and stops to place a paint mark on the left side of the road. This marks the beginning of the no-passing zone in the opposite direction. A trip through the site in the opposite direction, following the same procedure, completes the determination of the location of the no-passing zones for both directions of that site. Figure 2 explains this procedure in more detail. This one-vehicle method essentially assumes a zero-height object. There is no practical way to adjust this object height. The method is therefore likely to be conservative, especially on hills where 3.5-foot high objects could be seen some distance further than zero-height objects.

The state-of-the-art review provided the researchers with knowledge of where NCDOT and other agencies stand concerning the determination of no-passing zones. The review also assured the researchers that no current one-vehicle methods or research on this subject remained uncovered. With this assurance and the formulation of several promising alternatives to the two-vehicle method, the researchers began to construct an experiment to evaluate the possible methods. The alternatives considered by researchers at this point consisted of the one-vehicle, camcorder, rangefinder, photolog/videolog, speed detection, and RC vehicle methods.

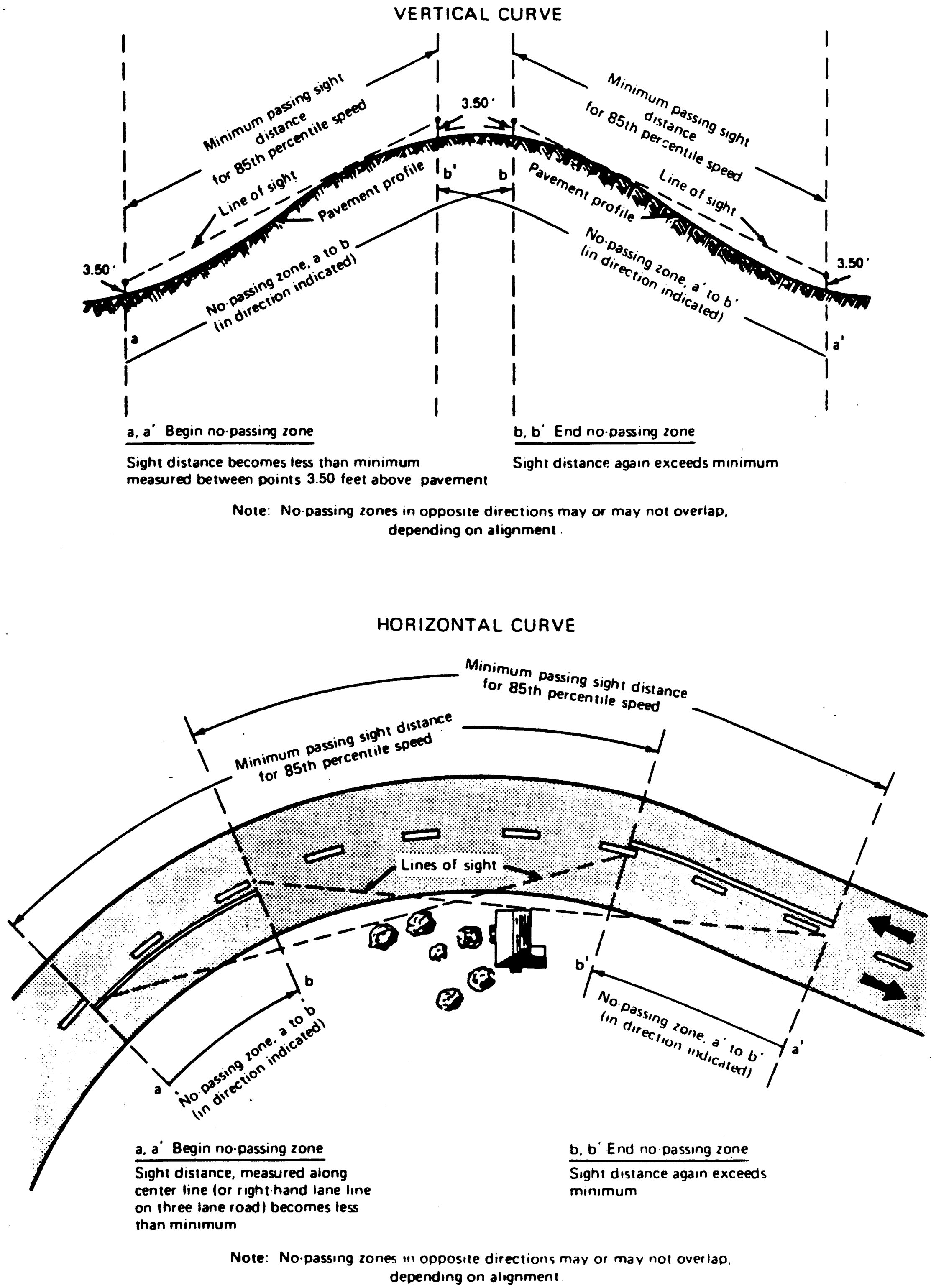


Figure 2: One-Vehicle Method
Source: FHWA, 1988

1) Approach curve or crest of hill in one direction, from left to right in this figure, in vehicle, reducing speed to 10 kph or so just before center of curve or hill.

2) Stop at the estimated point at which the vista opens up and one can see ahead the required sight distance (point b). Spray paint mark on right side of road. This mark denotes the end of the no-passing zone for the current direction of travel.

3) Reset the DMI to 0.0 and proceed, coming to a stop when the DMI measures the required passing sight distance (point a'). Spray paint mark on left side of road. This mark denotes the beginning of the no-passing zone for travel in the opposite direction.

4) Follow steps 1 - 3 traveling in the opposite direction, right to left in this figure.

Hint: When the technician is unsure of when minimum passing sight distances are met while exiting a curve or hill, sighting down the ditch-line for a straight distance greater than the required passing sight distance can be considered the point of the vista opening up.

Figure 2: One-Vehicle Method (Cont.)

METHODOLOGY

Current and New Methods

Before embarking on a detailed evaluation, the researchers narrowed the field of possible methods to a manageable number. To do this, the researchers constructed a matrix, shown in Table 4, of the features of the possible methods. Important considerations included equipment required, manpower required, costs, and possible accuracy.

The project team met with the project technical committee to select the more promising methods to test based on Table 4. Committee members and the project team agreed to evaluate the current one-vehicle method, the current two-vehicle method, the rangefinder method, and the speed detection method. All methods to be tested require one pass in each direction to completely pre-line a curve or hill. Each method would be compared to the walking method, which is assumed to give the most accurate position of the no-passing zone since the rope or chain is a known distance and the crew can move at a slow pace.

The one-vehicle and two-vehicle emerged as experimental methods simply because they are the two that are currently in use in North Carolina and an evaluation of their performance is needed. The relatively low cost and apparent ease of the procedure led to the speed detection method being selected as a promising one. The fact that radar guns are easily obtained and can be used for other purposes, such as speed studies, also was a plus.

The selection process actually yielded two separate methods in the

Table 4: Method Features

Technique	Function	Required Equipment (in addition to one vehicle)	Required Manpower	Associated Costs	Required Trips to Site	Calculations Required (Y/N)	Can Simultaneously Collect Other Data (Y/N)	Travel Speed	Passing Sight Distance Measurement (Chord/Arc)	Equipment Used For Other Studies
Manual (Walking)	Obtains site distance using observers	Field poles, hand measuring device	Two for field work, one for data review	$25-75$ (measuring device)	One to sight and pre-line	No	No	walking speed	Chord	Yes
One-Vehicle (Estimate)	Obtains site distance estimate using vehicle	Measuring instrument for one vehicle	One for field work	$20,000 (instrumented vehicle)	One to sight and pre-line	No	No	45 mph	Chord	Yes
Two-Vehicle	Obtains site distance using instrumented vehicle	Instrumented vehicle (c.b., digital odometer, etc.)	Two for field work, one for data review	$40,000 (two instrumented vehicles)	One to sight and pre-line	No	No	45 mph	Arc	Yes
Distance Detection	Obtains site distance using instrument	Rangefinder, calculating device, DMI	One for field work, one for data review	$100-$400 (optical rangefinder) $4500-$7000 (laser rangefinder)	One to sight and pre-line	Yes	No	stationary	Chord	No
Speed Detection	Obtains site distance using instrument	Radar gun, Lidar gun, DMI	One for field work, one for data review	$4500-$7000 (radar/lidar)	One to sight and pre-line	Yes	No	stationary	Chord	Yes
Photolog/ Videolog	Obtains site distance using instrumented vehicle	Instrumented vehicle	One for field work, one for data review	$60,000 (instrumented vehicle)	One to sight, One to pre-line	Yes	Yes	55 mph	Arc	Yes
Camcorder	Obtains site distance using instrument	Camcorder, VCR, calculating device, DMI	One for field work, one for data review	$1000 (camcorder and VCR)	One to sight, One to pre-line	No	No	stationary	Chord	Yes
Remote-control Vehicle	Obtains site distance using instrument	Remote-control car, hand measuring device, guiderail	One for field work, one for data review	$400 (R/C kit and measuring device)	One to sight and pre-line	No	No	stationary	Chord or Arc	No

rangefinder category, the only difference being the actual device used. An optical rangefinder, which cost only about $100, merited testing merely because of its low initial cost and simplicity. The second device selected to be evaluated as a rangefinder was a relatively new device--the laser gun using lidar technology. Speed or distance can be obtained with the device, an asset which led to its selection despite its higher price of $4500 to $7000. The method also did not require calculation of distance using speed as did the speed detection method.

The photolog/videolog method did not warrant detailed evaluation due to its high cost. The camcorder method appeared too inaccurate and too time-consuming to be practical. It required one-trip to the site to record video footage and a second trip, after viewing video footage, to pre-line the road. In addition, a trial field test revealed that the video images of vehicles were too small to accurately measure at typical passing sight distances. A remote-control vehicle required too much set-up time, would be difficult to see and control at typical passing sight distances, and would likely be unstable on rough roadway shoulders.

Improving the Methods

Before embarking on a detailed evaluation of the remaining methods, the researchers attempted to improve and polish the procedures. Researchers borrowed a radar gun with virtually identical characteristics to the Falcon model listed in Table 3 from NCDOT's Traffic Engineering Branch. It was a K-15 model made by MPH Industries, Inc. The radar gun method required extensive testing to determine the best procedure for obtaining sight distance. Calculation of sight distance requires recording the time for a receding vehicle to travel from the observer until its imaginary 1.0668 m (3.5 ft) high marker disappears, and recording the vehicle's average speed during that time. After many trials varying the speed sampling rate, the researchers found that the best compromise of ease and accuracy was to record a speed reading near the beginning and ending of the vehicle's journey and average the two. Getting numerous speed readings, while possibly more accurate, requires either a good memory or an audio tape recorder to speak into. Obtaining only two readings keeps the method simple yet accurate enough since most travelers maintain a relatively constant speed over 300 meters or less. The researchers found that a simple stopwatch would take care of the timing duties. With a speed and an elapsed time, a sight distance is calculated. A 12-volt battery pack to power the radar gun rounds out the equipment needs.

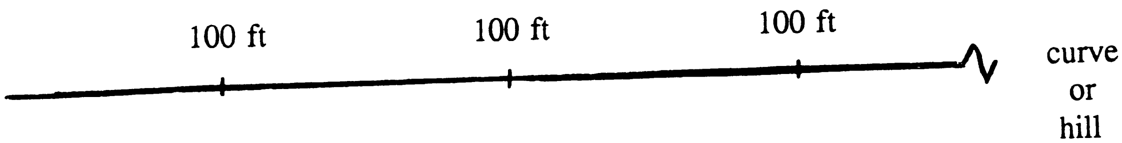
With the radar, laser, or rangefinder methods, field practice with the equipment revealed that sampling a receding vehicle is easier than sampling an approaching vehicle. When a vehicle is approaching, the data collector is often surprised when it first appears and delays starting the stopwatch or getting a rangefinder or laser reading. When using a receding vehicle, the data collector sees the vehicle approaching from behind, is ready to begin as soon as the vehicle reaches his or her position, and can anticipate the time at which its 1.0668 m point is no longer in sight.

In addition to the equipment already mentioned, all three new methods require a measuring wheel during the process of actually determining the start of the no-passing zone. The laser method requires a 12-volt battery pack. With these methods, it is assumed that the end of the no-passing zone is determined by finding where the "vista" opens up when exiting the curve or hill. The rangefinder and laser gun methods use the same simple worksheet shown in Figure 3. The radar gun method worksheet, shown in Figure 4, is similar but has an additional section for computations.

Each of the three new methods begins when the technician chooses a location, near the beginning of the curve or hill, where he or she believes there is sight distance approximately equal to the required passing sight distance. The technician then uses the method to obtain a sight distance estimate. The technician then moves either forward or backward 30.48 m (100 ft) according to the sight distance reading. Another sight distance reading is obtained. This process continues until two particular readings are obtained--one slightly lower than the required passing sight distance and one slightly higher. The position of the actual start of the no-passing zone can then be interpolated. Ideally, the technician can do this with the minimum of two sight distance measurements. However, three or more readings might be required. The team documented step-by-step procedures for each of the three new methods which are included in the Appendix.

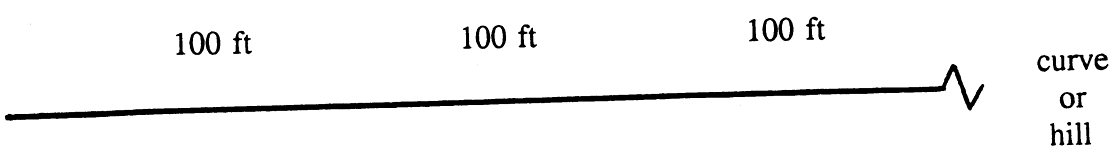
Another technique considered for obtaining the start of the no-passing zone with the three new methods dealt with randomly moving back and forth

Rangefinder Method
Cars Required:
Sketch:



Sight Distance:

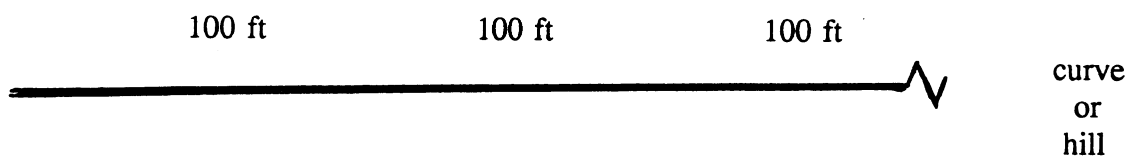
Laser Method
Cars Required:
Sketch:



Sight Distance:

Figure 3: Rangefinder and Laser Methods Worksheets

Radar Method
Cars Required:
Sketch:



Trial#	Beginning Speed (kph)	Ending Speed (kph)	Elapsed Time (sec)	Sight Distance (m)
1				
2				
3				
4				

Sight Distance = (Beginning Speed + Ending Speed) X (5 / 36) X Elapsed Time

Figure 4: Radar Method Worksheet

obtaining sight distance readings until the reading equaled the required passing sight distance plus or minus a predetermined tolerance value. This method proved too time-consuming and unstructured upon field testing, so the researchers settled on the 30.48-m increment method.

Experimental Design

The researchers designed a thorough and controlled test of the accuracy of the two current methods and the three proposed methods relative to the walking method. Each method would yield its own starting point of a no-passing zone at the actual site. The position of this point would be recorded as plus or minus a certain distance from the point obtained using the walking method (plus defined as towards the curve or hill, minus defined as away from the curve or hill).

The team defined a site as a curve or a hill which causes sight distance to fall below the required passing sight distance. The team determined that a forty-site sample size stayed within budget and time constraints of the project while still providing an adequate data set for statistical analysis. The researchers wanted twenty sites from the Piedmont region of North Carolina and twenty sites from the Mountain region in order to determine each method's effectiveness across different types of terrain. Division Eight proved ideal for data collection in the Piedmont region due to a large number of good sites and its proximity to Raleigh. Their experienced two-vehicle team agreed to assist with that method and the experienced one-vehicle team from Division Six agreed to make a trip to sites in Division Eight to perform that method. Researchers chose Division

Thirteen for the Mountain sites. The experienced two-vehicle crew in Division Thirteen agreed to perform that method at the chosen sites for the project.

The researchers also wanted a balance between curves and hills in each region, resulting in four sets of ten sites based on region and type (curve or hill). Initially, the team decided to also include different speed zones in the experiment, but decided that a method working for a 88 kph (55 mph) zone is adequate for slower speed zones requiring shorter passing sight distances.

The researchers compiled lists of potential sites suggested by Division Eight and Thirteen personnel. The lists eventually contained approximately double the number of sites the researchers needed for the experiment. Good sites were on two-lane highways with 88 kph (55 mph) speed limits with hills and curves that occasionally restricted passing, and with few intersections. From the twenty or so sites listed in each set, the researchers chose ten at random for the data collection. The team selected analysis of variance (ANOVA) as the method of statistical analysis for determining the most accurate method. The researchers also considered other measures of effectiveness such as conservatism (extending a no-passing zone is preferable to providing a zone that is too short), reliability, equipment cost, time and labor cost, and training needs to recommend the best method.

RESULTS

Data Collection

Two members of the research team collected the data for the Piedmont and Mountain sites on two different week-long data collection excursions. Only one team member (Brown) performed the one-person methods. The second team member assisted with the walking method, with recording the time each method required at each site, and with tasks between methods. The team used the K-15 radar gun borrowed from NCDOT Traffic Engineering Branch, a ProLaser II laser gun borrowed from Kustom Signals, Inc., and a 1000 Rangematic optical rangefinder purchased from Bass Pro Shops. The team recalibrated the equipment as specified by the manufacturer each day of data collection.

The team collected data in Division Eight on April 12-15, 1995. First, the team completed a site description form, shown in Figure 5, to record information on each of the approximately twenty curves and twenty hills suggested previously as potential sites. The team then randomly chose ten curves and ten hills for data collection. Table 5 lists the chosen sites. Piedmont (Division Eight) sites were in Chatham County. Once chosen, each site required a visit in which the two team members performed, in random order, each of the three new methods (radar, laser, and rangefinder). The team performed the walking method last. Performing each method resulted in identification of a point on the roadway indicating the start of the no-passing zone according to the particular

Name________________________________ Date/Time________________________________

{{{{{{{{{{{{{{{{{{{{{{{{{{{{Site Selection of Curves}}}}}}}}}}}}}}}}}}}}}}}}}}}}}

Route Data

Route________________________________

Starting Ref. Pt.________________________________

Direction of Travel________________________________

Posted Speed Limit________________________________

Curve Data

Curve # ________________________________

Odometer Reading________________________________

Curvature: Right ☐ Left ☐ Crest ☐

Sharpness: Low ☐ Medium ☐ High ☐

Comments:____

____

____

Curve Sketch

Figure 5: Site Selection Data Form

Table 5: Sites

SITE	COUNTY	TYPE*	ROUTE	START @	DIRECTION	DISTANCE FROM START (MILES)
1	CHATHAM	R	NC 751	US 64	NORTH	0.4
2	CHATHAM	L	NC 751	US 64	NORTH	2.3
3	CHATHAM	R	NC 751	US 64	NORTH	2.8
4	CHATHAM	R	NC 751	US 64	NORTH	4.2
5	CHATHAM	C	NC 751	US 64	NORTH	4.9
6	CHATHAM	L	NC 751	US 64	NORTH	6.5
7	CHATHAM	R	NC 751	US 64	NORTH	7.3
8	CHATHAM	L	NC 751	US 64	NORTH	8.5
9	CHATHAM	C	SR 1008	SR 1717	NORTH	0.2
10	CHATHAM	L	SR 1721	US 15-501	EAST	2.6
11	CHATHAM	C	SR 1717	US 15-501	EAST	0.2
12	CHATHAM	C	SR 1008	SR 1717	SOUTH	0.3
13	CHATHAM	C	SR 1008	SR 1717	SOUTH	3.1
14	CHATHAM	R	SR 1008	SR 1717	SOUTH	8.5
15	CHATHAM	L	SR 1008	SR 1717	SOUTH	10.2
16	CHATHAM	C	SR 1008	SR 1717	SOUTH	11.3
17	CHATHAM	C	US 64	SR 1506	EAST	3.2
18	CHATHAM	C	US 64	SR 1506	EAST	7.7
19	CHATHAM	C	US 64	SR 1572	EAST	0.0
20	CHATHAM	C	US 64	SR 1572	EAST	3.2
21	BUNCOMBE	R	NC 151	CANDLER	SOUTH	0.9
22	BUNCOMBE	L	NC 151	CANDLER	SOUTH	4.5
23	BUNCOMBE	L	NC 151	CANDLER	SOUTH	5.2
24	BUNCOMBE	R	NC 151	CANDLER	SOUTH	6.8
25	HENDERSON	C	NC 191	CO. LINE	SOUTH	1.2
26	BUNCOMBE	C	NC 191	NC 146	NORTH	0.4
27	BUNCOMBE	R	NC 191	NC 146	NORTH	1.9
28	BUNCOMBE	R	NC 191	NC 146	NORTH	2.5
29	BUNCOMBE	C	SR 3136	**	NORTHEAST	0.6
30	BUNCOMBE	C	SR 3136	**	NORTHEAST	1.0
31	BUNCOMBE	R	SR 3136	**	NORTHEAST	1.3
32	BUNCOMBE	C	SR 3136	**	NORTHEAST	1.8
33	BUNCOMBE	C	SR 3136	**	NORTHEAST	2.4
34	BUNCOMBE	C	SR 3136	**	NORTHEAST	2.7
35	BUNCOMBE	L	SR 3136	**	NORTHEAST	3.4
36	BUNCOMBE	C	US 74-A	SR 2811	NORTHWEST	0.3
37	BUNCOMBE	L	US 74-A	SR 2811	NORTHWEST	1.0
38	BUNCOMBE	C	US 74-A	SR 2811	NORTHWEST	1.3
39	BUNCOMBE	C	US 74-A	SR 2811	NORTHWEST	4.6
40	BUNCOMBE	R	US 74-A	SR 2811	NORTHWEST	6.2

* R = curve to right, L = curve to left, C = crest

** Second signalized intersection east of NC 25 method. The team measured the distance from this point to some common reference position such as a mailbox or roadsign. After the walking method was performed, the team recomputed the no-passing zone starting points of the three new methods to be plus or minus X meters from the no-passing zone starting point obtained using the walking method.

The following week on April 17, 1995, the experienced Division Six one-vehicle method technician spent a half-day with one of the team members (Brown) to obtain the starting points at each site using the one-vehicle method. Then, on June 13, 1995, Division Eight sent their experienced two-vehicle team to spend a half-day with the same team member (Brown) obtaining starting points at each site for that method. The team converted the starting points from both methods to relative distances from the walking method in the same manner as with the new methods.

A similar procedure ensued for the Mountain region, with several minor changes. The manufacturer of the laser gun had no demonstration model available to borrow during the first trip to Division Thirteen on May 22 - 25, 1995. A second trip had to be made on June 9, 1995, to obtain data for the laser gun method. Secondly, the Division Six one-vehicle technician could not make the trip to Division Thirteen. During the first trip, therefore, a team member who had been trained by Division Six (Brown) performed the one-vehicle method at the sites in Division Thirteen using a measuring wheel instead of a DMI- equipped vehicle.

In both regions, the data collection team assumed a 304.8 m (1000 ft) sight distance standard. The team chose this, rather than the current standard of 274.32 m (900 ft) to avoid bias with current markings while still evaluating the methods at a reasonable distance.

Overall, the data collection in both regions went smoothly. The data collection took approximately thirty hours in each region, for a total of sixty hours. The weather was fair during the entire data collection period. Stiff breezes on a few days did slightly affect the team member's ability to steady the laser gun. Spring foliage was basically constant for the entire data collection period. All the equipment involved performed well. The problems that occurred were minor, including trouble in finding suitable places to park along the road or shoulder and passers-by asking questions.

The laser method proved to be the most troublesome method to perform. At six of the forty sites, the laser gun failed to give a reading due to minor obstructions or hindrances (one road sign post, one case of overhanging foliage which obstructed the laser beam but not sight distance, and four cases of very sharp curves). The rangefinder method also had difficulties. It proved hard to use when vehicles entered dark shadows, making the two images in the viewfinder hard to discern. At one site, the shadows prevented any sight distance estimates using the optical rangefinder.

Analysis

The data collection resulted in a set of data from forty sites with ten entries per site as shown in Table 6, minus the six failed laser method attempts

Table 6: The Initial Data

PIEDMONT CURVES

Deviation from walking method N.P.Z. starting point (ft.)*

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
Site 1	143.10	89.40	69.40	-56.80	27.80
2	-9.20	24.40	25.90	-202.70	-247.60
3	57.00	108.00	43.00	80.40	104.30
4	88.90	126.10	27.10	87.00	119.70
5	-24.60	-98.40	17.10	-342.50	-283.40
6	34.00	144.50	38.30	-35.40	79.70
7	90.20	-60.20	51.90	176.10	21.00
8	171.40	121.80	**	100.90	170.30
9	112.90	142.70	**	-23.30	134.90
10	117.00	64.00	**	23.80	-78.00
Average:	78.07	66.23	38.96	-19.25	4.87

PIEDMONT HILLS

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
Site 11	-20.10	26.90	12.60	91.20	0.30
12	27.70	46.60	-0.30	247.00	129.00
13	94.80	85.80	94.80	48.80	68.70
14	-1.00	77.80	-51.90	-26.00	-31.90
15	-81.60	22.50	-13.80	10.10	-8.00
16	-84.60	61.20	-88.30	-148.40	-15.80
17	-114.40	62.60	-55.80	83.50	46.50
18	-191.10	31.50	-175.60	-25.80	11.00
19	39.30	204.00	56.80	253.20	-136.10
20	-164.60	-14.10	-16.20	9.40	-40.80
Average:	-49.56	60.48	-23.77	54.30	2.29

*Positive is toward curve or hill, negative is away from curve or hil
**Missing

Table 6: The Initial Data (Cont.)

MOUNTAIN CURVES

Deviation from walking method N.P.Z. starting point (ft.)*

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
Site 21	227.20	69.50	-3.30	-27.60	69.00
22	29.50	20.30	-16.80	-253.50	-106.50
23	-286.10	-63.30	-288.00	-518.20	-405.80
24	36.70	1.70	112.50	-616.80	41.50
25	161.20	135.60	262.00	-36.30	140.00
26	32.40	146.50	-2.30	-95.10	262.00
27	-49.10	24.60	-66.20	-504.50	-162.10
28	40.60	76.30	219.20	-164.30	-104.80
29	100.80	94.80	**	-135.70	-227.50
30	**	184.80	**	84.90	229.10
Average:	32.58	69.08	27.14	-226.71	-26.51

MOUNTAIN HILLS

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
Site 31	-28.60	20.60	-107.40	43.10	186.10
32	2.90	55.70	-62.20	151.00	-68.50
33	56.50	55.40	-150.40	37.20	-87.20
34	-103.80	-7.40	24.60	-59.50	-242.50
35	-55.00	-12.20	35.00	213.30	-61.20
36	-31.50	-12.70	-161.30	-217.50	-184.00
37	-3.00	-76.40	-92.50	-367.30	-191.00
38	-107.30	-81.00	43.60	-83.00	-208.00
39	36.70	71.70	11.30	-251.70	-1.80
40	75.30	78.10	**	-273.30	-123.00
Average:	-15.78	9.18	-51.03	-80.77	-98.11

and the one failed rangefinder attempt. Before any analysis, the team converted all the data set to SI units (meters) as shown in Table 7. The researchers, with statistical advice from Dr. Charles Proctor at N. C. State University, ran an analysis of variance on the data using SAS with the aid of the SAS primer (SAS Institute, Inc., 1985). Dr. Proctor ran a data check program which he had developed and recommended that the log of each data point be used in this analysis in order to normalize the data. Table 8 shows the analysis of variance results for both the original data set, Y, and the log of this data set, TY.

In addition to analyzing the data in Table 7, the researchers employed a weighting system which increasingly penalized data points as they differed from zero. This penalized methods which lacked precision but may have had an average error, across forty sites, near zero. The researchers also wanted to more heavily penalize values on the positive side (i. e., where the method recommended shorter no-passing zones than the walking method). This would help highlight any methods which may result in safety or liability problems. Figure 6 shows the weighting scale the team formulated to accomplish both of these goals. The chosen weighting system penalizes all values by multiplying them by a certain weight factor as determined by a linear equation. The minimum weight factor was one for an error of zero. The maximum weight factor was ten for the positive values and five for the negative values, causing the conservative data points to be less penalized. The team considered other weighting methods, including one that doubled each positive value and then squared all values. However, this resulted in some extremely high values which

Table 7: The Initial Metric Data

PIEDMONT CURVES

Deviation from walking method N.P.Z. starting point (m)*

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
				3	4
Site 1	43.62	27.25	21.15	-17.31	8.47
2	-2.80	7.44	7.89	-61.78	-75.47
3	17.37	32.92	13.11	24.51	31.79
4	27.10	38.44	8.26	26.52	36.48
5	-7.50	-29.99	5.21	-104.39	-86.38
6	10.36	44.04	11.67	-10.79	24.29
7	27.49	-18.35	15.82	53.68	6.40
8	52.24	37.12	**	30.75	51.91
9	34.41	43.49	**	-7.10	41.12
10	35.66	19.51	**	7.25	-23.77
total, abs. value				339	381
Average:	23.80	20.19	11.87	-5.87	1.48

PIEDMONT HILLS

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
				5	3
Site 11	-6.13	8.20	3.84	27.80	0.09
12	8.44	14.20	-0.09	75.29	39.32
13	28.90	26.15	28.90	14.87	20.94
14	-0.30	23.71	-15.82	-7.92	-9.72
15	-24.87	6.86	-4.21	3.08	-2.44
16	-25.79	18.65	-26.91	-45.23	-4.82
17	-34.87	19.08	-17.01	25.45	14.17
18	-58.25	9.60	-53.52	-7.86	3.35
19	11.98	62.18	17.31	77.18	-41.48
20	-50.17	-4.30	-4.94	2.87	-12.44
				282	144
Average:	-15.11	18.43	-7.25	16.55	0.70

*Positive is toward curve or hill, negative is away from curve or hill
**Missing

Table 7: The Initial Metric Data (Cont.)

MOUNTAIN CURVES

Deviation from walking method N.P.Z. starting point (m)*

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
Site 21	69.25	21.18	-1.01	-8.41	21.03
22	8.99	6.19	-5.12	-77.27	-32.46
23	-87.20	-19.29	-87.78	-157.95	-123.69
24	11.19	0.52	34.29	-188.00	12.65
25	49.13	41.33	79.86	-11.06	42.67
26	9.88	44.65	-0.70	-28.99	79.86
27	-14.97	7.50	-20.18	-153.77	-49.41
28	12.37	23.26	66.81	-50.08	-31.94
29	30.72	28.90	**	-41.36	-69.34
30	**	56.33	**	25.88	69.83
Average:	9.93	21.06	8.27	-69.10	-8.08

MOUNTAIN HILLS

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
Site 31	-8.72	6.28	-32.74	13.14	56.72
32	0.88	16.98	-18.96	46.02	-20.88
33	17.22	16.89	-45.84	11.34	-26.58
34	-31.64	-2.26	7.50	-18.14	-73.91
35	-16.76	-3.72	10.67	65.01	-18.65
36	-9.60	-3.87	-49.16	-66.29	-56.08
37	-0.91	-23.29	-28.19	-111.95	-58.22
38	-32.71	-24.69	13.29	-25.30	-63.40
39	11.19	21.85	3.44	-76.72	-0.55
40	22.95	23.80	**	-83.30	-37.49
Average:	-4.81	2.80	-15.55	-24.62	-29.90

Table 8: ANOVA Results for Initial Metric Accuracy Data

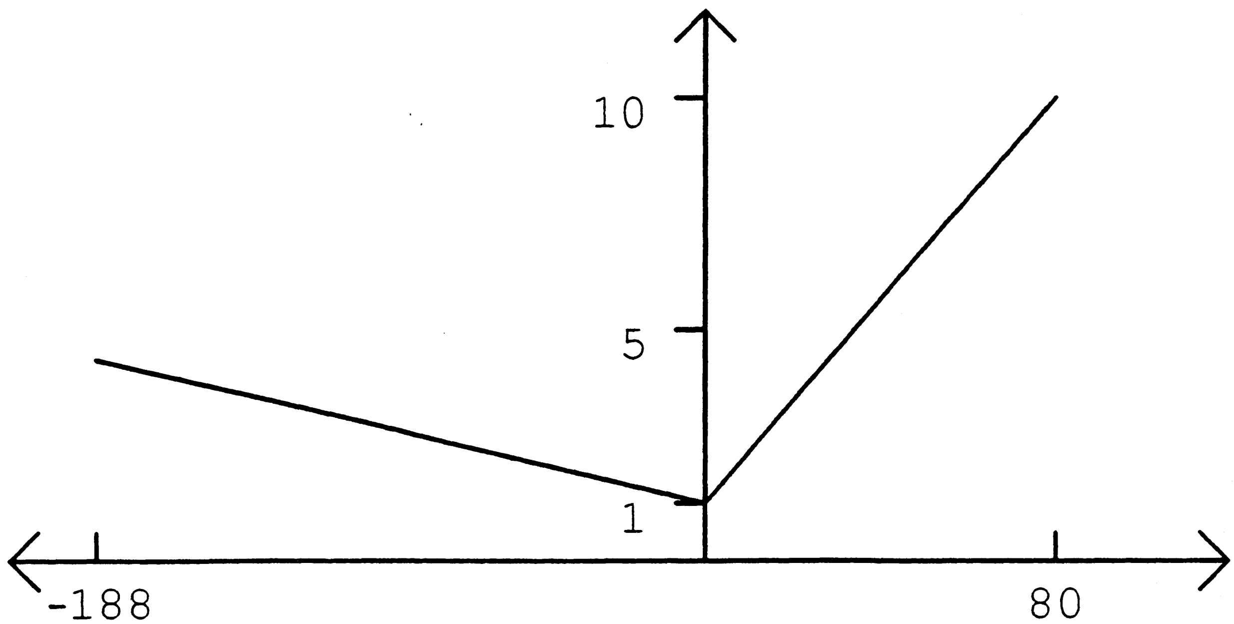
Dependent variable is deviation in start of no passing zone from walking method, in meters.

Source*	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Significance Probability
R	1	7083	7083	9.77	0.002
T	1	6692	6692	9.23	0.003
M	4	19076	4769	6.58	<0.001
R*T	1	729	729	1.00	0.318
R*M	4	9216	2303	3.18	0.015
T*M	4	1075	269	0.37	0.829
R*T*M	4	1830	458	0.63	0.641
Model	19	45702	2405	3.32	<0.001
Error	173	125448	725		
Corrected Total	192	171150			

Dependent variable is natural log of deviation in start of no passing zone from walking method, in meters.

Source*	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Significance Probability
R	1	5.24	5.24	3.68	0.057
T	1	11.36	11.36	7.99	0.005
M	4	19.04	4.76	3.34	0.011
R*T	1	0.70	0.70	0.49	0.483
R*M	4	13.67	3.42	2.40	0.052
T*M	4	6.16	1.54	1.08	0.367
R*T*M	4	2.89	0.72	0.51	0.730
Model	19	59.08	3.11	2.19	0.004
Error	173	246.19	1.42		
Corrected Total	192	305.26			

* R = Region, T = Site Type (curve or crest), and M = Method.



Weight Factor vs. Raw Metric Data Value (m)

<u>Negative Values</u>

Maximum Negative Value: -188

Weighted Value =
Raw Value(0.0266 X Raw Value + 1)

<u>Positive Values</u>

Maximum Positive Value: 80

Weighted Value =
Raw Value (0.125 X Raw Value + 1)

Figure 6: Weighting Scale

were too harsh as values receded from zero.

With the newly weighted data shown in Table 9, the team ran another ANOVA procedure, using the log of the values as before. Table 10 shows the results of this analysis (T for initial data, TY for log data). All analyses in this report used the 0.05 level for statistical significance. An initial look at the data indicated a significant difference among methods. T-tests of the means of the methods showed no significant differences among the rangefinder, radar, laser, and one-vehicle methods, but that the two-vehicle method was significantly different from the other four methods. T-tests on the means of TY for the five methods revealed that the two-vehicle method had performed significantly worse than the other four methods as far as accuracy.

The output also revealed that significant differences occurred between regions for the two-vehicle method, namely that it performed significantly more accurately in the Piedmont region. Readers should remember that experienced crews performed the two-vehicle method in both regions. Lastly, the researchers noted that the methods did not vary significantly in accuracy for curves versus hills.

The researchers next looked at conservatism as a measure of effectiveness. While the weighting system incorporated penalties for less conservative values, the team also looked at the number of sites in the original unweighted data set at which a method recommended a no-passing zone which was too short. The two-vehicle and one-vehicle methods scored the highest number of negative (conservative) values and were the only methods in which the number of

Table 9: Weighted Metric Data

PIEDMONT CURVES

Deviation from walking method N.P.Z. starting point,(m)*

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
Site 1	116.23	55.59	38.23	19.74	11.21
2	2.87	9.55	10.27	92.72	121.62
3	28.89	74.28	19.66	47.43	70.36
4	55.12	94.82	10.86	53.36	87.29
5	7.95	37.28	6.25	192.71	146.85
6	14.46	118.08	16.88	11.73	46.82
7	56.34	21.08	25.37	163.64	7.96
8	156.41	89.73	**	66.85	154.75
9	79.61	115.70	**	7.51	105.65
10	84.20	34.03	**	9.26	28.35
Average:	45.41	35.74	17.26	6.15	1.57

PIEDMONT HILLS

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
Site 11	6.43	10.76	4.40	57.29	0.09
12	11.16	21.90	0.09	291.62	98.33
13	60.76	52.26	60.76	23.32	37.68
14	0.31	45.18	17.85	8.43	10.49
15	29.88	8.65	4.35	3.44	2.49
16	31.17	31.93	32.78	61.81	5.00
17	44.72	32.98	19.35	50.17	21.84
18	85.74	13.12	76.74	8.36	3.78
19	17.46	209.75	28.75	304.50	55.43
20	70.57	4.45	5.14	3.18	13.69
Average:	16.96	31.40	7.67	27.01	0.72

*Positive is toward curve or hill, negative is away from curve or hill
**Missing

Table 9: Weighted Metric Data (Cont.)

MOUNTAIN CURVES

Deviation from walking method N.P.Z. starting point,(m)*

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
Site 21	252.29	38.31	1.01	8.99	37.91
22	12.08	7.65	5.33	125.65	41.00
23	148.83	22.31	150.23	360.11	247.66
24	15.96	0.53	79.17	474.42	18.76
25	141.28	106.53	323.26	12.06	112.17
26	13.60	120.76	0.71	35.80	323.26
27	16.78	9.64	23.48	345.39	69.19
28	18.22	43.90	237.19	70.40	40.21
29	66.75	60.76	**	55.22	108.31
30	**	177.42	**	51.44	255.94
Average:	13.69	37.98	10.88	107.80	8.61

MOUNTAIN HILLS

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck
Site 31	9.33	7.78	41.42	19.72	179.53
32	0.91	27.98	21.87	126.88	24.41
33	28.54	27.77	62.87	16.25	32.30
34	39.75	2.30	9.64	20.80	118.19
35	19.04	3.83	15.01	226.34	21.47
36	10.35	3.99	68.75	101.91	81.57
37	0.92	27.68	34.64	213.52	85.68
38	41.37	29.63	20.03	30.48	95.97
39	15.96	40.08	3.90	124.41	0.55
40	43.06	45.43	**	139.54	48.88
Average:	5.00	3.10	17.52	29.53	37.15

Table 10: ANOVA Results for Weighted Metric Accuracy Data

Dependent variable is weighted deviation in start of no passing zone from walking method, in meters.

Source*	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Significance Probability
R	1	30781	30781	5.77	0.017
T	1	58941	58941	11.04	0.001
M	4	106434	26608	4.98	<0.001
R*T	1	13819	13819	2.59	0.110
R*M	4	41199	10300	1.93	0.108
T*M	4	12148	3037	0.57	0.686
R*T*M	4	8601	2150	0.40	0.806
Model	19	271922	14312	2.68	<0.001
Error	173	923677	5339		
Corrected Total	192	1195600			

Dependent variable is natural log of the weighted deviation in start of no passing zone from walking method, in meters.

Source*	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Significance Probability
R	1	4.51	4.51	2.24	0.136
T	1	22.86	22.86	11.36	<0.001
M	4	25.17	6.29	3.13	0.016
R*T	1	1.17	1.17	0.58	0.446
R*M	4	20.11	5.03	2.50	0.044
T*M	4	8.59	2.15	1.07	0.375
R*T*M	4	3.63	0.91	0.45	0.771
Model	19	86.05	4.53	2.25	0.003
Error	173	348.17	2.01		
Corrected Total	192	434.22			

* R = Region, T = Site Type (curve or crest), and M = Method.

negative values outnumbered the number of positive values. The positive to negative ratios for the rangefinder, radar, laser, two-vehicle, and one-vehicle methods were 22:17, 31:9, 17:17, 18:22, 18:22, respectively. Although the two-vehicle and one-vehicle methods had the best ratios, they both had two extremely high positive values (> 45.72m or 150 feet) as did the rangefinder method. The laser and radar methods had two and one extremely high values, respectively.

Researchers used data compiled during the equipment selection stage to compare initial equipment costs. Table 4 shows that the two-vehicle method was the most costly, at $40,000 for two vehicles equipped with digital DMIs and a paint sprayer for marking. The one-vehicle method costs half of that at $20,000. Just above the the one-vehicle method in cost was the laser method using the laser gun ($4600 for the model used in the study) and some accessories, plus the cost of a non-instrumented vehicle (estimated at $18,000), all totalling $22, 700. The equipment cost for the radar method tallied about $19,600 including the radar gun ($1500 for the radar gun used in this study), accessories, and a non-instrumented vehicle. The rangefinder method proved the most economical in initial equipment costs. It required the optical rangefinder ($100), accessories, and the non-instrumented vehicle, for a total of $18,200.

The team subjectively accounted for training and data collector discomfort. Based on conversations with the two-vehicle and one-vehicle teams, the two methods require about the same amount of training. The one-vehicle method, however, is more judgemental on the part of the technician. He or she must get a "feel" for when the vista opens up rounding a curve or cresting a hill. The point that the lead truck disappears when using the two-vehicle method is easier to discern. Data collector discomfort was important because the team member performing the three newly developed methods had to find a safe and adequate place to park near each site to measure the sight distance. The fact that each site required the team member to park and perform the new methods outside of the vehicle makes the two-vehicle and one-vehicle methods more favorable. In both of these methods, the technician can measure all sites from within the vehicle and in constant motion, except for two brief moments per site with the one-vehicle method in which the technician must stop to administer paint marks. Bad weather would also make the three new methods more difficult and uncomfortable to perform.

The team based reliability estimates on the number of times that site distance could be measured at a site. The two-vehicle, one-vehicle, and radar methods produced results at all forty sites. The laser failed at six sites, while the rangefinder failed at one site. Conceivably, the radar method stands a better chance of failing than the two-vehicle or one-vehicle method due to its similarity to the rangefinder and laser methods in measuring sight distance. The human eye works in all cases for the two-vehicle and one-vehicle methods.

Lastly, the team considered time and labor costs associated with each method. The times to perform each method were recorded at each site and are shown in Table 11. In viewing these data, readers must remember that they do not include the time to drive between sites. If there are long drive times between

Table 11: Time Data

Time to perform method, in minutes

Method:	Rangefinder	Radar	Laser	Two-Truck	One-Truck	Walking
Site 1	7.5	11	19.5	1	1	15
2	10.75	19.5	11.25	1	1	9.75
3	10.5	11	14.25	1	1	10.75
4	9.5	9	9.5	1	1	10
5	10	9.5	6	1	1	12
6	4.5	4.25	5	1	1	8.75
7	12.75	12.75	9.25	1	1	9.25
8	6.25	6.5	7.75	1	1	8.75
9	5.5	7.5	4.25	1	1	8.75
10	8	6.5	10	1	1	9.25
11	5.25	9.75	5.75	1	1	9.5
12	3.25	5.75	14	1	1	7.25
13	4	6.5	3.75	1	1	10
14	5.75	8	5.5	1	1	9.75
15	5.75	8	5.75	1	1	9.75
16	4.25	5.25	9.25	1	1	8.25
17	10.5	13.25	14.25	1	1	7
18	6	8	5	1	1	9.5
19	5.25	5.75	10.5	1	1	9
20	2.75	8.75	3.75	1	1	8.75
21	7	8.25	8.25	1	1	6.75
22	7	4.25	4	1	1	9.75
23	6.25	15	3.5	1	1	10.75
24	4.5	5.5	6	1	1	8
25	4.25	6.25	8.25	1	1	8.5
26	3.75	5	3.5	1	1	8.75
27	4	5	2.5	1	1	8.25
28	4.5	5.25	4	1	1	7.5
29	4.25	7	3.5	1	1	8.5
30	7	9.25	4.25	1	1	8.25
31	6.5	10.25	3	1	1	8.75
32	7	8.5	4	1	1	8.5
33	7.5	6.75	7.5	1	1	9
34	5.5	5	3.75	1	1	12.75
35	5.75	8.5	7	1	1	8
36	6	11.25	4	1	1	9.75
37	5	5.5	5.25	1	1	9
38	2.75	7.5	4.5	1	1	7.25
39	4	4.5	4.25	1	1	9
40	3.75	12.25	4	1	1	8.75
AVERAGES	6.10625	8.18125	6.73125	1	1	9.16875

sites, the two-vehicle method fairs relatively worse than the other four methods which only tie up one technician and one vehicle. Readers must also remember that the study sites were primarily on numbered routes with relatively high traffic volumes. Methods which rely on timing or viewing traffic--like the radar, laser, and rangefinder methods--could take longer to perform on roads with low traffic volumes. The analyst performed t-tests on these data using a spreadsheet, and Table 12 shows the results. The mean times for the radar method were significantly longer than the mean times of both the laser and rangefinder methods (which were not significantly different from each other). The two-vehicle and one-vehicle methods required a constant one minute per site, which means two minutes of person labor per site for the two-vehicle method. The labor required for both the one-vehicle and two-vehicle methods proved significantly different from the labor required by the three new methods.

CONCLUSIONS

Summary

The team used information compiled in the analysis of the data to compare and contrast five methods for determining passing sight distance, three of which were new methods. The primary method used in North Carolina is the two-vehicle method, while the one-vehicle method is the exclusive method of choice in three North Carolina DOT divisions. In selecting a new method, the team wanted to choose one that primarily maintains or improves accuracy and

Table 12: T-Test Results on the Time Required to Perform the New Methods

Methods	Mean time, minutes	Std. dev. time, sec.	Calculated t-value	Significance probability
Rangefinder vs.	6.1	2.4	-1.17	0.248
Laser	6.7	3.8		
Rangefinder vs.	6.1	2.4	-4.99	<0.001
Radar	8.2	3.2		
Laser vs.	6.7	3.8	-2.19	0.017
Radar	8.2	3.2		

Note: There were 40 time observations for each method.

saves time. The researchers considered new methods that use a laser gun, radar gun, and rangefinder.

The team conducted an experiment to test the accuracy of the five methods relative to the walking method, which is very slow and labor-intensive but is considered the most accurate available method. The team collected accuracy data at forty sites equally split among Piedmont and Mountain regions, and split between curves and hills. The team recorded the time required to perform each method, and considered equipment costs, conservatism, and training in making recommendations. Table 13 summarizes the relative performance of all five methods tested on all measures of effectiveness considered.

Recommendations

The team recommends the current one-vehicle method as the method highway agencies should use to measure passing sight distance, because it was the method which best met all measures of effectiveness. Its accuracy was not statistically different from the three new methods and was significantly better than the two-vehicle method, based on the weighting scale used. It produced more negative, or conservative, values than any of the new methods, as one would expect with its zero-height object assumption, and was tied with the two-vehicle method on that measure. It produced a reading at all forty sites, an indication of its reliability. While the one-vehicle method equipment cost was tied for second highest among the five methods, its cost was not much higher than the new methods and many of the instrumented vehicles

Table 13: Summary of the Relative Effectiveness of the Methods Tested

Measure \ Method	Range-finder	Radar	Laser	Two-Vehicle	One-Vehicle
Accuracy	+	+	+	-	+
Conservatism	-	-	+	+	+
Equipment Cost	+	+	+	-	+
Training Needed	-	-	-	+	+
Technician Discomfort	-	-	-	+	+
Reliability	-	+	-	+	+
Time/Labor Cost	-	-	-	+	+

A "+" indicates a relatively positive outcome, a "-" indicates a relatively negative outcome.

required are already in use in North Carolina with the two-vehicle method. The one-vehicle method required the lowest amount of labor per site, and would fare even better relative to the other methods if the sites were far apart or had low traffic volumes. Lastly, the one-vehicle method requires no more training than the three new methods and enables the technician to measure multiple sites with minimal stopping and no exiting of the vehicle. The procedure for the one-vehicle method, described briefly earlier, was depicted graphically in Figure 2.

During this project, the team noted that the topic of passing sight distance measurement required additional research in several areas. The primary area of inquiry should be on incorporating automatic data collection techniques like those marketed by Roadware and Mandli. The North Carolina DOT could measure sight distance simultaneously with many other data such as pavement management and sign inventory data. This may result in great savings in data collection and storage while making useful integrated databases more widely available. Another area of this topic that needs further research deals with travel efficiency and accident potential as measures of effectiveness for the methods of measuring passing sight distance. Efficiency of a roadway likely increases with shorter no-passing zones, but so does accident frequency. Unfortunately, there is little quantitative evidence to guide field personnel on how to best treat that trade-off.

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Appendix: New Methods

RADAR GUN METHOD

1) Prepare equipment and supplies (radar gun, stopwatch, mechanical DMI, spray paint, worksheet).
Note: Refer to instructions accompanying each device.

2) Approach the curve or crest and estimate the point where the no-passing zone most likely begins: this is the point to start estimating sight distance.

3) Wait for a receding vehicle; start stopwatch when vehicle reaches your position. Obtain a speed reading as soon as possible after starting stopwatch.

4) Obtain a speed reading just prior to the vehicle disappearing over hill or around curve. Stop stopwatch when the estimated 1.0668 m (3.5 ft) high point on the vehicle disappears.

5) Record and plot data and compute sight distance for this trial on the worksheet.

6) If sight distance is less than the required sight distance, use the DMI to move to a point 30.48 m (100 ft) farther away from curve or hill. If sight distance is greater than required sight distance, use the DMI to move to a point 30.48 m (100 ft) closer to curve or hill.

7) Repeat steps 3 - 6 until the sight distance values are obtained on both sides of the required sight distance (one higher and one lower).

8) Interpolate to find point of actual required sight distance.

9) Using the DMI, find the point computed in step 8; administer a paint mark on road indicating start of no-passing zone.

LASER GUN METHOD

1) Prepare equipment (laser gun, mechanical DMI, battery pack, spray paint, worksheet).
   Note: Refer to instructions accompanying each device.

2) Approach the curve or crest and estimate the point where the no-passing zone most likely begins; this is the point to start estimating sight distance.

3) Lock the laser gun in on a vehicle moving away from you and towards the curve or crest.

4) Obtain last possible reading of distance to vehicle.

5) Record and plot sight distance on worksheet.

6) If sight distance is less than the required sight distance, use the DMI to move to a point 30.48 m (100 ft) farther away from curve or hill. If sight distance is greater than required sight distance, use the DMI to move to a point 30.48 m (100 ft) closer to curve or hill.

7) Repeat steps 3 - 6 until the sight distance values are obtained on both sides of the required sight distance (one higher and one lower).

8) Interpolate to find point of actual required sight distance.

9) Using the DMI, find the point computed in step 8; administer a paint mark on road indicating start of no-passing zone.

RANGEFINDER METHOD

1) Prepare equipment and supplies (rangefinder, mechanical DMI, spray paint, worksheet).
Note: Refer to instructions accompanying each device.

2) Approach the curve or crest and estimate the point where the no-passing zone most likely begins; this is the point to start estimating sight distance.

3) Follow a vehicle moving towards curve or hill and obtain a distance reading as near as possible to point at which the estimated 1.0668 m (3.5 ft) -high point on the vehicle disappears.

4) Record and plot sight distance on worksheet.

5) If sight distance is less than the required sight distance, use the DMI to move to a point 30.48 m (100 ft) farther away from curve or hill. If sight distance is greater than required sight distance, use the DMI to move to a point 30.48 m (100 ft) closer to curve or hill.

6) Repeat steps 3 - 5 until the sight distance values are obtained on both sides of the required sight distance (one higher and one lower).

7) Interpolate to find point of actual required sight distance.

8) Using the DMI, find the point computed in step 8; administer a paint mark on road indicating start of no-passing zone.