Research Report
KTC-08-21/SPR330-07-2I

KENTUCKY TRANSPORTATION CENTER

EVALUATION OF PAVEMENT MARKING PERFORMANCE

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EVALUATION OF PAVEMENT MARKING PERFORMANCE

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in cooperation with

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16. Abstract

The objective of the investigation was to evaluate the useful life of pavement markings. The Manual on Uniform Traffic Control Devices (MUTCD) provides general guidelines for the application and installation of pavement markings. However, performance requirements for various types of pavement markings are not included. Retroreflectivity data were collected throughout Kentucky on various longitudinal pavement markings using mobile and manual techniques. Data were collected on two-year old and one-year old lines. The retroreflectivity levels were analyzed and the several recommendations were made. Minimum levels of retroreflectivity should be set for determining what roads to restripe annually. These values should be lower than the passing/bonus thresholds used in the Quality Control/Quality Assurance (QA/QC) program. It is recommended that yellow lines should be above 100 mcd/m^2/lux and white lines should be above 150 mcd/m^2/lux. Retroreflectivity measurements should be collected and used to determine which roads should be painted each year. The current Maintenance Rating Program (MRP) can be used to facilitate this process. An inventory of striped roads should be maintained to allow a determination of when specific roadway sections were last restriped. The effect of the amount of beads per gallon on retroreflectivity should be studied further; however it seems fewer beads could be used.

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EXECUTIVE SUMMARY

The primary objective of the investigation was to evaluate the useful life of pavement markings. The evaluation also led to a methodology to determine what roadways should be restriped each year in Kentucky.

A total of 480 locations were selected across the state with 40 in each highway district. Thirty locations were selected that had been painted one year before data collection and 10 locations that had been painted two years prior to data collection. The one-year data were not available for all districts. Up to three lines were collected at each site. The time frame was based on the line that was randomly selected for each site; therefore the time since painted may not be accurate for all lines. It was assumed that each line was painted in the same year.

The data clearly show that striped lines can still produce passing retroreflectivity levels even after two years. White lines maintain levels above bonus after one year and above passing after two years. Yellow lines maintain levels near the passing limit after one year and just under passing after two years. Sixty percent of all lines striped had passing levels after one year and nearly half of all lines striped had passing levels after two years. The levels maintained show that is not necessary to restripe many roads annually.

The data collected indicated that retroreflectivity of striped lines are not directly affected by roadway characteristics such as lane width, shoulder width and number of lanes. ADT did not have a measurable effect on retroreflectivity, likely due to higher ADT roads typically having wider lanes. Truck percentage seemed to have little effect on retroreflectivity. Patterns were noted for two-lane rural roads; however, the sample sizes were too small to be significant. Region and district have the largest effect on failure rate. The eastern areas of the state typically have a high percentage of curvy and narrow roads with high truck percentages.

Higher amounts of beads per gallon slightly raise the initial retroreflectivity levels; however bonus levels are achieved at the lowest beads per gallon levels for yellow centerlines. Additionally, lines with the highest amounts of beads per gallon tend to lower the retroreflectivity levels after one year. For white edgelines the maximum retroreflectivity levels were achieved at about seven pounds of beads per gallon. More or fewer beads tend to lower the average retroreflectivity levels (initial readings and one year later).

Studies of others show that retroreflectivity levels less than current passing levels can provide adequate visibility. Furthermore, some research of others indicates that the same levels could be used for yellow and white lines. Retroreflectivity ranging from 70 to 170 have been found to provide adequate visibility in various studies.

The following recommendations result from the research:

1. Minimum levels of retroreflectivity should be set for determining what roads to restripe annually. It is recommended that yellow lines should be above 100 $mcd/m^2/lux$ and white lines should be above 150 $mcd/m^2/lux$.

2. Retroreflectivity measurements should be collected and used to determine which roads should be painted each year. The current Maintenance Rating Program (MRP) can be used to facilitate this process.

3. An inventory of striped roads should be maintained to allow a determination of when specific roadway sections were last restriped.

4. The effect of the amount of beads per gallon on retroreflectivity should be studied further; data suggests fewer beads could be used.

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1.0 INTRODUCTION

The Manual on Uniform Traffic Control Devices (MUTCD) provides general guidelines for the application and installation of pavement markings. However, performance requirements for various types of pavement markings are not included. Kentucky's Standard Specifications for Road and Bridge Construction and all pavement marking projects contain certain materials composition requirements as well as performance measures for retroreflectivity that are evaluated after a "proving period" that varies by material type. The performance measures are used for contract payment purposes to ensure the markings are applied in an acceptable and consistent manner. Other markings are installed with a specified "warranty" period which requires that the material maintain minimum retroreflectivity levels and other measures of effectiveness for a specified period of time. However, minimum maintained retroreflectivity levels and other performance measures are not currently used to determine material selection for specific applications or to predict the useful life of different materials under different conditions. Some installations of pavement markings have been observed to prematurely fail or deteriorate at an accelerated pace. Others exhibit exceptional levels of performance and last much longer than anticipated. Overall, there is a need to understand the useful life of various pavement markings including paints, thermoplastics, and tapes. Issues to be addressed should include material specifications, application procedures, useful life, and costs.

The objective of the investigation was to evaluate the useful life of pavement markings. The evaluation should lead to a methodology to determine what roadways should be restriped each year in Kentucky.

In 2006 about 33,670 miles of pavement markings were painted on Kentucky's state-maintained highway system; of which 21,100 were yellow lines and 12,570 were white lines. These lines were painted by one of three contractors: Reynolds, Central Seal or Oglesby. The contractors paint these lines between April and late October each year.

The Kentucky Transportation Cabinet (KYTC) rates pavement markings based on retroreflectivity. Retroreflectivity is a measure of an object's ability to reflect light back towards a light source along the same axis from which it strikes the object (1). Glass beads are embedded into pavement markings in order to achieve this type of reflection.

The contractors are paid based on a Quality Control/Quality Assurance (QC/QA) system. This encourages the contractor to ensure the minimum retroreflectivity readings are met. The contractors can adjust the retroreflectivity by changing the amount of paint used per mile and the number of beads per gallon of paint. The contractor takes readings at randomly selected zones using a handheld device 30 to 60 days after the line has been painted (QC). Data for higher volume roads are measured using a mobile collection technique provided by Precision Scan. These readings are used to determine if the line fails, passes, or bonuses. Twenty percent of the QC locations are tested by a district representative (QA). A KYTC representative (from the Division of Materials) is contacted if there is a discrepancy between QC and QA results. These specifications are outlined in Kentucky Methods 64-202-08 for handheld measurements and KM 64-203-08 for mobile readings (see http://transportation.ky.gov/materials/KYMethods.htm). The contractors had the opinion that the mobile readings are typically lower than the handheld readings.

2.0 LITERATURE SEARCH

A literature review was conducted relating to research of longitudinal retroreflective pavement markings. Most of the available literature focuses on the effectiveness and durability of pavement markings under wet or nighttime conditions. There is also extensive research on specific pavement marking materials: retroreflective tape, thermoplastic materials, lead-based vs. water-based paints, small vs. large glass beads, etc, as well as their effectiveness on specific roadway materials: concrete, asphalt, and seal coat.

One study evaluated New Jersey's three-year fixed-schedule restriping strategy to determine if it is consistent with the actual service life of the pavement markings (2). The results suggested that the threshold value of an acceptable versus unacceptable level of retroreflectivity was between 80 and 130 mcd/m^2/lux for drivers younger than 55 and between 120 and 165 mcd/m^2/lux for drivers older than 55. These results are consistent with conclusions reached by other investigators in similar research, where results generally ranged between 70 and 170 mcd/m^2/lux. The study indicates that minimum levels of retroreflectivity could be used for yellow centerlines and white lanelines. Furthermore, the study suggested that striping lines with values less than 165 mcd/m^2/lux would produce the greatest relative increase in driver satisfaction (all drivers).

Interim visibility indices were developed for each age group per pavement marking type. On the basis of the threshold between acceptable and unacceptable retroreflectivity, New Jersey DOT used the indices to determine and prioritize needs and to quantify needed related resources and then to develop its pavement marking management system (2). This approach also allows for cost-benefit and life-cycle analysis for different pavement-marking materials.

Other studies suggest lower retroreflectivity levels may be acceptable. An NCHRP report from 1996 found that 85% of test subject 60 and older found a retroreflectivity of 100 mcd/m^2/lux to be adequate or more than adequate (3). A Transportation Research Report from 1998 analyzed pavement marking visibility related to crash data (4). This research study found that a threshold of 150 mcd/m^2/lux was recommended from a safety standpoint.

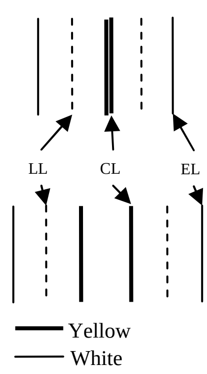
3.0 PROCEDURE

The 2006 QC/QA data were obtained from each highway district. Each QC/QA sheet contained up to five average retroreflectivity readings and the dates painted and checked for a location on the state-maintained system. This information, as well as the line color and type, was collected from each sheet and compiled into a database. Additionally, the percentage of how many readings passed the minimum requirement was added to the database. The database was examined to ensure that each record has a valid location and retroreflectivity reading. This database was matched to the Highway Performance Monitoring System (HPMS) to obtain roadway geometrics and traffic volumes for each location. HPMS is a system used to inventory the roadway characteristics of Kentucky's state highways. Approximately 2,500 locations were matched to HPMS. The same process was used for the 2005 QC/QA data resulting in approximately 1,000 matching locations.

Ten 2005 locations and thirty 2006 locations were randomly selected from each of the twelve highway districts. It was verified that the random sample represented the state's highway system classifications adequately. Not all highway districts were represented since 2005 data were unavailable for districts 3, 5, 6, 10 and 11. Furthermore, no data were available in Jefferson County for 2005 or 2006 due to Jefferson County's high traffic volumes mandating mobile testing.

Data were collected from March to May of 2007 using an LTL 2000 Pavement Marking Retroreflectometer. The meter obtains reflectivity in millicandelas per lux per meter-sqaured ($mcd/m^2/lux$). In this report, retroreflectivity, whether referred to as levels or readings, will be in units of $mcd/m^2/lux$. Ten readings were collected on each line type. Data were collected as close to the measured location as possible. However, the collection area was moved, if necessary, to ensure that the roadway was straight and data were not collected in areas of poor pavement conditions. In addition, areas with auxiliary lanes and driveways or access roads were avoided.

Data were collected using the form presented in Appendix A. Data were collected for up to three line types at each location. For undivided highways, data were collected on the white edgeline, white laneline and yellow centerline. For divided highways, data were collected on the white edgeline, white laneline and yellow edgeline at the median (this was categorized as a centerline for consistency). The following diagram shows these lines.



Data could be collected in either travel direction as long as it was collected in the same direction as it was painted. This is always in the direction of travel except for centerlines. Therefore, the direction of the centerline was listed on the list of locations. The higher reflectivity numbers were used in the event that this information was unavailable or seemed inaccurate (i.e. data were sampled in both directions). Since the random location was selected based on a QC/QA data record, it was ensured that data be collected consistent with the QC/QA data. For example, data were collected on the northbound white edgeline if the random site based on a white edgeline reading in the northbound direction. This effort was to ensure that data were collected on the same line that data was available. A sample of the QA/QC data sheet is shown in Appendix B.

Daily work reports for 2006 were obtained from the contractors for each highway district with the exception of District 12. A sample of a daily work report is shown in Appendix C. Each report outlined the county, route and milepoint range painted that day. In addition, the paint color, line type, line width (four or six inch) and road type (MP or RS) were shown. The total mileage for each road type is calculated on the form. The total paint (in gallons) and the number of beads were shown for daily report. This information was used to calculate beads per gallon and gallons per mile for each day.

4.0 RESULTS

Data Collection

A total of 480 locations were selected across the state with 40 in each highway district. Thirty locations were selected that had been painted one year before data collection and 10 locations that had been painted two years prior to data collection. The one-year data were not available for all districts. Below is a table summarizing the number of sites in each district as well as the number of lines collected at each site. Up to three lines were collected at each site.

	Sites		Lines	
District	1-Year	2-Year	1-Year	2-Year
1	8	26	10	56
2	9	25	13	47
3		18		39
4	10	30	14	52
5		27		55
6		29		56
7	10	29	16	62
8	9	20	13	31
9	7	27	10	47
10		23		47
11		30		55
12	4	11	8	22
Total	57	295	84	569

The time frame was based on the line that was randomly selected for each site; therefore the time since painted may not be accurate for all lines. It was assumed that each line was painted in the same year.

Several highway districts assisted in collecting data. Below is a table showing each district's contribution in terms of number of sites.

Number of Lines	YEAR	
District*	1-Year	2-Year
1	10	56
2	7	35
6		44
8	9	23
9	10	47
11		38
12	8	28
KTC	40	298

*District 7 collected data used in a separate evaluation

The data were collected fairly uniformly throughout the state:

Region	W	Y
CENTRAL	115	118
EAST	87	102
WEST	105	126
Grand Total	307	346

Line Types

Data were collected on up to three lines at each site: centerlines, edgelines and lanelines. White lines are either lanelines or edgelines. Yellow lines are edgelines on divided highways, centerlines on undivided highways and essentially lanelines on roads with two-way left turn lanes (TWLTL). The following table shows the count of collected data by line type.

		Count	
Color	Type	2-Year	1-Year
White	Edgeline	26	230
	Laneline	1	50
	All	27	280
Yellow	Edgeline	1	44
	TWLTL	1	11
	Centerline	55	234
	All	57	289

As previously noted, contractors are paid based on passing and bonus retroreflectivity readings. These limits differ for yellow and white lines. The following table shows the passing and bonus limits for yellow and white.

Lowest Retroreflectivity Readings Needed		
Color	**Pass**	**Bonus**
Yellow	175	225
White	250	300

The average retroreflectivity is shown by line type in the following table. Passing numbers are underlined and bonus numbers are double-underlined.

Color	Type	30-60 Days	Average 1 Year	2 Years
White	Edgeline	342	283	268
	Laneline	371	281	300
	All White	344	282	269
Yellow	Edgeline	251	204	159
	TWLTL	220	154	139
	Centerline	241	174	158
	All Yellow	242	178	157

The data are also presented, graphically, in Appendix D. Lines marking the top and bottom of the passing range are shown. The reason that the white laneline two-year old paint lines show a slightly higher retro reading than the one-year old lines is that data were only collected in 2006. Therefore, the two-year old lines and one-year old lines were a different sample of lines. In addition, the data are not as robust due to the small sample size of white lanelines.

Graphs were made representing the percent of readings that passed, were at or above bonus, and failed versus time-since-painted. The retroreflectivity readings from the QC/QA datasheets were taken 30 to 60 days since the lines were painted. The 2005 (two-years since painted) and the 2006 (one-year since painted) were also used. These graphs were prepared for all data as well as for each line type and are giving in Appendix E.

Other Factors

The majority of the field data was collected on white edgelines and yellow centerlines. The sample sizes for the other line types were too small for detailed analysis. Therefore, the following analysis was conducted on white edgelines and yellow centerlines.

The average retroreflectivity was summarized by Average Daily Traffic (ADT). Three ADT ranges were used to categorize the data in an effort to provide adequate sample sizes. Yellow centerlines, two-lane white edgelines and multi-lane white edgelines had different ADT ranges due to their different characteristics. The average retroreflectivity and number for each one-year old line type is shown in Appendix F-1 for each ADT category. Similarly, the average retroreflectivity and number for each two-year old line type is shown in Appendix F-2 for each ADT category.

The same data were summarized by lane widths with three categories for yellow centerlines. This data are shown in Appendix F-3 for the one-year old lines and in Appendix F-4 for the two-year old lines. This analysis was conducted in order to determine if ADT and lane width have a combined effect on retroreflectivity. However, there is a direct relationship between roads with high ADTs and wide lanes which confounds the analysis. It should be noted that a large portion of the sample had no lane width data.

The HPMS database contains data based on percent trucks. The fields for percent single-unit truck and percent combination truck were combined to obtain the percent of trucks. The retroreflectivity data are shown below based on three groups of percent of trucks.

	Average Retro	
Percent Trucks	1-Year	2-Year
0-5	284	282
6-10	283	245
> 10	274	319

These factors were also analyzed based on the percentage in each retroreflectivity category (bonus, pass and fail) for the one-year old lines (collected with the LTL). This was done in order to better characterize failing lines. The data is summarized by region below.

	Percent		
Region	Fail	Pass	Bonus
CENTRAL	31	34	36
EAST	57	26	16
WEST	32	32	36

There a very high percentage of failure in the east region largely due to the two-lane, rural, curvy roadways of eastern Kentucky (District 12 had a 91% failure rate). There is also a high volume of coal trucks in this region. The data are summarized by district below.

	Percent		
District	Fail	Pass	Bonus
1	18	25	57
2	38	40	21
3	41	23	36
4	35	40	25
5	13	38	49
6	39	34	27
7	39	29	32
8	45	29	26
9	57	34	9
10	53	26	21
11	55	25	20
12	91	9	0

It should be noted that District 5 has a large sample of data collected using the mobile collection process.

The data were separated into the two largest samples: two-lanes, rural yellow centerlines and two-lane, rural white edgelines. There was a slightly higher failure rate for yellow centerline on two-lane rural roads for roads with higher truck percentages. The following table shows these results.

2-Lane, Rural Yellow Centerlines

	Fail		Pass		Bonus	
Truck Percent	Percent	Count	Percent	Count	Percent	Count
0 to 5	51	54	40	42	9	10
6 to 10	54	56	31	32	15	16
Over 10	67	6	22	2	11	1

The failure rate was highest for roads with ADTs above 2,500. The following table shows these results.

2-Lane, Rural Yellow Centerlines

	Fail		Pass		Bonus	
ADT	Percent	Count	Percent	Count	Percent	Count
> 1,000	54	15	29	8	18	5
1,000 – 2,500	53	17	31	10	16	5
< 2,500	59	16	30	8	11	3

The same tables were created for two-lane, rural white edgelines. The same patterns were seen with a slightly higher percentage for low truck volumes.

2-Lane, Rural White Edgelines

Truck Percent	Fail Percent	Fail Count	Pass Percent	Pass Count	Bonus Percent	Bonus Count
0 to 5	34	20	28	16	38	22
6 to 10	28	27	29	28	43	41
Over 10	44	4	22	2	33	3

2-Lane, Rural White Edgelines

ADT	Fail Percent	Fail Count	Pass Percent	Pass Count	Bonus Percent	Bonus Count
< 2,500	36	4	18	2	45	5
2,500 – 5,000	38	9	25	6	38	9
> 5,000	33	10	30	9	37	11

Cumulative Distributions

Cumulative distributions were created for yellow centerlines (Appendix G-1) and white edgelines (Appendix G-2). Lines marking the top and bottom of the passing range are shown as dashed lines. These diagrams indicate the percentage of lines that had averages at or below various levels. It can be seen that a small portion of yellow centerlines (about 12%) had a retroreflectivity at or below 100 after two years. Similarly, about 12% of white edgelines had a retroreflectivity at or below 150 after two years. Research has concluded that lines above these levels provide adequate visibility for drivers.

Paint and Beads

The striping contractors used the daily work reports to quantify the pounds of beads and gallons of paint used each day. Additionally, the total mileage striped was recorded on these reports. The beads per gallon and gallons per mile were summarized as daily averages by district for the 2006 data. Daily averages greater than 50 and less than three gallons per mile were omitted due to incorrect data. A few daily averages under three beads per gallon were also removed. The following table shows these values for four and six-inch lines.

	2006 Daily Average			
	Beads per Gallon		Gallons per Mile	
District	4-inch	6-inch	4-inch	6-inch
1	6.8	7.3	16.6	24.9
2	6.7	6.9	16.6	25.0
3	6.9	7.5	16.8	24.0
4	7.0	7.0	16.5	25.0
5	7.9	9.2	13.7	18.0
6	7.8	7.7	16.8	23.2
7	7.9	8.6	15.1	26.3
8	6.3		16.6	
9	7.9	7.3	15.1	20.7
10	7.9		17.0	
11	7.8	7.9	17.0	24.4
Grand Total	**7.4**	**8.0**	**16.0**	**22.1**

The data are similar for white and yellow lines.

The amount of pounds of beads per gallon was compared to the average retroreflectivity for each district. Graphs were made for yellow centerlines and white edgelines and for two time frames: 30-60 days and one-year. Two-year data were not used since only 2006 daily work reports were obtained and the two-year lines were striped in 2005. Appendix H-1 shows the relationship between retroreflectivity and beads per gallon for yellow centerlines. The beads per gallons averages were calculated for any daily work sheet indicating a yellow centerline was striped that day. It is possible that other line types were striped that day. Appendix H-2 shows the relationship between retroreflectivity and beads per gallon for white edgelines. The beads per gallons averages were calculated for any daily work sheet indicating a white edgeline was striped that day. Again, it is possible that other line types were striped that day (such as white skip lines, ramps, gores, etc.).

Second-order polynomial trendlines were added to each graph in Appendix H. These lines help indicate the general trend of the retroreflectivity as beads per gallon increases. A slight increase in retroreflectivity was noticed for the yellow centerline data (Appendix H-1) with higher bead quantities for the 30-60 day data. The opposite trend was noticed for the one-year data. Appendix H-2 showed a peaking in retroreflectivity at about seven pounds of beads per gallon for both the 30-60 day data and the one-year data.

<u>Mobile Data</u>

Mobile data was collected by Precision Scan for 2,721 lines painted in 2004 through 2006. The lines were measured 30 to 60 days after they were painted. Each line was coded as white edgeline, white skip or yellow centerline. It was assumed that the yellow centerlines were actually yellow edgelines (i.e. divided roadways). The following table shows the number of measurements for each type of line.

Year Painted	White Edge	White Skip	Yellow Edgeline	All
2004	324	130	283	737
2005	369	145	231	745
2006	525	247	467	1,239
All	**1,218**	**522**	**981**	**2,721**

The average retroreflectivity reading was calculated for each line type. The following table shows the average retroreflectivity by line type and year. The data show that the 2005 data were generally higher than the other two years for all three line types.

Year Painted	White Edge	White Skip	Yellow Edgeline
2004	321	328	228
2005	374	366	246
2006	342	305	231
All	**346**	**327**	**234**

The average retroreflectivity was also summarized by line type and highway district. Not all districts had data available.

District	White Edge	White Skip	Yellow Edgeline
1	181		214
3	334	283	222
4	389	324	273
5	346	326	231
6	344	374	229
7	348	277	256
8	385	377	268
9	356	319	268
11	321	322	229
All	**346**	**327**	**234**

The same levels were used to determine whether a measurements passed, bonus or failed. Appendix I-1 shows the percent in each category for each line type. The percentages in each category were compared by collection method as well. Sufficient data were available for white edgelines for both collection methods (LTL and mobile). This comparison is shown in Appendix I-2.

The retroreflectivity levels collected using the LTL (30-60 days after striped) were comparable to the mobile data levels. This is shown in Appendix I-3 for each line type.

Case Study

Highway District 7 assisted in the collection of additional data. The district collected data at 147 sites resulting in 227 lines. The data were collected in February of 2008 using the handheld LTL meter. The form shown in Appendix A was used to collect the data resulting in the average of 10 readings per line. The data were similar to the data collected by KTC and the other districts (predominately yellow centerlines and white edgelines). The date of striping was not obtained for each location due to the effort of the task and the redundancy for such data. The following table shows the retroreflectivity for each line type and the number of lines collected.

Line Type	Average Retro	Number of Lines
W-EL	286	90
W-LL	310	8
Y-CL	189	110
Y-EL	205	17
Y-TW	173	2

It can be assumed that most of the lines measured were striped the year prior; however, some may have been striped two years prior.

It should be noted that District 7's effort provides a case study for each district collecting retroreflectivity data prior to the striping season in an effort to determine what lines should be striped that year.

HD-21 Paint

Data were collected on the Hal Rogers Parkway in Laurel County in April of 2007. The locations were chosen based on records indicating that HD-21 paint was used. The lines were reportedly striped in August of 2003. There is, however, some confusion as to whether the lines were restriped in 2005 with the typical paint. The white edgelines averaged a retroreflectivity of 196 and the yellow centerlines averaged at 134. Both of which would be very high readings for four-year old lines and slightly lower than typical two-year old lines (both of which were failing levels).

Data were also collected on the AA highway in Lewis and Mason Counties in May of 2007. Again, these locations were chosen for their HD-21 lines. The white edgelines were striped in September of 2005; however, the date is unknown for the yellow centerlines. The white edgelines average retroreflectivity was 280 and the yellow centerlines average of 112. The white edgeline were well above passing, almost bonus; which is unusual for a two-year old line. The yellow centerline had a retroreflectivity below passing; which is normal for a two-year old.

Maintenance Ratings Program

The Maintenance Ratings Program (MRP) collects a variety of roadway maintenance data on Kentucky's roadways each year. Roughly 300 sections are evaluated in each of the twelve highway districts. The locations are randomly selected using a methodology that adequately selects locations based on road class. Retroreflectivity data have not been collected at each location each year due to the availability of the meter, road maintenance, construction, and traffic conditions.

5.0 CONCLUSIONS

The data clearly show that striped lines can still produce passing retroreflectivity levels even after two years. White lines maintain levels above bonus after one year and above passing after two years. Yellow lines maintain levels near the passing limit after one year and just under passing after two years. Sixty percent of all lines striped had passing levels after one year and nearly half of all lines striped had passing levels after two years. The levels maintained show that is not necessary to restripe many roads annually.

The data collected indicated that retroreflectivity of striped lines are not directly affected by roadway characteristics such as lane width, shoulder width and number of lanes. ADT did not have a measurable effect on retroreflectivity, likely due to higher ADT roads typically having wider lanes. Truck percentage seemed to have little effect on retroreflectivity. Patterns were noted for two-lane rural roads; however, the sample sizes were too small to be significant. Region and district have the largest effect on failure rate. The eastern areas of the state typically have a high percentage of curvy and narrow roads with high truck percentages.

Higher amounts of beads per gallon slightly raise the initial retroreflectivity levels; however bonus levels are achieved at the lowest beads per gallon levels for yellow centerlines. Additionally, lines with the highest amounts of beads per gallon tend to lower the retroreflectivity levels after one year. For white edgelines the maximum retroreflectivity levels were achieved at about seven pounds of beads per gallon. More or fewer beads tend to lower the average retroreflectivity levels (initial readings and one year later).

The mobile data is comparable to the LTL retroreflectivity levels.

The latest Kentucky Standard Specifications have increased the passing and bonus levels by 50. The proposed levels are:

2009 Standards
Lowest Retroreflectivity Readings Needed

Color	Pass	Bonus
Yellow	225	275
White	300	350

Studies show that retroreflectivity levels less than current passing levels can provide adequate visibility. Furthermore, some research indicates that the same levels could be used for yellow and white lines. Retroreflectivity ranging from 70 to 170 have been found to provide adequate visibility in various studies.

6.0 RECOMMENDATIONS

1. Minimum levels of retroreflectivity should be set for determining what roads to restripe annually. These values should be lower than the passing/bonus thresholds used in the QC/QA program. It is recommended that yellow lines should be above 100 $mcd/m^2/lux$ and white lines should be above 150 $mcd/m^2/lux$. These values are based on the findings in this report and research conducted on older drivers and crash data.

2. Retroreflectivity measurements should be collected and used to determine which roads should be painted each year. The current Maintenance Rating Program (MRP) can be used to facilitate this process.

    a. Data should be collected at 300 randomly selected locations in each district.
    b. The sites should be the same locations used in the MRP.
    c. This data should be reported to the MRP such that redundant data are not collected.
    d. If possible the data should be collected in February.
    e. Roadways with retroreflectivity under the minimums levels should be restriped.

3. An inventory of striped roads should be maintained to allow a determination of when specific roadway sections were last restriped.

4. The effect of the amount of beads per gallon on retroreflectivity should be studied further; however it seems fewer beads could be used.

7.0 REFERENCES

1. Debaillon, C. and P. Carlson, "Updates to Research on Recommended Minimum Levels for Pavement Marking Retroreflectivity to Meet Driver Night Visibility Needs," Federal Highway Administration, FHWA-HRT-07-059, October 2007.

2. Parker, N. and M. Meja, Evaluation of Performance of Permanent Pavement Markings, In *Transportation Research Record 1824,* TRB National Research Council, Washington, D.C., 2003 pp. 123-132.

3. Graham, J.R., J.K. Harold, and L.E. King. Pavement Marking Retroreflectivity Requirements for Older Drivers. In *Transportation Research Record 1529,* TRB National Research Council, Washington, D.C., 1996 pp. 65-70.

4. Lee J.-T., T.L. Maleck, and W.C. Taylor. Analysis of the Correlation Between Pavement Marking Visibility and Nighttime Accidents. Presented at the 77th Annual Meeting of the Transportation Research Board, Washington, D.C., 1998.

APPENDIX A

Retroreflectometer Data Sheet

RETROREFLECTOMETER DATA SHEET

Collector's Name:____________________ Date:_____________________

Location ID:__________ Yellow Dir: __________ Time:_____________________

County:_____________ Route:______________ MP:________________

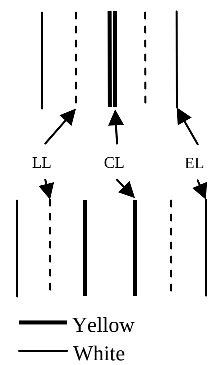
Location Description:_____________________________ Parking: ___________________

# of Lanes:_____ Lane Width:_______ Shoulder Width:_____________

Divided / Undivided / TWLTL Rumble Strips ☐ Shoulder Type:_____________

Dir		**Dir**		**Dir**	
Loc		**Loc**		**Loc**	
Color		**Color**		**Color**	
LTLID:		LTLID:		LTLID:	

Location:
LL-Lane Line
CL-Centerline
EL-Edgeline



Checklist
- ☐ Calibrate
- ☐ Set ID on LTL
- ☐ Avoid Driveways
- ☐ Avoid auxiliary lanes
- ☐ Collect on good pavement

Increasing MP:
NB
WB

Previous Reading: **(Be sure to collect data on the same line as below)**

Retro:________ Date:________ Direction: _____ Color:______ Location:______

APPENDIX B

QAQC Data Sheet

STRIPING REFLECTIVITY TEST

WHITE

DATE PAINTED: 05/20/06   FIRST DATE TO TEST: 06/19/06   LAST DATE TO TEST: 07/19/06

TEST SITE:	SEGMENT #1			SEGMENT #2			SEGMENT #3		
ZONE:	#1	#2	#3	#1	#2	#3	#1	#2	#3
DATE CHKD:	07/08/2006			07/08/2006			07/08/2006		
COUNTY:	Lincoln			Lincoln			Lincoln		
ROUTE:	27			38			39		
SEGMENT MP:	17.8			0			7.6		
ZONE MP:	18.4			0.6			8.1		
LOCATION:	NBEL			NBEL			NBEL		
READING NO:	READING	READING	READING	READING	READING	READING	READING	READING	READING
1	263			342			332		
2	285			338			342		
3	289			357			347		
4	309			348			348		
5	338			342			348		
6	335			353			388		
7	330			335			387		
8	321			346			410		
9	294			355			417		
10	300			374			414		
11	275			359			429		
12	305			376			446		
13	302			378			414		
14	299			395			404		
15	288			383			419		
16	294			409			410		
17	300			381			432		
18	305			363			429		
19	306			377			411		
20	300			377			408		
	20	20	100%	20	20	100%	20	20	100%

TEST SITE:	SEGMENT #4			SEGMENT #5		
ZONE:	#1	#2	#3	#1	#2	#3
DATE CHKD:	07/08/2006			07/08/2006		
COUNTY:	Lincoln			Lincoln		
ROUTE:	39			39		
SEGMENT MP:	14.6			7		
ZONE MP:	14.1			6.6		
LOCATION:	SBEL			SBEL		
READING NO:	READING	READING	READING	READING	READING	READING
1	365			384		
2	332			357		
3	341			395		
4	313			405		
5	355			396		
6	332			394		
7	343			402		
8	330			411		
9	331			389		
10	344			412		
11	355			397		
12	360			412		
13	340			417		
14	330			424		
15	354			424		
16	336			435		
17	334			415		
18	331			409		
19	364			437		
20	344			396		
	20	20	100%	20	20	100%

REFLECTIVITY REQUIREMENTS	
MINIMUM:	250
BONUS:	300

LEGEND:

EL=EDGELINE
CL=CENTERLINE
WBL=WESTBND LANE
EBL=EASTBND LANE
SBL=SOUTHBND LANE
NBL=NORHTBND LANE

MILES STRIPED	
M P	
CH NO.	MILES
	37.750
R S	
CH NO.	MILES

* 40% PAID WHEN PASSING PAINT REPORT RECEIVED

Number Of Segments Tested	5
Number Of Segments Failed	0
SECTION PASSES	

TEST BY: Teresa Harrison

RESIDENT ENGINEER

Initial Pay 60%				
CH NO:				
MILES:	22.650			

	RAND. # 1	RAND. # 2	RAND. # 3
SEGMENT LENGTH:	7.6	7.6	7.6
RANDOM INSPECTION #:	0.5	1.3	5.5

362.06

Pay 40% Upon Reflectivity Acceptance				
CH NO:				
MILES:	15.100			

MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN
301.9	0	0	364.4	0	0	396.75	0	0	341.7	0	0	405.55	0	0

QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN	QA MEAN

% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.	% DIFF.
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

APPENDIX C

Daily Work Report

Daily Work Report

4" YELLOW

Date 08/10/2006 Truckno. BRUTUS Driver JASON REYNOLDS Striper MIKE SHELTON

District 8 Precipitation Temperature (AM/PM) Road Conditions

Time	County	Road	MP	RS	DIR	LINE	Milepost From - To	Lineal Feet M P	Miles M P	Lineal Feet R S	Miles R S
	ADAIR	61	X		N	CL	0-.1	1352	0.26		0.00
									0.00		0.00
	ADAIR	61	X		N	CL	0-21.9	183940	34.84		0.00
	ADAIR	768		X	W	CL	12.79-17.47		0.00	47252	8.95
	ADAIR	768		X	W	CL	21-27		0.00	58820	11.14
									0.00		0.00
									0.00		0.00
									0.00		0.00
									0.00		0.00
									0.00		0.00
									0.00		0.00
									0.00		0.00
									0.00		0.00
									0.00		0.00
									0.00		0.00
									0.00		0.00
							TOTALS	185292	35.09	106072	20.09

	MP	PAID MP		RS	PAID RS	
Total miles of stripe	35.09318182			20.08939394		
60% TOTAL	21.06			12.05		
40% TOTAL	14.04			8.04		

MATERIALS USED	QUANTITY	BATCH NO.
	[illegible]	
PAINT	620	MP2000C
BEADS	5610	#09
	6401	

LEGEND:

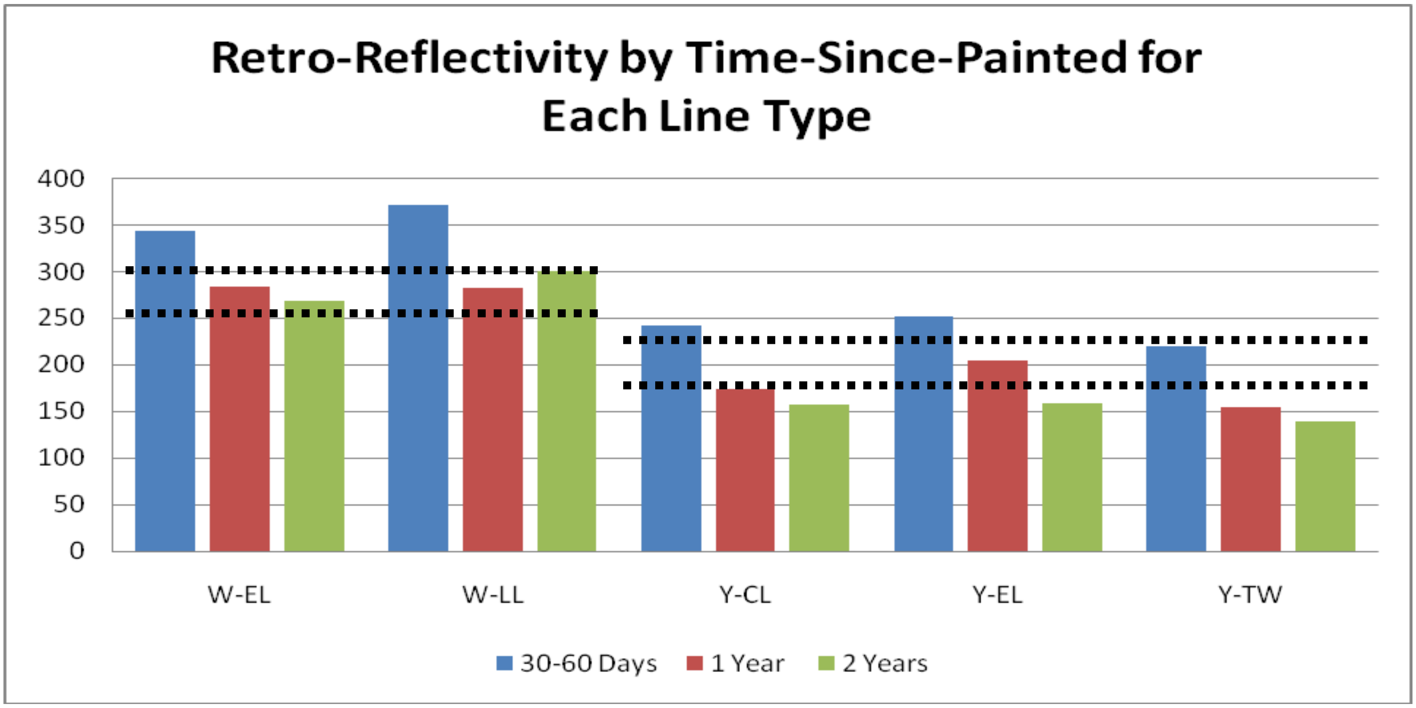
EL=EDGELINE CL=CENTERLINE
SK=SKIP
WBL=WESTBND LANE
EBL=EASTBND LANE
SBL=SOUTHBND LANE
NBL=NORHTBND LANE

16.72629426

NOTES:

APPENDIX D

Retroreflectivity by Time-Since-Painted for Each Line Type

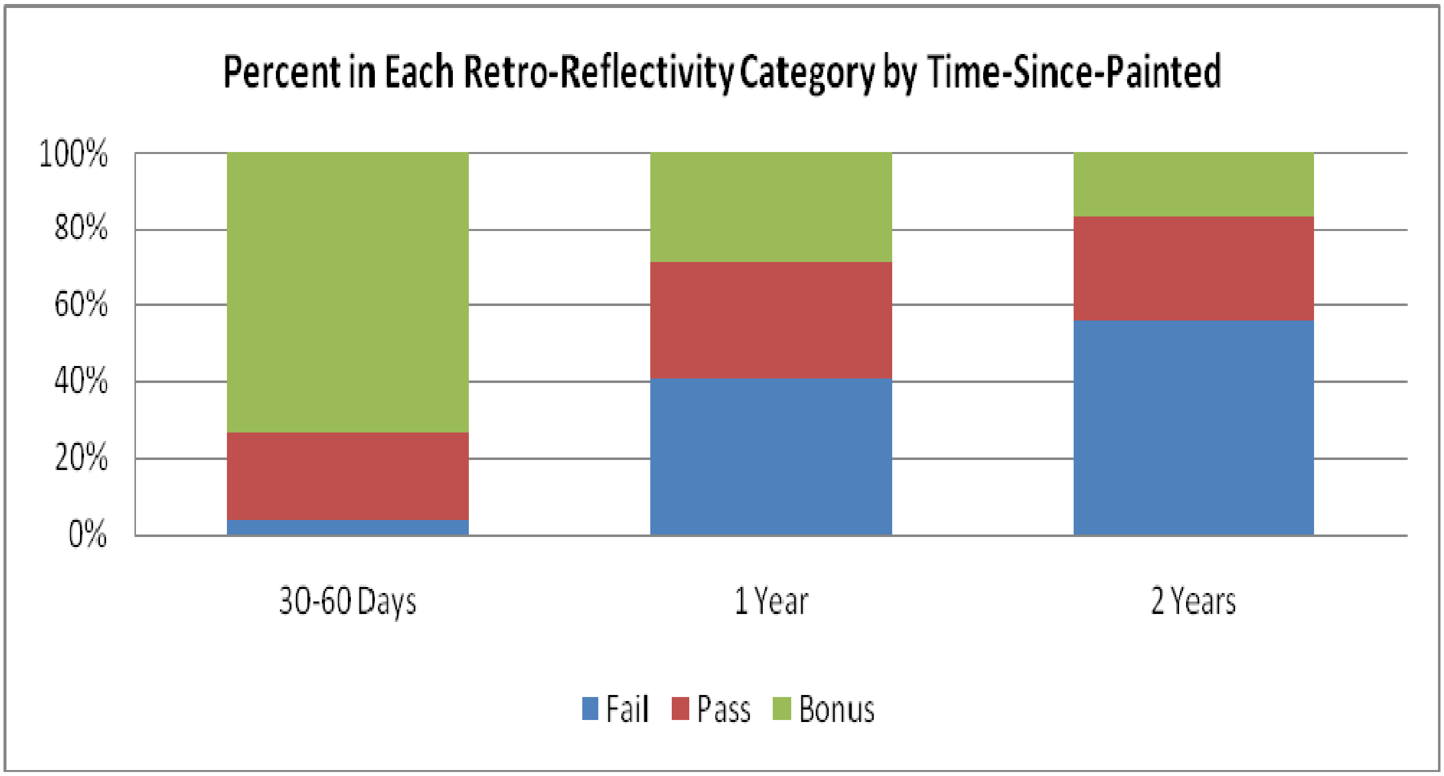


Dashed lines represent the bonus threshold (upper) and passing threshold (lower)

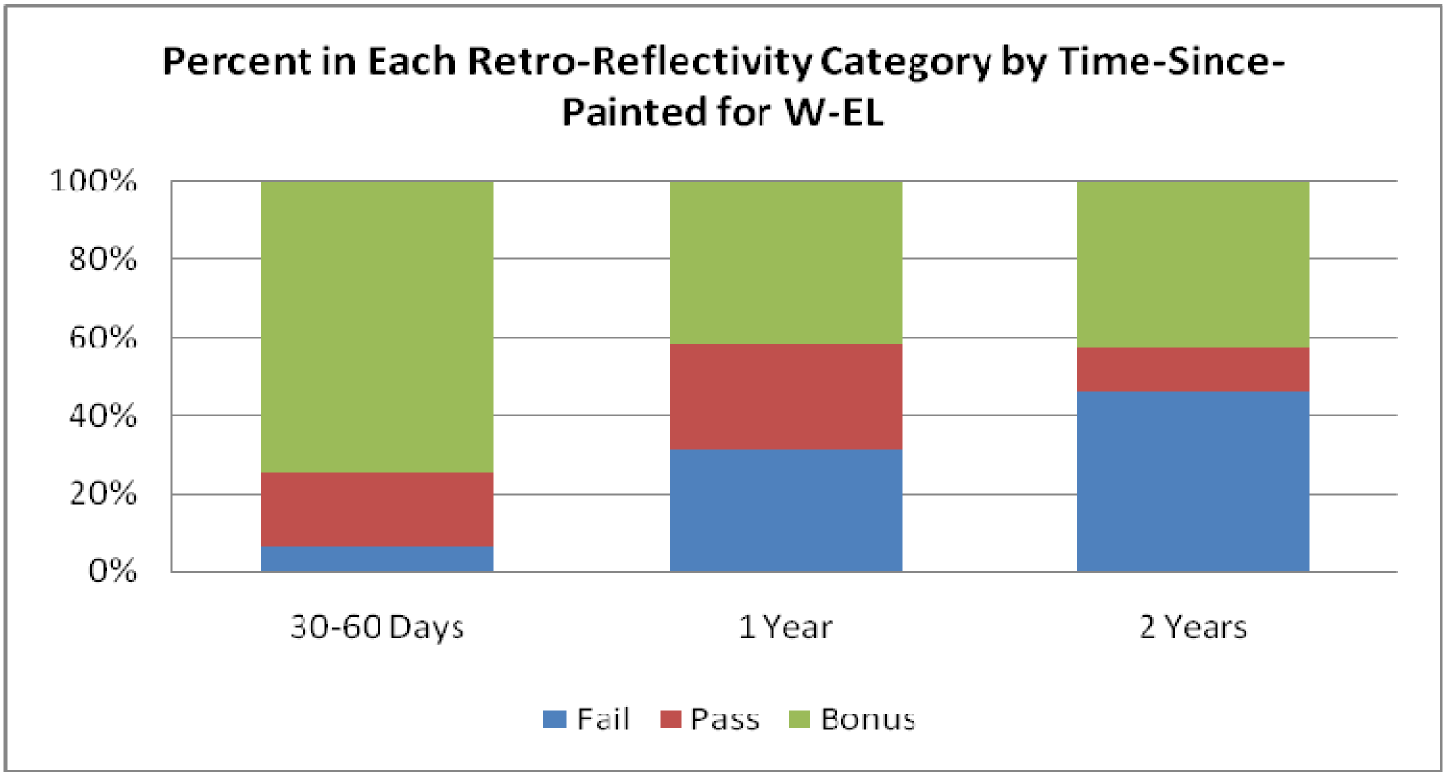
APPENDIX E

Percent Passing, Bonus and Failing

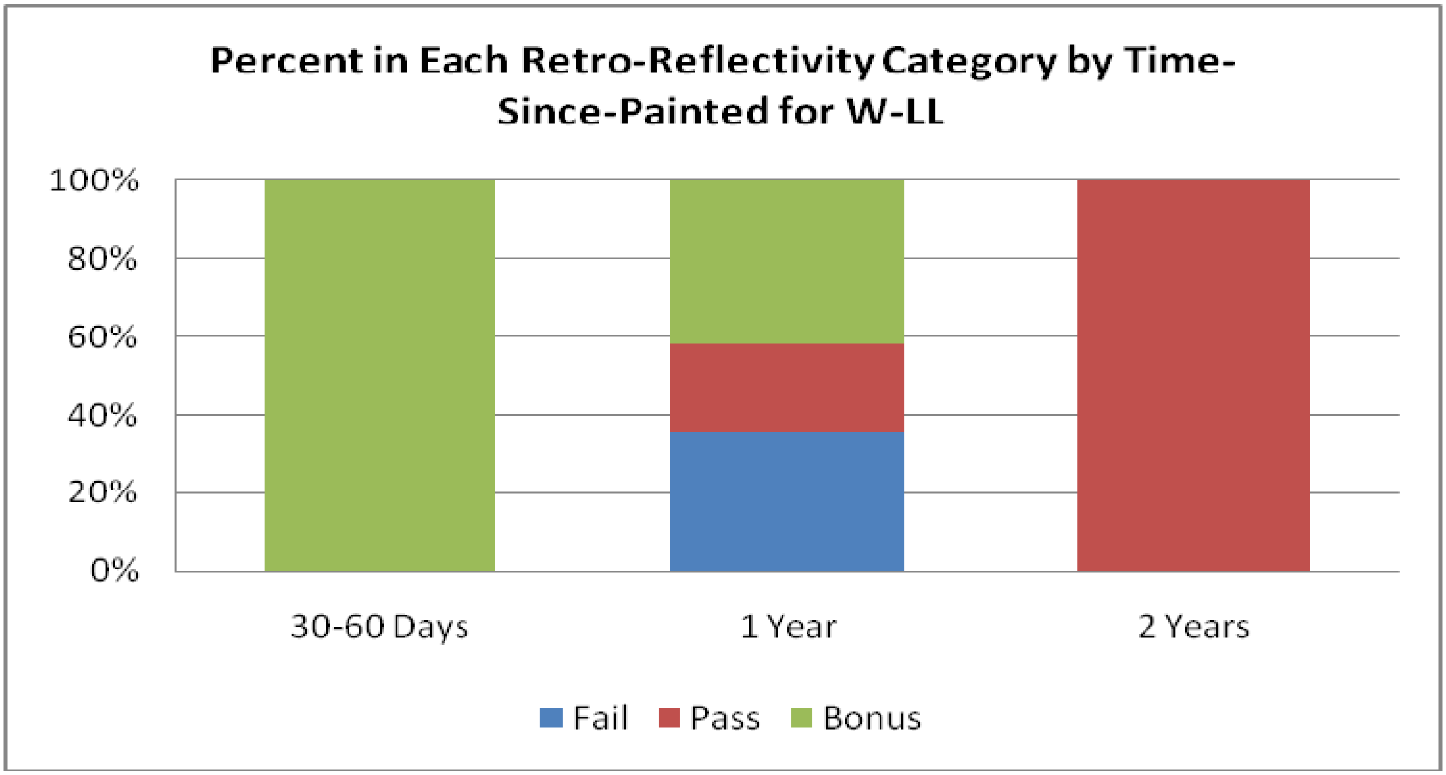
Appendix E-1.



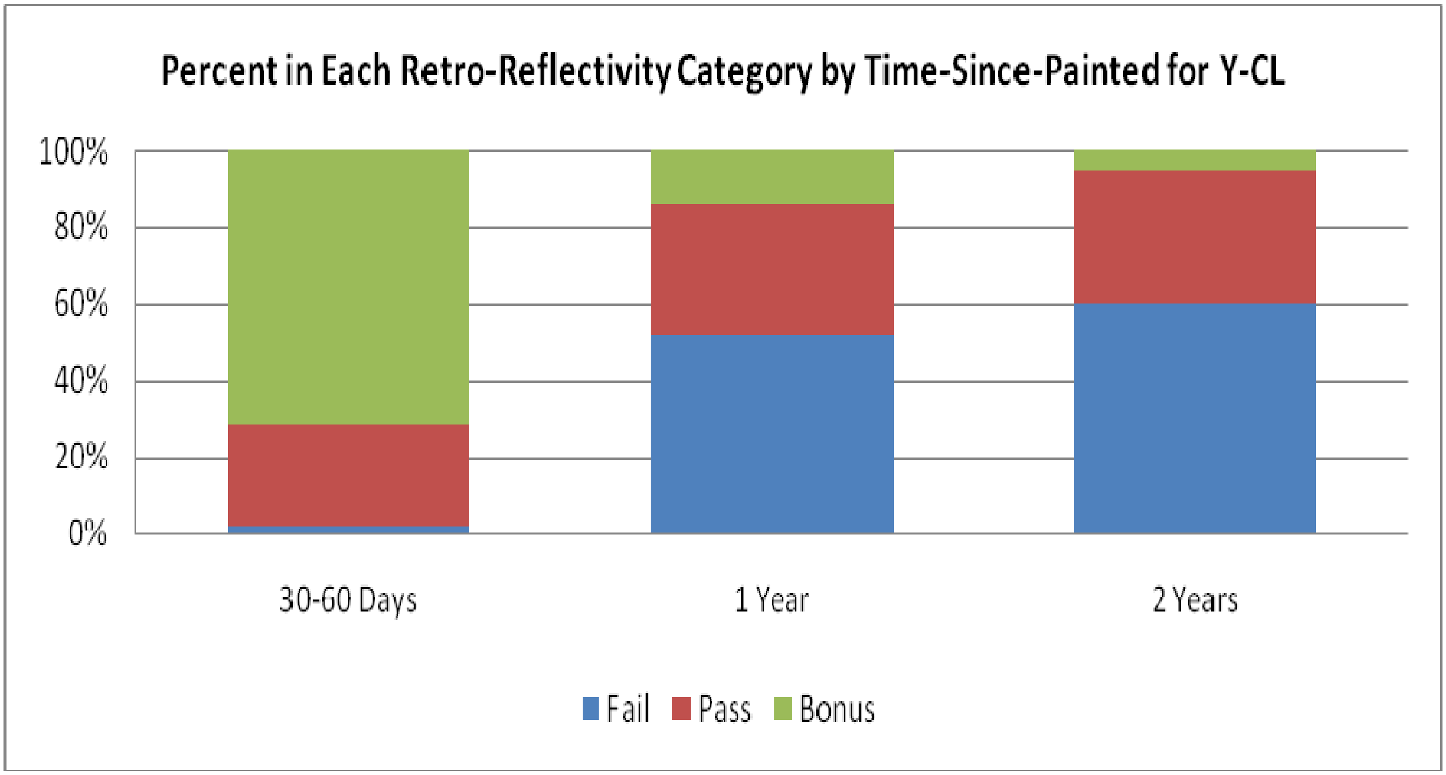
Appendix E-2.



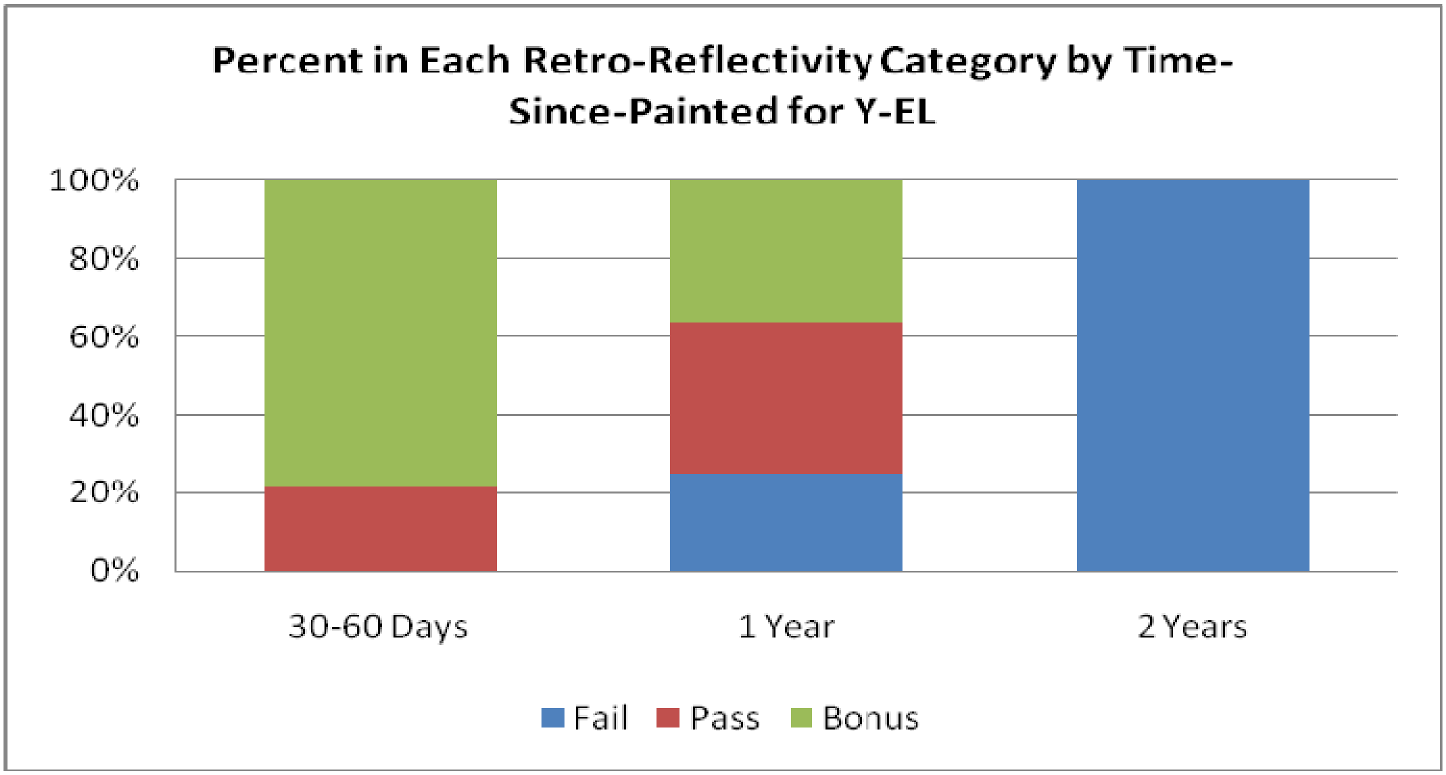
Appendix E-3.



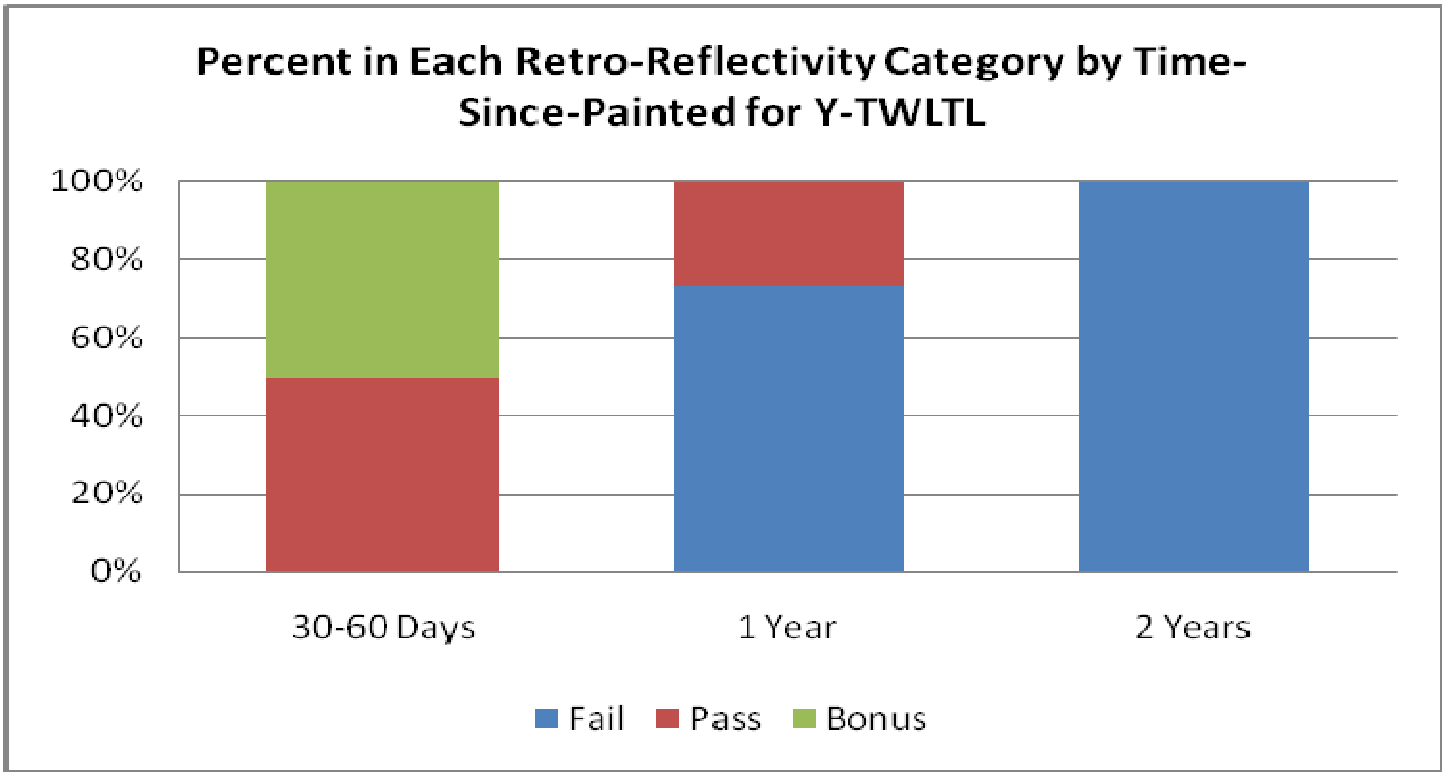
Appendix E-4.



Appendix E-5.



Appendix E-6.



APPENDIX F

Retroreflectivity by Various Factors

Appendix F-1a. Retroreflectivity and Number of Lines by ADT for 1-Year Old Lines

Multi-Lane White Edgeline		
ADT Range	Average Retro	Count
< 1,000	308	17
1,000 – 2,500	281	24
> 2,500	271	14

2-Lane White Edgeline		
ADT Range	Average Retro	Count
< 2,500	282	73
2,500 – 5,000	268	65
> 5,000	271	37

Yellow Centerline		
ADT Range	Average Retro	Count
< 10,000	176	56
10,000 – 20,000	164	78
> 20,000	180	100

Appendix F-1b. Retroreflectivity and Number of Lines by ADT for 2-Year Old Lines

Multi-Lane White Edgeline		
ADT Range	Average Retro	Count
< 1,000	332	1
1,000 – 2,500		0
> 2,500	248	1

2-Lane White Edgeline		
ADT Range	Average Retro	Count
< 2,500	234	8
2,500 – 5,000	309	6
> 5,000	266	10

Yellow Centerline		
ADT Range	Average Retro	Count
< 10,000	162	20
10,000 – 20,000	146	15
> 20,000	162	20

Appendix F-2a. Retroreflectivity and Number of Lines by ADT and Lane Width for 1-Year Old Lines

ADT Range	Lane Width (feet)	Retro	Count
< 1,000	< 10	178	20
	10	188	9
	> 10	161	3
1,000 - 2,500	< 10	155	18
	10	164	13
	> 10	166	8
> 2,500	< 10	176	2
	10	193	22
	> 10	185	45

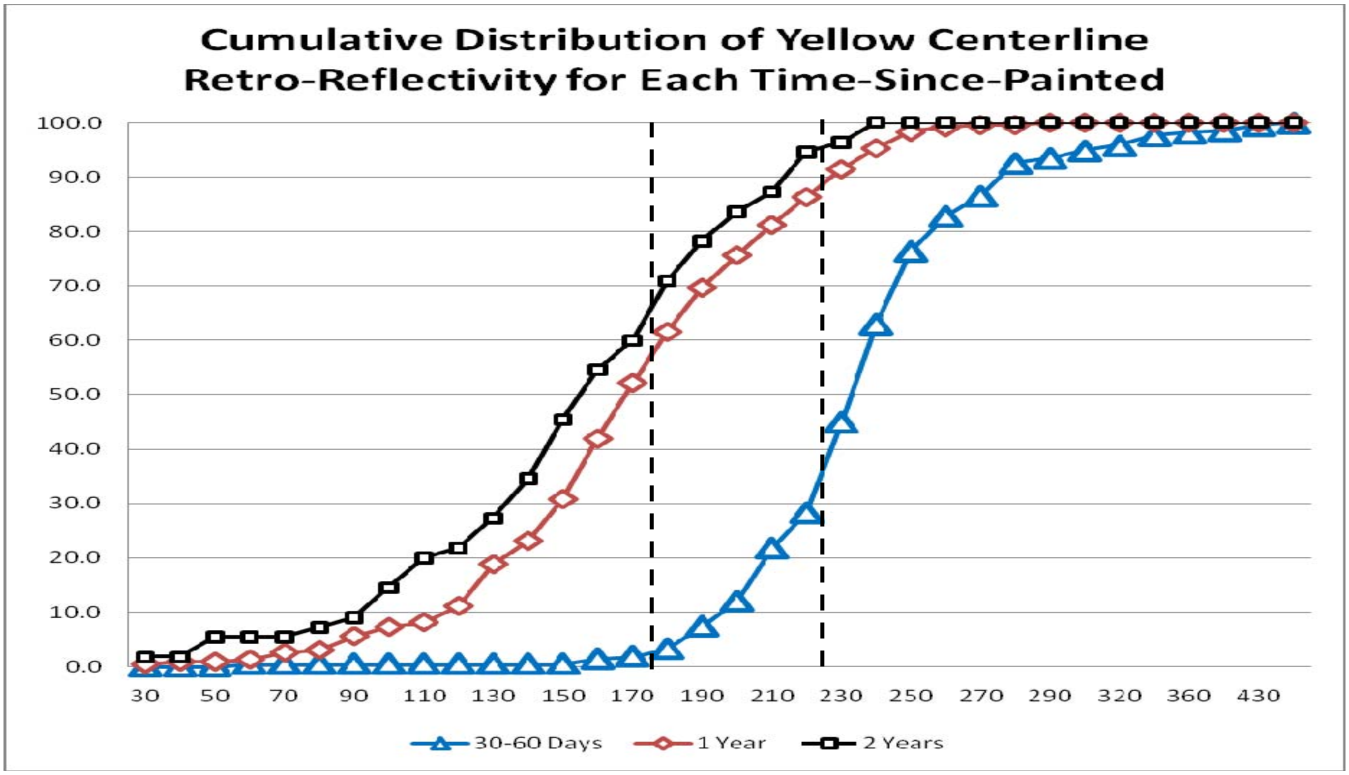
Appendix F-2b. Retroreflectivity and Number of Lines by ADT and Lane Width for 2-Year Old Lines

ADT Range	Lane Width (feet)	Retro	Count
< 1,000	< 10	165	5
	10	145	3
	> 10	191	2
1,000 - 2,500	< 10	149	2
	10	166	6
	> 10	168	4
> 2,500	< 10		0
	10	138	7
	> 10	192	7

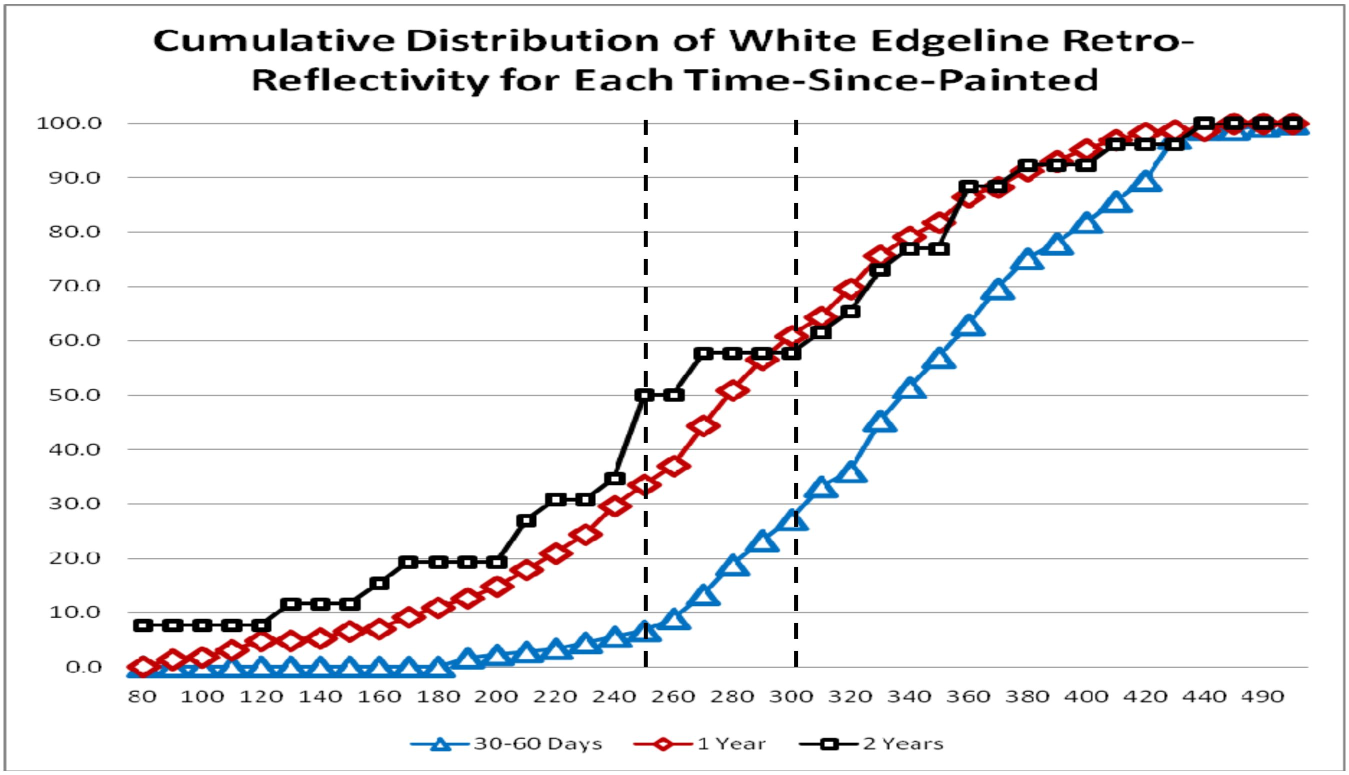
APPENDIX G

Cumulative Distributions by Line Type

Appendix G-1.



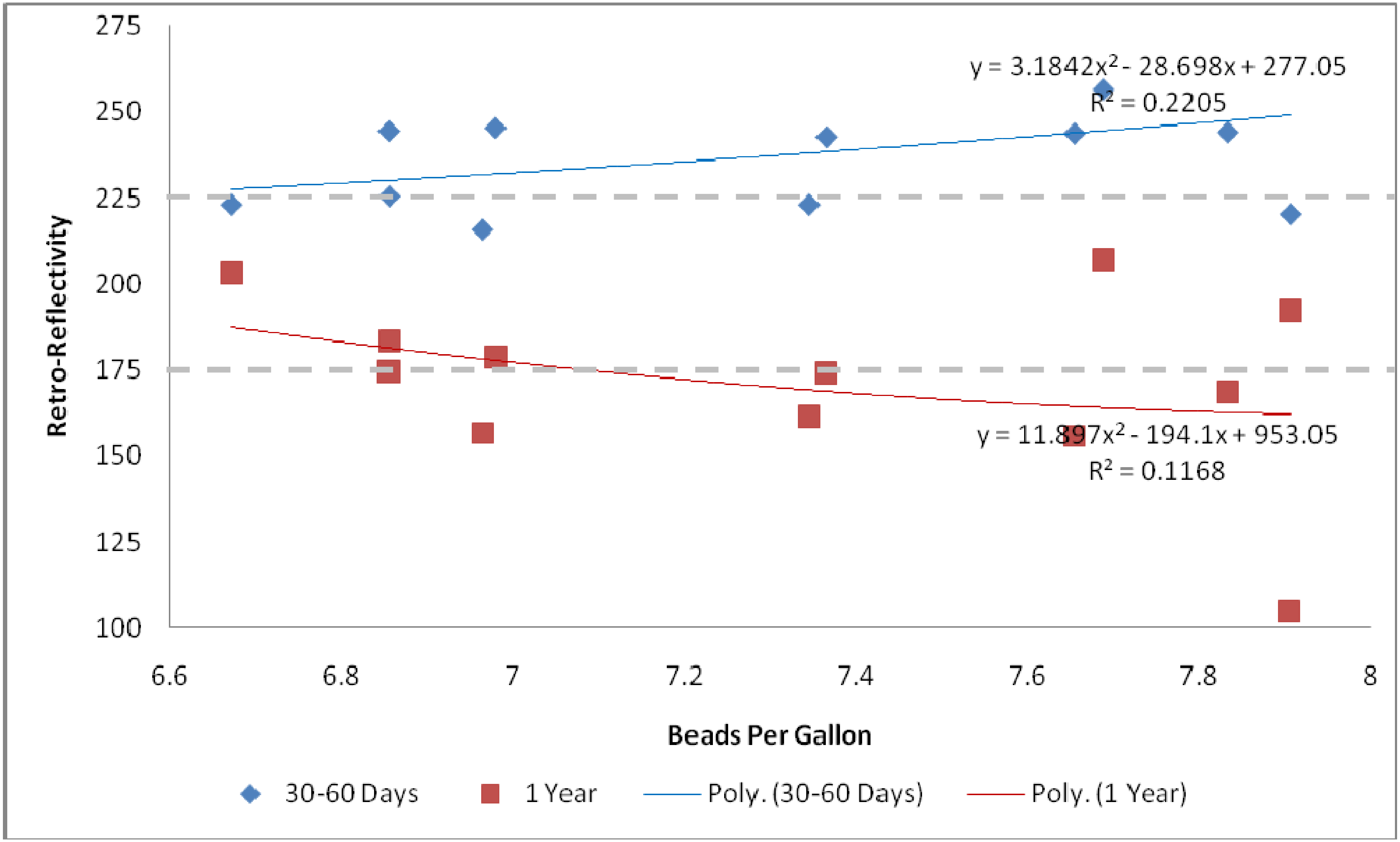
Appendix G-2.



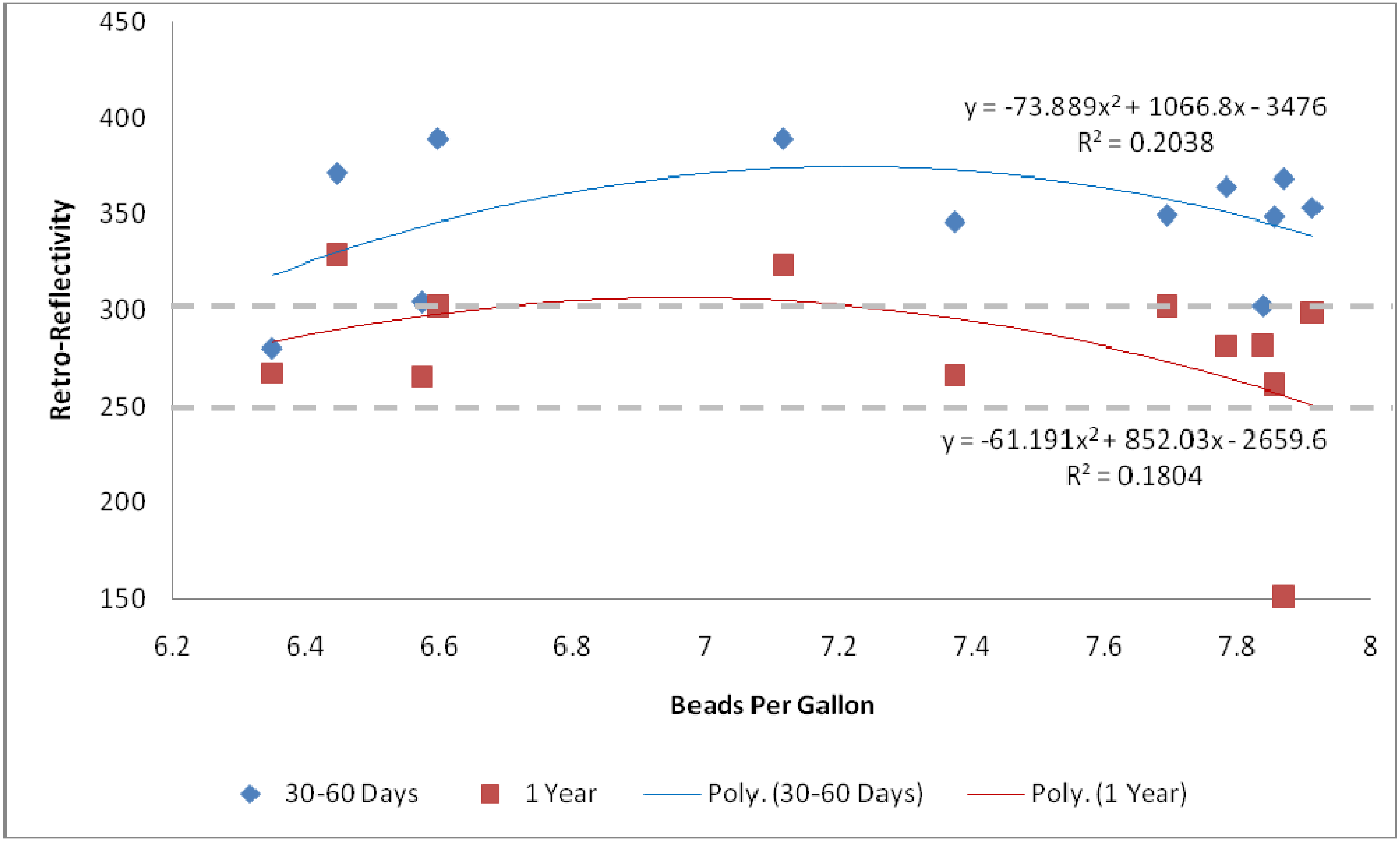
APPENDIX H

Retroreflectivity versus Beads per Gallon

Appendix H-1. **Retroreflectivity versus Pounds of Beads per Gallon for Yellow Centerlines (based on highway district data)**



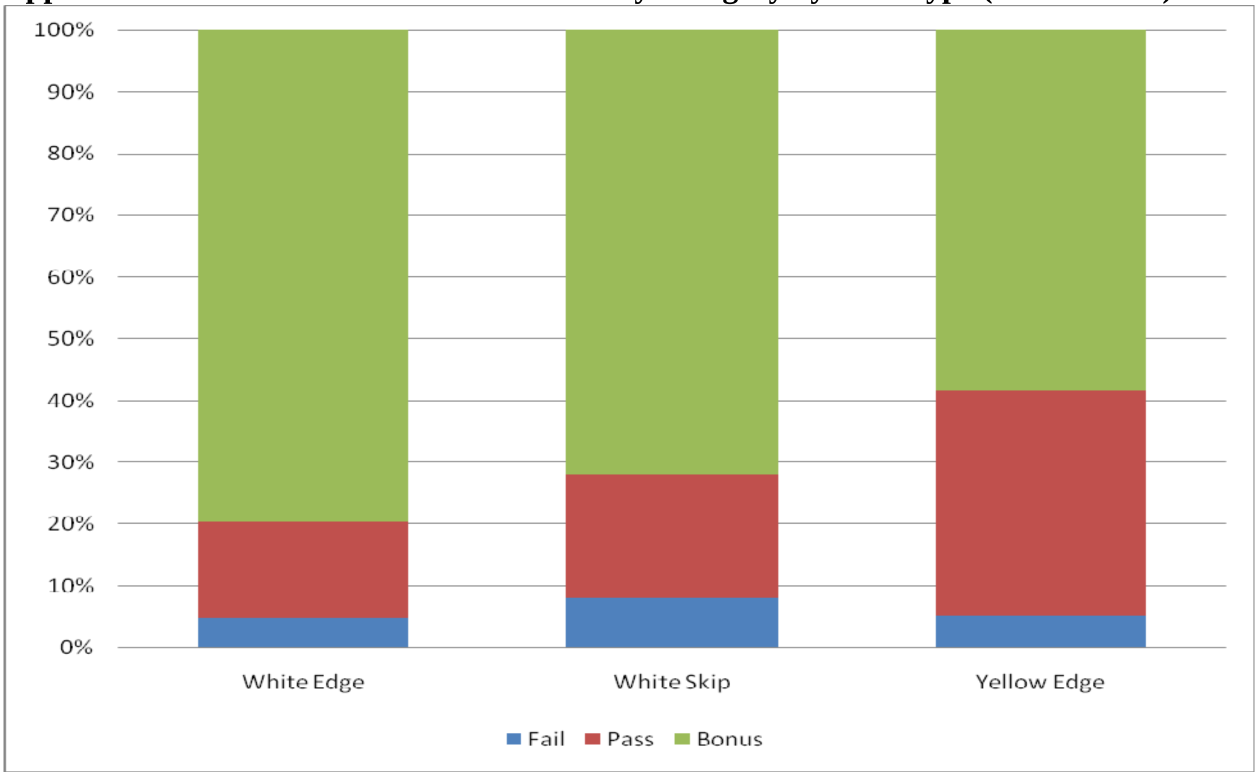
Appendix H-2. Retroreflectivity versus Pounds of Beads per Gallon for White Edgelines (based on highway district data)



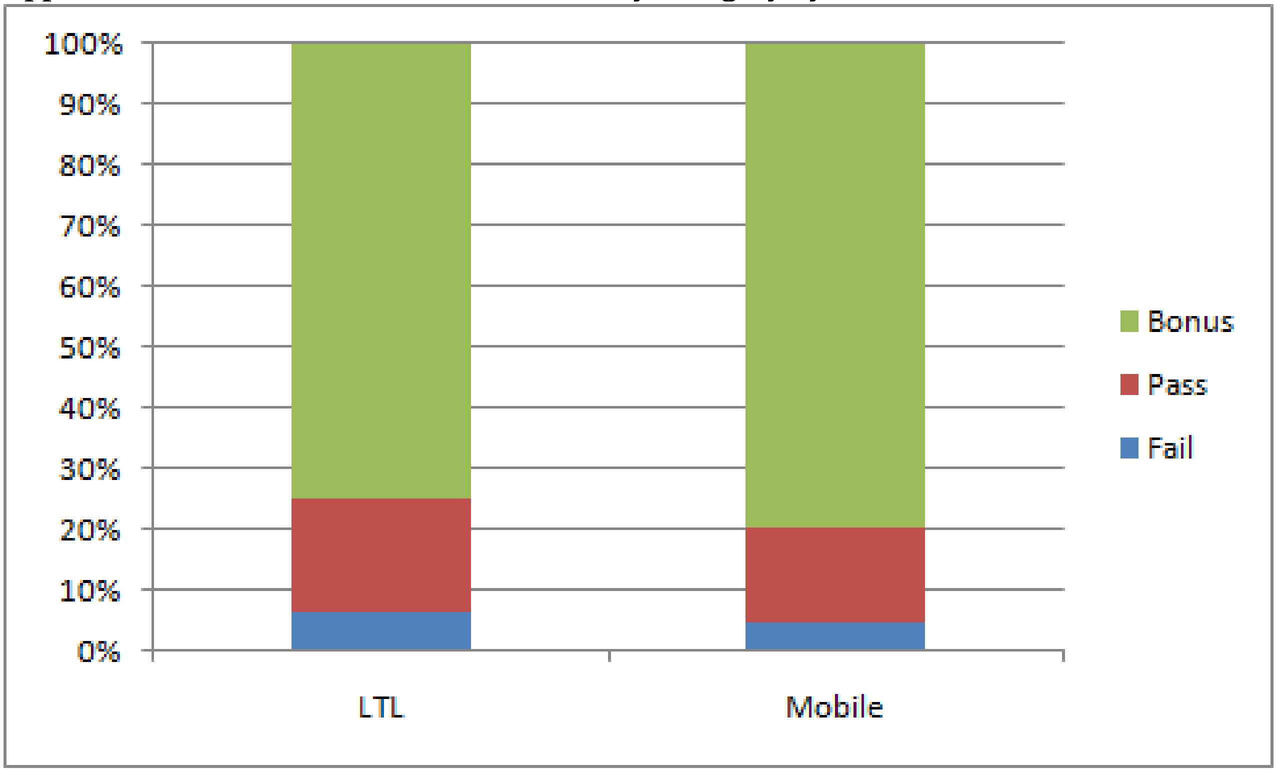
APPENDIX I

Mobile Data Summary

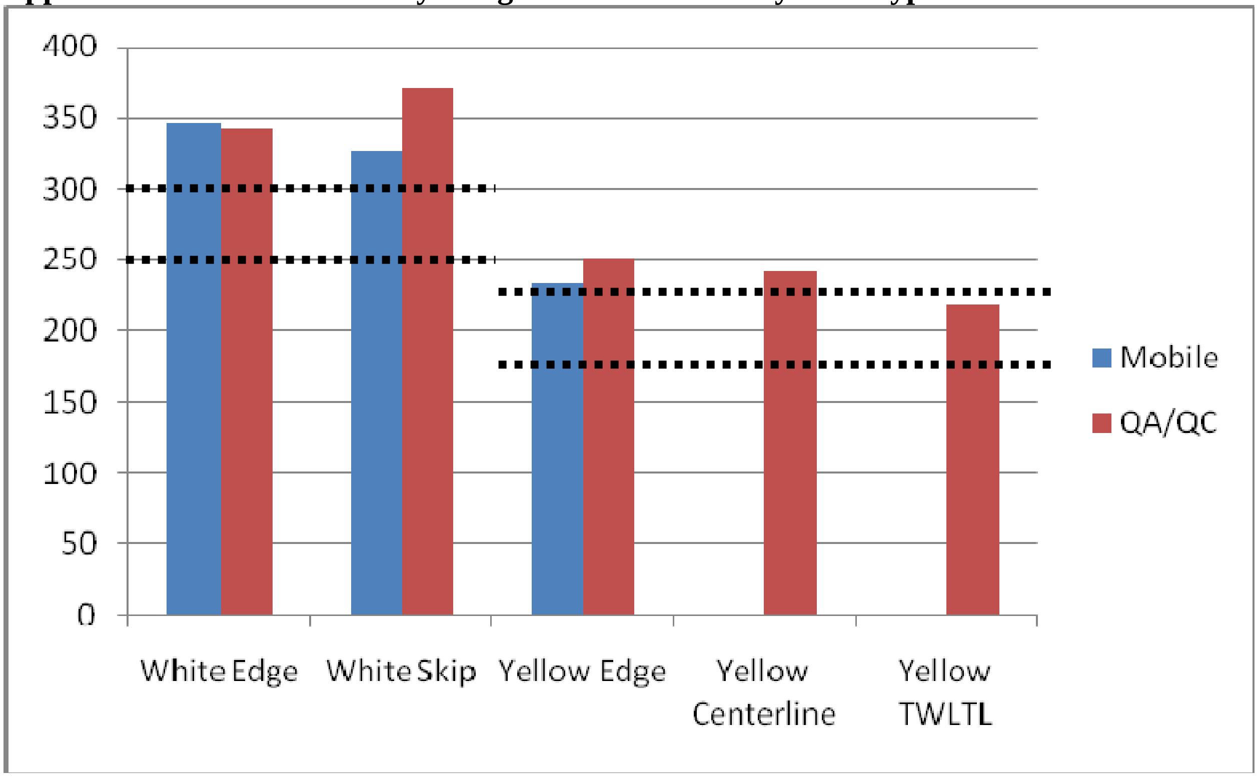
Appendix I-1. Percent in each Retroreflectivity Category by Line Type (Mobile Data)



Appendix I-2. Percent in each Retroreflectivity Category by Collection Method



Appendix I-3. Retroreflectivity using Mobile and LTL by Line Type



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