FHWA-NJ-2002-028

Evaluation of the Performance of Permanent Pavement Markings and Retroreflectors in Snowplowable Raised Pavement Markers (SRPMs)

FINAL REPORT
September 2006

Submitted by

Neville A. Parker, Ph.D., P.E.
Herbert G. Kayser Professor of Civil Engineering
The City College of the City University of New York

NJDOT Research Project Manager
Vincent F. Nichnadowicz

In cooperation with

New Jersey
Department of Transportation
Bureau of Research and Demonstration
and
US Department of Transportation
Federal Highway Administration

DISCLAIMER STATEMENT

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA-NJ-2002-028	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of the Performance of Permanent Pavement Markings and Retroreflectors in Snowplowable Raised Pavement Markers (SRPMs)		5. Report Date September 2006 6. Performing Organization Code CUNY
7. Author(s) Parker, Neville PhD, PE		8. Performing Organization Report No. FHWA-NJ-2002-028
9. Performing Organization Name and Address CUNY Institute for Transportation Systems The City College of the City University of New York Convent Avenue & 138th Street New York, NY 10031		10. Work Unit No. 1/2001 to 1/2002 11. Contract or Grant No.
12. Sponsoring Agency Name and Address New Jersey Department of Transportation PO Box 600 Trenton, NJ 08625	Federal Highway Administration U.S. Department of Transportation Washington, D.C.	13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

In anticipation of federal retroreflectivity standards for pavement markings, the New Jersey Department of Transportation undertook to evaluate their three-year fixed schedule re-striping strategy, to see if it is consistent with the actual service life of pavement markings. One of the primary tasks was to develop a threshold value of retroreflectivity level below which a pavement marking will no longer be considered "bright enough" to be useful for motorist nighttime guidance.

Two types of data were collected:

1. Measured retroreflectance by LaserLux and LTL2000 retroreflectometers.
2. Subjective ratings from the New Jersey driving public.

Multiple regression techniques were used to correlate the average ratings reported by all study participants for designated lengths of pavement markings and the corresponding measured retroreflectivity. The results suggested that the threshold value of acceptable versus unacceptable levels of retroreflectivity to be between 80 and 130mcd/m^2/lux, for New Jersey drivers of age less than 55 years, and between 120 –165 mcd/m^2/lux for drivers of age greater than 55 years. These results are consistent with conclusions reached by other investigators on similar research, with results generally ranging between 70-170 mcd/m^2/lux.

The analysis further suggested that concentrating resources on re-striping pavement markings with retroreflectivity below 130mcd/m^2/lux would achieve a greater relative increase in driver satisfaction than re-striping pavement markings with retroreflectivity above 130mcd/m^2/lux, in New Jersey. Based on the three year NJDOT restriping policy, the results of the research has indicated that restriping in this year (2002) is justified by only 78% for yellow centerlines (YCL) on route US 30, 30% for white edge lines (WEL) on route US9, 7% for WEL on route US 130, 28% for skip lines (SPL) on route NJ55 and 60% for SPL on route NJ55. Clearly, this suggests that some of the sections in these routes can continue to perform satisfactorily for more years before need for re-striping. To eliminate the risk of "underrestriping" or "overrestriping", the use of performance-based approaches, by making use of the interim visibility indices (IVI) developed from the retroreflectivity data collected on 597.7 miles of pavement marking edge, centerline and skip lines, is recommended.

17. Key Words Pavement markings, retroreflectivity, visibility index	18. Distribution Statement		
19. Security Classif (of this report) Unclassified	20. Security Classif (of this page) Unclassified	21. No. of Pages 96	22. Price

Acknowledgments

This report was prepared as the final part of a research study on the "Evaluation of the Performance of Permanent Pavement Markings and Retroreflectors in Snowplowable Raised Pavement Markers (SRPM's)", initiated by the New Jersey Department of Transportation (NJDOT). The Principal Investigator greatly appreciates the assistance of Atlas Flasher & Supply Co., for its role as subcontractor, with technical support from Precision Scan L.L.C, for their involvement in field data collection by both mobile LaserLux and handheld LTL2000 retroreflectometers. The principal investigator also recognizes the invaluable assistance of graduate research assistant, Salutari Massawe, who carried the major day-to-day responsibilities attendant on the conduct of the project, as well as processing the vast amount of field data collected in this project, and undergraduate research assistant Rory Christian for his contribution in preparing some of the graphic representations of the data, particularly the bubble charts of driver perception of retroreflectivity of pavement markings.

TABLE OF CONTENTS **Page**

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

NJTPA	New Jersey Transportation Planning Authority
DVRPC	Delaware Valley Regional Planning Commission
SJTPO	South Jersey Transportation Planning Organization
FHWA	Federal Highway Administration
NJDOT	New Jersey Department of Transportation
NJDOMV	New Jersey Department of Motor Vehicles
mi	mile(s)
mi/h	miles per hour (not mph)
km/h	kilometers per hour

in	**inch(es)**
m	**meter(s)**

SUMMARY

This report, presents the findings from a research project, termed "EVALUATION OF THE PERFOMANCE OF PARMANENT PAVEMENT MARKINGS AND RETROREFLECTORS IN SNOWPLOWABLE RAISED PAVEMENT MARKINGS".

In anticipation of federal retroreflectivity standards for pavement markings, the New Jersey Department of Transportation undertook to evaluate their three-year fixed-schedule re-striping strategy, to see if it is consistent with the actual service life of the pavement markings. One of the primary tasks was to develop a threshold value of retroreflectivity level below which a pavement marking will no longer be considered "bright enough" to be useful for motorist nighttime guidance.

Two types of data were collected: measured retroreflectivity by LaserLux and LTL2000 retroreflectometers; and, subjective rating from the New Jersey driving public. Retroreflectivity data were collected on 597.7 line miles of pavement marking edge and skip lines. The rating data were collected by conducting a survey, whereby members of the New Jersey driving public were invited to drive their cars at night, along a 32-roadway mile circuit connecting routes, NJ 55, US 322, NJ 42 and US 30 to rate the nighttime visibility of the pavement markings. Based on New Jersey Department Motor Vehicle data, a panel of 64 raters, characterized by reasonable approximation of age and gender demographics, was selected to guarantee statistical reliability of the ratings. An interviewer rode along with each rater asking questions about the brightness/visibility of the pavement markings within pre-marked sections of the roadway. Multiple regression techniques were used to correlate the average scores reported by all study participants for each specific roadway section and the corresponding measured retroreflectivity.

The results suggested that the threshold value of acceptable versus unacceptable level of retroreflectivity appeared to be between 80 and 130mcd/m2/lux, for New Jersey drivers of age less than 55 years, and between 120 –165 mcd/m2/lux for drivers of age greater than 55 years.
This result is consistent with conclusions reached by other investigators on similar research, with results generally ranging between 70-170 mcd/m2/lux.

Based on the rating panel used, the analysis further suggested that, concentrating resources on re-striping New Jersey pavement markings with retroreflectivity below 130mcd/m2/lux would achieve a greater relative increase in driver satisfaction than re-striping pavement marking with retroreflectivity above 130mcd/m2/lux.
The Interim Visibility Indices (IVI) were developed for each age group based on pavement marking type, for use by NJDOT in determining and prioritizing needs and quantification of related resources required, based on the threshold between acceptable retroreflectivity and unacceptable retroreflectivity, when developing the

new pavement marking management system. This will also allow for cost benefit/life cycle analysis for different pavement marking material.

INRODUCTION

Problem Summary

The actual service life of the pavement markings is of concern to both the NJDOT and FHWA.   Currently, there are no minimum pavement marking retroreflectivity requirements specified in the Manual on Uniform Traffic Control Devices (MUTCD). Consequently, the FHWA requested all the State DOT's, including NJDOT, to evaluate their program in order to determine if their current practice of a three-year-cycle re-striping strategy is consistent with the actual service life of the pavement markings.

According to the Traffic Control Devices Handbook [1,2], pavement markings must define the path of safe travel and must be clearly visible in daylight, in darkness, and periods of adverse weather, such as rain or fog. Nighttime visibility of the pavement markings have been improved by embedding glass beads (Figure 1), so that the directional light from the car headlamps is retro-reflected, back in the direction of the approaching vehicle (Figure 5). Consequently, striped roads with properly emplaced beads offers a tremendous improvement in nighttime visibility, and some improvement under wet weather conditions. Unfortunately, pavement markings deteriorate with time. Eventually, all or most of the beads will disappear, and the beneficial effect of the beads is gone. Ultimately the road has to be re-striped. Fixed schedule re-striping strategy is questionable in terms of both sufficiency and economy, because, while this may be sufficient for some of the highways (or even excessive in some cases leading to unnecessary replacement cost), it may be deficient for some roadway sections.   This is because the rate of deterioration of pavement marking retroreflectivity is increased with high traffic volumes, high truck percentage, and quality control in applying the marking material. Furthermore, different pavement-marking materials have different life cycles [3]. The conceptual diagram in Appendix 19 illustrates this fact further. Assuming that the Initial retroreflectivity is about 350mcd/m2/lux for both routes 1-5, the rate of deterioration is indicated to be maximum for Route 5 and minimum for Route 1.

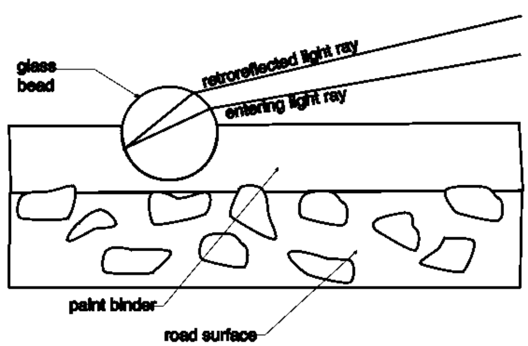


Figure 1: Glass Beads

Assuming a threshold level of retroreflectivity of 130mcd/m2/lux, restriping after three years will mean some of the roads will be under re-striped for a period of time (e.g., Route 5 which has a service life of about only 1.5 years), increasing risk of accidents, while some roads will be over re-striped (e g., Route 1 which has a service life of about 6 years) leading to unnecessary expenditure. The cost effective decision of where and when to re-stripe therefore needs the knowledge of all of the above, plus the acceptance quality level and actual retroreflectivity level of newly installed markings.

As a response towards finding solutions for the shortcomings of their current re-striping strategy, the NJDOT initiated a research project aiming to:

- Determine the actual service life of various pavement marking materials and SRPM retroreflectors.
- Determine acceptable portable and mobile instrumentation to measure retroreflectance values using the 30-meter CEN instruments evaluated by HITEC (Specifically, LTL2000, Ecodyn, and Laser Lux).
- Evaluate the visibility models developed by others, for use by the Department.
- Get recommendations on procedures for periodic measurement of the reflectance values of the pavement markings and SRPM's retroreflectors.
- Establish the visibility index (VSI) concept corresponding to the retroreflectometers measurement. (1)

Literature Review

A literature search has revealed the existence of a wide variety of information and investigative research on the topic of roadway delineations, in particular pavement markings. Growing interest in the retroreflectivity of pavement markings has given rise to significant research efforts. The Federal Highway Administration (FHWA) has been very instrumental in most of the research projects reviewed to date. This can be linked to the fact that the FHWA has a congressional mandate to determine the minimum levels of retroreflectivity that will best serve the driving public's needs and still be practical from a funding and maintenance point of view.

During the execution of this project, 64 pavement-markings documents were reviewed as part of knowledge acquisition. Of the 64 documents reviewed, 39 are cited in this final report while the remaining 35 are shown in the bibliography. A brief summary of the literature is presented below, and the corresponding literature relevance matrix is presented in Appendix 16. The matrix comprises the individual literature and their degree of relevancy to the research objectives, as judged by the researcher. The scale below has been chosen to represent the different levels of relevancy of the various literatures

- Not relevant
* Slightly relevant
** Fairly relevant
*** Very relevant

This matrix can be useful in identifying literature for further studies.

Literature Summary

End Detection Distances

Research[4] to determine the end detection distances obtainable under favorable pavement marking materials conditions found that the observer age had a highly significant effect on pavement marking visibility. CARVE (Computer Aided Road Marking Visibility Evaluator) has been developed to systematically investigate driver visual needs in terms of nighttime pavement marking visibility and allows the formulation of minimum retroreflectivity recommendations.[5] A research to enhance CARVE was funded by the Federal Highway Administration, U.S. Department of Transportation, Washington, D.C..[5] This research used the results of extensive pavement marking visibility to calibrate CARVE. A study[4] found that there was a significant difference in the subjective rating of retroreflectivity of the pavement marking between older and younger drivers.

Markings

Traffic paint is by far the most widely used marking materials. Alkyd and modified alkyd are reported as the most widely used painted markings. The Texas and New York State DOTs extensively use chlorinated polyolefin paints. The Virginia Department of Transportation, VDOT, used large glass beads in line painting operations in the Lynchburg District from August 1993 to October 1995. In 1994, (VDOT) began using waffle tape on Interstates, limited access highways, and other high volume roads. Waffle tape was used because of its desirable durability and retroreflectivity characteristics. A number of States, including California, Pennsylvania, Colorado, and Kansas has adopted a paint bead combination of 10 to 11 mil (0.25 to 0.28 millimeters) wet paint thickness with four pounds per gallon (0.48 kilograms per liter) of No. 40 to No. 80 mesh beads with good results.[6] Both the Texas and New York State DOT has extensively used Chlorinated Polyolefin paints on their roadways. Because of environmental concerns, State Highways are mandating the use of volatile organic compound (VOC)– free paints on their roadways.[6] The estimated service life of painted markings is a function of site-specific variables, with average daily traffic (ADT) most commonly used. Six to twelve months in-service life is considered a reasonable target for most highway agencies under normal conditions while three months may be acceptable for roadways with very high traffic density.[6]

Thermoplastic markings, when properly applied, perform excellently. One of the advantages of thermoplastic is its durability. Depending on the material used and the roadway characteristics, thermoplastic can provide virtually maintenance-free delineation for years. Thermoplastic pavement markings are reported as having a longer service life and better visibility when compared to painted markings. One policy[7] recommended for traffic stripes and traffic marking has been outlined as follows:

- All permanent longitudinal center, edge, and lane lines, and edge lines on ramps and left turn slots shall be long life epoxy resin traffic stripes.
- All permanent diagonal gore lines, arrows and other pavement symbols shall be long life thermoplastic traffic markings.
- Traffic paint (latex or alkyd) shall be used when traffic stripes or traffic markings are required on intermediate pavement layers that need to be opened to traffic due to stage construction.

RPMs

Raised Pavement Markings(RPM's) are considered a durable marking device with the ability to provide both day and night visibility during adverse weather conditions. The expected service life of conventional RPM's is greater than 10 years for non-retroreflective (white and yellow); and for retroreflective RPM's, service life ranges from less than 1 1/2 years for severe conditions to 10 years on rural low-density roads. The damage to RPM's from snowplow activity, is costly and has led to the development of a snowplowable marker. A study conducted in New Jersey, where annual snowfall ranges from 15 to 20 inches, suggested that the expected life of the steel-hardened casing could be conservatively estimated at 10 years and the life of the replaceable lens insert at 3-4 years.[8]

The approach to routine maintenance of RPM's varies among highway agencies. The California Transportation Institute (CALTRANS), where replacement of RPM's is based on the number of missing RPM's, specifies that RPM's should be replaced when 8 or more non-retroreflective RPM's are missing in a 100-foot (30-meter) section, and when two successive retroreflective RPM's are missing.[6] CALTRANS, in areas where there is little snow, replaces more than 1.6 million retroreflective and non-retroreflective RPM's annually. The policy used in Florida is similar, specifying replacement if 8 or more consecutive RPM's are missing. In Massachusetts RPM's are replaced if 30% or more are missing in a section of roadway. Washington State DOT replaces more than two million RPM's annually at a price of $2.40 per unit.[6]

When RPM's are used to supplement painted markings, there is a possibility of painting over the RPM during repainting operations. A research project [6] initiated by the Federal Highway Administration (FHWA) with the State of California led to the development of an optical Retro-Skip Device to detect the presence of RPM's to avoid painting over them. This device was successfully tested at speeds up to 65 miles per hour with approximately 99% accuracy. The only drawback was that paint guns could not operate fast enough at higher speeds. This equipment is currently in use in California and shows promise in decreasing the number of RPM's that are painted over.

Evaluation of Retroreflectivity

The evaluation of the retroreflectometers conducted by the Highway Innovative Technology Evaluation Center (HITEC) was partly prompted by the U. S. Department of Transportation and Related Agencies Appropriation Act of 1992. In this Act, Congress required the Department of Transportation to revise the Manual on Uniform Traffic Control Devices (MUTCD) to include " a standard for a minimum level of retroreflectivity that must be maintained for pavement markings and signs which apply to all roads open to public travel".(9,5) For many years, U.S. transportation agencies used a 12 or 15 meter viewing geometry for the measurement of pavement marking retroreflectivity.(10) However, this evaluation conducted by (HITEC) was limited to 30-meter geometry pavement markings retroreflectometers, which is the standard for measuring pavement-marking retroreflectivity adopted by the American Society of Testing and Materials (ASTM).(11,12,10) This geometry simulates the performance of a marking that is located 30 meters in front of a vehicle. This is the same geometry used by the European Committee on Standardization (CEN).(11,10) ASTM Specification D6359, Standard Specification for Minimum Retroreflectance of Newly Applied Pavement Markings Using Portable Hand-Operated Instruments, addresses minimum values of newly applied pavement markings. ASTM specifies that a specific sampling technique should yield a minimum retroreflectance of 250 $mcd/m^2/lux$ on new white pavement markings, and a minimum of 175 $mcd/m^2/lux$ on new yellow pavement markings.(10)

No national calibrated standards for retroreflectivity currently exist in the United States. However, the National Institute for Standards and Technology (NIST), the agency responsible for maintaining standards in the United States is presently seeking funding to develop facilities that will be able to produce calibration plaques.(13)

Retroreflectivity Levels

The average initial value of retroreflectivity is approximately 250 and 500 mcd/m2/lx, for paint and thermoplastic, respectively, with a maximum initial retroreflectivity reaching 450 or 850 mcd/m2/lx for paints or thermoplastics, respectively.(14)

Several researchers, have recommended establishing minimum levels of retroreflectivity based on PMs types and colors. In 1991, Graham and King reported that 90% of test subjects rated a retroreflectance of 93 mcd/m2/lx as adequate or more than adequate.(15) Graham et al reported that 85% of test subjects aged 60 years and above rated markings retroreflectance of 100 mcd/m2/lx as adequate or more than adequate.[16] In another study, Migletz et al found a retroreflectivity range of 80 to 130 mcd/m2/lx to be adequate under favorable dry driving conditions.[17] A Minnesota DOT study recommended the use of 120 mcd/m2/lx based on data collected using a mobile retroreflectometer.[18] A recent research study by Zwahlen and Schnell derived a speed-related set of minimum retroreflectivity values that encompass a wide range of retroreflectivity values.[19] These values were based on the human visual luminance contrast threshold data collected by Blackwell in 1946 and use a driver preview time of 3.65 seconds for roads without raised pavement markers (RPMs), and 2.0 seconds for roads with RPMs. For example, the retroreflectivity minimum values for fully striped two-lane highways (edge lines and centerline) un-supplemented by RPMs ranged from 30 to 620 mcd/m2/lx for speeds from 25 mph (40 km/h) to 75 mph (120 km/h), respectively. For a speed range of 45 to 75 mph (72 to 120 km/h), a typical range for rural highways, the minimum value doubles according to this relationship for every 10 mph (16 km/h) increment. For example, the minimum retroreflectivity for 45 mph (72 km/h) and 55 mph (88 km/h) highways is 85 and 170 mcd/m2/lx, respectively. Some researchers chose a minimum retroreflectivity of 100 mcd/m2/lx in their evaluation of pavement marking retroreflectivity without validating this threshold value.[20,21]

Pavement marking color has been reported to affect the retroreflectivity properties of PM materials. It is commonly accepted that yellow markings have retroreflectivity values equivalent to about 70 to 80% of white marking retroreflectivity. Retroreflectivity readings collected on test decks in Alabama and Kentucky consistently showed yellow paint, thermoplastic, and tape markings to have lower retroreflectivity levels than white markings of the same type.[14] Scheuer et al found that yellow paint has less retroreflectivity than white paint, although both have the same decay rate.[21] Studies by Zwahlen and Schnell found the average detection distance of white taped longitudinal lines to be 35-38 meters longer than that of yellow taped lines,[22] although in a later study they reported no increase in the detection distance as a result of substituting white centerlines for yellow centerlines.[23] They also found that supplementing a yellow centerline with white edge lines doubled the detection distance.[24]

Recently, there has been an increased interest in the U.S. in the advantages of all-white pavement marking systems, as used in Europe, particularly with recent moves by countries such as Australia and Norway to adopt an all-white pavement marking system. A recent report by a U.S. team of traffic engineers who visited four European countries concluded that an all-white system could work in the U.S..[25] Currently, proposals are being solicited by the National Cooperative Highway Research Program (NCHRP) for a feasibility study of an all-white marking system in the U.S. (Project 4-28 FY 2000).

Edge line brightness is reported to play a larger role in driver perception of pavement marking visibility than does centerline brightness. Exploratory driver eye scanning experiments indicate that drivers have the tendency to fixate almost exclusively on the right edge line when asked to detect the end of pavement markings along a fully marked road.[26]

Crash Based Quality Levels

A study that directly addressed the relationship between Pavement Markings retroreflectivity and crashes was conducted by Lee et al.[27] The authors used a linear regression model to describe this relationship. The model was based on data collected over a four-year period from four regions in Michigan, each having distinct highway, weather, and traffic characteristics. The authors, however, were unable to establish a correlation between nighttime crashes and long line retroreflectivity. The likely reason for this poor correlation was attributed to the limited data used in the study and to the high level of retroreflectivity retained by the long lines throughout the study period.

A crash-based minimum retroreflectivity values 140 to 156 mcd/m2/lux was established by Nasser Aboud of California and Brian L. Bowman of Auburn University, using Mirolux 12, a 15-meter geometry retroreflectometer. They recommend a retroreflectivity threshold of 150mcd/m2/lux for use by practitioners when traffic safety is the primary concern.[28]

.

RESEARCH APPROACH

Data Collection

<u>Field Measurements</u>
Field measurements for the pavement markings retroreflectivity were done by a **Laser Lux** (mobile) and **LTL2000** (Hand held) units from Precision Scan. Efforts to get **Ecodyn** mobile retroreflectometers for calibration and measurements purposes failed, because none were available from any of the retroreflectometers suppliers/hirers in the USA. The Ecodyn can measure both pavement markings and RPMs retroreflectivity while traveling at highway speeds.

LaserLux
Retroreflectivity data were collected for all pavement markings and skip lines on 597.7 line miles (Appendix 5) of selected south New Jersey highways using a van-mounted Laser Lux retroreflectometers (Figure 2). The van was equipped with an on-board computer that provided a real time display of retroreflective profile of the measured markings overlaid on video and as a printout.[29]

The device measures pavement-marking retroreflectivity, while moving at a highway speed of up to 65mph, once each 100 milliseconds, using a scanning laser (Figures 3 & 4). Figure 4 shows the configuration of the mobile Retroreflectometers. The laser lux software allows the user to predefine low and high threshold values, allowing rejection of retroreflectivity readings which seem invalid, such as a reading off of the marking (too low values) or a reading of a raised pavement marker (too high values)

Figure 2: LaserLux Van.

Figure 3: LaserLux Unit

The **LaserLux** retroreflectometer uses a scanning laser beam at 1/3 scale geometry to scan the pavement marking roughly 32,000 times per hour, while traveling at highway speeds, under all ambient light conditions, using either the North American or European standard geometries.

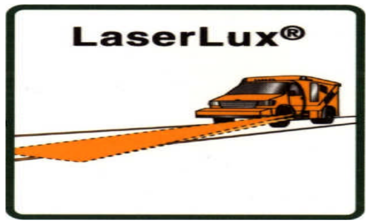


Figure 4: LaserLux Scanning Geometry

LaserLux uses a 30-meter equivalent geometry-measurement, 10meter in front of the device at an angle $\alpha=1.0^o$ and $\beta=88.6^o$ that is similar, but not identical, to that recommended by CEN/ASTM (Figure 5) .

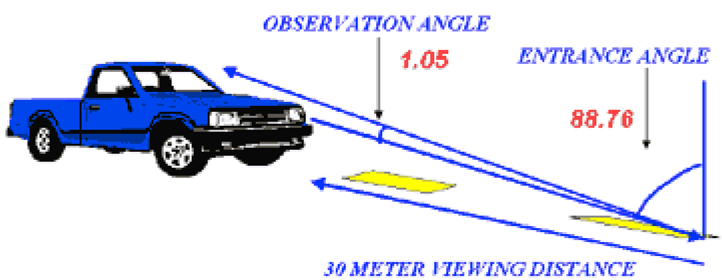


Figure 5: 30-Meter Geometry

Prior to data collection, field verification of the calibration of the unit was performed daily by the operators.

LTL 2000

The LTL 2000 Retroreflectometer was used to take data on the calibration circuit on Routes US 322, US 130, and NJ 45. Twenty-two measurements were taken on each half-line mile for thirty-two pre-selected sections, which totaled to about 704 measurements. Traffic control problems rendered white skip lines inaccessible, and therefore measurements were not taken.

LTL 2000 is a handheld portable retroreflectometer, and the only 30-meter geometry pavement marking retroreflectometers with traceability to an Accredited National Standards Laboratory.[29] (Figure 6)

Figure 6: LTL 2000

Calibration was performed once every two hours of continuous use, or just before taking measurements in case the unit had been turned off for thirty minutes or more. This was done by the use of calibration blocks owned by the operators (Figure7).

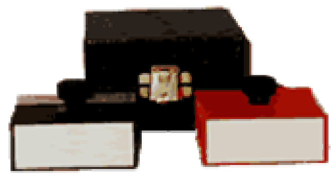


Figure 7: LTL 2000 Calibration Blocks

Rating Survey

With regard to pavement markings, the question is how bright is bright enough? At what point in the scale of measurement does one consider a marking to be too deteriorated to be effective for motorist guidance? To answer this question, a public perception based survey was conducted, whereby members of the New Jersey driving public were invited to drive their cars after dark, along the 32 roadway mile rating circuit connecting routes, NJ 55, US 322 NJ 42 and US 30 (Appendix 3), and to rate the nighttime visibility of the pavement markings. An Interviewer rode along with each rater asking questions about the brightness/visibility of the pavement markings within pre-marked sections of the roadway.

Survey Forms

Two types of survey forms were developed:

i.) *Rater registration forms*
These forms were developed to include all necessary particulars and driving information for each participant. The information gathered was used to judge the suitability of the corresponding participant, and as an agreement to participate on the study for the payment of $50 dollars (Appendix 6).

ii.) *Rating forms*
These forms were developed to include all necessary information for the route and section being rated, type of markings, rater number, weather and light condition during the time of rating, questions and the visibility rating scale. One form per rating section per rater was required, which resulted in total requirements of (20RPclws+28RP antclws)*72Raters = 3456≈ 3,500 forms (Appendix7).

Rating Panels

The establishment of the rating panel for this study, targeted participants who are licensed New Jersey drivers distributed over 3 age group :
<33 years of age, 33-55 years of age, and >55years of age

NJ Drivers' License Composition

According to New Jersey Driver Age Profile Summary from NJ DMV, there were 5,881,199 licensed drivers as of 12/30/2000. When grouped by age category they are distributed as in Table 1 below:

Table 1: <u>Distribution of NJ Licensed Drivers by Age and Gender.</u>

Age Group (Years)	Number of Licensed Drivers		Percent of Licensed Drivers(%)		Total %
	Male	Female	Male	Female	
<33	793,962	764,556	13.5	13.0	26.5
33-55	1,405,607	1,411,488	23.9	23.9	47.8
>55	752,793	764,556	12.7	13.0	25.7
Total	2,952,362	2,940,600	50.1	49.9	100.0

Panel Composition

Table 1 above shows that, for all practical purposes:

- The Male- Female participants ratio should reflect 50:50 relationship.
- The <33 year age group is represented in roughly the same proportion as the >55 age groups.
- The 33-55 year age group can be approximated as being equal to the other two groups.

Table 2 below, shows the practical implication of the field exercise. It shows the percentage of the rating panel members for each road segment necessary to meet the requirements for age and gender demographic distributions in New Jersey.

Table 2: Distribution of New Jersey Drivers by Age and Gender

Age Group (Years)	Percent of Licensed Drivers(%)		Total %
	Male	Female	
<33	12.5	12.5	25
33-55	25.0	25.0	50
>55	12.5	12.5	25
Total	50.0	50.0	100.0

The above distribution interprets to a minimum possible panel size of 8 raters as shown in Table 3 below.

Table3: **Minimum Acceptable Rater Panel to Meet Requirement Specified in Table 2**

Age Group (Years)	Percent of Licensed Drivers (%)		Total %
	Male	Female	
<33	1	1	2
33-55	2	2	4
>55	1	1	2
Total	4	4	8

From a statistical point of view, the above panel size as a whole is within a permissible error of 0.6 at a probability level of 0.05. But the errors for the individual age groups at the same probability level of 0.05 is not within the permissible range, and therefore more panel members were needed to bring down the error to the permissible range.

In this study the panel size was increased to a minimum of 64 (Table 4) raters to allow for:

1. Reasonable approximation of age and gender demographics in New Jersey.

2. Statistical reliability for:
    - The panel as a whole of within a permissible error of <0.3 at a probability level of 0.05.
    - Each of the age groups <33 and >55, of within a permissible error of <0.5 at the probability level of 0.05.
    - The 33-55 age group of within a permissible error of <0.3 at a probability level of 0.05.

Table 4: **Targeted Panel Size**

Age Group (Years)	Percent of Licensed Drivers (%)		Total %
	Male	Female	
<33	8	8	16
33-55	16	16	32
>55	8	8	16
Total	32	32	64

Table 5 is the actual number of respondents versus those interviewed in this research.

Table 5: **Number of Respondents vs. Interviewees**

	<33		33-55		>55	
	Respond	**Interview**	**Respond**	**Interview**	**Respond**	**Interview**
Male	**16**	**8**	**16**	**16**	**9**	**8**
Female	**8**	**8**	**17**	**16**	**8**	**8**
Total	**24**	**16**	**33**	**32**	**17**	**16**

Total Respondents = 74
Total Interviewees = 72

Rater Recruitment, Orientation and Survey

Recruitment

Both public advertisements in local newspaper, churches, and telephone recruiting techniques were used to recruit qualified NJ drivers who were willing to participate in the study. Recruitment area was confined within a 15 mile radius of Bellmawr City. Bellmawr City, located in Camden County New Jersey, was used as a marshalling point near the Atlas Flasher's office, where the office yard served as equipment storage. A rater registration form was used as a screening questionnaire to approve the suitability of the participants. (Appendix 6)

Orientation

Study participants assembled at the Atlas Flasher's office facility in the evening of 20^{th} December 2001 for a two-hour orientation session before the start of the survey. Participants were introduced to how some of the survey questions were going to be asked and how to respond to each particular question, and explanation for the grading system that was to be employed in answering pavement-marking questions. As part of this orientation, participants were reminded to abide by the restrictions specified in their driving license, and to obey all other traffic laws including wearing seat belts and observing the speed limit.

Field Survey

Automobiles and Communication

Participants were requested to use their cars to conduct the survey for the payments of $50/car/night. Before the start of the survey, the cars were checked to see if their headlights had been inspected and that the windshield and the headlights were clean. The participants were also requested and agreed to use their cell phones for communications to and from Atlas Flasher's main office during the survey.

Rating Circuit Preparation

The rating circuit was thirty-two miles long (Appendix 3). The starting point was near the Atlas Flasher's office located at Bellmawr City in Camden County, New Jersey. The circuit was defined in two phases. Phase 1 (clockwise) proceeded south from Bellmawr along Route US 30, and turned west along Route NJ 168 to connect to Route US 322, and continued west up to Route NJ 55, where it turned and proceeded North back to the starting point. Phase 2 (anticlockwise) proceeded south along Route NJ 55 down to Route US 322, where it turned east to Route NJ 42 and then north back to the turning point. Forty-four half-mile segments (16 anticlockwise and 28 clockwise) were marked out along the entire circuit. These sections were selected based on the retroreflectivity measurements of the pavement markings report, which were done by the LaserLux. Selected sections were those for which the measurement did not vary significantly from beginning to the end. The measured retroreflectivity values within the selected segments ranged from 92.2mcd/m2/lux to 286.4mcd/m2/lux

Before the start of the survey, the selected sections were marked on the actual roadway with a pavement marker spray to show the rating post number, start and end of each pre-selected segment. At the beginning of each pre-selected segment, a cone with reflector was placed on the road shoulder and the rating post number was marked on the pavement with white color spray (Figure.8.) A similar cone without reflector and the rating post number written on the pavement by an orange color spray was used to show the end of each segment (Figure. 8). This allowed the interviewer, who rode in the back seat of the car, to know precisely where a pavement-marking segment began and ended, and to ask the pavement marking questions at the appropriate time. Cones had to be maintained throughout the survey period. Two Atlas Flasher employees were assigned the task of continuously driving the entire circuit, one clockwise and the other anti clockwise, to ensure that all the reference cones were in position. Occasionally, a cone was found knocked down or disappeared entirely, and was replaced.

i) Start of survey section 1 *ii) End of survey section 1*

Figure 8: Cones to Show Start and End of Survey Sections

Conduct of the Survey

After the orientation, each participant was given a chance to get familiarized with the survey forms and to ask questions. After the participants declared to be clear about what they were supposed to do, they were allowed to leave the office and proceed to the study circuit with the interviewer riding in the back seat from where the entire interview was conducted. During the survey, raters were instructed to focus their eyes on the road in the manner in which they are accustomed. The study was conducted with the headlights on low beam, but drivers were allowed to turn the high beams on whenever they felt it necessary. No respondent was reported to need high beam during the entire study.

Questionnaires

The Pavement Markings and SRPM's rating forms (Appendix 7) were designed such that the star symbol (*) was used to identify which particular questions should be asked in each of the half mile sections of the line-miles that were marked out on the entire rating circuit. During the interview, as the car driven by the respondent passed the cone marking the beginning of the section, the interviewer asked the respondent the rating question corresponding to that particular road section and rating post number as marked on the corresponding rating card. Each half line-mile roadway segment was marked out such that the retroreflectivity remained relatively constant throughout the section so that respondents were able to take time to consider their response. All respondents were able to answer the rating questions in each half-mile section. The answers were provided according to the following rating scale:

A - Very clearly visible (Excellent)

B - Visible with no difficulties

C - Visible with some difficulties

D - Visible with great difficulties

E – Invisible

No coaching was given ahead of time as to what characteristics of a pavement marking the raters should use to assign a rating. The entire process was left to the raters' freedom of choice, so that the determination of what is acceptable should not be influenced by the opinion of any other person.

During the interview five other questions, not directly related to pavement marking visibility rating, were asked with intention to camouflage the primary purpose of the study (Appendix 7). This was thought important because if the raters were made knowledgeable of the primary purpose of this study, they could focus too much on the pavement marking along the entire course rather than in the pre-selected section. Priority was given to the pavement marking and SRPMs questions to ensure that the additional questions did not interfere with the rating questions. The number of questions that can be asked was controlled by the ability of the interviewer to write down the answer before the next question needed to be asked. Most of the additional questions in this study were not asked because of this factor.

Data Analysis

Definitions

To correlate the subjective rating of pavement marking performance with objective measurements, visibility terms were defined as follows:

- *Present Visibility*: The ability of pavement markings on a specific section of a roadway to be visible by motorist at highway speed in its existing conditions.
- *Individual Present Visibility Rating:* An independent rating by an individual of the present visibility of a pavement marking on a specific section of the roadway. The ratings range in a scale of 1-5 (1 for invisible and 5 for excellent visibility)
- *Present Visibility Rating* (PVR): The mean of the individual ratings made by the members of the specific panel
- *Present Visibility Index* (PVI): A mathematical combination of values obtained from certain physical measurements so formulated as to predict the PVR for those pavement markings prescribed limits.
- *Performance Index*: (PI) A summary of PVI over a period of time

Calibration Data

Hand Held Unit

An LTL 2000 retroreflectometer was used to take about twenty-two readings on each of the 23 half-mile sections selected along the calibration circuit (Appendix 2). The average readings of each section was computed for analysis (Appendix 8).

Mobile Unit

Measurements taken by the LaserLux Retroreflectometer along the same calibration circuit, corresponding to the same 23 half-mile roadway sections were extracted from the report and the average for each section computed (Appendix 9). Each LaserLux measurement represents the average of about five discrete measurements taken over a half a mile interval of line mile sections, and therefore the comparison of the LaserLux with the LTL 2000, may only be performed using averages for coincident marking intervals.

Measurement Comparison of LTL 2000 vs. LaserLux

Comparison of the data clearly shows a trend. The graph in Figure 10 shows that while there are some discrepancies, the LTL 2000 retroreflectometer measurements tend to follow the peaks and valleys of the LaserLux Retroreflectometer measurements.

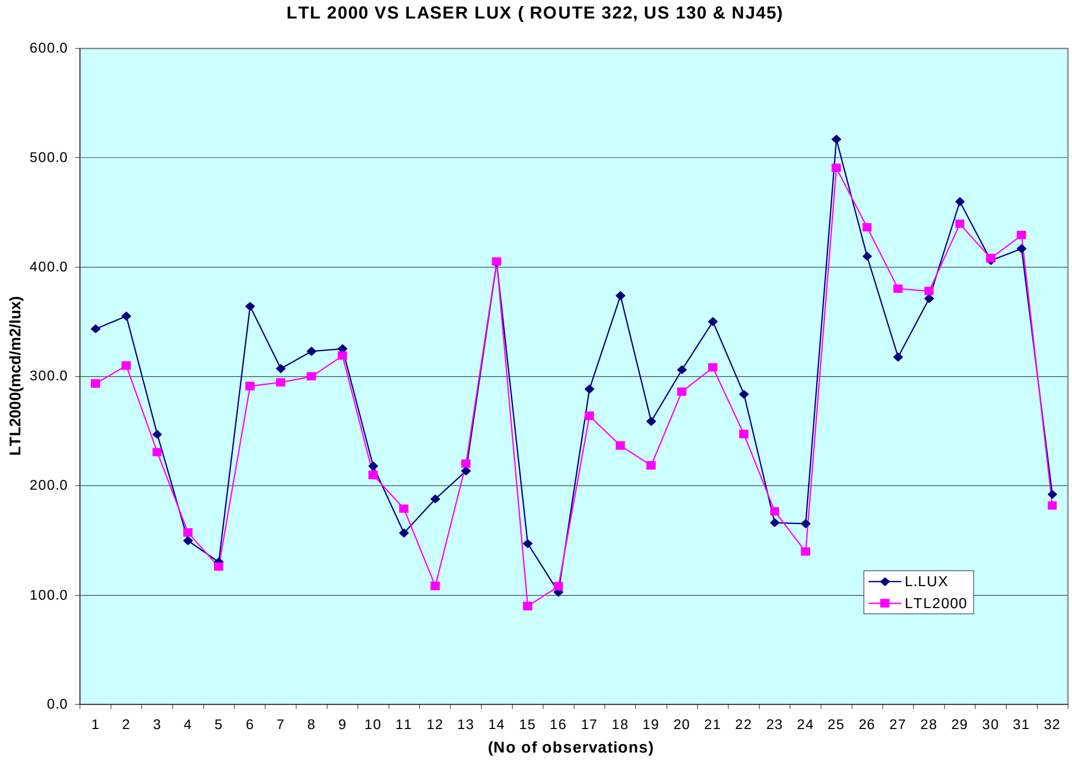


Figure 9: LTL 2000 vs. LaserLux Measurements

Statistical Analysis of the Data

One of the objectives of this project was to observe the degree of correspondence between the mobile unit (LaserLux) and handheld unit (LTL 2000). A regression model was developed using LTL2000 readings as the independent variable (X) and LaserLux readings as dependent variable (Y), as below:

$$\mathbf{Y = \beta_o + \beta_1 X_1}$$

$$\mathbf{Y_{LASERLUX} = 40.23 + 0.92X_{LTL2000}}$$

t-statistic (2.33) (15.5)

R2 =0.89

Conceptual Validity

The above relationship is valid conceptually with reasonable magnitude for the coefficients and all the signs.

Statistical Significance

For the Null hypothesis, h_o: $\beta_o = 0$, and the Alternative hypothesis, h_1: $\beta_o \neq 0$, at 95%confidence, level $\Rightarrow$ 5% significance level,

N = Number of observations =33; K= Number of independent variable =1
DF = Degree of freedom = N-K= 33-1 = 32.

From t-distribution tables

Control statistics ($t_{\alpha/2}$: N-K) =(0.025: 32) = ± 2.042

⇒

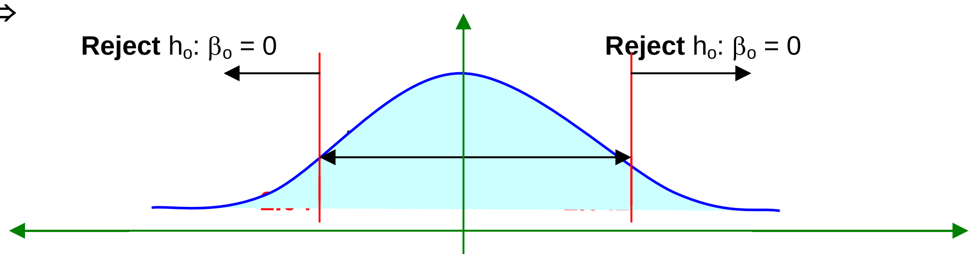


Figure 10: Control Statistics

t-statistic for the $\beta_{o} =$ 2.33, which falls in the region of **Reject,** h_o: $\beta_o = 0$, which implies that the constant of the equation is statistically significant, and therefore the graph does not pass through the origin, but intercept at point 40.23.

The variable (slope) t statistic of 17.25 falls in the region of Reject, h_o: $\beta_o = 0$, and accept the alternative, h_1: $\beta_o \neq 0$, which implies that statistically it is significant in this relationship.

The outcome model is therefore:

$$\mathbf{Y_{LASERLUX} = 40.23 + 0.92X_{LTL2000}}$$

Figure11 shows the graphical relationship between these two units (LTL2000 vs LaserLux) and the pertinent test statistics.

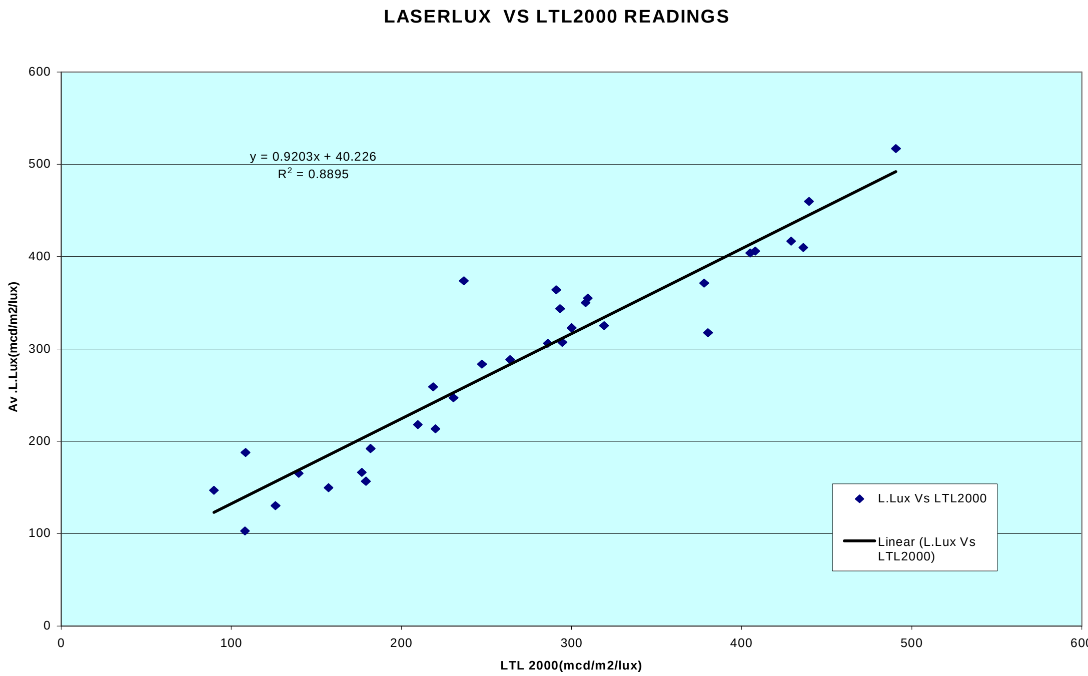


Figure 11: LaserLux vs. LTL 2000 Correlation

<u>Rating Data</u>

Two types of data were collected:

- Measured retroreflectivity of the pavement markings.
- Night brightness ratings provided by the study participants.

To simplify data management the rating scores provided by the study participants were assigned a number. A scale of (1-5) was used for each corresponding letter grade as shown in Table 6.

Table 6: Assigned Numbers to Rating Scores

<u>RATING SCORE GRADES</u>		<u>ASSIGNED NUMBER</u>
A - *Very clearly visible (Excellent*)	**-**	**5**
B - *Visible with no difficulties*	**-**	**4**
C - *Visible with some difficulties*	**-**	**3**
D - *Visible with great difficulties*	**-**	**2**
E – *Invisible*	**-**	**1**

A data file incorporating the rating scores and all the possible visibility influencing factors was created and compiled in a separate volume.

The mean value of the ratings for each pavement marking study section was calculated by computing the average of the assigned numbers corresponding to the participants rating scores.

Variations in Rating Scores by Gender

Of the 64 respondents interviewed the ratio of women to men was 1:1 (i.e. 50% women and 50% men). Statistically there was no significant variation in the rating of pavement markings by gender for any of the pavement marking types (Appendix 10:bubble charts).

Variations in Rating Scores by Age

A significant difference was observed in rating pavement markings by age. It was observed that the older group tended to rate with lower expectations than the younger group (Appendix 11: Bubble Charts). The oldest group rated the pavement markings significantly lower than one or more of the other age category.

Correlation Analysis

Correlation between LaserLux measured retroreflectivity and the New Jersey driver's nighttime visibility rating scores revealed that the two variables have no linear relationship. R^2 value of only 0.25, which is too small, resulted from linear regression analysis using average laser lux readings as an independent variable and the average rating scores as dependent variable (Appendix 12).

Curvilinear regression was the second attempt whereby correlation between these two variables was established by fitting various curve functions to the data. Several curve functions were tried and the polynomial function of 4^{th} order was found to have the best fit. The R^2 values calculated for the 4^{th} order polynomial function are: 0.98, 0.99, and 0.97, for data representing white edge lines, yellow center lines, and skip lines, respectively (Appendix 13), and R^2 of 0.97 for data representing both white edge lines, yellow center lines and skip lines (Figure 12).

The R^2 achieved in both cases is above 0.90, which is preferred in any regression analysis. The interpretation is that there is a strong correlation between the measured retroreflectivity and the participants night visibility ratings. Clearly there are other variables, that could affect how high a participant would rate a pavement marking nighttime brightness/visibility of the pavement markings, but it might be that the influence from such other factors is insignificant.

The slope of the fitted function is initially high and rapidly tapers off until the slope is almost zero. The interpretation of this relationship is that level of satisfaction reported by the New Jersey study participants improves significantly as the retroreflectivity of the markings increases from zero to about 125mcd/m2/lux. As the retroreflectivity increases from 125 to 200mcd/m2/lux, there is still an increase but the amount of increase per unit of increase in retroreflectivity of the markings is very small. Above 200 mcd/m2/lux, the relative increase of satisfaction of the drivers is relatively insignificant when compared to the increase seen below 125mcd/m2/lux.

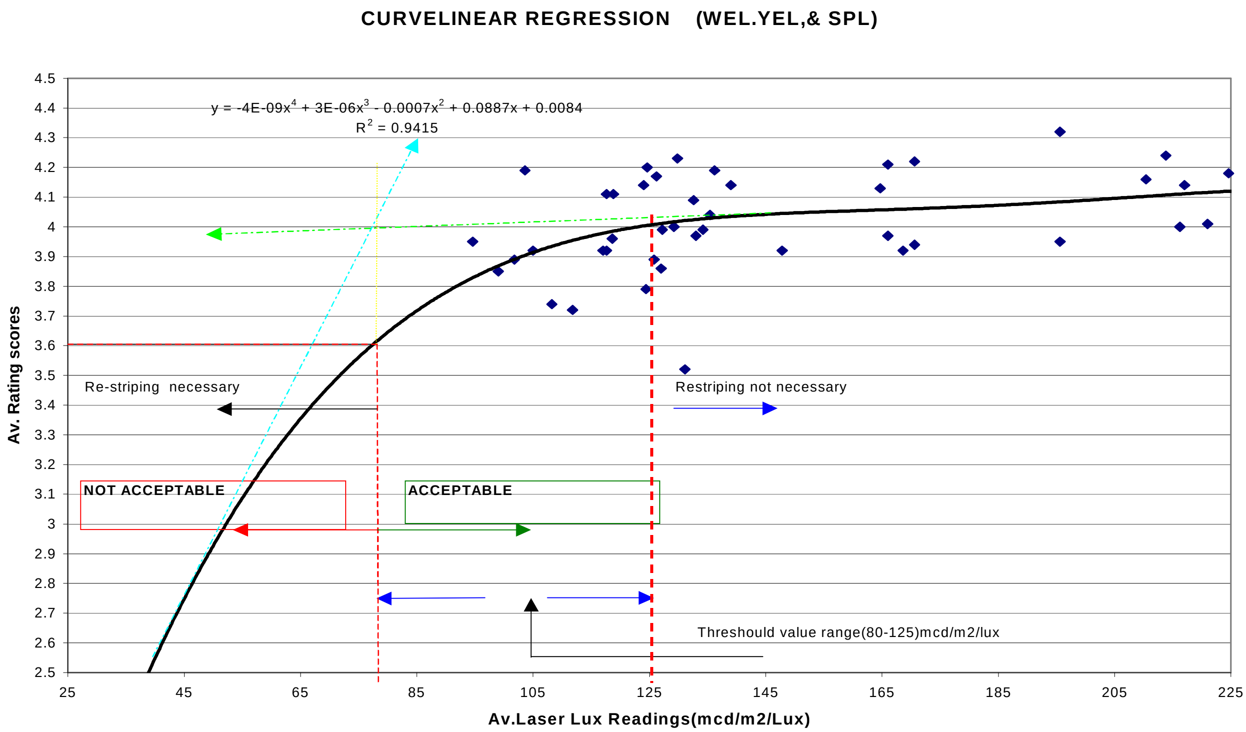


Figure 12: Curvilinear Regression (WEL, SPL and YCL)

These results suggest that concentrating resources on re-striping pavement markings with retroreflectivity below 125mcd/m2/lux would achieve a greater relative increase in driver satisfaction, than restriping pavement marking with retroreflectivity above 125mcd/m2/lux.

Threshold Value

The above polynomial suggests that the threshold value of acceptability versus unacceptability is somewhere between 80-125 mcd/m2/lux.

To try to further isolate a threshold value, a different type of analysis was performed which relates retroreflectivity and the percentage acceptable. The rating scores were combined such that the ratings of **A or B** were considered **acceptable** and ratings of **C, D, or E** were considered **unacceptable**. In the analysis, an overall score of acceptable was assigned to the pavement marking if **90%** or more of the participants rating that marking gave it a score of acceptable. Figure 13 below shows a scatter plot of the pavement markings retroreflectivity against their corresponding acceptability ratings.

Each point represents one of the pavement marking type (WEL, SPL, or YCL), and shows both the average of a half mile measured retroreflectivity and the percentage of study participants rating the marking as acceptable.

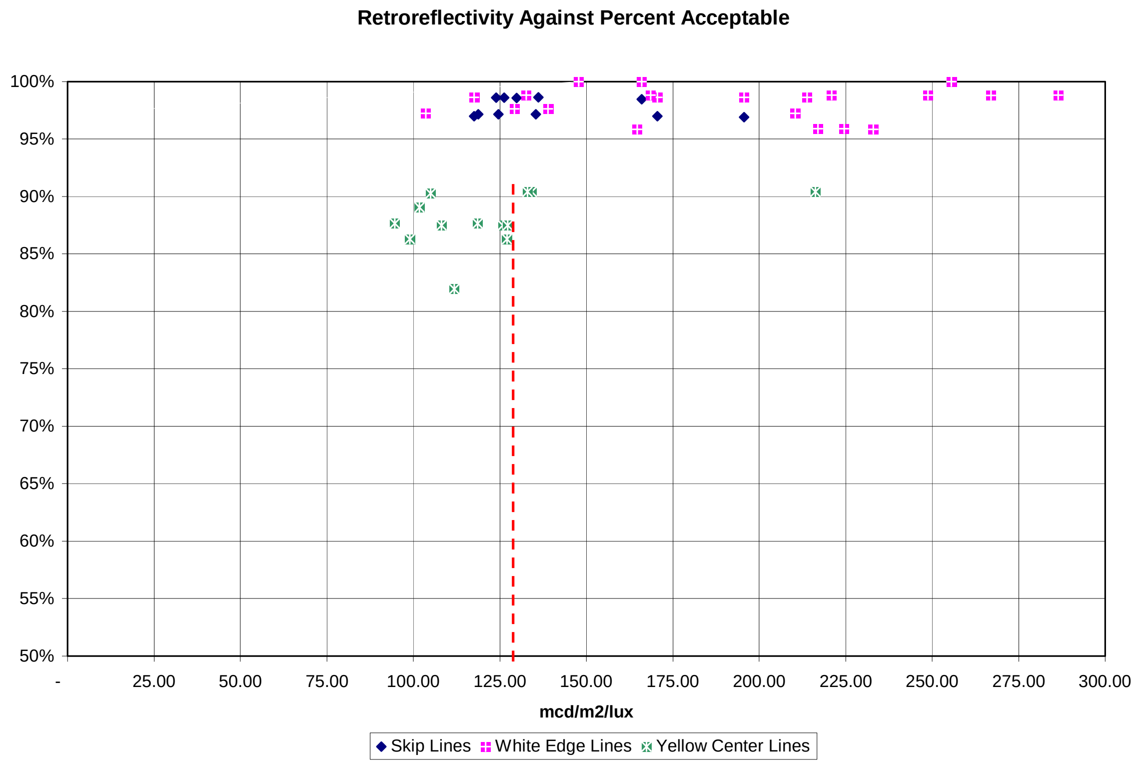


Figure 13: Retroreflectivity vs. Percent Acceptable

From Figure 13 above, the following is observed:

- No pavement marking less than 90mcd/m2/lux were surveyed.
- All WEL and SPL above 105mcd/m2/lux were considered acceptable by more than 90% of the participants
- All pavement markings above 128 mcd/m2/lux were acceptable by more than 90% of the study participants
- No YCL (except one section) between 105-128 mcd/m2/lux was considered acceptable by 90% of the participants.
- The threshold between acceptability and unacceptability would appear to fall in a range between 105 and 128 mcd/m2/lux.

Visibility Modeling

Development

The technique of multiple regression analysis was used to arrive at the Present Visibility Indices (PVI's) by successive stepwise iterations. Decisions on which variables to leave behind and which to be carried forward for the next iteration was dictated by their conceptual validity and statistical significance, after each iteration.

The calibration process proceeded systematically, testing each variable in turn until the best model (in terms of some summary statistics for 95% confidence level) was attained (Appendix 12).

Figure 7 below shows the attained Interim Visibility Indices (IVI's), while Figure 8 shows a trial application for retroreflectivity levels ranging from 65-350 mcd/m^2/lux.

Table 7: Interim Present Visibility Indices

AGE (Yrs)	TYPE OF PAVEMENT MARKING	INTERIM VISIBILITY INDEX
<33	White Edge Lines (WEL)	$Y_{RS} = X_{RL}^{0.282}$ *(16.4)*
	Skip Lines (SPL)	$Y_{RS} = X_{RL}^{0.296}$ *(24.7)*
	Yellow Center lines (YCL)	$Y_{RS} = X_{RL}^{0.257}$ *(15.4)*
33-55	White Edge Lines (WEL)	$Y_{RS} = X_{RL}^{0.290}$ *(22.5)*
	Skip Lines (SPL)	$Y_{RS} = X_{RL}^{0.292}$ *(21.6)*
	Yellow Center lines (YCL)	$Y_{RS} = X_{RL}^{0.257}$ *(17.3)*
>55	White Edge Lines (WEL)	$Y_{RS} = X_{RL}^{0.262}$ *(12.3)*
	Skip Lines (SPL)	$Y_{RS} = X_{RL}^{0.246}$ *(13.1)*
	Yellow Center lines (YCL)	$Y_{RS} = X_{RL}^{0.243}$ *(17.8)*
BOTH AGE GROUPS	WEL,YCL,& SPL.	$Y_{RS} = 1.1 X_{RL}^{0.244}$ *(2.4) (17.8)*

<u>NOTE</u>: RS = Rating Scores
RL = Measured retroreflectivity (mcd/m2/lux)
( ) = t- statistics

Table 8: Interim Present Visibility Index Application

AGE YRS	TYPE OF PAVEMENT MARKINGS	INTERIM VISIBILITY INDEX	X-RL (mcd/m2/lux)							Trial range 65-350mcd/m2/lux								
			65	70	90	100	115	120	125	130	150	160	165	170	175	250	300	350
<33	White Edge Lines	Y(RS)=X^0.282	3	3	4	4	4	4	4	4	4	4	4	4	4	5	5	5
	Skip Lines	Y(RS)=X^0.296	3	4	4	4	4	**4**	4	4	4	4	5	5	5	5	5	5
	Yellow Center Lines	Y(RS)=X^0.257	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	5
33 - 55	White Edge Lines	Y(RS)=X^0.290	3	3	4	4	4	4	4	4	4	4	4	4	4	5	5	5
	Skip Lines	Y(RS)=X^0.292	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5
	Yellow Center Lines	Y(RS)=X^0.257	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	5
>55	White Edge Lines	Y(RS)=X^0.262	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5
	Skip Lines	Y(RS)=X^0.246	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4
	Yellow Center Lines	Y(RS)=X^0.243	3	3	3	3	3	3	3	3	3	3	4	3	4	4	4	4
All Ages	WEL,SPL,& YCL	Y(RS)=1.1X^0.244	**3**	**3**	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**5**
% ACCEPTABLE			**0%**	**10%**	**40%**	**50%**	**60%**	**60%**	**60%**	**80%**	**80%**	**90%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

From ***Table 8*** above the following can be observed:

- Retroreflectivity of less than 70mcd/m2/lux is unacceptable for all pavement marking types by any of the study participants from any age group.

- Retroreflectivity of 130mcd/m2/lux and above for all pavement marking type is acceptable by all study participants of all age group except for SPL and YCL for the oldest group >55 years of age.

- Raters with age > 55 years require retroreflectivity of at least 160mcd/m2/lux for SPL and at least 165mcd/m2/lux for the YCL.

CONCLUSION

The following conclusions are made from the study:

- Comparison of the data collected using Mobile LaserLux and handheld LTL 2000 is useful in understanding the strengths and the weaknesses of the resulting database. What was apparent from the comparison between LaserLux and LTL 2000 hand held unit is that LaserLux readings tend to be higher than LTL2000 readings ranging from about 40% for low retroreflectivity (50mcd/m2/lux), about 16% for retroreflectivity of about 150mcd/m2/lux, and about 0% for higher values of about 500mcd/m2/lux.

- Only pavement marking retroreflectance appeared to be significant in determination of driver rating, i.e., driver ratings were minimally affected by other environmental factors, such as oncoming vehicles, street lights, etc..

- The threshold value of acceptable versus unacceptable retroreflectivity appears to be between 80 and 130mcd/m2/lux, for New Jersey drivers <55 years of age, and between 120 –165 mcd/m2/lux for drivers >55 years of age. This finding is consistent with conclusions reached by other investigators on similar research, with results generally ranging between 70-170 mcd/m2/lux. (Appendix 14).

- From the curvilinear regression curve approach (Figure12), acceptability versus unacceptability percentile chart (Figure 13), and the results of the IVI test (Table 8), it can be advised that concentrating resources on re-striping pavement markings with retroreflectivity below 130mcd/m2/lux would achieve a greater relative increase in driver satisfaction than re-striping pavement marking with retroreflectivity above 130mcd/m2/lux.

- The Interim Visibility Indices (IVI) developed can be a useful tool for NJDOT in determining and prioritizing needs and quantification of related resources required, based on the threshold between acceptable retroreflectivity and unacceptable retroreflectivity, when developing the new pavement marking management system. This will also allow for cost benefit/life cycle analysis of different pavement marking material.

DISCUSSION AND RECOMMENDATIONS

Equipment Calibration

From Figure 9 it is observed that the handheld LTL 2000 data tend to follow the peaks and valleys of the mobile LaserLux data throughout the calibration circuit Route US 322, NJ 42 & US 130. Either LaserLux or LTL 2000 can be used to collect pavement marking retroreflectivity data along the New Jersey Highways. Both types of devices have their advantages and disadvantages :

- Initial cost for LaserLux is high, exceeding about $180,000 including all necessary equipment, while initial cost for LTL2000 is below $17,000.
- The operating cost of the mobile unit, maintenance, fuel, depreciation, and technical support, are also higher, though given the ease of collecting large quantities of data, unit cost may be lower.
- The mobile unit can collect pavement retroreflectivity at highway speeds without the need for traffic control devices. A mobile unit can also collect data for the white skip lines, which are essentially inaccessible with handheld units unless significant traffic control resources are employed. The use of the mobile unit may reduce the number of person-hours required to collect the data, as only two people are needed to drive and operate the equipment. The handheld unit only requires one person to take a reading, but several others may be needed for traffic control purposes.
- Another important advantage of a mobile unit is that data is collected continuously along the roadway rather than at the discrete locations as the hand held unit. Data collected with a mobile unit provide a total representation of the pavement marking along a roadway rather than merely a sample–based series of point locations. LTL2000 like all other handheld units operate on a point of contact basis and are calibrated in a controlled environment, and therefore are believed to provide readings that are more accurate. LaserLux mobile unit is dependent on handheld devices for calibration. It also must be considered that the use of LTL2000 for data collection meets present ASTM recommendations.
- Both the handheld LTL2000 and the mobile LASERLUX units have unique benefits, but the final decision and selection of the most appropriate equipment is most dependent on the type of monitoring program that New Jersey DOT will implement, the available workforce, and resources available to conduct the work.
- It is recommended that LaserLux be used for monitoring and LTL2000 for quality assurance and acceptance.

Threshold Value

The acceptable minimum value of retroreflectivity was isolated from the data collected in three different approaches:

- In the first approach the polynomial function of fourth order fitted to the data (Figure 12) indicated that the minimum value would range from (80 to 125) mcd/m2/lux.
- In the second approach where retroreflectivity was related to the percentage acceptable (Figure13), the minimum acceptable value was indicated in the range between (105-128) mcd/m2/lux.
- In the third attempt, a range of retroreflectivity values was tested by the developed interim visibility indices for each age group and each pavement marking type. The results indicated that the minimum acceptable values are as follows:
  - between 90- 130mcd/m2/lux for age group <33 and (33-55) years;
  - between 120-130mcd/m2/lux for WEL, 160mcd/m2/lux for skip lines, and 165mcd/m2/lux for yellow centerline for age group >55 years, implying that older people are rating the night time visibility with lower expectations than the younger group.

  These findings are consistent with the findings from other investigators on similar types of research which indicated that an acceptable minimum value of retroreflectivity generally ranges between (70-170) mcd/m2/lux (Appendix 14).
- From Figure 13, it was observed that there is no YCL-pavement marking, except one section, below retroreflectivity value of 128mcd/m2/lux that was considered acceptable by 90% of the participants. In Table 8*,* it is observed that there is no pavement marking with retroreflectivity level below 130mcd/m2/lux that is considered acceptable by the age group > 55 years, and also no yellow pavement marking less than 165mcd/m2/lux is considered acceptable by the same age group. This is compatible with the existing literature, which shows that pavement marking color has been reported to affect the retroreflectivity properties of PM materials.
- It is commonly accepted that yellow markings have retroreflectivity values equivalent to about 70-80% of white markings retroreflectivity.[28]
- Several research findings indicate that white marking maintains higher retroreflectivity and provide longer detection distances than yellow marking, and that drivers use the white edge line for detecting the maximum preview distance available to them.

Service Life of the Pavement Markings

The time from pavement marking installation to when the pavement marking reaches the minimum acceptable level of retroreflectivity is the service life of the pavement marking. At the end of service life, pavement markings need to be replaced. The use of a fixed replacement schedule has its shortcomings because, while this may be sufficient for some highway and material type it can also be excessive in some cases leading to unnecessary maintenance cost. For example, evaluation of the pavement marking measured retroreflectivivity using the suggested threshold value of 130mcd/m2/lux, (Appendix18) demonstrated the following:

- No pavement marking younger than 3 years qualify for re-striping this year, with the exception of Route US 130 WEL, that qualified for only 17%.
- Rate of deterioration of the pavement marking varies from road to road and from section to section, regardless of pavement age. For example, from the measured retroreflectivity in this survey, sections qualifying for restriping this year are as follows:

  Route US 9 WEL 30%, route US 30 YCL 78%, route US 130 WEL 7%, Route NJ 55 SPL 28% and Route NJ 42 SPL 60% while the age of both pavement markings is 3 years (Appendix18).

Based on the three year NJDOT restriping policy, restriping in this year (2002) is justified by 78% for YCL on route US 30, 30% for WEL on route US9, 7% for WEL on route US 130, 28%, for SPL on route NJ55 and 60%, for SPL on route NJ55. Clearly most of the sections in these routes can perform for more years before a need for re-striping. To eliminate the risk of "under restriping" or "over restriping", the use of performance-based approaches by making use of the developed IVI is recommended (Table 7). A performance based approach will also better manage the early risk in application of the markings as the contractors will have a greater responsibility to get the application right and for the long-term retroreflectance performance of the installed material.

Initial Retroreflectance*.*

From the pavement marking construction schedule and database (Appendix 15), it was noted, and verified, that the oldest pavement markings and SRPM's were installed in 1999, and were therefore at most 2 ½ years old. Given that some of the markings did not pass the rating test, there is a suggestion that the replacement cycles in some cases might be less than the current 3 years. This is particularly the case for yellow lines (Appendix 18).

The newest pavement markings and SRPM's were installed in 2001, and were therefore less than one year old. The summary statistics of the measured Laserlux retroreflectivity of these new (1yr old) markings were as follows:

RTE NJ47, WEL	Restriped 2001
Summary statistics	
	RL(mcd/m2/lux)
Mean	356.369338
Standard Error	4.629175308
Median	366
Mode	376
Standard Deviation	78.42320305
Sample Variance	6150.198777
Kurtosis	0.373112805
Skewness	-0.501044678
Range	411
Minimum	129
Maximum	540
Sum	102278
Count	287

RTE NJ49, WEL	Restriped 2001
Summary statistics	
	RL(mcd/m2/lux)
Mean	286.7264151
Standard Error	5.899389053
Median	279.5
Mode	313
Standard Deviation	60.73792775
Sample Variance	3689.095867
Kurtosis	0.277845124
Skewness	0.513072294
Range	299
Minimum	145
Maximum	444
Sum	30393
Count	106

RTE I-295, WEL	Restriped 2001
Summary statistics	
	RL(mcd/m2/lux)
Mean	304.5135135
Standard Error	4.203110713
Median	305.5
Mode	323
Standard Deviation	36.15652549
Sample Variance	1307.294335
Kurtosis	-0.171928322
Skewness	-0.148806198
Range	168
Minimum	213
Maximum	381
Sum	22534
Count	74

RTE NJ45,YCL	Restriped 2001
Summary statistics	
	RL(mcd/m2/lux)
Mean	276.2857143
Standard Error	8.665752651
Median	279
Mode	229
Standard Deviation	64.84855484
Sample Variance	4205.335065
Kurtosis	-0.649435575
Skewness	-0.150738981
Range	273
Minimum	123
Maximum	396
Sum	15472
Count	56

RTE NJ45,SPL	Restriped 2001
Summary statistics	
	RL(mcd/m2/lux)
Mean	391.3181818
Standard Error	10.21278749
Median	389.5
Mode	330
Standard Deviation	67.74396832
Sample Variance	4589.245243
Kurtosis	-0.095719576
Skewness	-0.289869681
Range	294
Minimum	206
Maximum	500
Sum	17218
Count	44

From the above summary, it can be said that the minimum specification retroreflectance should be set higher than the highest observed mode values which are:

- WEL: 376mcd/m^2/lux
- SKIP: 330 mcd/m^2/lux
- YEL: 229 mcd/m^2/lux

In contrast, Field evaluation of pavement marking materials by AASHTO 1996 Volume 1, specifications on new installed retroreflectance are in the following ranges:

- WEL: 250- 450 mcd/m^2/lux
- SKIP: 250- 450 mcd/m^2/lux
- YEL: 500-850 mcd/m^2/lux

Research is recommended to determine the acceptance quality level, and actual retroreflectivity level of newly installed markings for New Jersey Highways.

Retroreflectance of the Pavement Markings

This research has revealed that pavement marking retroreflectance is the most powerful influencing factor of nighttime visibility. It is therefore recommended that the NJDOT strengthen its commitment to "paint and bead" material by finding ways to increase the retroreflectance of those markings and to ensure that the application process works consistently with little variability.

It is recommended that research be commissioned to enhance the "paint and bead" application process, to improve the quality control, and to reduce the variability in the initial retroreflectance.

From a visibility point of view, RPMs may be the most favorable supplement for retroreflectance because RPMs extend the visibility range. The use of RPMs would especially benefit older motorist and would allow for wet weather visibility. The non-availability of Ecodyn equipment rendered recommendations for SRPM's moot. The data were collected on the detection – presence or absence – of SRPM's with the LaserLux, and on panel ratings. Detection of SRPM's would be consistent with the state of the practice replacement strategy, which is based on number of consecutive missing SRPM's.

Additional research is needed to determine the actual durability of RPMs in New Jersey Highways.

Selection of Pavement Marking Materials.

There are numerous factors to consider when selecting a pavement marking material. These factors include the type and condition of the pavement, ability to install the marking over the existing markings, level of service or quality of the marking desired for a given highway, geographic locations, and pavement management activities. These same factors greatly influence the service life of the markings. Because of the numerous factors to be addressed, and the magnitude of the analysis, the researcher did not have sufficient information to develop guidelines concerning the use of particular pavement marking for particular situations. An alternative method for making decisions about pavement marking, especially durable marking, is to consider performance-based specifications. For example, in this approach, the performance criterion could be that minimum retroreflectivity of 130mcd, for example, would be maintained for a period of three years.

Research is recommended to determine the effectiveness of various pavement marking materials for New Jersey Highways.

Way Forward

There is a need for a “Pavement Marking Management System” for New Jersey DOT, which will allow choice of pavement marking material on the bases of field performance and optimal use. A Pavement Marking Management System will also require development of a pavement marking retroreflectivity GIS database, which will stand as a powerful tool in the analysis of the pavement marking retroreflectivity data. A continuously updated GIS database will provide the ability to efficiently review and query retroreflectivity data for pavement marking type, condition, location, jurisdictional purposes, and real time information based on the pavement marking monitoring data for both an administration and analysis point of view (Appendix 17).

A research project to develop a “pavement marking management system”, based on a pavement marking GIS database, is recommended.

REFERENCES

1. Neville Parker. **Evaluation of the Performance of Retroreflectors in Snowplowable Raised Pavement Markers.** Final Proposal, Research Problem Statement Number 2000-35, New Jersey Department of Transportation, 2001.
2. U.S. Department of Transportation, Federal Highway Administration. **Manual on Uniform Traffic Control Devices**. *1988 Edition*.
3. W. A. Sarasua, et al. **"Methods and Considerations for Evaluating the Retroreflectivity of Pavement Markings"**. Paper No. 00-0854, *TRB 79^TH^ Annual Meeting*.
4. H.T. Zwahlen and T. Schnell. **"Visibility of Road Marking as a Function of Age, Retroreflectivity Under Low-Beam & High-Beam Illumination at Night."** In *Transportation Research Record 1692,* TRB, National Research Council, Washington, D.C., 1999, pp. 152-163.
5. T. Schnell and H. T. Zwahlen. **"Computer Based Modeling to determine the visibility and Minimum Retroreflectivity of Pavement Markings."** In *Transportation Research Record 1692,* TRB, National Research Council, Washington, D.C., 1999.
6. U.S. Department of Transportation, Federal Highway Administration. **Roadway Delineation Practices Handbook**. Publication No. FHWA-SA-93-001, August 1994.
7. H.T. Zwahlen and T. Schnell. **"Visibility of New dashed Yellow and White Center Stripes as a Function of Material Retroreflectivity."** In *Transportation Research Record 1553,* TRB, National Research Council, Washington, D.C.,*1996, pp. 73-80.*
8. Flint Trading, Inc., March 2001(Supplier).
9. LIGHTS, UNITS, AND TERMINOLOGY; **Physics of Light, Light Units and Terminology, Metric Systems, & Light Measurement**.
10. Highway Innovative Technology Evaluation Center. **Technical Evaluation Report, Summary of Evaluation Findings For 30-Meter Handheld and Mobile Pavement Marking Retroreflectometers**, March 2001.
11. Highway Innovative Technology Evaluation Center. **Technical Evaluation Report, Evaluation Findings of the Ecodyn Mobile Pavement Marking Retroreflectometer,** January 2000.
12. Highway Innovative Technology Evaluation Center. *Technical Evaluation Report, Evaluation Findings of the LTL 2000 Handheld Pavement Marking Retroreflectometer,* January 2000.
13. **"Reflectorized Devices for Driver Information."** In *Transportation Research Circular 306,* TRB, National Research Council, Washington, D.C., 1986, pp.1-2.
14. **Summary of Results of Field and Laboratory Evaluations of Pavement Marking Materials. Vol. 1: Field Evaluations**. National Transportation Product Evaluation Program, American Association of

State Highway and Transportation Officials, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996.

15. Graham, J. R., and L. E. King. **“Retroreflectivity Requirements for Pavement Markings.”** Transportation Research Record, No. 1316, pp. 18 – 23, Washington, D.C., 1991.
16. Graham, J. R., J. K. Harrold, and L. E. King. “**Pavement Marking Retroreflectivity Requirements for Older Drivers.”** Transportation Research Record, No. 1529, pp. 65 – 70, Washington, D.C., 1996.
17. Migletz, J., J. L. Graham, K. M. Bauer, and D. W. Harwood. “**Field Surveys of Pavement-Marking Retroreflectivity.**” Transportation Research Record, No. 1657, pp. 71-78, Washington, D.C., 1999.
18. Loetterle, F. E., R. A. Beck, and J. Carlson. “**Public Perception of Pavement Marking Brightness**.” Transportation Research Board 78th Annual Meeting, Washington, D.C., January 10-14, 1999
19. Zwahlen, H. T., and T. Schnell. “**Minimum In-Service Retroreflectivity of Pavement Marking.**” 79th Annual Meeting,Transportation Research Board, Washington, D.C., January 9-13, 2000.
20. Andrady, A. L. “**Pavement Marking Materials: Assessing Environment-Friendly Performance.”** National Cooperative Highway Research Program, Report 392. Transportation Research Board, Washington, D.C., 1997.
21. Scheuer, M., T. L. Maleck, and D. R. Lighthizer. “**Paint-Line Retroreflectivity over Time.”** Transportation Research Record, No. 1585, pp. 53 – 63, Washington, D.C., 1997.
22. Zwahlen, H. T. and T. Schnell. **“Visibility of New Pavement Markings at Night Under Low-Beam Illumination.”** Transportation Research Record, No. 1495, pp. 117–127, Washington, D.C., 1995.
23. Zwahlen H. T. and T. Schnell. **“Visibility of New Dashed Yellow and White Center Stripes as Function of Material Retroreflectivity.”** Transportation Research Record, No. 1553, pp. 73–80, Washington, D.C., 1996.
24. Zwahlen H. T. and T. Schnell. **“Visibility of New Centerline and Edge Line Pavement Markings.”** Transportation Research Record, No. 1605, pp. 49-61, Washington, D.C., 1997.
25. *Innovative Traffic Control Technology and Practice in Europe.* Federal Highway Administration, U.S. DOT, August 1999.
26. Zwahlen, H. T., and T. Schnell. **“Driver Eye Scanning Behavior at Night as a Function of Pavement Marking Configuration.”** Transportation Research Board 76th Annual Meeting, Washington, D.C., January 12-16,1997.
27. Lee, J-T, T. L. Maleck, and W. C. Taylor. **“Analysis of the Correlation Between Pavement Marking Visibility and Night-Time Accidents.”** Transportation Research Board 77th Annual Meeting, Washington, D.C., January 11-15, 1998.

28. Nasser Abboud, Auburn University **“Establishing Crash-based Retroreflectivity Thresholds.”** TRB 2002 Annual meeting CD ROM.
29. **Precision Scan, L.L.C**. *Safety and System Integration*

BIBLIOGRAPHY

1. A.L. Andrady. **"Pavement Marking Materials: Assessing Environment-Friendly Performance."** Transportation Research Board Research Triangle Institute. NCHRP Report 392, 1997, 66p.

2. David B. Clerke, Wayne A Sarasua, and J. Clifton Collins. **"Measurement and Evaluation of Pavement marking Retroreflectivity: South Carolina's Experience"** TRB Paper Number 01-3491.

3. B. H. Cottrell. *Evaluation of Pavement Marking for Improved Visibility During Wet Night Condition.* Virginia Transportation Research Council, May 1996.

4. M.V. Jagannath and A.W. Roberts. "**Snowplowable Raised Pavement Markers in New Jersey (Abridgment)."** Transportation Research Record 651, 1977, pp. 39-42.

5. J. Migletz, J.L. Graham and D.W. Harwood. "**Field Surveys of Pavement-Marking Retroreflectivity."** Transportation Research Record – Journal of the Transportation Research Board 1657, 1999, pp. 71-78.

6. H.T. Zwahlen and T. Schnell. **"Driver Preview Distances at Night Based on Driver Eye Scanning Recordings as a Function of Pavement Marking Retroreflectivities."** Transportation Research Record – Journal of the Transportation Research Board 1692, 1999, pp.129-141.

7. M. Scheuer, T.L. Maleck, D.R. Lighthizer. **"Paint-Line Retroreflectivity Over Time."** Transportation Research Record 1585, 1997, pp. 53-63.

8. H.T. Zwahlen and T. Schnell. **"Visibility of New Centerline & Edge Line Pavement Markings."** Transportation Research Record 1605, 1997, pp. 49-61.

9. J.R. Graham, J.K. Harrold, L.E. King. "**Pavement Marking Retroflectivity Requirements for Older Drivers."** Transportation Research Record 1529, 1996, pp. 65-70.

10. G.F. Jacobs, T.L. Hedlom, T.I. Bradshaw, N.A. Hodson and R.L. Austin. **"Detectability of Pavement Markings Under Stationary and Dynamic Conditions as a Function of Retroreflective Brightness."** Transportation Research Record 1495, 1995, pp. 68-76.

11. Premark's 20/20 Flex. High Performance Performed Thermoplastic, March 2001 (Supplier).

12. Highway Markings, Inc, March 2001 (Supplier).

13. Highway Innovative Technology Evaluation Center. Technical Evaluation Report, Evaluation Findings of the LaserLux Mobile Pavement Marking Retroreflectometer, January 2000.

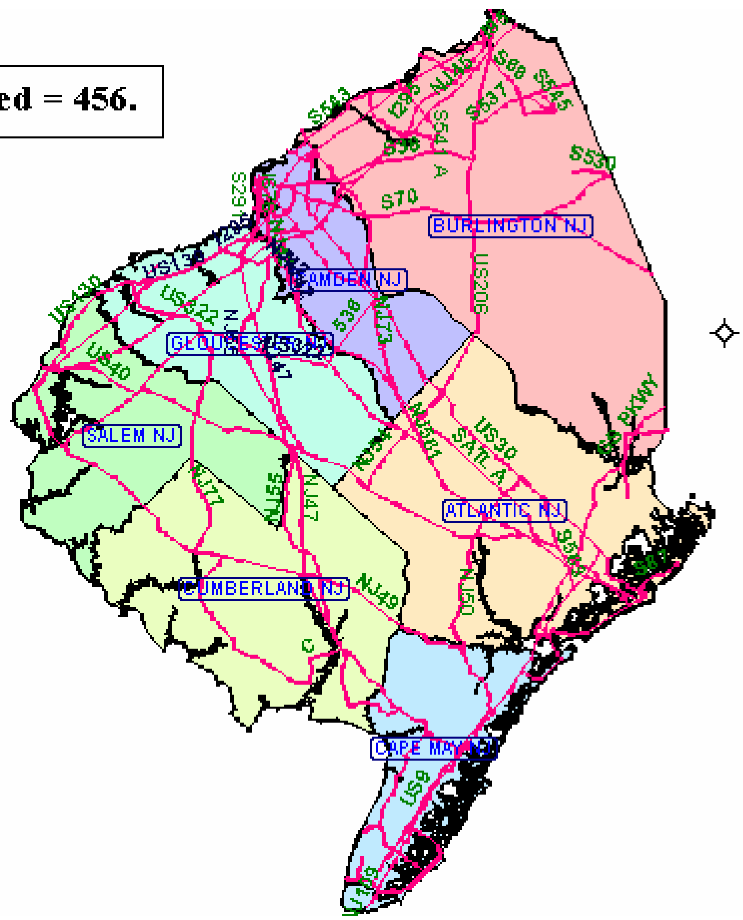
14. Francis E. Loetterle, AICP, Richard A Beck, PE and Jim Carlison. *Minnesota Department of Transportation Paper on Public Perception on Pavement Marking Brightness.*

15. **James S. Kalchbrennr**, *Potter Industry ,Inc*. *Signing and Marking Material*
16. **Vince Dravitzki,** Opus central Laboratory**.** *Materials and tools for better road markings*
17. **Norbert H Maerz,** University of Missouri. *Automated real time pavement marking retroreflectivity measurement.*
18. **Chris Davies,** *potters Industry***,** *July 9,1999***.** *Retroreflectivity Instruments-1999*.
19. **HITEC** . *Evaluation of six Pavement Marking Retroreflectometers.(*MX30,LTL 2000, FRT10, Mirolux Plus, LaserLux, and Ecodyn.)
20. **MASTRAD** *Quality and Test Systems*. *ZVR 1000 VISUAL ER RETROREFLECTOMETER*
21. **ASCE Research News** *Performance of Six Retroreflectometers*.
22. **GAMMA SCIENTIFIC**. *RPM 1200 Retroreflectometers*
23. **Mirolux Products, Inc.** Advertisement on New Raised Pavement Marker Retroreflectometer to be made available, November, 2001.
24. **3M**: *Liquid Pavement Marking series 1200*
25. **3M**: *Wet Reflective Pavement Marking Tape Series 820*
26. Tomas Schnell and Phillip J. Ohme. **"Evaluation of Various Strategies to Increase Pavement Marking Visibility for Older Drivers."** TRB Paper No 02:3365
27. Ahmad et al **"Florida University Methods of Application of Thermoplastic Pavement Markings: A Comparison between concrete and Asphalt Roadway Surfaces"** TRB, CD ROM 2002
28. **3M**: Wet Reflective Removable Tape Series 750.
29. Benjamin H. Virginia **"Transporation Research Council: Determining the Effectiveness of Pavement Marking Materials."** TRB, CD ROM 2002
30. Rich, Maki and Morena **"Development of Pavement Marking Management System: Measurement of Glass Sphere Loading in Retroreflective Pavement Paints."** TRB, CD ROM 2002
31. *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S. Department of Transportation, Federal Highway Administration, 1988.
32. *Pavement Traffic Marking: Materials and Application Affecting Serviceability*. National Cooperative Highway Research Program, Synthesis of Highway Practice No. 17. Highway Research Board, Washington, D.C., 1973.
33. *National Transportation Statistics*. Bureau of Transportation Statistics, U.S. Department of Transportation,Washington, D.C., 1997.
34. Critical Analysis Reporting Environment (CARE) Computerized Database. University of Alabama.

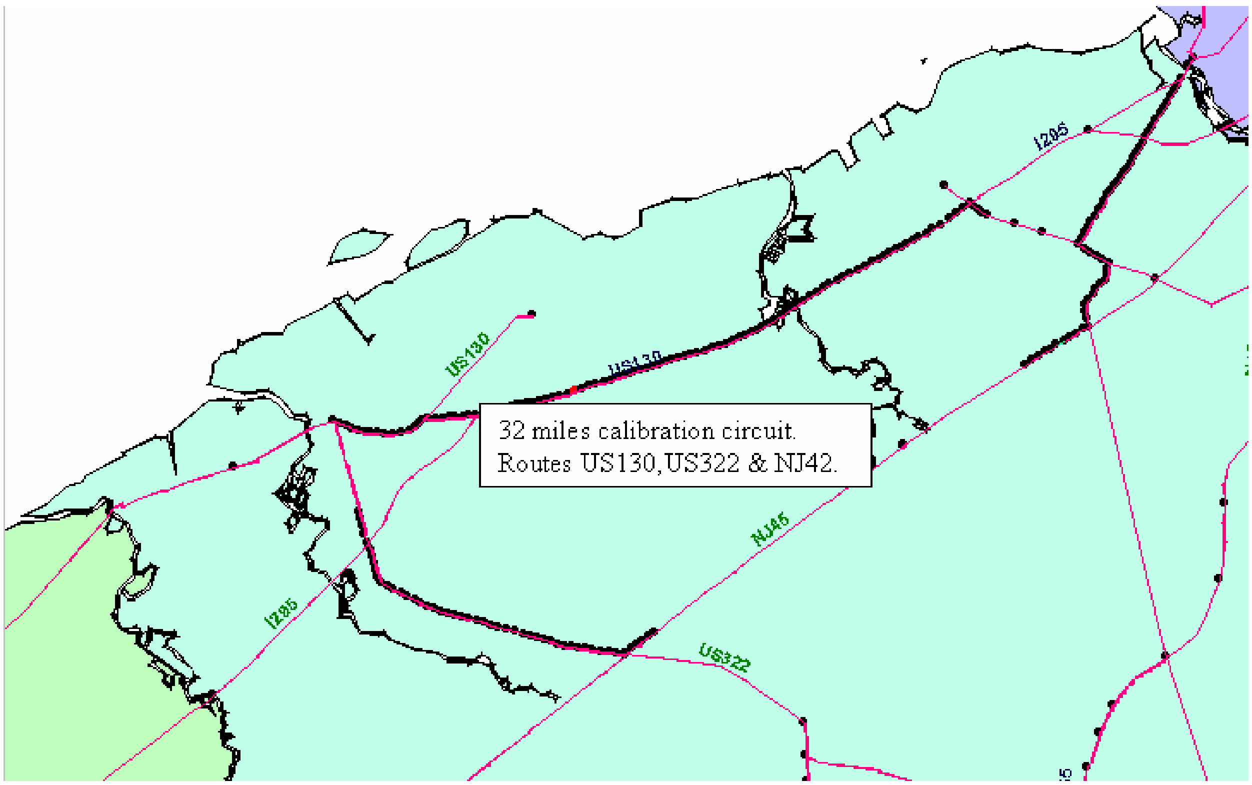
APPENDICES

APPENDIX 1: SELECTED ROADWAY MILES FOR SURVEY

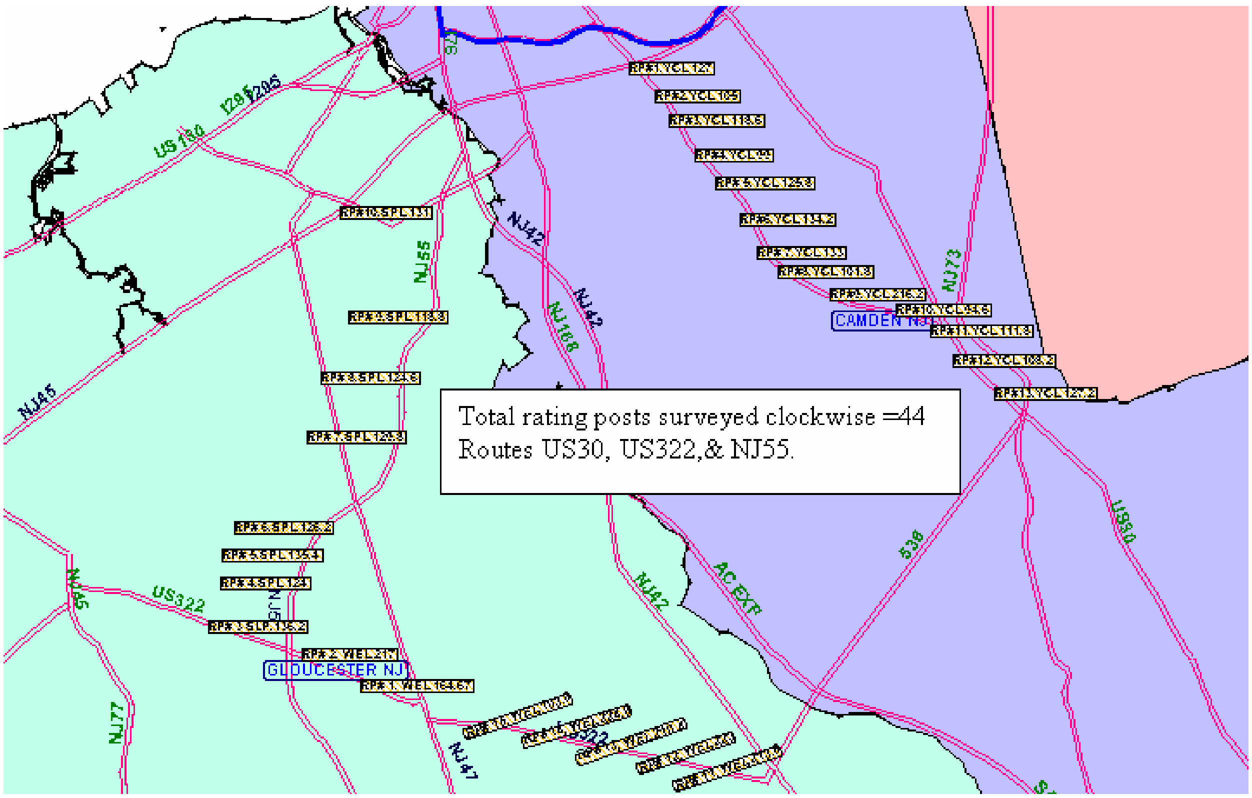
Total milege surveyed = 456.

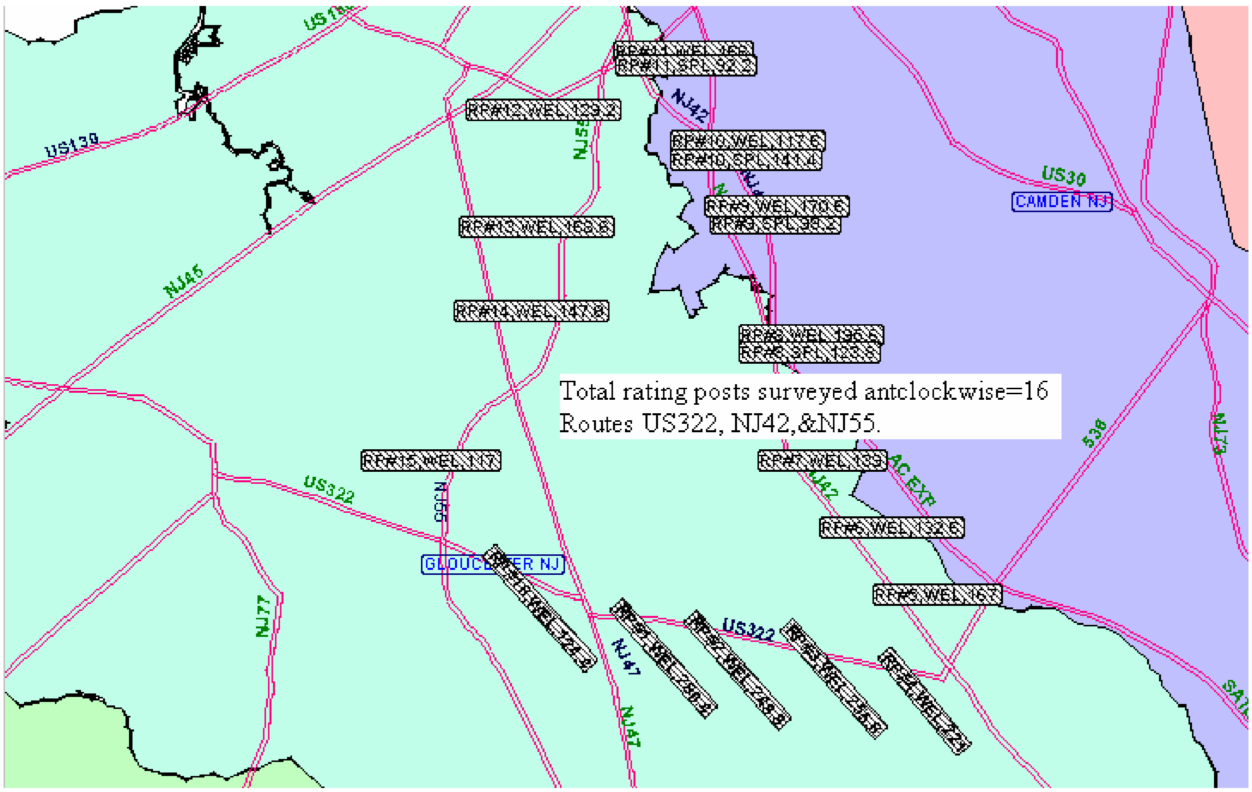


APPENDIX 2: EQUIPMENT CALIBRATION CIRCUIT

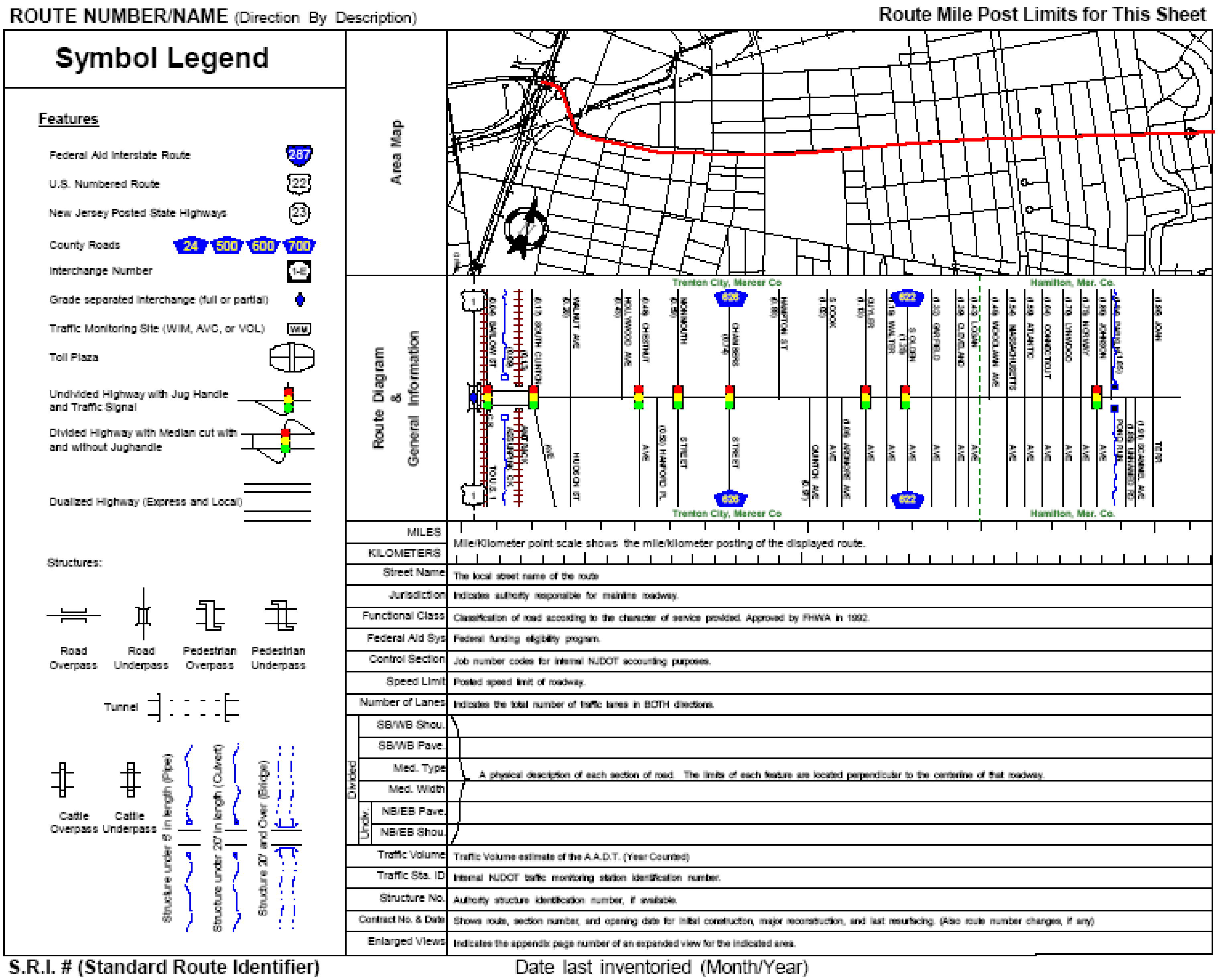

32 miles calibration circuit.
Routes US130,US322 & NJ42.
US130
US130
I295
I295
NJ45
US322

APPENDIX 3: RATING CIRCUIT (Clockwise and Anticlockwise)


Total rating posts surveyed clockwise =44
Routes US30, US322,& NJ55.
US 130
I295
NJ55
NJ42
NJ168
NJ73
US30
AC EXP
538
NJ45
US322
NJ77
NJ47
CAMDEN NJ
GLOUCESTER NJ


Total rating posts surveyed antclockwise=16
Routes US322, NJ42,&NJ55.
RP#11,SPL,92.2
RP#12,WEL,129.2
RP#10,WEL,117.6
RP#10,SPL,141.4
RP#9,WEL,170.6
RP#13,WEL,163.6
RP#14,WEL,147.8
RP#15,WEL,117
RP#7,WEL,139
RP#6,WEL,132.6
RP#5,WEL,167
US130
NJ45
NJ55
NJ42
US30
CAMDEN NJ
US322
GLOUCESTER NJ
NJ47
NJ77
AC EXP
536

APPENDIX 4: STRAIGHT LINE DIAGRAM DATA BASE (Legend)


ROUTE NUMBER/NAME (Direction By Description)
Route Mile Post Limits for This Sheet
Symbol Legend
Features
Federal Aid Interstate Route
U.S. Numbered Route
New Jersey Posted State Highways
County Roads
Interchange Number
Grade separated interchange (full or partial)
Traffic Monitoring Site (WIM, AVC, or VOL)
Toll Plaza
Undivided Highway with Jug Handle and Traffic Signal
Divided Highway with Median cut with and without Jughandle
Dualized Highway (Express and Local)
Structures:
Road Overpass
Road Underpass
Pedestrian Overpass
Pedestrian Underpass
Tunnel
Cattle Overpass
Cattle Underpass
Structure under 5' in length (Pipe)
Structure under 20' in length (Culvert)
Structure 20' and Over (Bridge)
Area Map
Route Diagram & General Information
Trenton City, Mercer Co
Hamilton, Mer. Co.
MILES
KILOMETERS
Mile/Kilometer point scale shows the mile/kilometer posting of the displayed route.
Street Name
The local street name of the route
Jurisdiction
Indicates authority responsible for mainline roadway.
Functional Class
Classification of road according to the character of service provided. Approved by FHWA in 1992.
Federal Aid Sys
Federal funding eligibility program.
Control Section
Job number codes for internal NJDOT accounting purposes.
Speed Limit
Posted speed limit of roadway.
Number of Lanes
Indicates the total number of traffic lanes in BOTH directions.
Divided
SB/WB Shou.
SB/WB Pave.
Med. Type
Med. Width
Undiv.
NB/EB Pave.
NB/EB Shou.
A physical description of each section of road. The limits of each feature are located perpendicular to the centerline of that roadway.
Traffic Volume
Traffic Volume estimate of the A.A.D.T. (Year Counted)
Traffic Sta. ID
Internal NJDOT traffic monitoring station identification number.
Structure No.
Authority structure identification number, if available.
Contract No. & Date
Shows route, section number, and opening date for initial construction, major reconstruction, and last resurfacing. (Also route number changes, if any)
Enlarged Views
Indicates the appendix page number of an expanded view for the indicated area.
S.R.I. # (Standard Route Identifier)
Date last inventoried (Month/Year)

APPENDIX 5: TOTAL MILEAGE LASERLUX REPORT (Summary)

TOTAL MILEAGE REPORT

Route	Direction	Line	From	To	Mileage	File	Date	Avg. RL
I-130	South	White Edge	MP 58.24	MP 45.68	12.6	1AM01B00	10/22/2001	363
I-295	North	White Edge	Jct NJ 168	Jct NJ 73	8.1	1AS05A00	10/28/2001	299
NJ 168	South	White Skip	Nicholson Avenue	NJ 42	9	1AO03A00	10/24/2001	340
NJ 42	North	White Skip	NJ 168	NJ 41	5.7	1AO03C00	10/24/2001	121
NJ 42	North	White Edge	Jct 322	US 30	18.7	1AO03700	10/24/2001	161
NJ 45	South	Yellow Edge	Jct 130	Jct 322	10.5	1AR01F00	10/27/2001	244
NJ 45	North	Yellow Edge	Main Street	Jct 130/45	5.8	1AN02J00	10/23/2001	275
NJ 45	North	White Edge	MP 22	MP 20	2.1	1AN01K00	10/23/2001	281
NJ 45	South	White Edge	MP 20	MP 22	1.7	1AN01J00	10/23/2001	335
NJ 45	South	White Skip	MP 22.69	MP 28.5	6.1	1AN01H00	10/23/2001	365
NJ 45	North	White Skip	MP 3	MP 10.8	5.9	1AN01G00	10/23/2001	396
NJ 47	South	White Edge	NJ 45/47	NJ 49	35.5	1AP01P00	10/25/2001	359
NJ 49	West	White Edge	Bradriff Road	NJ 77	10.6	1AP01Q00	10/25/2001	294
NJ 55	North	White Skip	Begin 4-Lane / NJ 50	NJ 42	39	1AO03E00	10/24/2001	146
NJ 55	South	White Edge	NJ 42	End 4-Lane / NJ 50	39.5	1AO03D00	10/24/2001	208
NJ 77	North	White Edge	Jct NJ 49	Jct 45	22.7	1AP01R00	10/25/2001	365
NJ 83	East	White Edge	Jct NJ 47	Jct US 9	3.4	1AS05300	10/28/2001	375
NJ 83	West	White Edge	Jct US 9	Jct NJ 47	3.7	1AS05200	10/28/2001	423
NJ Turnpike	North	White Edge	MP 15.8	MP 24.8	9	1AP01T00	10/25/2001	187
US 130	South	Yellow Edge	MP 25	MP 12.21	12.7	1AN02H00	10/23/2001	278
US 130	South	White Skip	MP 25	MP 12.21	12.8	1AN01E00	10/23/2001	423
US 130	North	White Edge	MP 0.00	MP 34.18	33.5	1AM02300	10/22/2001	300
US 30	East	Yellow Edge	MP 4.15	Jct 536/MP 18	13.9	1AN02K00	10/23/2001	123
US 322	West	White Edge 2	Jct NJ 42	US 130	20.5	1AS05800	10/28/2001	215
US 322	West	White Edge	MP 49	Jct NJ 42	27.7	1AS05600	10/28/2001	212
US 322	West	Yellow Edge	Jct 45	Jct 130	8.6	1AR01G00	10/27/2001	221
US 322	West	White Skip	Delancy Avenue / Pleasantville	NJ 42	32.5	1AO03600	10/24/2001	276
US 322	East	Yellow Center	MP 3	MP 11.8	8.2	1AN02I00	10/23/2001	220
US 322	East	White Skip	MP 3	MP 10.8	7.6	1AN01F00	10/23/2001	272
US 322	East	White Edge 2	MP 23.02	MP 46.06	22.8	1AM02100	10/22/2001	265
US 322	East	White Edge	MP 3	MP 23.02	19.2	1AM01C00	10/22/2001	363
US 40	West	White Edge	MP 46.98	MP 0.00	45.2	1AM02200	10/22/2001	255
US 9	North	White Edge	Jct NJ 83	US 322	21.3	1AS05400	10/28/2001	171
US 9	South	White Edge 3	Jct NJ 52	MP 16.5	16.6	1AS05100	10/28/2001	189
US 9	South	White Edge 2	Jct NJ 30	Jct NJ 52	9.3	1AS04400	10/28/2001	151
US 9	South	White Edge	Green Drive / Tuckerton	Jct NJ 157	22.6	1AS04300	10/28/2001	217
				Total Mileage	**597.7**			

APPENDIX 6: RATER REGISTRATION FORMS

RATER REGISTRATION FORM

RATER NUMBER:………………….

NAME:	**Address:**
	Tel No:

AGE GROUP*(circle one):* 1)<33years 2)33-55 years 3)> 55years

GENDER*(circle one):* 1)Male 2)Female

HIGHEST EDUCATION ATTAINED*(Circle one*):
1)High school diploma 2)College diploma 3)Baccalaureate degree 4)Post baccalaureate degree

DRIVING EXPERIENCE (yrs)*:* *(circle one)* 1)less than 1yr. 2)Btwn 1-5yrs 3)More than 5Yrs

LICENSE CHARACTERISTICS:

Operator license No…………………………….. Expiration date……………………..

Class code *(circle one)* 1) D.Auto 2)E.Motor cycle 3)Moped 4)Other

Restrictions (*circle one*) 1)Corrective lenses 2)Prosthetic device 3)Mechanical device 4)Hearing Impairment 5)Attached restrictions.

VEHICLE REGISTRATION:

Vehicle Plate Number……………………………………..

Vehicle Identification number……………………………..

Year manufactured…………………………………………

Are the head lights alignment inspected(*circle one* 1)Yes 2)No

Date of the last Inspection……………………………………..

AGREEMENT:
Duration of the exercise:……………………………………….
Payments………………………………………………………..
Willing to participate(*circle one*) 1)yes 2)No
Signature…………………………………………………………

OTHERS

APPENDIX 7: RATING FORM

NJDOT PAVEMENT MARKINGS & SRPM's
RETROREFLECTIVITY RATING CARD

ROUTE No...US 322...

RATER No.................. ***MILE POST 18.00 to 24.50...***

RATING POST No ......1......... ***DIRECTION Anticlockwise (W-E)***

From MP18.80 (To MP 19.30(	**COUNTY** GLOUCESTER	**DATE** **Start time.........Finish time........**

HIGHWAY TYPE(*Circle one*)	**UNDIVIDED**	**1)2L, 2)3L, 3)4L, 4)5L, 5)6L,**
	DIVIDED	**1) 2L, 2)3L, 3) 4L, 4)5L, 5)6L.**

WEATHER(*Circle one*) 1)Clear; 2)Rainy 3)Cloudy;	**NIGHT CONDITION**(*circle one*): **Moon:** *Yes No* **Str. Lights:** *Yes No*

TYPE OF MARKINGS(*circle one*) **1)** REL-WHITE 2) SKIP-WHITE **3)**SKIP-YELLOW **3** LEL-YELLOW

PAV.TYPE(*circle one*) AC 2)PCC

TYPE OF SRPM's (*circle one*) 1) BI-DIR.-YELLOW 2)MONO DIR.-YELLOW 3) MONO-DIR. WHITE

Interviewer's name...........	***Supervisor's name & signature*** ....

Question No 1

a)Please rate the left edge line on this section of the road!
*b)Please rate the right edge line on this section of the road!
c)Please rate the skip line of this section of the road!
d)Please rate the Raised Pavement Markers YELLOW
*e)Please rate the Raised Pavement Markers WHITE

	EDGE LINES		SKIP LINES	SRPM			
	*White (REL)	Yellow (LEL)		BI.DIR. (Yellow)	MONO. DIR (Yellow)	*MONO.DIR (White)	
A							***Very clearly visible*** (*Excellent*)
B							***Visible with no difficulties***
C							***Visible with some difficulties***
D							***Visible with great difficulties***
E							***Invisible***

Question No 2

Do you know the meaning of different colours for centerline and edge lines?

YES	NO	I AM NOT SURE

Question No 3

Which line do you think is brighter

RIGHT EDGE LINE	LEFT EDGE LINE	BOTH	I DONT KNOW

Question No 4

Which line is more helpful when driving at night?

RIGHT EDGE LINE	LEFT EDGE LINE	BOTH	I DONT KNOW

Question No 5

Which colour would you prefer as a highway left edge line.

WHITE	YELLOW	ANY	I DONT KNOW

Question No 6

Do you know the differences between yellow and white lines?

YES	NO	I AM NOT SURE

Comments if any ……………………………..

APPENDIX 8: LTL 2000 CALIBRATION DATA

ROUTE	TYPE OF MARKING	ID #	REF.	READINGS												
				1	2	3	4	5	6	7	8	9	10	11	12	13
NJ45																
(S-N)																
	WEL	1	JCT322	31	168	214	248	279	246	286	301	308	353	325	333	343
		2	MAINST	256	243	382	272	213	223	219	317	261	273	322	293	302
	YEL	3	FRANK	224	249	194	209	250	225	208	197	223	224	231	230	256
		4	YDIVHWY	127	142	140	134	132	113	150	157	162	166	168	178	274
US130	**YEL**	5	MP25	128	22	47	70	49	180	230	188	230	208	138	140	184
(N-S)		6	MP23.5	242	320	348	259	322	259	290	250	266	303	324	296	302
		7	MP21.5	300	338	298	297	204	311	308	276	358	307	289	227	332
		8	MP19.4	327	339	307	290	345	296	327	337	287	320	304	311	309
		9	MP17.4	313	351	318	271	337	297	368	319	289	329	336	300	323
		10	MP14.0	216	206	201	197	208	233	198	173	240	212	204	209	201
		11	BFBR	373	45	219	43	244	149	290	38	371	19			
	WS	12	CRO9	13	83	133	46	106	186	191						
US130	**YEL**	13	JCT322	221	248	263	233	224	237	181	204	197	217	203	231	209
(S-N)		14	MP15.5	411	416	393	400	398	411	414	408	399	402	371	445	411
		15	CPD	51	134	80	126	65	83							
		16	CPD2	44	134	170	162	177	146	128	154	136	122	112	97	165
US322	**WEL**	17	JCT130	278	195	264	289	322	294	293	351	213	278	296	246	288
W-E		18	JNJ45	282	289	245	269	282	268	239	262	273	257	256	118	149
		19	TRUSIG	202	286	221	290	174	199	93	141	209	184	101	168	239
		20	EINTSIG	286	297	312	277	287	269	282	269	302	279			
		21	TLSIG	342	304	295	305	332	271	313	380	390	151			
	YEL	22	WLTSIG	229	242	246	266	252	221	253	241	238	207	266	253	243
US130	**WEL**	23	MP25	275	225	231	142	168	105	193	206	267	214	178	173	145
N-S		24	PAST25	167	141	26	117	161	185	164	144	129	206	156	181	217
		25	MP23.8	487	550	548	532	464	507	507	526	528	524	468	452	452
		26	MP23.4	387	404	383	435	446	417	470	478	339	421	437	492	472
		27	MP21.1	361	392	437	430	412	272	272	364	425	447	413	464	417
		28	MP19.4	469	376	412	431	347	417	420	352	383	340	362	375	386
		29	MP17.9	424	514	474	478	486	493	513	503	459	446	409	419	421
		30	MP17.1	447	462	436	407	403	405	377	399	378	446	454	379	395
		31	MP14.7	377	468	479	499	468	393	320						
		32	MP14.2	110	104	139	156	183	152	158	168	212	222	195	220	236

ROUTE	TYPE OF	ID #	REF.	14	15	16	17	18	19	20	21	22			
	MARKING														
(S-N)															0
	WEL	1	JCT322	313	338	318	353	293	346	332	350	375	6453	22	**293.3**
		2	MAINST	404	510	464							4954	16	**309.6**
	YEL	3	FRANK	273	218	235	228	248	251	220	254	226	5073	22	**230.6**
		4	YDIVHWY										2043	13	**157.2**
US130	**YEL**	5	MP25	121	170	144	113	19	131	150	68	42	2772	22	**126.0**
(N-S)		6	MP23.5	276	341	270	326	280	281	288	316	243	6402	22	**291.0**
		7	MP21.5	335	212	282	333						5007	17	**294.5**
		8	MP19.4	287	255	280	295	266	243	287	289		6301	21	**300.0**
		9	MP17.4	293	332	330	280	342	321	328	325	317	7019	22	**319.0**
		10	MP14.0	228	237	231	226	212	215	210	195	162	4614	22	**209.7**
		11	BFBR										1791	10	**179.1**
	WS	12	CRO9										758	7	**108.3**
US130	**YEL**	13	JCT322	208	225	221	224	203	235	231	221	205	4841	22	**220.0**
(S-N)		14	MP15.5	442	397	378	420	441	389	378	390	397	8911	22	**405.0**
		15	CPD										539	6	**89.8**
		16	CPD2	37	40	75	89	58	57	57			2160	20	**108.0**
US322	**WEL**	17	JCT130	308	301	284	273	213	235	159	199	228	5807	22	**264.0**
W-E		18	JNJ45	219	173	164	211	212	140	281	356	261	5206	22	**236.6**
		19	TRUSIG	292	332	248	278	162	282	181	247	280	4809	22	**218.6**
		20	EINTSIG										2860	10	**286.0**
		21	TLSIG										3083	10	**308.3**
	YEL	22	WLTSIG	257	255	262	241	233	238	260	270	268	5441	22	**247.3**
US130	**WEL**	23	MP25	253	44	187	161	127	179	158	134	123	3888	22	**176.7**
N-S		24	PAST25	111	131	130	144	64	80	122	114	181	3071	22	**139.6**
		25	MP23.8	499	509	472	452	453	426	472	488	479	10795	22	**490.7**
		26	MP23.4	491	476	437	467	473	461	457	355	398	9596	22	**436.2**
		27	MP21.1	360	381	373	401	394	328	359	330	333	8365	22	**380.2**
		28	MP19.4	344	319	347	320	395	432	395	372	320	8314	22	**377.9**
		29	MP17.9	429	437	379	438	406	439	392	287	424	9670	22	**439.5**
		30	MP17.1	418	412	384	353	369	424	357	419	451	8975	22	**408.0**
		31	MP14.7										3004	7	**429.1**
		32	MP14.2	204	177	182	193	185	168	81	300	255	4000	22	**181.8**

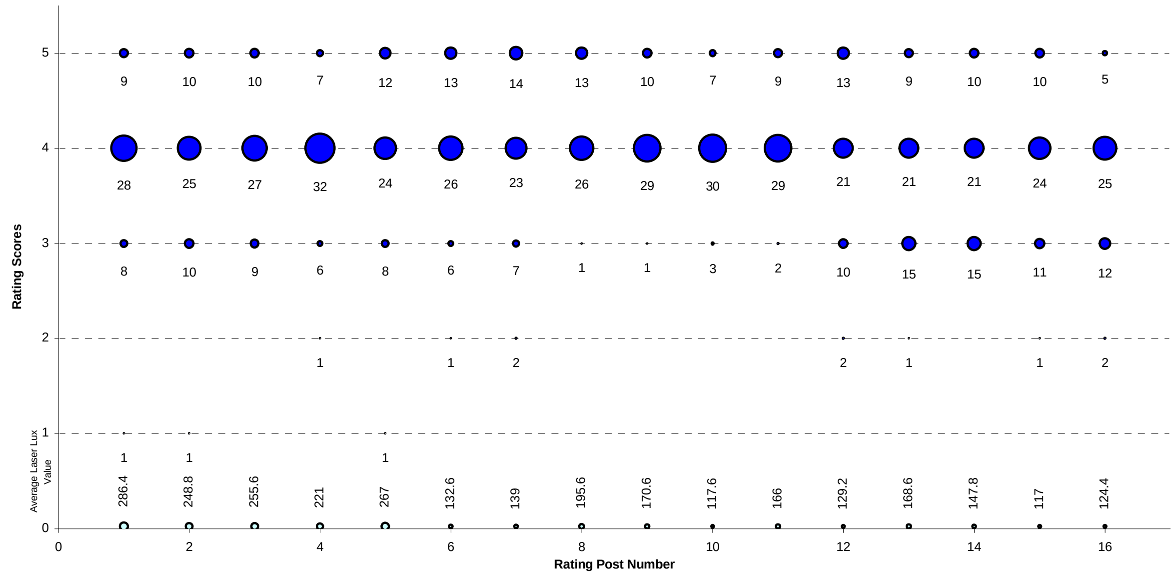
APPENDIX 9: LASER LUX CALIBRATION DATA

Table 9.1. Corresponding Laser Lux Average Readings

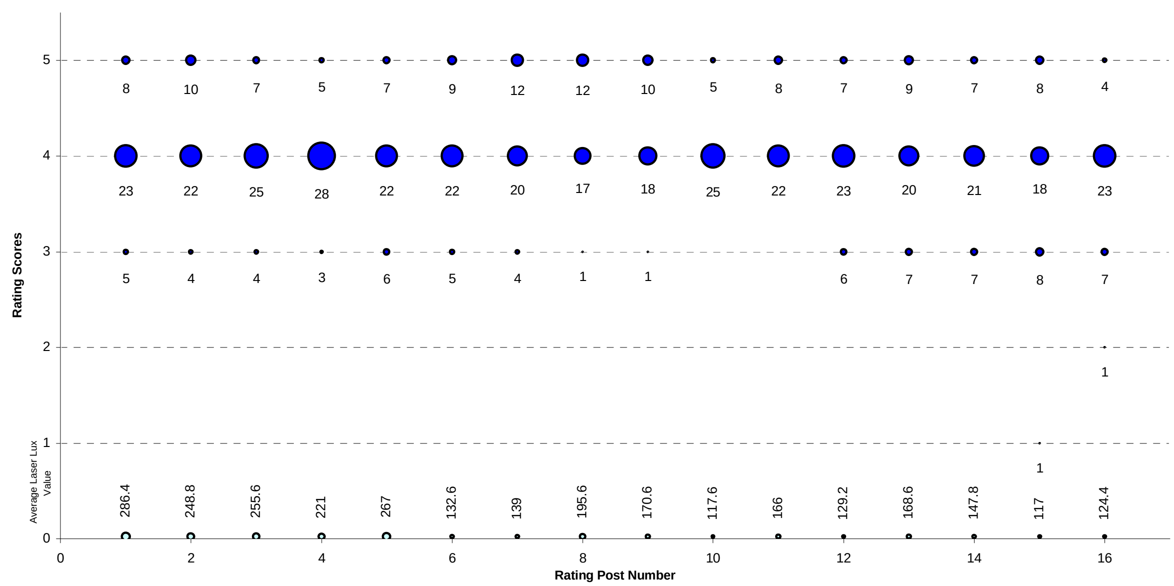
ROUTE	TYPE OF MARKING	ID #	REF.	0.5 MILE FROM MP	CORRESPONDING VIDEO CHANGE	0.1M AVERAGE L.LUX READINGS (mcd/m2/Lux) 1	2	3	4	5	TOTAL	N	AVERAGE
NJ45	WEL	1	JCT322	18.2	0.1	340	291	379	357	351	1718	5	**343.6**
(S-N)		2	MAINST	18.9	0.7	336	357	336	320	427	1776	5	**355.2**
	YEL	3	FRANK	23.59	1	229	229	212	266	299	1235	5	**247.0**
		4	YDIVHWY	27.45	4.8	179	147	123			449	3	**149.7**
US130	YEL	5	MP25	25	0.1	117	165	142	125	102	651	5	**130.2**
(N-S)		6	MP23.5	23.9	2.5	356	360	376			1092	3	**364.0**
		7	MP21.5	21.5	3.4	298	319	317	302	300	1536	5	**307.2**
		8	MP19.4	19.4	5.1	327	330	336	314	308	1615	5	**323.0**
		9	MP17.4	17.4	7.1	308	323	324	333	339	1627	5	**325.4**
		10	MP14.0	14	11.4	206	201	217	259	207	1090	5	**218.0**
		11	BFBR	12.4	12.4	218	201	210	216		627	4	**156.8**
	WS	12	CRO9	24.5	0.5	197	179				376	2	**188.0**
US130	YEL	13	JCT322	12.2	0.2	206	228	211	217	206	1068	5	**213.6**
(S-N)		14	MP15.5	15.5	3	405	397	409	415	393	2019	5	**403.8**
		15	CPD	21.2	12.8	164	130				294	2	**147.0**
		16	CPD2	24.8	12.6	98	0	134	179		411	4	**102.8**
US322	WEL	17	JCT130	3	0.1	203	263	286	340	350	1442	5	**288.4**
W-E		18	JNJ45	10.8	7.5	337	384	435	379	334	1869	5	**373.8**
		19	TRUSIG	5.1	2.1	195	309	285	238	268	1295	5	**259.0**
		20	EINTSIG	5.7	2.7	191	328	329	301	381	1530	5	**306.0**
		21	TLSIG	6.6	3.6	328	329	301	381	412	1751	5	**350.2**
	YEL	22	WLTSIG	3.7	0.7	232	245	247	362	332	1418	5	**283.6**
US130	WEL	23	MP25	25	0	229	156	146	160	141	832	5	**166.4**
N-S		24	PAST25	24.5	0.6	171	197	202	150	107	827	5	**165.4**
		25	MP23.8	23.8	1.2	508	545	504	511		2068	4	**517.0**
		26	MP23.4	23.4	1.6	402	384	434	420		1640	4	**410.0**
		27	MP21.1	22.1	2.9	386	418	404	380	0	1588	5	**317.6**
		28	MP19.4	19.4	5.6	407	402	380	357	310	1856	5	**371.2**
		29	MP17.9	17.9	7.1	478	490	445	469	417	2299	5	**459.8**
		30	MP17.1	17.1	7.9	377	408	457	393	395	2030	5	**406.0**
		31	MP14.7	14.7	10.3	410	330	361	470	513	2084	5	**416.8**
		32	MP14.2	14.2	10.8	275	154	139	195	198	961	5	**192.2**

APPENDIX 10: BUBBLE CHARTS BY GENDER

White Right Edge Lines
Male Raters
Anticlockwise

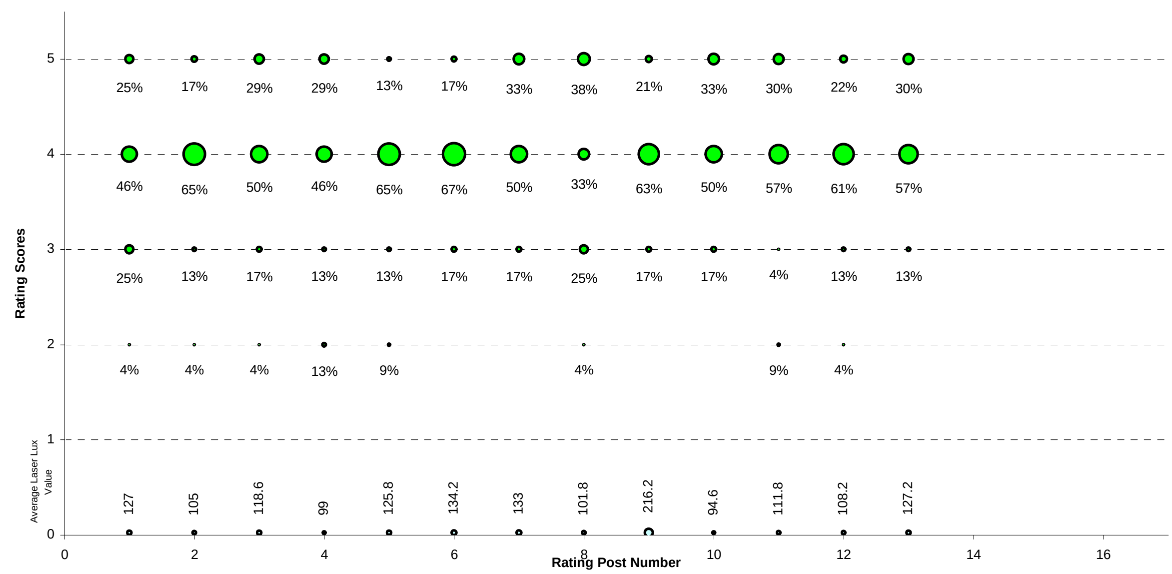


White Right Edge Lines
Female Raters
Anticlockwise

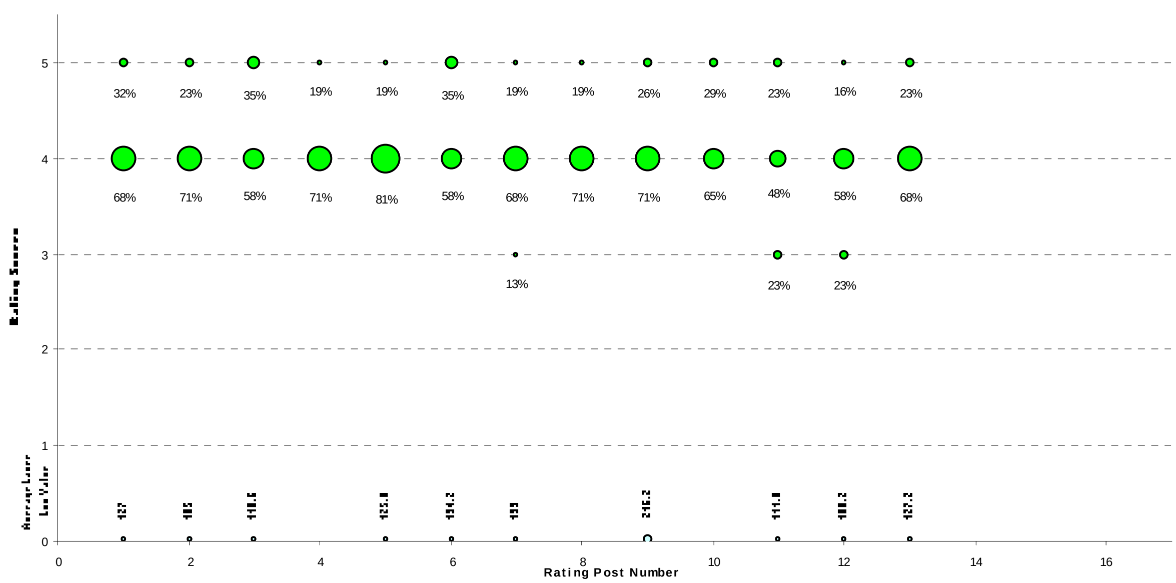


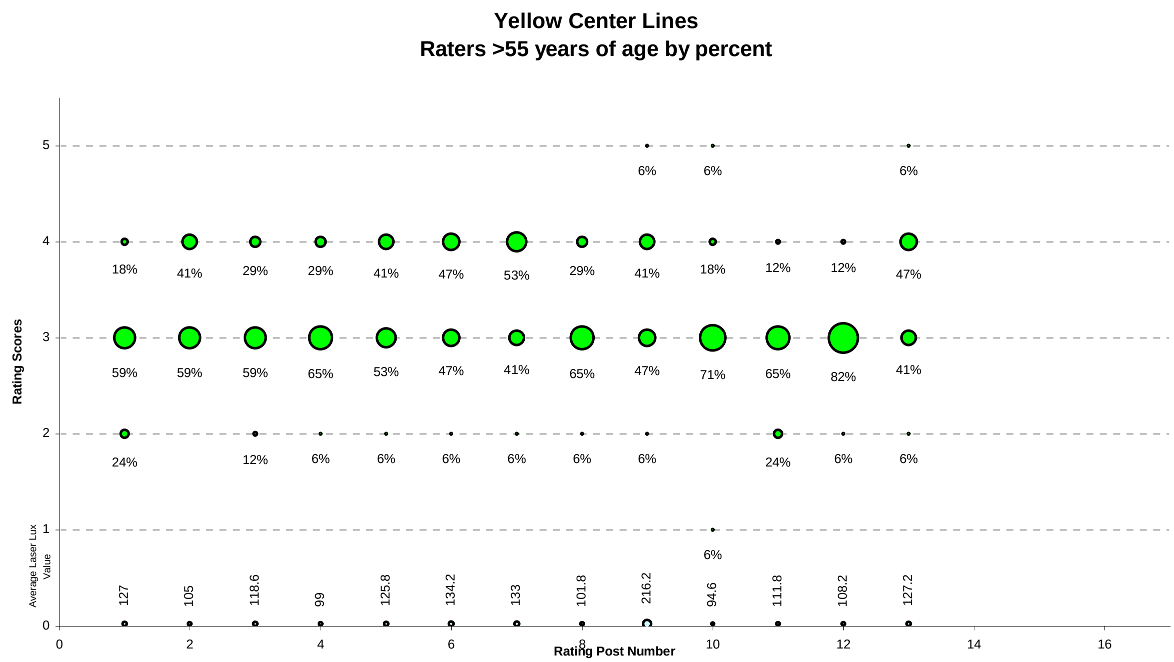
APPENDIX 11: BUBBLE CHART BY AGE

Yellow Center Lines
Raters <33 years of age by percent



Yellow Center Lines
Raters 33-55 years of age by percent





Yellow Center Lines
Raters >55 years of age by percent
Rating Scores
Average Laser Lux Value
Rating Post Number
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16
6%
6%
6%
18%
41%
29%
29%
41%
47%
53%
29%
41%
18%
12%
12%
47%
59%
59%
59%
65%
53%
47%
41%
65%
47%
71%
65%
82%
41%
24%
12%
6%
6%
6%
6%
6%
6%
24%
6%
6%
6%
127
105
118.6
99
125.8
134.2
133
101.8
216.2
94.6
111.8
108.2
127.2

APPENDIX 12: REGRESSION ANALYSIS METHODOLOGY COMPUTER PRINTOUTS (SUMMARY)

VALIDATION METHODOLOGY

Conceptual validity of the model.
Regression parameters were checked for **correct signs** and **reasonable magnitude**

> **i)** A “**plus”** sign means the visibility variable moves in the **same direction** as the independent variable (*rating score*).
>
> **ii)** A “**minus”** sign means the visibility variable moves in **opposite direction** as the independent variable (*rating score*).

Statistical tests and evaluation from regression computer print out

Over all test
i)*The multiple coeff. of determination* R^2**:** (Range **from 0~1**) This is a measure of how well the plane represented by the regression equation fits the observed data points. **0** ⇒ **no** relationship between dependent variable (Rating scores) and independent variables(L.Lux measurements, etc). Closer to **1.0** the better the relationship.

ii)*Adjusted* R^2 : Defined as $\mathbf{R^2=[R^2-k/(n-1)][(n-1)/(n-k-1)]}$
Where **n**=number of observations, and **K**=number of independent variables, were used to ascertain that the increases in R^2 is not from the influence of additional dependent variables.

iii)*The F-Test for overall significance*: $\mathbf{F=(R^2/k)/[(1-R^2)/(n-k-1)]}$.This was used to test the **null** hypothesis that all of the true regression parameters are zero.

IV)*Standard error of the estimate (SEE):* The smaller the standard error the closer the relationship between the dependent and independent variables.

Testing individual parameters
i) *Standard error of the regression coefficient (SERC).* This was used to check the reliability of that particular parameter. The smaller the SERC relative to the estimated parameter, the closer the parameter is to the true value.

ii) *The t-test*

The t-test statistics: =(Regression coefficient)/[SERC]

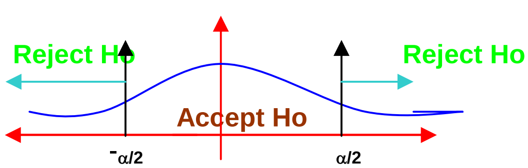


Figure 14: T-test Statistics

-Null Hypothesis Ho: $\beta_K == \mathbf{0}$
-Alt. Hypothesis Hi…$\beta_K \neq 0$
-Significance level = α%
-From t-distribution tables
control statistics = $(t_{\alpha/2}\ ,\ _{n-k})$

Each individual calculated coefficient from computer print out was checked against a null hypothesis $H_{O.}$ The null hypothesis "H_O" was accepted for the parameters falling within the range,($-_{\alpha/2}$ to $+_{\alpha/2}$), meaning that the coefficients are statistically not significant. The null hypothesis "H_O" was rejected for the parameters falling outside the range,

(**$-_{\alpha/2}$ to $+_{\alpha/2}$**), meaning that the coefficients are **statistically significant.**

Modeling

Both **linear and non-linear** considerations were tried. Dummy variables were used to treat streetlights and type of highway.

Definition of terms

Y=Rating scores

X1=Highway type

X2=Street Lights

X3=pavement marking age

X4 = Av L. Lux (mcd/m2/lux)

Dummy variables:

Z1= { 1 if undivided highway
{ 0 otherwise

Z2 ={ 1 streetlights "ON"
{ 0 otherwise

Estimating equation

Linear considerations (Appendix 14)

$$Y = \beta_0 + \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 X_3 + \beta_4 X_4$$

<u>*MODEL 1*</u> **:** Two variables and two dummy variables

After 1st and 2nd iterations variables Z_2 nad Z_3 turned out to be statistically insignificant and therefore they were left behind.

Resulting linear model considered

$$Y = 2.71 + 0.00748 X_4$$
(6.09) (3.17)

t-critical =($t_{\alpha/2}$, $_{n-k}$) n=24, k=1 thus n-k=23; t=2.069

Analysis
- Conceptually valid (both signs correct)
- Adjusted R^2 =0.28 < 0.75(recommended) : **Not acceptable**
-**The t -test**: At 5% significance level t-critical=2.069 ,both coefficients falls outside Ho acceptance region meaning they are statistically significant.

Decision
Due to a very low R^2 =0.28 the liner relationship between these variables does not exist and therefore this model was rejected.

Non-linear consideration
(Appendix 14)

$$Y = \beta_0 Z_1^{\beta 1} Z_2^{\beta 2} X_3^{\beta 3} X_4^{\beta 4}$$

The above equation was linearized for linear regression analysis by the use of natural logarithms.

$$LnY = Ln\beta 0 + \beta 1 LnZ_1 + \beta 2 LnZ_2 + \beta 3 LnX_3 + \beta 4 LnX_4$$

After 1st ,2nd and 3rd attempt the dummy variables Z_1 ,Z_2 and X_3 for all pavement marking types for each age group cases ended up being statistically insignificant and therefore they were left behind. The end equations were reconverted back to their original forms by applying an exponential function to both sides of the equations. Below is the summary of the computer print outs.

NON LINEAR RELATIONSHIP,SPL:AGE <33 YEARS

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.991127857
R Square	0.98233443
Adjusted R Square	0.980728469
Standard Error	0.055448758
Observations	13

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.880650209	1.88065	611.6802	5.41827E-11
Residual	11	0.033820212	0.003075		
Total	12	1.91447042			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.010622005	0.055237928	0.192296	0.851015	- 0.110955915	0.13219993	- 0.11095592	0.132199925
X Variable 1	0.295556223	0.011950275	24.73217	5.42E-11	0.269253831	0.32185861	0.26925383	0.321858615

NON LINEAR RELATIONSHIP, SPL:AGE 33 - 55 YEARS

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.988484828
R Square	0.977102255
Adjusted R Square	0.975020642
Standard Error	0.062507763
Observations	13

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.834036193	1.834036	469.3967	2.26202E-10
Residual	11	0.042979424	0.003907		
Total	12	1.877015617			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.006596681	0.062269737	0.105937	0.917539	- 0.130458155	0.143652	-0.1304582	0.143651517
X Variable 1	0.291861899	0.013471235	21.66556	2.26E-10	0.262211896	0.321512	0.2622119	0.321511902

NON LINER RELATIONSHIP,WEL:AGE >55 YEARS

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.96580346
R Square	0.93277632
Adjusted R Square	0.92666508
Standard Error	0.09852107
Observations	13

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.481515441	1.481515	152.632815	8.6197E-08
Residual	11	0.106770421	0.009706		
Total	12	1.588285862			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0141655	0.098145911	0.144331	0.88784943	-0.2018523	0.230183	-0.20185	0.230183
X Variable 1	0.26231707	0.021232571	12.35447	8.6197E-08	0.21558447	0.30905	0.215584	0.30905

NON LINEAR RELATIONSHIP,YCL: AGE <33 YEARS

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.95668132
R Square	0.91523915
Adjusted R Square	0.91138638
Standard Error	0.08770336
Observations	24

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.827234953	1.82723	237.554	2.84129E-13
Residual	22	0.169221331	0.00769		
Total	23	1.996456284			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.10268401	0.084633966	1.21327	0.23789	-0.072836283	0.278204	-0.072836	0.278204
X Variable 1	0.25692589	0.016669665	15.4128	2.8E-13	0.222355082	0.291497	0.2223551	0.291497

NON LINEAR RELATIONSHP,YCL:AGE 33 - 55 YEARS

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.965297918
R Square	0.93180007
Adjusted R Square	0.928700074
Standard Error	0.077951298
Observations	24

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.826451732	1.82645173	300.58098	2.5789E-14
Residual	22	0.133680908	0.0060764		
Total	23	1.96013264			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.084093558	0.075223205	1.11792043	0.2756605	-0.07190999	0.240097	-0.07191	0.24009711
X Variable 1	0.256870819	0.014816104	17.3372714	2.579E-14	0.22614407	0.287598	0.22614407	0.28759757

NON LINEAR RELATIONSHIP, SPL:AGE > 55 YEARS

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.94148904
R Square	0.88640161
Adjusted R Square	0.88123805
Standard Error	0.09890359
Observations	24

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.679210452	1.6792105	171.66471	7.22408E-12
Residual	22	0.215202233	0.0097819		
Total	23	1.894412685			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.08344114	0.095442219	0.8742582	0.3914218	-0.114494122	0.281376	-0.1144941	0.2813764
X Variable 1	0.24629933	0.018798479	13.102088	7.224E-12	0.207313631	0.285285	0.20731363	0.28528503

NON LINEAR RELATIONSHIP,WEL: AGE <33 YEARS

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.97853167
R Square	0.95752424
Adjusted R Square	0.95398459
Standard Error	0.08020706
Observations	14

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.740263593	1.740264	270.5140658	1.34964E-09
Residual	12	0.077198068	0.006433		
Total	13	1.817461661			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.02275846	0.07929414	0.287013	0.778997992	-0.15000863	0.195526	-0.15001	0.195526
X Variable 1	0.28221176	0.017158534	16.44731	1.34964E-09	0.244826529	0.319597	0.244827	0.319597

NON LINEAR RELATIONSHIP, WEL: AGE 33-55 YEARS

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.988403964
R Square	0.976942396
Adjusted R Square	0.975020929
Standard Error	0.060120026
Observations	14

ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	1.837698913	1.837699	508.4357	3.42399E-11	
Residual	12	0.043373011	0.003614			
Total	13	1.881071924				

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.026065187	0.059435739	0.438544	0.668783	- 0.103434161	0.155565	-0.1034342	0.1555645
X Variable 1	0.290004524	0.012861356	22.54852	3.42E-11	0.261982037	0.318027	0.26198204	0.318027

NON LINEAR RELATIONSHIP,YCL:AGE >55 YEARS

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.98150874
R Square	0.96335941
Adjusted R Square	0.96030603
Standard Error	0.06398314
Observations	14

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.291630402	1.29163	315.505656	5.5465E-10
Residual	12	0.049126108	0.004094		
Total	13	1.34075651			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.01296591	0.063254883	0.204979	0.84102451	-0.124854643	0.150786	-0.1248546	0.15078645
X Variable 1	0.24312898	0.013687784	17.76248	5.5465E-10	0.213305858	0.272952	0.21330586	0.2729521

NON LINER RELATIONSHIP,WEL,SPL,&YCL: FOR ALL AGE GROUPS.

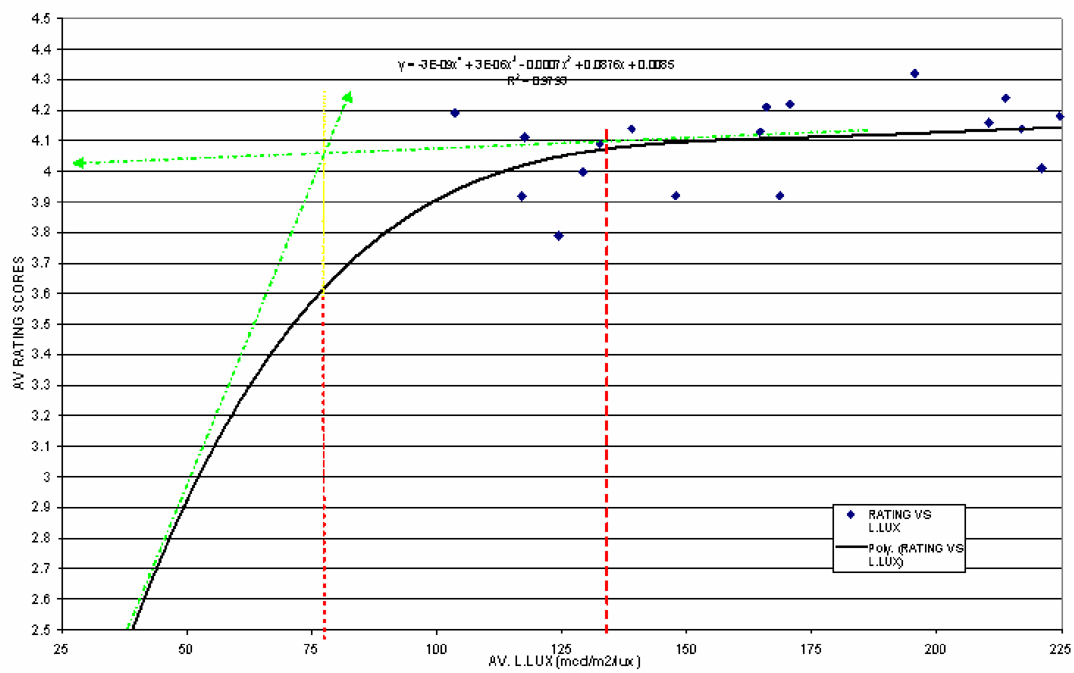
SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.932847632
R Square	0.870204704
Adjusted R Square	0.867443102
Standard Error	0.07375342
Observations	49

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.714054629	1.7141	315.10865	1.7949E-22
Residual	47	0.255659647	0.0054		
Total	48	1.969714276			

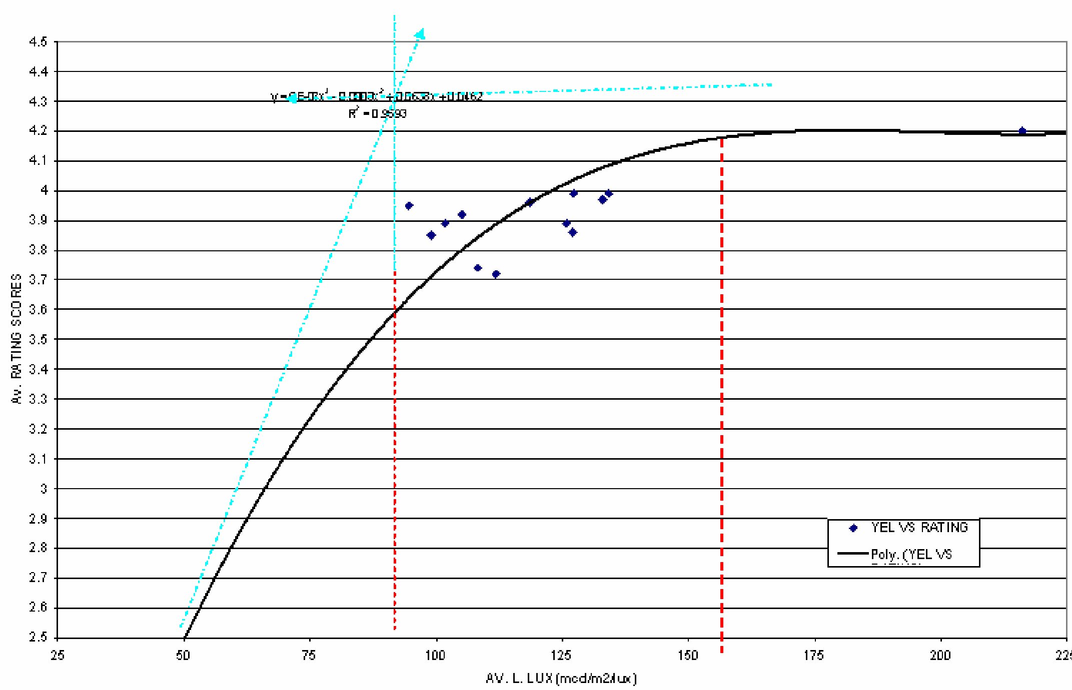
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.164423442	0.06832954	2.4063	0.0200982	0.02696227	0.3018846	0.026962	0.3018846
X Variable 1	0.244168896	0.013754987	17.751	1.795E-22	0.21649746	0.2718403	0.216497	0.2718403

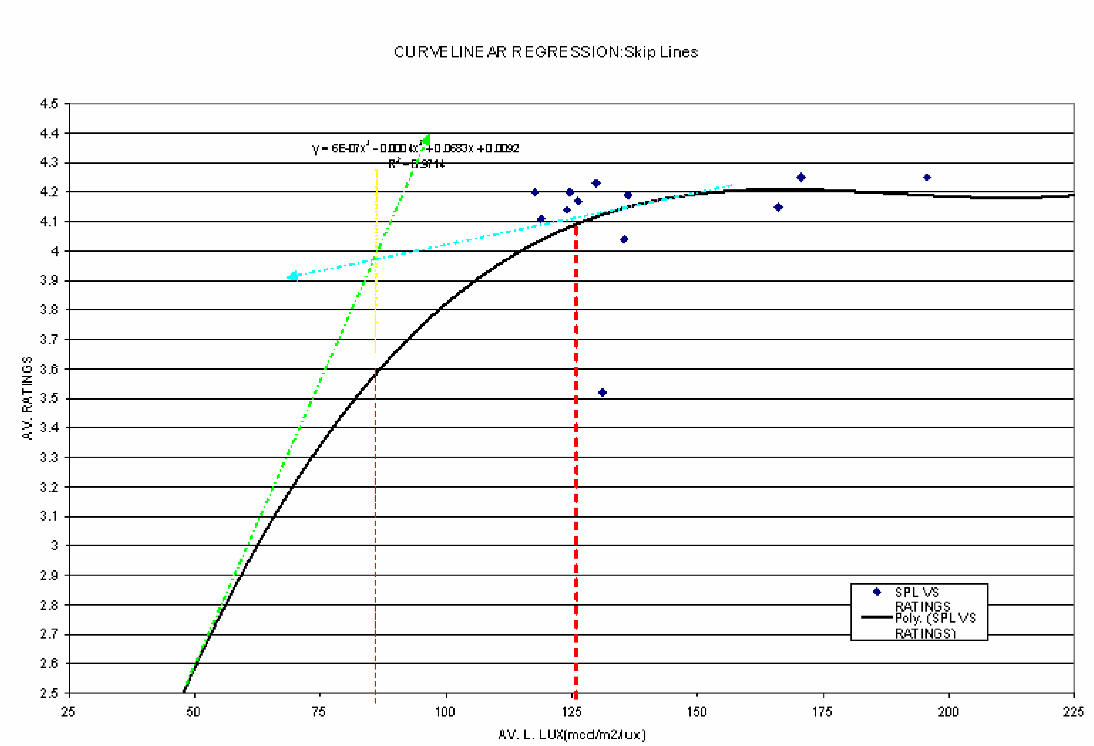
APPENDIX 13: CURVILINEAR REGRESSION CURVES

CURVELINEAR REGRESSION: White Edge Lines



CURVELINEAR REGRESSION:Yellow Center Lines




CURVELINEAR REGRESSION:Skip Lines
AV. RATINGS
AV. L. LUX(mcd/m2/lux)
SPL VS RATINGS
Poly. (SPL VS RATINGS)
4.5
4.4
4.3
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
25
50
75
100
125
150
175
200
225

APPENDIX 14: THRESHOULD VALUES FROM OTHER RESEARCHERS

EXPERIENCE FROM LITERATURE REVIEW

Paints and Thermoplastics

The maximum initial value of R_L is between **450 and 850mcd/m2/lux**
The average initial value of retroreflectivity is between **250 and 500mcd/m2/lux** .
(*SOURCE DATA BASE FORM 2100 SAMPLES*)

Researcher

BLACKWELL 1946	**85-170 mcd/m2/lux** (based on 88km/h)
GRAHAM & KING 1991	**93mcd/m2/lux sufficient for <60 yrs** **100mcd/m2/lux sufficient for >60 yrs**
SOME RESEARCHERS	**100mcd/m2/lux** (without validating)
VINCE DRAVITZKI (New Zealand**)**	**70-150 mcd/m2/lux**) (based on 30meter geometry)
MIGLETZ(*TRR, No 1657,pp71-78, Washington DC*)	**80-130mcd/m2/lux**
MINNESOTA DOT (2001)	**120mcd/m2/lux** (threshold based on L.Lux.)
NASSER BRIAN (California) TRB 2002	**150mcd/m2/lux** (based on crash statistics)

It is commonly accepted that **yellow** markings have RL values equivalent to about **70 to 80 % of white** markings

Recently there has been an increased interest in the US in the advantage of all white pavement marking system as used in Europe, Australia and Norway.

Currently proposals are being solicited by the National Cooperative Highway Research Program (NCHRP) for a visibility study of an all white marking system in the U.S (Project 4-28 fy 2000)

APPENDIX 15: NJDOT RESTRIPING RECORD

ROUTE		REGION	M.P.O.	M.P.	TO	M.P.	91	92	93	94	95	96	97	98	99	00	01	02	AS-BUILT	EPOXY (CALCULATED) L.F.	THERMO LINES L.F.	THERMO SYMBOLS S.F.	BI. DIR. (YELLOW)	MONO. DIR. (YELLOW)	MONO. DIR. (WHITE)
US	9	SOUTH	SJTPO	3.06	TO	30.72	91				95				99			02		604,270	120,854	3,021	2,230	122	81
US	9	SOUTH	SJTPO	31.84	TO	52.58	91				95				99			02		439,191	87,838	2,196	686	30	55
US	9	SOUTH	DVRPC	54.85	TO	59.89	91					96			99			02		106,446	21,289	532	400		
US	30	SOUTH	DVRPC	0.96	TO	27.95	91					96			99					640,491	128,098	3,202	3,304	1,630	8,005
US	30	SOUTH	SJTPO	27.95	TO	58.23	91					96			99					723,677	144,735	3,618	[illegible]	[illegible]	[illegible]
NJ	38	SOUTH	DVRPC	0.00	TO	19.23		92				96			99			02		464,085	92,817	2,320	125	140	787
NJ	40	SOUTH	SJTPO	1.85	TO	24.63			93				97			00				490,750	98,150	2,454	1,277	603	771
NJ	40	SOUTH	DVRPC	24.63	TO	32.62			93				97			00				170,280	34,056	851	785	170	210
NJ	40	SOUTH	SJTPO	32.62	TO	64.05			93				97			00				697,541	139,508	3,488	1,668	135	105
NJ	41	SOUTH	DVRPC	0.00	TO	4.95				94					99			02		104,544	20,909	523	160		20
NJ	41	SOUTH	DVRPC	10.74	TO	13.98				94					99			02		76,982	15,396	385			
NJ	42	SOUTH	DVRPC	0.00	TO	14.28	91				95				99			02		357,694	71,539	1,788		60	120
NJ	44	SOUTH	DVRPC	0.00	TO	9.60				94				98			01		AS-BUILT	93,171	12,579	915			
NJ	45	SOUTH	SJTPO	0.00	TO	8.79				94				98			01		AS-BUILT	148,865	14,482	951			
NJ	45	SOUTH	SJTPO	9.43	TO	12.48				94				98			01		AS-BUILT	51,654	5,025	330			
NJ	45	SOUTH	DVRPC	12.48	TO	17.77				94				98			01		AS-BUILT	89,590	8,716	572			
NJ	45	SOUTH	DVRPC	18.16	TO	28.51				94				98			01		AS-BUILT	175,285	17,053	1,119			
NJ	47	SOUTH	SJTPO	0.66	TO	51.79				94				98			01		AS-BUILT	822,723	72,903	3,261			
NJ	47	SOUTH	DVRPC	51.79	TO	52.36				94				98			01		AS-BUILT	9,172	813	36			
NJ	47	SOUTH	DVRPC	52.82	TO	62.29				94				98			01		AS-BUILT	152,380	13,503	604			
NJ	47	SOUTH	DVRPC	62.66	TO	74.98				94				98			01		AS-BUILT	198,239	17,566	786			
NJ	48	SOUTH	SJTPO	0.00	TO	4.26				94				98			01		AS-BUILT	66,070	3,136	42			
NJ	49	SOUTH	SJTPO	0.00	TO	53.78				94				98			01		AS-BUILT	806,058	53,948	3,933			
NJ	50	SOUTH	SJTPO	0.00	TO	18.56				94				98			01		AS-BUILT	304,961	9,203	443			
NJ	50	SOUTH	SJTPO	19.18	TO	26.08				94				98			01		AS-BUILT	113,374	3,421	165			
NJ	52	SOUTH	SJTPO	0.00	TO	2.74				94				98			01		AS-BUILT	13,998	8,353	265			
NJ	54	SOUTH	SJTPO	0.00	TO	11.88				94				98			01		AS-BUILT	174,799	16,452	502			
NJ	55	SOUTH	SJTPO	20.00	TO	38.50	91				95				99			02		437,475	87,495	2,187	60		
NJ	55	SOUTH	DVRPC	38.50	TO	60.53	91				95				99			02		523,433	104,687	2,617			
NJ	56	SOUTH	SJTPO	0.00	TO	9.23				94				98			01		AS-BUILT	133,143	10,971	997			
NJ	68	SOUTH	DVRPC	0.00	TO	7.97				94					99			02		180,840	36,168	904	240		12
NJ	70	SOUTH	DVRPC	0.00	TO	33.43		92				96			99			02		738,938	147,788	3,695	1,776	200	100
NJ	72	SOUTH	DVRPC	0.00	TO	11.47			93					98			01		AS-BUILT	153,608	8,070	610			
NJ	73	SOUTH	DVRPC	6.24	TO	34.10			93			96			99			02		668,844	133,769	3,344	640	3,070	5,025
INTERSTATE	76	SOUTH	DVRPC	0.00	TO	1.94	91				95				99			02		47,903	9,581	240		75	300
NJ	77	SOUTH	SJTPO	0.00	TO	17.52				94				98			01		AS-BUILT	285,993	10,170	712			
NJ	77	SOUTH	DVRPC	17.52	TO	22.55				94				98			01		AS-BUILT	82,109	2,920	205			
NJ	83	SOUTH	SJTPO	0.00	TO	3.84				94				98			01		AS-BUILT	63,623	234	0			
NJ	87	SOUTH	SJTPO	0.00	TO	1.72			93				97			00				40,867	8,173	204	0	0	0
NJ	90	SOUTH	DVRPC	2.00	TO	3.22				94					99			02		33,026	6,605	165			
NJ	109	SOUTH	SJTPO	1.34	TO	3.06				94					99			02		38,042	7,608	190	10		
US	130	SOUTH	SJTPO	0.00	TO	8.79	91				95				99			02		185,646	37,129	928	690	1,021	1,441

ROUTE		REGION	M.P.O.	M.P.	TO	M.P.	91	92	93	94	95	96	97	98	99	00	01	02	AS-BUILT	EPOXY (CALCULATED) L.F.	THERMO LINES L.F.	THERMO SYMBOLS S.F.	BI. DIR. (YELLOW)	MONO. DIR. (YELLOW)	MONO. DIR. (WHITE)
US	130	SOUTH	DVRPC	8.79	TO	14.29	91				95				99			02		131,196	26,239	656	[illegible]	[illegible]	[illegible]
US	130	SOUTH	DVRPC	23.53	TO	29.40	91				95				99			02		148,355	29,671	742			
US	130	SOUTH	DVRPC	30.34	TO	58.28	91				95				99			02		713,977	142,795	3,570		92	650
NJ	140	SOUTH	SJTPO	0.00	TO	0.96				94					99			02		20,275	4,055	101	80		20
NJ	143	SOUTH	DVRPC	0.00	TO	2.35				94				98			01		AS-BUILT	37,359	672	74			
NJ	147	SOUTH	SJTPO	0.00	TO	4.20				94				98			01		AS-BUILT	115,163	17,884	146			
NJ	152	SOUTH	SJTPO	0.00	TO	3.16				94					99			02		66,739	13,348	334	210		25
NJ	154	SOUTH	DVRPC	0.00	TO	1.70				94				98			01		AS-BUILT	34,013	10,738	1,561			
NJ	157	SOUTH	SJTPO	0.00	TO	0.91				94				98			01		AS-BUILT	16,080	556	0			
NJ	162	SOUTH	SJTPO	0.00	TO	0.73			93				97			00				16,051	3,210	80	0	0	0
NJ	167	SOUTH	SJTPO	0.00	TO	0.62				94				98			01		AS-BUILT	13,094	52	323			
NJ	167	SOUTH	DVRPC	1.67	TO	2.83				94				98			01		AS-BUILT	24,499	98	603			
NJ	168	SOUTH	DVRPC	0.00	TO	10.81				94				98			01		AS-BUILT	231,066	57,606	3,209			
NJ	187	SOUTH	SJTPO	0.00	TO	0.47				94				98			01		AS-BUILT	11,944	4,720	267			
US	206	SOUTH	SJTPO	0.00	TO	6.27			93					98			01		AS-BUILT	133,481	8,698	296			
US	206	SOUTH	DVRPC	6.27	TO	35.61			93					98			01		AS-BUILT	624,615	40,701	1,383			
US	206	SOUTH	DVRPC	36.27	TO	38.45			93				97			00				51,797	10,359	259	0	0	0
INTERSTATE	295	SOUTH	SJTPO	0.95	TO	8.93	91				95			98			01			244,637	48,928	238	0	734	1,540
INTERSTATE	295	SOUTH	DVRPC	8.93	TO	57.72	91				95			98			01			1,495,717	299,144	1,454	0	4,489	9,415
US	322	SOUTH	DVRPC	2.25	TO	32.96			93				97			00				674,019	134,804	3,370	2,121	1,110	1,140
US	322	SOUTH	SJTPO	32.96	TO	50.10			93				97			00				407,444	81,489	2,037	0	1,925	2,000
NJ	324	SOUTH	DVRPC	0.90	TO	1.51			93				97			00				31,891	6,378	159	0	0	0
INTERSTATE	676	SOUTH	DVRPC	0.00	TO	3.79	91			94					99			02		99,462	19,892	497			

APPENDIX 16: LITERATURE RELEVANCE MATRIX

TABLE7. Literature Relevancy Matrix

Nº	Literature	Pavement marking types and specifications	Retroreflectivity of Pavement Marking	Snowplowable Raised Pavement Markings	Visibility models and Retroreflectometer measurements	Service Life of Pavement Markings	Maintenance Requirements and Replacement Cycles
1	LIGHTS, UNITS, AND TERMINOLOGY; physics of light, light units and terminology, metric systems, & light measurement. **http://energy.arce.ukans.edu/book/light/units.htm**	-	-	-	**	-	-
2	Title: Evaluation of Pavement marking for improved Visibility during Wet Night condition. Virginia Transportation Research Council (www.azfms.com/Doc Reveiws/Sep96/art6.htm)	**	**	**	**	-	-
3	Title: Computer Based Modeling to determine the visibility and Minimum Retroreflectivity of Pavement Markings. *Thomas Schnell, University of Iowa* *And* *Helmut T. Zwahlen, Ohio University, Athens Ohio*	-	***	*	**	-	-
4	Title: Reflectorized Devices for Driver Information. Transportation Research Board (Http://nationalacademies.org/trb/publication/tris/out_of_print.html)	-	**	**	-	-	-
5	Title: Snowplowable Raised Pavement Markers	-	-	***	-	-	**

Scale:

- \- not relevant
- * slightly relevant
- ** fairly relevant
- *** very relevant

TABLE7. Literature Relevancy Matrix

Nº	Literature	Pavement marking types and specifications	Retroreflectivity of Pavement Marking	Snowplowable Raised Pavement Markings	Visibility models and Retroreflectometer measurements	Service Life of Pavement Markings	Maintenance Requirements and Replacement Cycles
	in New Jersey. Transportation Research Board (Http://nationalacademies.org/trb/publications/tris/out_of_print.html)						
6	Title: Field Surveys of Pavement-Marking Retroreflectivity. Transportation Research Board (http://nationalacademies.org/trb/bookstore)	*	***	-	**	-	-
7	Title: Visibility of Road Marking as a function of Age, Retroreflectivity Under Low-Beam & High-Beam Illumination at Night. Transportation Research Board (http://nationalacademies.org/trb/bookstore	-	**	-	***	-	-
8	Title: Pavement Marking Materials: Assessing Environment-Friendly Performance. Transportation Research Board Research Triangle Institute (http://nationalacademies.org/trb/bookstore)	*	-	-	-	-	-
9	Title: Driver Preview Distances at Night Based on Driver Eye Scanning Recordings as a Function of Pavement Marking Retroreflectivity. Transportation Research Board (http://nationalacademies.org/trb/bookstore)	-	-	-	**	-	-
				-	-	-	

Scale:

- \- not relevant
- * slightly relevant
- ** fairly relevant
- *** very relevant

TABLE7. Literature Relevancy Matrix

N°	Literature	Pavement marking types and specifications	Retroreflectivity of Pavement Marking	Snowplowable Raised Pavement Markings	Visibility models and Retroreflectometer measurements	Service Life of Pavement Markings	Maintenance Requirements and Replacement Cycles
10	Title: Paint-Line Retroreflectivity Over Time. Transportation Research Board (http://nationalacademies.org/trb/bookstore)	*	*				**
11	Title: Visibility of New Centerline & Edge Line Pavement Markings. Transportation Research Board (http://nationalacademies.org/trb/bookstore)	-	-	-	*	-	-
12	Title: Pavement Marking Retroreflectivity Requirements for older drivers. Transportation Research Board (http://nationalacademies.org/trb/bookstore)	-	**	-	*	-	-
13	Title: Visibility of New dashed Yellow and White Centre Stripes as a Function of Material Retroreflectivity. Transportation Research Board (http://nationalacademies.org/trb/bookstore)	-	**	-	*	-	-
14	Title: Detestability of pavement Markings under stationary and dynamic conditions as a function of Retroreflective Brightness. Transportation Research Board (http://nationalacademies.org/trb/bookstore)	-	***	-	***	-	-
15	Premark's 20/20 Flex (Supplier) (http://www.flinttrading.com/premark20_20.htm)	***	*	-	-	**	*

Scale:

- \- not relevant
- * slightly relevant
- ** fairly relevant
- *** very relevant

TABLE7. Literature Relevancy Matrix

Nº	Literature	Pavement marking types and specifications	Retroreflectivity of Pavement Marking	Snowplowable Raised Pavement Markings	Visibility models and Retroreflectometer measurements	Service Life of Pavement Markings	Maintenance Requirements and Replacement Cycles
21	Title: Technical Evaluation Report, Summary Evaluation Findings for 30-Meter Handheld and Mobile Pavement marking Retroreflectometers Highway Innovative Technology evaluation Centre (HITEC). (www.cerf.org/hitec/eval/Completed/retro.htm)	-	-	-	***	-	-
22	Title: US Department of Transportation, Federal Highway Administration. Manual on Uniform Traffic Control Devices.	***	-	***	-	-	-
23	Title: US Department of Transportation, Federal Highway Administration. Roadway Delineation Practices Hand Book .	***	***	***	-	***	***
24	Title: Public Perception of Pavement marking Brightness Transportation Research Board (http://nationalacademies.org/trb/bookstore)	-	***	-	***	***	*
25	Title: Methods and considerations for evaluating the retroreflectivity of pavement markings Transportation Research Board (http://nationalacademies.org/trb/bookstore)	*	***	-	***	*	**
26	Title: Signing and Marking Materials Transportation Research Board (http://nationalacademies.org/trb/bookstore)	-	***	-	-	-	-
27	Title: Materials and Tools for better road markings.	***	***	-	***	***	***

Scale:

- \- not relevant
- * slightly relevant
- ** fairly relevant
- *** very relevant

TABLE7. Literature Relevancy Matrix

Nº	Literature	Pavement marking types and specifications	Retroreflectivity of Pavement Marking	Snowplowable Raised Pavement Markings	Visibility models and Retroreflectometer measurements	Service Life of Pavement Markings	Maintenance Requirements and Replacement Cycles
	Transportation Research Board (http://nationalacademies.org/trb/bookstore)						
28	Title: Measurement and Evaluation of Pavement Marking Retroreflectivity: South Carolina's Experience. Transportation Research Board (http://nationalacademies.org/trb/bookstore)	-	***	-	***	-	-
29	Title: Laserlux, Automated real time pavement marking retroreflectivity measurements. Transportation Research Board (http://nationalacademies.org/trb/bookstore)	-	***	-	***	-	-
30	Title: Retroreflectivity instruments - 1999 Transportation Research Board (http://nationalacademies.org/trb/bookstore)	-	***	-	***	-	-
31	HITEC Evaluations on Pavement Marking Retroreflectometers (www.cerf.org/hitec/news/reports.htm)				**		
33	ZVR1000 visual Retroreflectometers Budget price model (http://www.onyxnet.co.uk/clients/mastrad/zvr.htm)				*		
34	ASCE Research News http://www.asce.org/transportation/researchdetails.cfm?				*		

Scale:

- \- not relevant
- * slightly relevant
- ** fairly relevant
- *** very relevant

TABLE7. Literature Relevancy Matrix

Nº	Literature	Pavement marking types and specifications	Retroreflectivity of Pavement Marking	Snowplowable Raised Pavement Markings	Visibility models and Retroreflectometer measurements	Service Life of Pavement Markings	Maintenance Requirements and Replacement Cycles
35	Precision Scan Safety by System Integration *http:// www.precisionscan.com/about_us.htm*				*		
36	RPM 1200Retroreflectometers *www.gamma-sci.com*				**		
37	Mirolux Product,Inc. *http://www.miroluxproducts.com*						
38	3M Stamark Liquid Pavement Marking Series1200 www.3M.com/tcm		***			**	*
39	3M Wet Reflective Pavement Marking Tape Series 820 www.3M.com/tcm		***			**	*
40	3M Wet Reflective Removable Tape Series750 www.3M.com/tcm		***			**	*

Scale:

- \- not relevant
- * slightly relevant
- ** fairly relevant
- *** very relevant

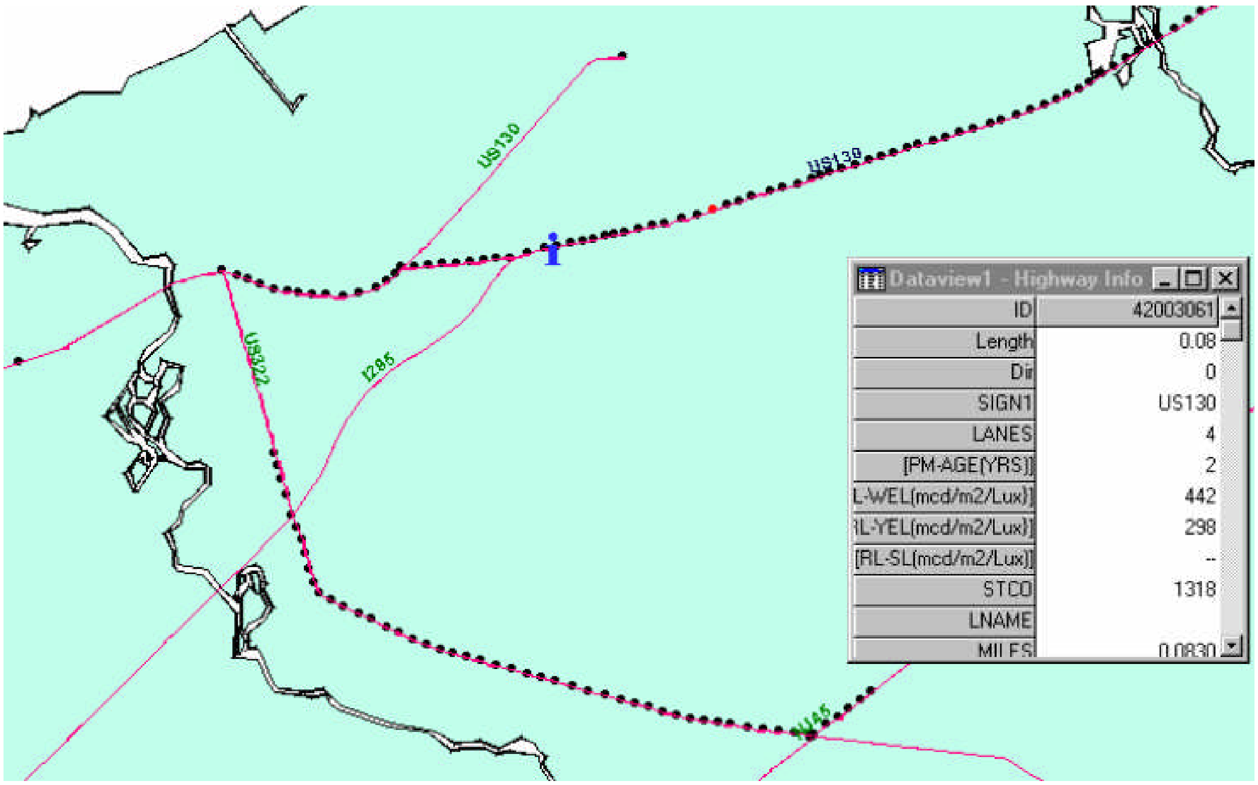
TABLE7. Literature Relevancy Matrix

Nº	Literature	Pavement marking types and specifications	Retroreflectivity of Pavement Marking	Snowplowable Raised Pavement Markings	Visibility models and Retroreflectometer measurements	Service Life of Pavement Markings	Maintenance Requirements and Replacement Cycles
41	Evaluation of Various Strategies to increase Pavement Marking Visibility for older Driver TRB Paper No 02-3365		**	*			
42	Methods of Application and a Bonding Strength of Thermoplastic Pavement Marking: Comparison between Concrete and Asphalt Roadway Surfaces	*				*	**
43	Establishing a crush-based retroreflectivity threshold. TRB 2002 Annual meeting CD ROM.	*				*	**
44	Determining The effectiveness of pavement marking materials TRB 2002 CD ROM					**	*
45	Development of a Pavement Management System: Measurement of Glass Sphere Loading in Retroreflecrive Pavement Paint TRB 2002 CD ROM		**			*	*

Scale:

- \- not relevant
- * slightly relevant
- ** fairly relevant
- *** very relevant

APPENDIX 17: PAVEMENT MARKINGS GIS DATABASE (Maptitude Platform)


US130
US130
US322
I295
NJ45
Dataview1 - Highway Info
ID 42003061
Length 0.08
Dir 0
SIGN1 US130
LANES 4
[PM-AGE(YRS)] 2
L-WEL(mcd/m2/Lux)] 442
RL-YEL(mcd/m2/Lux)] 298
[RL-SL(mcd/m2/Lux)] --
STCO 1318
LNAME

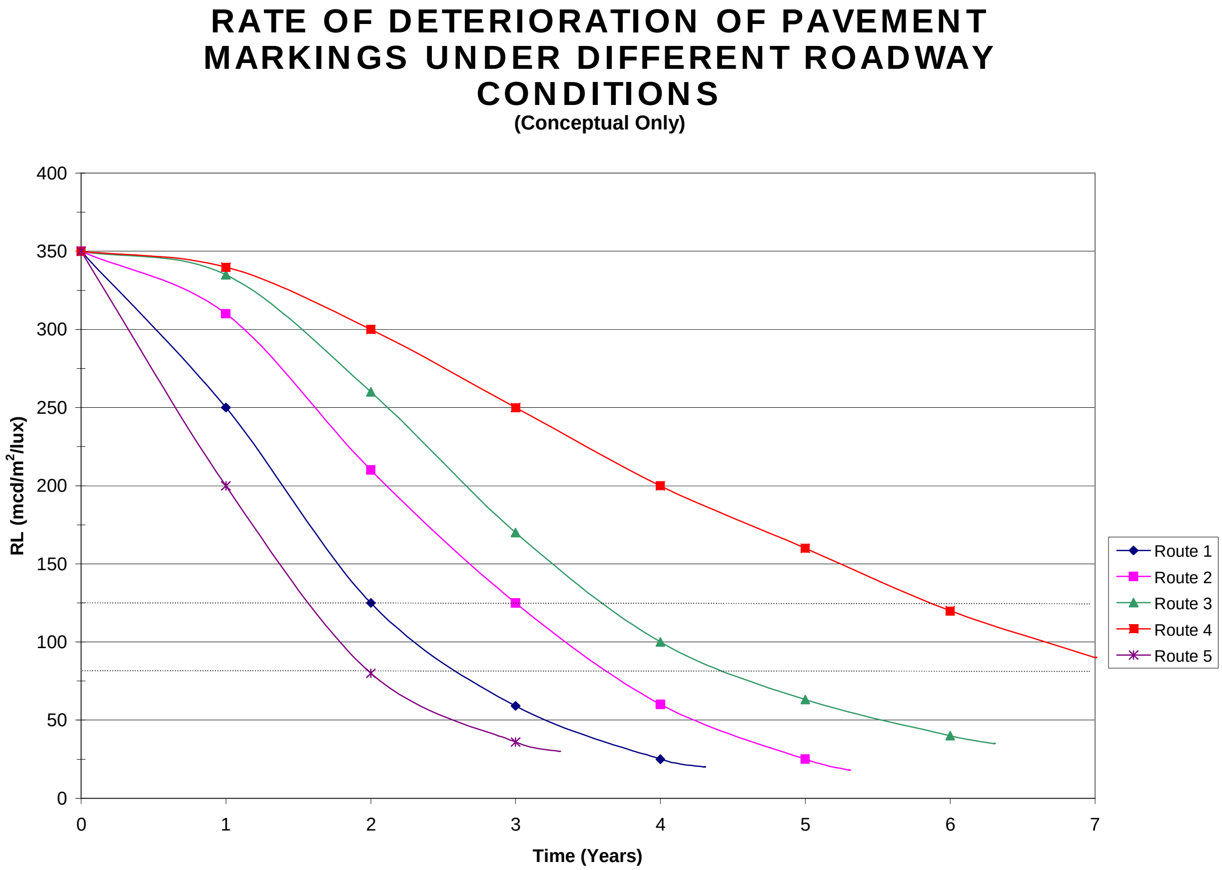
APPENDIX 18: IVI APPLICATION ON SURVEYED ROADS

Evaluation of the Measured Retroreflectivty

Route	Direction	PMs type	Start	End	Total Milage	Video Chainage		Average mcd	Qualified Sections for Re-Striping (miles)	% total Length	Total %	Age of PM's (years)
						Start	End					
US 9	South	White Edge	Green Drive/Tuckerton	Jct NJ 157	22.6	3.1	5	116.80	1.9	8%	30%	3
US 9	South	White Edge 2	Jct NJ 30	Jct NJ 52	9.3	1.1	2	113.00	0.9	10%		
US 9	South	White Edge 2	Jct NJ 30	Jct NJ 52	9.3	7.1	8	90.70	0.9	10%		
US 9	South	White Edge 2	Jct NJ 30	Jct NJ 52	9.3	9.1	9.3	109.70	0.2	2%		
US 322	West	White Edge	MP 49	Jct NJ 42	27.7	24.1	27.7	115.65	3.6	13%	17%	2
US 322	West	White Edge 2	Jct NJ 42	US 130	20.5	6.1	7	124.40	0.9	4%		
US 30	East	Yellow Edge	MP 4.15	Jct 536/MP 18	13.9	0.1	5	115.86	4.9	35%	78%	3
US 30	East	Yellow Edge	MP 4.15	Jct 536/MP 18	13.9	8.1	14	110.78	5.9	42%		
US 130	South	Yellow Edge	MP 25	MP 12.21	12.8	0.1	1	128.00	0.9	7%	7%	3
NJ Turnpike	North	White Edge	MP 15.8	MP 24.8	9	8.1	9	82.75	0.9	10%	10%	3
NJ 55	North	White Skip	Begin 4-Lane / NJ 50	NJ 42	39	13.1	16	118.40	2.9	7%	29%	3
NJ 55	North	White Skip	Begin 4-Lane / NJ 50	NJ 42	39	18.1	21	123.80	2.9	7%		
NJ 55	North	White Skip	Begin 4-Lane / NJ 50	NJ 42	39	23.1	24	126.90	0.9	2%		
NJ 55	North	White Skip	Begin 4-Lane / NJ 50	NJ 42	39	28.1	29	121.70	0.9	2%		
NJ 55	North	White Skip	Begin 4-Lane / NJ 50	NJ 42	39	33.1	34	125.70	0.9	2%		
NJ 55	North	White Skip	Begin 4-Lane / NJ 50	NJ 42	39	36.1	39	126.50	2.9	7%		
NJ 42	North	White Skip	NJ 168	NJ 41	5.7	0.1	1	120.60	0.9	16%	60%	3
NJ 42	North	White Skip	NJ 168	NJ 41	5.7	2.1	4	109.85	1.9	33%		
NJ 42	North	White Skip	NJ 168	NJ 41	5.7	5.1	5.7	97.80	0.6	11%		

NOTE: Sections qualifying for re-striping have average retroreflectivity of less than **130 mcd/m²/lux.**

APPENDIX 19: RATE OF DETERIORATION (Conceptual Only)


RATE OF DETERIORATION OF PAVEMENT MARKINGS UNDER DIFFERENT ROADWAY CONDITIONS
(Conceptual Only)
RL (mcd/m2/lux)
Time (Years)
0
50
100
150
200
250
300
350
400
1
2
3
4
5
6
7
Route 1
Route 2
Route 3
Route 4
Route 5