STATE OF FLORIDA

Mobile Retroreflectivity Unit (MRU) Surveying of Maintenance Rating Program (MRP) Sites

Research Report
FL/DOT/SMO/06-491

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January 2006

STATE MATERIALS OFFICE

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PAVEMENT MATERIALS SYSTEMS

The Pavement Material Systems section provides the Department with the technical expertise to ensure safe and durable pavement systems. This section interacts and partners with other central and district offices, the Federal Highway Administration, pavement industry, and other stakeholders. The Pavement Material System's Mission, Vision, and Value Statements are:

Mission
Make Florida's pavements safer, last longer, and perform better.

Vision
The best pavements in the country.

Values
Do it R.I.T.E (Respect, Integrity, Teamwork, and Excellence), Now!

To learn more about our people, functions, and services, we invite you to visit us at:

http://www.dot.state.fl.us/statematerialsoffice/pavement/pavementhome.htm.

EXECUTIVE SUMMARY

Pavement markings provide a level of safety and comfort for drivers, but they must be replaced periodically due to deterioration. A performance-based pavement marking maintenance specification is potentially more cost efficient and safer than using solely a material-based marking specification, however a performance specification requires the periodic assessment of pavement marking retroreflectivity. While pavement marking assessments are tedious and potentially hazardous when using handheld retroreflectometers, mobile-based retroreflectometers may assess markings at highway speeds which improves both safety and provides continuous retroreflectivity measurements over a significantly larger area. Thus, the condition of Florida's roads can be more accurately assessed.

The present document summarizes information obtained from a surveying of Maintenance Rating Program (MRP) sites by FDOT's newly acquired Mobile Retroreflectometer Unit (MRU). A total of 16 sections of Alachua County roadways were surveyed by the MRU. Data was analyzed and compared against visual surveys conducted by the district maintenance office. The information is presented in simple graphical and tabular format for quick reference.

PART I:

MOBILE RETROREFLECTIVITY OVERVIEW

OBJECTIVE

A rigorous study encompassing the surveying of over 1,400 miles of pavement striping was undertaken to explore the possibilities of using the Florida Department of Transportation's (FDOT's) newly acquired Mobile Retroreflectomer Unit (MRU) to evaluate roadway sections in conjunction with the existing Maintenance Rating Program (MRP). The aim of this study was quantitatively evaluate the retroreflectivity of pavement striping to supplement and compare with the subjective ratings which are currently conducted through visual surveys. Ultimately, the goal is to provide industry and the department a more objective and rapid way to convey the performance of the pavement striping.

BACKGROUND

The state of Florida has just over 12,000 centerline miles of roadway [1]. This translates into approximately 41,000 lane miles that need to be accounted for in order to ensure the safety and comfort of the driving public. While there are several important concerns with roadway upkeep such as pavement condition and speed control, pavement markings are also of concern. Pavement markings provide the directional guidance to safely travel roads in various conditions. The issue of pavement markings for traffic control is not a new one. The first known traffic control device was a grouping of colorful rocks delineating rows of traffic on a road near Mexico City around 1600AD [2]. The height of the industrial period brought about an onslaught of vehicles and traffic, and thus created a need for traffic control devices. While there were earlier instances of stop lines and crosswalks, the first use of longitudinal pavement markings in the United States arose in the 1920s as automotive traffic began to increase. Fortunately, the rocks of yesterday have become the much more dependable pavement markings of today.

Although research efforts have continued to improve the durability of pavement markings, their effectiveness is limited by their visibility. It is known that vision deteriorates as one grows older and there are typically higher accident rates among older drivers and those driving at night [3]. Drivers have come to depend on these pavement markings as guides, thus maintaining marking visibility may be significant to reducing the number of nighttime accidents and for driver comfort

Nighttime visibility of markings is typically provided through proper use of lighting and the ability of pavement markings to reflect headlamp light back to the driver (retroreflectance). Since lighting requires additional operating cost, it is used only in selected areas. Thus, the nighttime visibility of pavement markings is primarily dependent on their retroreflectivity.

The retroreflectance of pavement markings generally decreases over time for a variety of reasons such as abrasion by traffic, sun and heat exposure, application methods, material type and chemicals spilled on the road surface. Thus in order to ensure safety, a prescriptive specification has typically been employed for marking maintenance. Under this specification, the type of marking material and the method of application are controlled. The marking is then replaced after a predefined interval based on previous wear data. This tends to sacrifice either cost or safety since the markings are either replaced while still providing adequate service for drivers or after the retroreflectance has deteriorated to a point that they are no longer visible at night. For a performance specification, continuous assessment over the life of the markings is necessary to ensure their visibility and reduce unnecessary costs of remarking. There are several methods commonly used to assess the retroreflection of pavement markings such as visual nighttime inspection, using a handheld retroreflectometer, or using a mobile retroreflectometer. Ensuring the reflectancy of an entire state roadway system is both tedious (if not impossible) and dangerous when using the handheld instruments currently required by many state agencies. Thus pavement marking management systems typically do not assess an entire state roadway system. Based on the number of miles of pavement markings statewide, the safety of the operator and the possible introduction of operator bias, state-of-the-are mobile retroreflectometer units (MRUs) are gaining popularity among roadway engineers.

TESTING EQUIPMENT

The present report focuses on retroreflectivity data collected using a device commonly referred to as a "mobile retroreflectometer unit", or MRU. The present state-of-the-art retroreflectometer is fully automated. It consists of a full-sized van and a laser based retroreflectometer scanning device which can be mounted to either side of the vehicle. A photographic illustration of a mobile retroreflectometer unit is shown in Figure 1. The vehicle supplies all the electrical power required to perform testing with the retroreflectometer. Additionally, the vehicle houses all support systems, including a control panel and a data acquisition system to collect and store information from the traveled surface. A distance-measuring instrument (DMI) is provided to determine the position along the road. This longitudinal distance measurement is needed to associate the precise locations of the retroreflectivity measurements. An onboard GPS system and video monitoring equipment are also housed in the vehicle.

Figure 1. A Photographic Illustration of a Mobile Retroreflectometer Unit.

The current accepted working standard for handheld retroreflective measurement described in ASTM E 1710 uses a "30 meter geometry" which was initially set by the European Committee for Normalization (CEN) [6]. The standard was created to simulate the nighttime visibility for an average driver in a passenger car. This takes the form of a 1.2-meter eye height and a 0.65 meter illumination height 30 meters away from a ground based target (Figure 2). The standard also calls for a 1.05 degree angle between the emission source and the sensor. In order to use this geometry, but allow for a more user friendly application, many handheld and mobile CEN compliant units maintain the angles found in the 30 meter geometry, but typically monitor at a distance much less than 30 meters. FDOT's Mobile Retroreflectomer Unit uses a 1/3 rd scale of the standard 30 meter geometry.

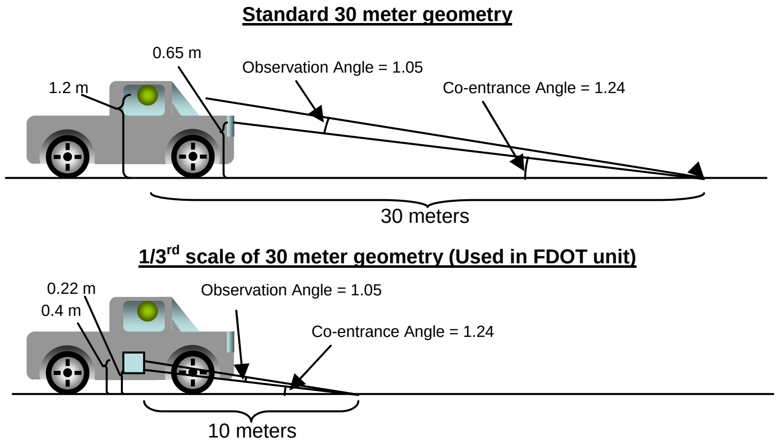

Figure 2. Standard 30 Meter Geometry and a 1/3rd Scale 30 Meter Geometry

ASTM E 1710 also specifies that handheld measurement must be taken in the direction of travel, the roadway must be dry and clean, and the retroreflectometer must be calibrated nearly every hour with a calibration standard [7]. In order to reduce field testing time, the standard calls for measurement stations whose spacing is based on the length of road and the type of marking. The main advantage of the MRU is that is preserves the same geometry as the handheld units, but can take many more measurements in the same amount of time, translating into a more accurate representation of overall retroreflectivity.

The principal component of the MRU is the laser scanning unit. Scanning is necessary for vehicle wander and to partially account for curves in the road, and is achieved by reflecting a helium neon laser off of a rotating mirror mounted inside the device (Figure 3). The retroreflected laser then returns to the unit where it is directed through frequency filters to reduce the effects of sunlight and other errors before entering a detector. The system as a whole may provide up to 18 scans a second and each scan acquires 200 sampling points from which the coefficient of retroreflectance is calculated

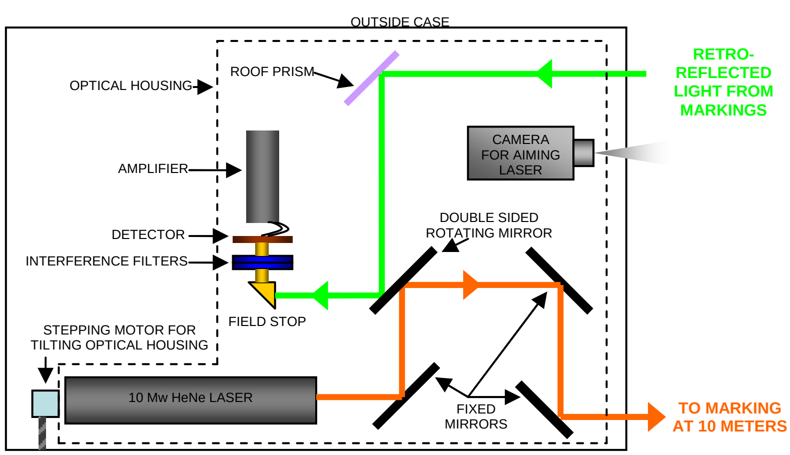

Figure 3. Internal Operations of the Retroreflectometer

DEFINING THE UNITS OF RETROREFLECTIVITY

Retroreflectance measurements are typically given in terms of millicandellas per meter squared per lux [4, 5]. This unit is essentially a fraction of emitted light reflected back into the direction of the light source. The significance of this unit may be found by studying the definitions of various terms associated with light such as luminous intensity, luminous flux, illuminance and luminance.

Luminous intensity is the intensity of light emanating from a source in a given direction (Figure 4). The magnitude of this vector is measured in terms of candles (cd), where 1 cd is the intensity of 1 candle. As an example a typical 100W light bulb emits an average of 110cd.

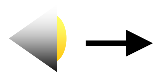

Figure 4. Luminous Intensity

The luminous flux is the sum of the luminous intensity of a source in all directions (Figure 5). Thus if the intensity is isotropic (emits evenly in all directions) then one can multiply by 4π to arrive at the luminous flux. Luminous flux is typically given in terms of lumens (or lm). As an example, the same 100W incandescent light bulb emits around 1400 lm.

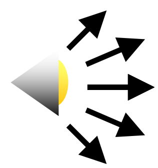

Figure 5. Luminous Flux

An increased value for the luminous intensity for a light source may not correspond to a bright image. This may be due to the area over which the luminous intensity is spread. Luminance is the luminous intensity of an emitting object divided by the plan area of the emitting object. It is typically expressed in terms of cd/m^2.

Illuminance is the metric that is typically used to describe a lighting level on a particular surface such as a table, or a wall. Illuminance is the luminous flux received on a plane per unit area of that plane. While the units are typically given in lux (lm/m^2), the plane may be oriented in many different angles, thus orientation of the plane should be given. It is important to note that this may not be based on what is seen by the observer on the plane as some surfaces (such as a table) may have a coating, or color which does not reflect its illumination.

Thus retroreflectance is the luminance (or brightness) of an object as detected by a sensor divided by the illuminance of the object by a light source.

Retroreflectance = Luminance/Illuminance = $\left(\frac{cd}{m^2}\right)\cdot(lux)^{-1} = \left(\frac{cd}{m^2}\right)\cdot\left(\frac{m^2}{lm}\right) = \frac{cd}{lm}$. (eq. 1)

The areas cancel since the area illuminated is the same as the area used to calculate the brightness. Since lumens in this calculation refer to the total luminous flux of the light source and cd is the luminous intensity of an area of interest, retroreflectivity is a measure of the fraction of the reflected light source intensity as received by the sensor.

CALIBRATION

To ensure measurement precision, calibration of the equipment is performed each time testing is performed with the unit. The calibration procedure calls for placing a manufacturer provided striping standard with a known retroreflectivity 10 meters in front of the unit on a flat surface and measuring its retroreflectivity (separate standards are used for the measurement of yellow and white striping). Figure 6 shows this process. A correction factor is then applied (if necessary) to the measured retroreflectivity to ensure good correlation with the standard used. Calibrations are performed each time a new stripe is run and each time the unit is moved from one side of the vehicle to the other.

Figure 6. Placement of Striping Standard for MRU Calibration

Additionally, the retroreflectivity of the calibration standards used are verified on a monthly basis by taking 40 measurements on each standard using an FDOT approved handheld retroreflectometer. The average of these readings is used as the calibration value.

The distance measuring instrument (DMI) is affected by factors such as tire pressure and tread wear. Therefore, the tire pressure is monitored frequently and the DMI is calibrated monthly on a “measured mile” to compensate for tread wear.

PART II:

SUMMARY AND RESULTS

DISCLAIMER

The Mobile Retroreflectometer Unit (MRU) is still in the research stages. Further study and comparison needs to be done to prove the accuracy and reliability of the testing equipment and analysis methods. Results presented in this report are solely the opinions of the authors based on preliminary data and do not constitute the endorsement of any guidelines or specifications related to the MRU, MRP, or pavement striping management practices.

MAINTENANCE RATING PROGRAM OVERVIEW

Once a newly placed pavement striping is accepted, it is considered a part of the Florida inventory of pavement markings and is assessed as a part of the state's Maintenance Rating Program (MRP). The MRP was enacted in Florida to provide feedback to the state legislature about the current condition of inventoried Florida roadways. In this program, several 0.10 mile long sites 4 distinct areas (Rural limited, Rural arterial, Urban limited, Urban arterial) are chosen at random for each district by the Central Office in Tallahassee three times a year.

The MRP takes into consideration five categories which include the pavement, roadside, traffic services, drainage, and aesthetics (or vegetation). Each item to be checked is given a unit value and all values are summed for a maximum total of 100. Anything less than 80 is subject for improvement. Pavement markings are assessed as a traffic service and are checked for distress, contamination, nighttime and daytime visibility. Nighttime visibility is assessed by driving at night at the rated speed with headlights on low beam and checking to see if the pavement marking can be seen 160 feet ahead of the vehicle (4 skip lines). Anything more than 10% deficiency of either the width of the stripe, or the nighttime visibility will fail the test. The individuals checking the retroreflectivity go through a yearly course to ensure consistency in measurements.

TESTING DETAILS

To form the basis of this study, 79 specific sites along 16 unique sections of Alachua Country roadway were selected for evaluation by both the MRP and MRU. Three distinct facility types were included in this investigation: Type 1 – Rural limited, Type 2 – Rural arterial and Type 4 – Urban arterial.

It is important to note the results reported in this section are based upon two significantly different evaluation processes for both the MRP and MRU ratings. More specifically, the MRP calls for evaluating only a few specific sites (each site is 1/10th mile long) along each section of roadway. The MRU is designed to collect continuous data at user defined recording intervals. Therefore, the same data collection practice that the MRP uses is not a feasible one to use with the MRU. For this project, MRU data was collected along the entire length of each section and report retroreflectivity statistics (e.g. average, min, max, std. dev.) in 0.10 mile increments. As an example, if mile post 1.50 was requested on a specific section, the MRP would evaluate and report the area from mile post 1.45 to 1.55

whereas the MRU would report the result of the average retroreflectivity value for each stripe in the area between mile post 1.40 to 1.60.

Additionally, MRP striping evaluation does not consider retroreflectivity as the sole basis of evaluation as the MRU does. The physical condition of the striping is also evaluated (cracking, peeling, delamination, contamination, etc.), and it's entirely possible that *a stripe can have cracking and deterioration which would cause it to fail the MRP but still have a good enough retroreflectivity value that it would pass by MRU standards.*

Reported MRP results also differ from those of the MRU in terms of what is reported. While the MRU results report retroreflectivity statistics for each stripe incrementally along the MRP site, the MRP reporting simply gives a pass or fail (Y or N) rating for striping. This pass or fail rating is not necessarily indicative of the condition of all the striping as a whole, but can be based solely on the condition of one stripe in one section of the site evaluated. More specifically, one of the major MRP failure criterions is if more than 10% (or 1/100th of a mile since a site is 1/10th of a mile) of an evaluated stripe shows a defect, the entire site fails. For example, if a vehicle skidded and left a 60 foot tire track along a single stripe at an MRP site, the entire section would be failed.

STRIPING NOMENCLATURE

A standard naming convention was devised to identify each stripe regardless of the number of lanes, whether or not the opposing traffic lanes are divided, any changes in the number of lanes along the section, etc. Table 1 shows an explanation of the nomenclature used.

Table 1. Explanation of Striping Nomenclature

Coding	Description of Coding
L	Denotes either the South or West direction of travel
R	Denotes either the North or East direction of travel
EL	Denotes the white edge line as the evaluated stripe
CL	Denotes the yellow center line as the evaluated stripe. **All** yellow striping is considered as a center lines. Thus yellow skip lines are considered center lines and not skip lines.
SL	Denotes the white skip line as the evaluated stripe. A # (1, 2, 3, etc.) is placed at the end of the L or R to denote how many skip lines there are along the section. They are numbered starting at the one closest to the center line and work outward.

As an example, the Northbound skip line closest to the center line would be named R1 SL, while the edge line in the same direction would be named R EL. Figures 7-10 show examples of the naming convention for several different scenarios. Consider the right lanes to be running north for all examples.

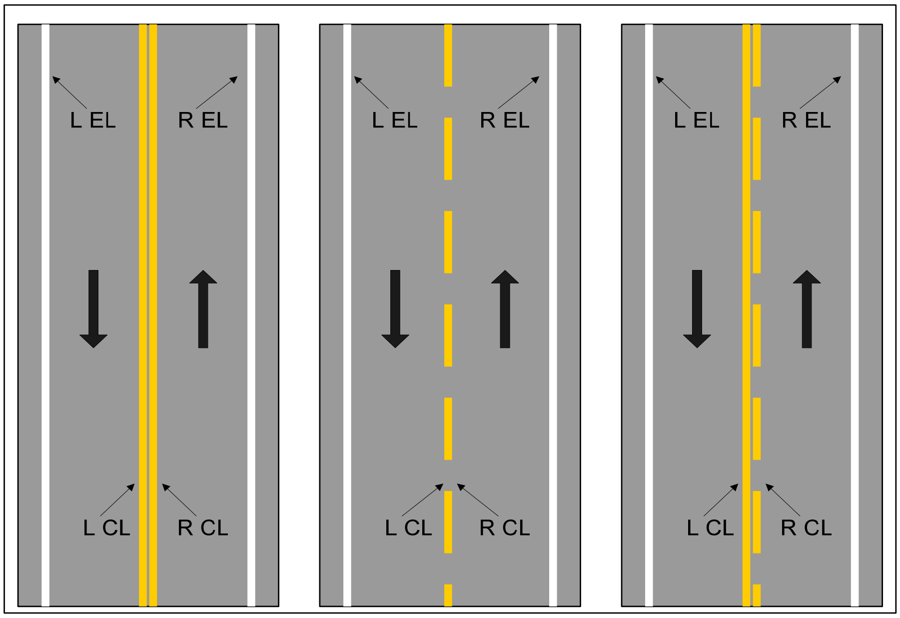

Figure 7. Nomenclature for 2 Lane Undivided Road

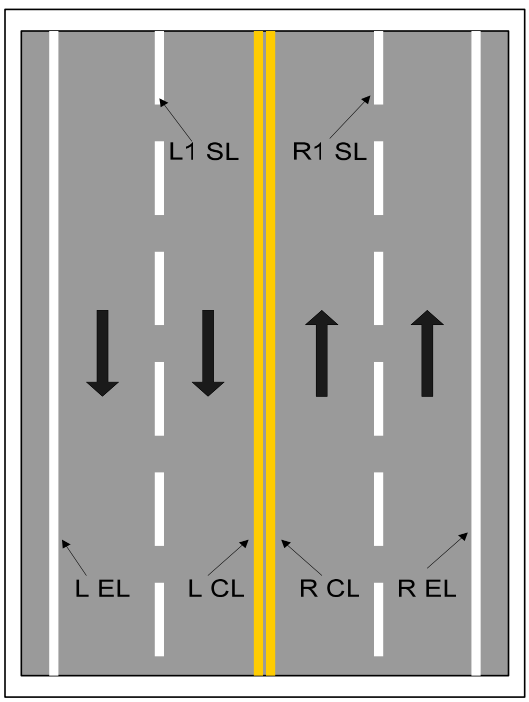

Figure 8. Nomenclature for a 4 Lane Undivided Road

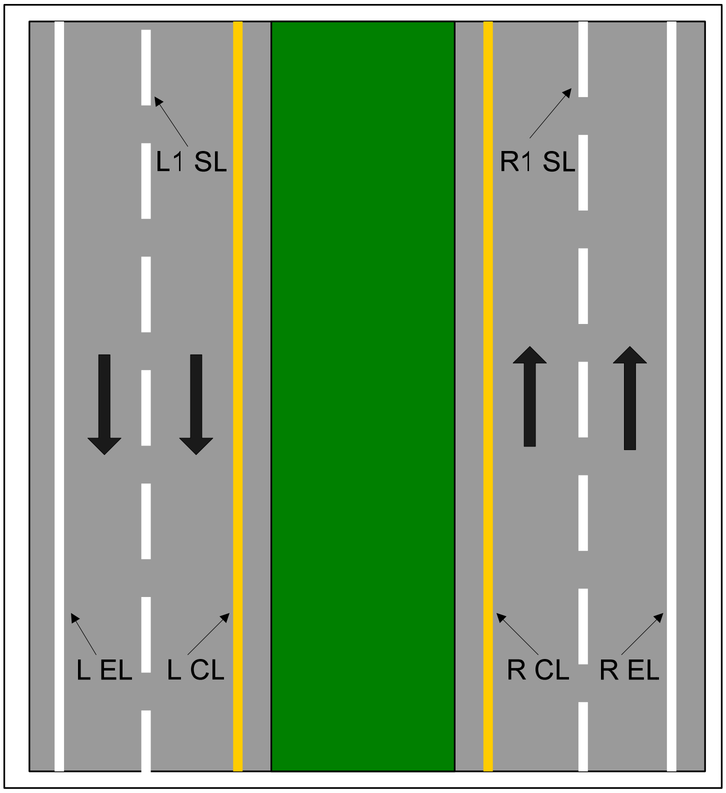

Figure 9. Nomenclature for a 4 lane Divided Road

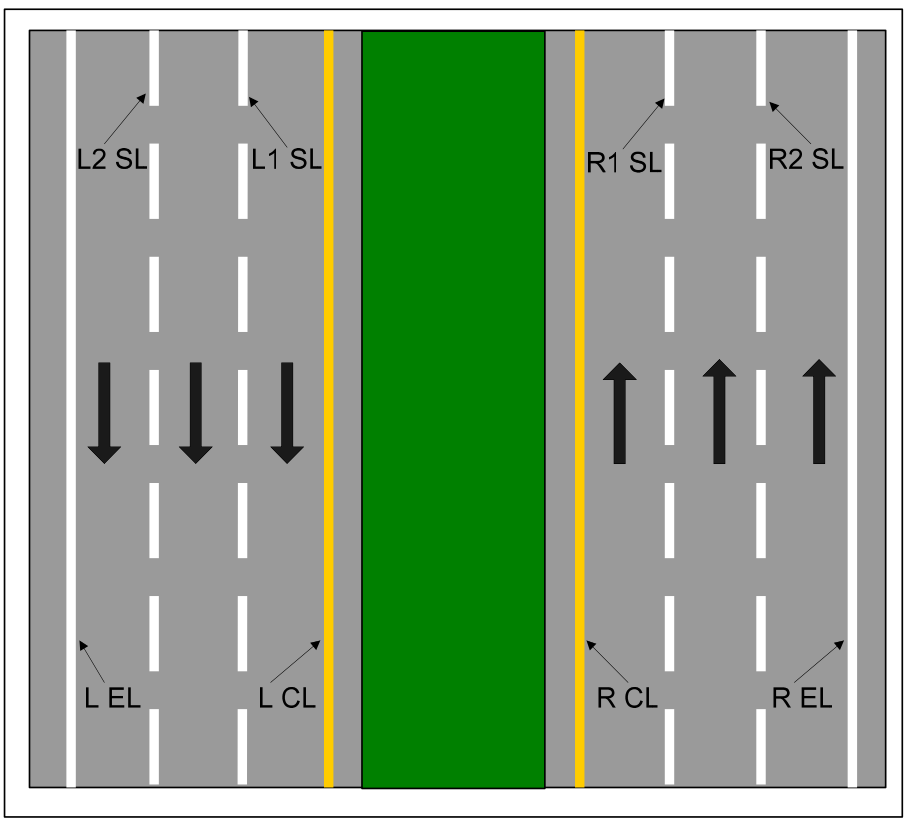

Figure 10. Nomenclature for a 6 Lane Divided Road

RESULTS

The following is a summary of the results of the MRP rating and retroreflectivity values for each site and section tested. A threshold of 150 mcd/m^2/lux was set to determine whether or not the stripe passed by MRU standards. This threshold is not based on any current standard or practice, but merely the opinions of the authors in regards to sufficient retroreflectivity. It should be understood that raising or lowering this threshold would significantly affect the number of sites which are passed or failed by the MRU. Retroreflectivity values which are less than 150 mcd/m^2/lux are highlighted in yellow and values below 120 mcd/m^2/lux are highlighted in red. To make MRU and MRP results more closely related, a pass/fail rating was created based on the retroreflectivity results. If a single stripe is defined as failing at an MRP site (anything highlighted in yellow or red), the whole site failed. The results are separated by facility type.

Table 2. Results for Facility Type 1 (Rural Limited) MRP Sites

Section	Mile Post	DIR	Retroreflectivity (mcd/m^2/lux)								Pass MRP	Pass MRU
			L EL	L2 SL	L1 SL	L CL	R CL	R1 SL	R2 SL	R EL		
26260000	0.3	N/S	344	392	307	305	279	406	396	358	Y	Y
	1.5	N/S	344	265	331	263	270	555	438	264	Y	Y
	2.5	N/S	418	527	374	262	319	415	362	317	Y	Y
	4.2	N/S	291	327	320	211	275	443	275	221	Y	Y
	5.5	N/S	276	351	245	205	233	423	297	301	Y	Y
	7.1	N/S	304	382	287	278	332	469	314	307	Y	Y
	7.3	N/S	308	414	244	286	344	463	253	311	Y	Y
	8.6	N/S	293	182	182	227	207	327	178	228	Y	Y
	10.2	N/S	144	489	293	273	299	485	218	192	Y	N
	11.7	N/S	273	398	360	223	282	376	226	278	Y	Y
	12.4	N/S	306	527	527	210	214	431	356	261	Y	Y
	12.9	N/S	319	515	518	233	200	426	416	288	Y	Y
	13.0	N/S	311	512	452	233	181	443	445	298	Y	Y
	14.2	N/S	248	480	216	290	228	587	396	292	Y	Y
	15.1	N/S	224	305	314	225	199	509	240	133	Y	N
	15.3	N/S	270	338	351	226	232	479	212	231	Y	Y
	16.3	N/S	227	384	197	205	250	430	262	222	Y	Y
	17.0	N/S	282	527	656	236	314	686	637	301	Y	Y
	17.8	N/S	280	278	220	252	266	522	373	271	Y	Y
	20.2	N/S	316	429	319	265	212	509	392	242	Y	Y
	21.0	N/S	255	479	246	238	240	472	322	249	Y	Y
	22.1	N/S	250	378	231	203	334	467	449	370	Y	Y
	22.4	N/S	258	427	259	238	298	377	372	293	Y	Y
	24.7	N/S	260	501	334	224	223	556	533	325	Y	Y
	25.1	N/S	223	277	326	236	230	309	259	238	Y	Y
	29.2	N/S	326	512	408	267	274	593	509	303	Y	Y
	33.3	N/S	265	386	272	266	288	322	321	233	Y	Y
	34.2	N/S	321	409	458	231	291	452	397	229	Y	Y
	34.7	N/S	279	263	350	253	286	640	396	245	Y	Y

Table 3. Results for Facility Type 2 (Rural Arterial) MRP Sites

Section	Mile Post	DIR	Retroreflectivity (mcd/m^2/lux)								Pass MRP	Pass MRU
			L EL	L2 SL	L1 SL	L CL	R CL	R1 SL	R2 SL	R EL		
26005000	11.3	E/W	207		N/A	189	207	N/A		296	N	Y
	12.2	E/W	237		N/A	154	152	N/A		240	N	Y
	12.6	E/W	244		N/A	168	164	N/A		279	Y	Y
26010000	5.5	N/S	164		354	158	167	286		391	N	Y
	6.9	N/S	167		399	182	177	314		443	Y	Y
	8.1	N/S	141		354	200	153	296		498	Y	Y
	8.4	N/S	155		339	186	149	320		537	---	N
26020000	9.4	N/S	383		181	201	226	196		412	---	Y
	16.9	N/S	340		274	237	179	202		446	---	Y
26050000	12.0	N/S	306		240	162	188	274		285	Y	Y
26060000	1.3	N/S	224		184	170	109	232		310	N	N
	19.1	N/S	216		325	161	163	236		287	Y	Y
26080000	16.1	E/W	276	N/A	N/A	142	157	N/A	N/A	289	Y	N
26090000	7.9	E/W	256	N/A	N/A	420	466	N/A	N/A	195	N	Y
	9.8	E/W	306	N/A	N/A	199	236	N/A	N/A	271	Y	Y
26110000	3.2	N/S	418			292*	292*			327	Y	Y
	4.7	N/S	436			287*	287*			386	Y	Y
	4.8	N/S	403			283*	283*			354	Y	Y
	5.1	N/S	360			262*	262*			379	Y	Y
	9.5	N/S	382			382*	382*			323	Y	Y
	11.2	N/S	434			357*	357*			384	Y	Y
26130000	16.7	E/W	175		N/A	143	151	N/A		281	Y	N
26220000	0.3	N/S	345		N/A	212*	212*	N/A		259	Y	Y

Notes:

******* *Data was collected along the center line in one direction only. Thus, the same value is reported for L CL and R CL.*

N/A *The stripe exists somewhere along the section, but it does not exist in the area of the MRP site.*

--- *An alternate site was chosen and was not evaluated by the MRP.*

Table 4. Results for Facility Type 4 (Urban Arterial) MRP Sites

Section	Mile Post	DIR	Retroreflectivity (mcd/m^2/lux)								Pass MRP	Pass MRU
			L EL	L2 SL	L1 SL	L CL	R CL	R1 SL	R2 SL	R EL		
26003000	0.4	E/W	176		126	357	357	179		145	Y	N
	2.5	E/W	161		129	258	258	147		151	N	N
26005000	0.3	E/W	319		269	160	191	374		359	Y	Y
	1.6	E/W	322		223	195	308	316		448	Y	Y
	3.0	E/W	279		279	203	261	224		352	Y	Y
	5.0	E/W	325		272	221	280	260		343	Y	Y
	5.2	E/W	272		346	271	234	190		265	Y	Y
	7.0	E/W	329		258	138	185	224		296	N	N
	7.2	E/W	318		218	141	190	222		365	N	N
	9.5	E/W	256		200	162	144	216		314	Y	N
26010000	12.6	N/S	218		276	121	198	284		345	---	N
	14.8	N/S	N/A		270	140	135	299		N/A	Y	N
	15.1	N/S	86		261	131	125	270		222	Y	N
26020000	3.8	N/S	481		218	187	146	194		374	N	N
	4.6	N/S	430		245	155	151	175		364	Y	Y
	18.0	N/S	530		383	198	230	289		481	N	Y
	18.7	N/S	544		380	326	284	393		617	Y	Y
26030000	14.1	N/S	289			115*	115*			372	Y	N
26040000	1.5	E/W	N/A			155*	155*			N/A	Y	Y
26070000	2.9	E/W	323	N/A	N/A	235	175	N/A	N/A	313	Y	Y
	10.4	E/W	244	N/A	316	207	175	254	N/A	305	N	Y
	17.3	E/W	456	N/A	293	223	244	314	N/A	348	Y	Y
26080000	0.4	E/W	260	N/A	285	136	117	244	N/A	224	Y	N
26090000	11.1	E/W	316	N/A	291	351	280	261	N/A	312	N	Y
	12.5	E/W	317	N/A	330	335	284	239	N/A	228	Y	Y
26110000	0.2	N/S	255			309*	309*			171	Y	Y
26130000	0.7	E/W	N/A		222	158	185	236		N/A	Y	Y
	1.9	E/W	N/A		239	154	175	286		N/A	Y	Y
26250000	1.1	N/S	292	197	198	232	332	203	217	341	N	Y
	1.3	N/S	221	230	181	227	235	227	232	229	N	Y
	7.0	N/S	308	N/A	N/A	225	221	N/A	N/A	325	Y	Y

Notes:

* *Data was collected along the center line in one direction only. Thus, the same value is reported for L CL and R CL.*

N/A The stripe exists somewhere along the section, but it does not exist in the area of the MRP site.

--- An alternate site was chosen and was not evaluated by the MRP.

Tables 5 and 6 show the average retroreflectivity and number of stripes failures broken down by facility and striping type, respectively. For all facility types, center lines were observed to have the lowest average retroreflectivity. Consequently, center lines (yellow in color) were observed to have the highest rate of failure overall, as they failed twice as frequently as edge and skip lines combined. This is not surprising as white tends to be a better reflector of light than yellow. As a whole, yellow center lines have a lower retroreflectivity than white stripes from their initial places. Results also showed that facility type 4 (Urban arterial) roadways had stripe failures at more than twice the rate of the other facility types combined. However, it is important to note that facility type one results is based on a single roadway which has recently been resurfaced.

Table 5. Average Retroreflectivity by Facility and Stripe Type

	Retroreflectivity (mcd/m^2/lux)		
Facility Type	**Edge Line**	**Skip Line**	**Center Line**
1	276	388	253
2	314	278	210
4	314	252	209

Table 6. Stripe Failures by Facility and Stripe Type

Facility Type	Number of Failures		
	Edge	**Skip**	**Center**
1	2	0	0
2	1	0	4
4	2	3	12

The MRP evaluation yielded 14 sites which failed the striping evaluation criteria. As previously mentioned, retroreflectivity is only one factor which the MRP takes into consideration when evaluating striping. Condition, width, and contrast are also taken into account when stripes are evaluated during the MRP. Based upon the initial information provided by the MRP, the striping failure mechanisms could not be determined, making it very difficult to properly compare MRU and MRP results. To solve this, MRP evaluators and other FDOT personnel met to discuss the results and examine ways to properly compare the data.

In total, 79 sites were evaluated by both the MRU and MRP. Of these tested sites, 14 failed by the MRP and 15 failed according to the MRU rating criteria (below 150 mcd/m^2/lux). Five sites failed both evaluations while 54 passed both, meaning there was agreement in the pass/fail rating on 59 sites and disagreement on 20 sites. Thus, the same rating was given approximately 75% of the time.

MRP Site Failure Follow Up

As it turned out from the personnel collaboration, MRP evaluators log the method of striping failure during their evaluation as a standard practice. Typically, if something other than retroreflectivity causes the stripe to be failed, it will be noted on the rating sheets. If no note is provided, the failure was due to retroreflectivity. Striping is evaluated during the day and night. During the day, inspectors evaluate each site on foot, and they mainly look at stripe width and condition. If the site failed for one of these reasons, a nighttime evaluation is not performed since the site has already failed. Retroreflectivity is principally assessed during nighttime evaluations (since retroreflectivity is vital for nighttime visibility). Thus, the results in Table 7 should be carefully evaluated. If a site failed for a reason other than retroreflectivity, then it may or may not have poor retroreflectivity. A breakdown of all failed sites is shown in Table 7 along with their retroreflectivity values and whether the site failed by the MRU, MRP, or both rating criteria. For comparison purposes, the MRP failure mechanism is also given.

Table 7. Sites Failing Either the MRU or MRP Evaluation or Both

Section Info		**Stripe Retroreflectivity (mcd/m^2/lux)**								**Pass MRU**	**Pass MRP**	**MRP Failure**
Section	**MP**	**LEL**	**L2SL**	**L1SL**	**LCL**	**RCL**	**R1SL**	**R2SL**	**REL**			
26003000	0.4	176		126	357	357	179		145	N	Y	
	2.5	161		129	258	258	147		151	N	N	Retro
26005000	7.0	329		258	138	185	224		296	N	N	Retro
	7.2	318		218	141	190	222		365	N	N	Peeling
	9.5	256		200	162	144	216		314	N	Y	
	11.3	207		N/A	189	207	N/A		296	Y	N	Retro
	12.2	237		N/A	154	152	N/A		240	Y	N	Retro
26010000	5.5	164		354	158	167	286		391	Y	N	Covered
	14.8	N/A		270	140	135	299		N/A	N	Y	
	15.1	86		261	131	125	270		222	N	Y	
26020000	3.8	481		218	187	146	194		374	N	N	Peeling
	18.0	530		383	198	230	289		481	Y	N	Peeling
26030000	14.1	289			115	115			372	Y	N	
26060000	1.3	224		184	170	109	232		310	N	N	Retro
26070000	10.4	244	N/A	316	207	175	254	N/A	305	Y	N	Peeling
26080000	0.4	260	N/A	285	136	117	244	N/A	224	N	Y	
	16.1	276	N/A	N/A	142	157	N/A	N/A	289	N	Y	
26090000	7.9	256	N/A	N/A	420	466	N/A	N/A	195	Y	N	Retro
	11.1	316	N/A	291	351	280	261	N/A	312	Y	N	Peeling
26130000	16.7	175		N/A	143	151	N/A		281	N	Y	
26250000	1.1	292	197	198	232	332	203	217	341	Y	N	Peeling
	1.3	221	230	181	227	235	227	232	229	Y	N	Peeling
26260000	10.2	144	489	293	273	299	485	218	192	N	Y	
	15.1	224	305	314	225	199	509	240	133	N	Y	

Table 7 shows that 6 sites were known to have been failed for retroreflectivity by the Maintenance Rating Program. Of these sites, the MRU failed half with its 150 mcd/m^2/lux criteria. One site that passed the MRU testing was within 2 mcd/m^2/lux of failing. Thus, it is not difficult to understand how a failing rating was given by the

MRP. Another site that passed the MRU retroreflectivity test but failed the MRP test had 3 of its 4 stripes at approximately 200 mcd/m^2/lux. One possible explanation for this discrepancy is that having several stripes on the lower side of the retroreflectivity scale would be more difficult to evaluate than three very reflective stripes and one poor stripe. An argument could be made that as far as driver visibility is concerned, it is better to have 3 very reflective stripes and one "failing" stripe than three marginal stripes and one very good one.

FURTHER MRU STUDIES

The current Maintenance Rating Program is based on a sampling process whereby sites are selected randomly for inspection. Obviously, with any type of sampling there is the potential that the sampled site is not an accurate representative of the entire section. In an effort to illustrate this and highlight the potential of the MRU in terms of finding areas with poor retroreflectivity, an example of a completely analyzed road is shown in this section.

MRU Data Reporting

A clear understanding of the MRU's data processing and reporting method is necessary in order to interpret the data presented in this section and to gage the reliability of the unit. In addition to the sheer amount of data which can be collected in a given amount of time versus handheld retroreflectivity units, another principal advantage of the MRU is the amount of samples reduced into one value.

For each user defined interval (note that it requires an experienced operator to determine a proper interval as vehicle speed and striping type play have a vast influence), the MRU reports the following critical statistics: Mile post range, number of samples collected, maximum retroreflectivity, minimum retroreflectivity, average retroreflectivity, standard deviation of samples and vehicle speed. Thus, in a 10 miles section reported in $1/10^{th}$ mile intervals, there would be 100 data points of the average retroreflectivity. However, these 100 data points could be based on anywhere from 100 to 100,000 plus samples depending on vehicle speed and the stripe measured. The manufacturer states that a good rule of thumb to obtain an accurate average is to ensure that a minimum of 40 samples comprise one data point. This recommendation was followed throughout the entirety of testing.

Data Reduction Procedures

While the MRU's data reporting method is a very good one and works well, it's always desirable to try and further reduce data if a good representation of the section can still be maintained. Most sections tested were found to have pavement changes throughout the section, and so the data was further reduced into conservative retroreflectivity values for each pavement change. A pavement change, for data analysis purposes, was simply defined as any change in pavement surface that could potentially cause a significant change in retroreflectivity. Typical examples of this are regions transitioning from asphalt to concrete, newer pavement to older, asphalt to bridges, etc.

For the purposes of this investigation, it was assumed if a given stretch of pavement was uniform, the retroreflectivity values would be very similar. The purpose of doing this is to define the performance of the section as a whole. If a chemical spill caused the striping to deteriorate in a small area of that same pavement stretch, it would not be highlighted by this method. However, it also would not be seen by an MRP inspection unless it just happened to be in the area that was randomly selected for inspection. Figure 11 shows an example of a pavement change that was logged during testing.

Figure 11. Example of Logged Pavement Change

As previously mentioned, a conservative value of retroreflectivity was obtained for each area of similar pavement in each section. The value is the retroreflectivity along the section to a 95% confidence. A 95% confidence, a commonly used statistical practice of identifying the uncertainty in the estimate of the true mean, was calculated by subtracting 1.96 times the pooled standard deviation from the arithmetic mean.

Examples of Analyzed Data

In Figure 12 below, the line "Section Value" represents the retroreflectivity to a 95% confidence at each pavement change, where each pavement change is a vertical shift of the black line. As you can see, there appears to be a very good correlation between pavement changes and retroreflectivity values.

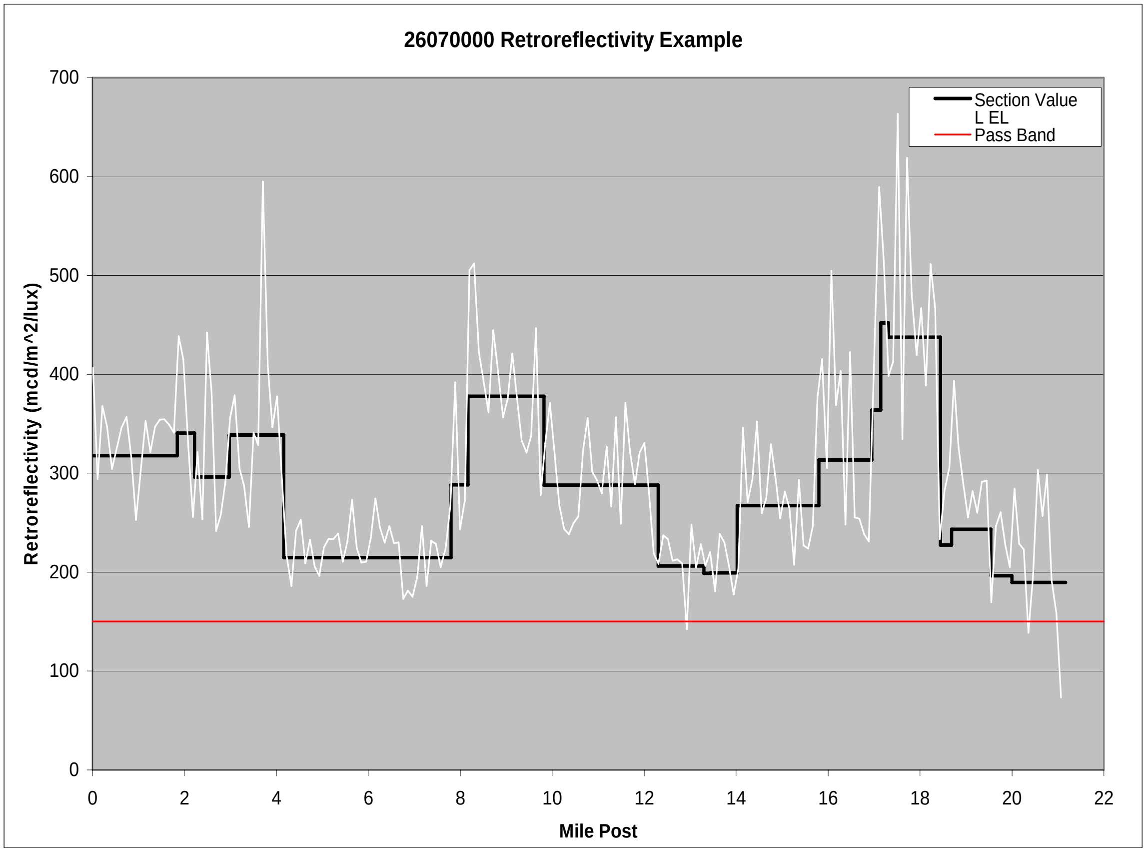

Figure 12. Example of Retroreflectivity Reduction on Section 26070000

Appendix A shows plots of the retroreflectivity values for all striping at each interval as well as the retroreflectivity to a 95% confidence at each pavement change for each section tested.

CONCLUSIONS

The following are the significant findings based on this study:

- In total, 79 sites were evaluated by both the MRU and MRP. 14 sites were failed by the MRP while 15 were failed by the MRU rating methodology.

- Of the sites tested and found to be in agreement for both MRP and MRU surveys, five failed both evaluations and 54 pass both. Thus, the same result pass/fail grade was achieved approximately 75% of the time.

- A 50% agreement was seen between the sites that failed the MRP due to retroreflectivity and the sites that failed the Mobile Retroreflectometer Unit testing.

- MRU results showed that yellow center lines are more sensitive to lower retroreflective values than edge and skip lines combined. Therefore, special attention should be paid to center lines and it is imperative that center line data be as accurate as possible.

- While further refinement and research is necessary to validate the MRU results, this study shows that the MRU has a significant merit to be an efficient and effective means of pavement striping evaluation.

- Based upon the retroreflectivity measurements from the MRU, continuous surveys could be used as a tool to quantify areas of low retroreflectivity for further study.

ACKNOWLEDGEMENTS

The authors would like to thank the following individuals for their outstanding contributions to this research and report: Dr. James Fletcher, Dr. Timothy Simmons, Jerry Moxley, Bob Daniels, Jamie Greene, Jimmy Jones, Vidal Francis and Christopher Falade.

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