STATE OF FLORIDA

MOBILE RETROREFLECTIVITY CHARACTERISITICS FOR PAVEMENT MARKINGS AT HIGHWAY SPEEDS

Research Report
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STATE MATERIALS OFFICE

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PAVEMENT MATERIAL SYSTEMS

The Pavement Material Systems provides the Florida Department of Transportation (FDOT) 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. To support these goals, presented are the Pavement Material System's Mission, Vision, and Value Statements.

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

One of the new functions of the Non-Destructive Testing Group, a unit of the State Materials Office in Gainesville, Florida, is to characterize the in-place retroreflective properties of Florida's pavement marking materials using a Mobile Retroreflectivity Unit (MRU). The basis for such a characterization is to ensure nighttime visibility and provide a level of safety and comfort for drivers.

Handheld retroreflectometers are the most commonly used device but are considered tedious and potentially hazardous. Mobile-based retroreflectometers are able to assess markings at highway speeds which improve both safety and efficiency. It has been determined that proper mobile retroreflectometer operation requires the knowledge of various operational factors, which have a significant impact on the performance of the instrument.

Surveying Florida's roadways for retroreflectivity is critical to the Department's effort to support informed highway planning, as well as policy and decision making. This requires the apportionment and allocation of funds as well as the determination of appropriate cost-effective strategies to rehabilitate and preserve existing highway transportation infrastructure.

The objective of this report is to provide an understanding of some of the operational characteristics collected from mobile retroreflectometer users so that this technology may be easily employed to provide dependable results.

KEY WORDS: Laserlux, mobile retroreflectivity, pavement markings, MRU, maintenance, visibility

1. INTRODUCTION

It is known that the rate of automobile accidents is three times higher at night than during the day [1]. While there are a variety of factors such as driver intoxication, fatigue, and weather that influence traffic accidents, road visibility also plays a critical role. Drivers depend on pavement markings and sign sheeting as guides, thus maintaining marking visibility may be significant to reducing the number of nighttime accidents and increasing driver comfort. Nighttime visibility of markings is provided through proper use of lighting and their reflectivity to headlamp light. In order to provide sufficient reflectivity, materials are placed on the surface of the marking to preferentially reflect light back in the direction of incidence. This effect is known as retroreflectance.

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. Due to the number of miles of pavement markings and the possible introduction of experimenter bias, mobile retroreflectometer units (MRU's) have become the state-of-the-art.

2. RETROREFLECTANCE

In order to create a retroreflective effect, small glass spheres (commonly called beads) are typically added to pavement markings. In this process, the incoming light is refracted by the initial surface of the bead and then passes through the glass. The portion of the refracted light that encounters the inner portion of the sphere in contact with the marking material is reflected. The remainder passes through the bead as lost light (Figure 1). The reflected light then passes back through the bead and is refracted once more by the surface of the sphere, back in the direction of the incoming light.

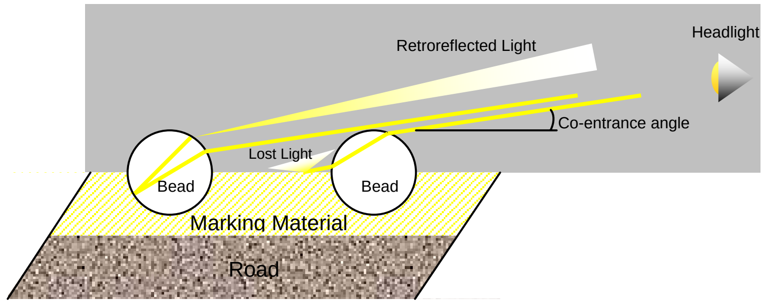

Figure 1. Method of creating a retroreflective effect using glass beads

2.1 Retroreflective Design Factors

For much of the driving public, the amount of light available for retroreflection by pavement markings is limited. This is due to the luminance of typical headlights and the limited illumination per surface area of the pavement caused by the angle between the headlight and the pavement (co-entrance angle). In order to reflect as much of the available light as possible, there are several marking design factors that can be adjusted to enhance the retroreflectivity (Table 1).

Table 1. Factors that Influence Pavement Marking Retroreflectivity [2]

Factor	Characteristic of Factor	Factor Effects
Glass Beads	Amount and Dispersion	Amount: bead surface area for retroreflectance Dispersion: scattering of reflection between beads
	Embedment Depth	Surface area available for retroreflectance, adhesion to binder material
	Refractive Index	Amount of light directed to reflecting binder surface
	Size	Surface area for retroreflection, wet weather performance
	Clarity	Diffusion of light within the bead
	Roundness	Direction of retroreflection
Binding Material	Color	White reflects more than yellow
	Type	Some materials are more durable than others
	Thickness	Marking longevity
Other Factors	Pavement Surface Roughness	Material adhesion
	Dirt or Other "Blinding" Material	Any object obscuring the view of the marking
	Type of Retroreflectometer Used for Measurements	Ability to reproduce measurements varies between instruments

While optimization of glass beads and the color of the binder material are important to the capture and return of light, the binder type and thickness as well as the pavement roughness can be significant for marking resiliency. Although the marking may be optimally designed and applied, significant factors such as the type of retroreflectometer used, or blinding materials such as dirt and snow can affect retroreflectivity as well.

2.2 Defining the Units

Retroreflectance measurements are typically given in terms of millicandellas per meter squared per lux [3, 4]. 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 2). The magnitude of this vector is measured in terms of candles (cd), where 1 cd is the intensity of 1 candle.

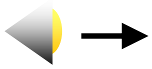

Figure 2. Luminous Intensity

The luminous flux is the sum of the luminous intensity of a source in all directions (Figure 3). 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).

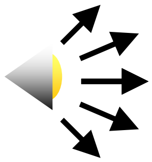

Figure 3. Luminous Flux

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.

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

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.

2.3 Standards of Retroreflection Assessment

Since the marking is designed to reflect light to its origin and the driver's eye is not at the same location as the headlight, the driver sees only the diffusion of light reflected by the marking. Thus the orientation of the driver with the marking and the headlight changes the retroreflectance sensed by the driver. There have been several methods used to provide the best representative assessment of pavement markings.

Conventionally, a subjective visual nighttime inspection has been employed. In this method that is currently performed by most state agencies, the operator either compares the sign with validation panels for markings with questionable retroreflectance, or judges retroreflectance based on a standard examined at the beginning of the analysis. The latter method requires the inspector to remember the color of the standard for all subsequent analyses during the inspection. Visual nighttime inspection accounts for age, vehicle and traffic factors, although it may introduce significant inspector bias [5].

In 1993, a United States Department of Transportation Appropriations Act stated that the Federal Highway Administration (FHWA) "..shall revise the MUTCD (Manual on Uniform Traffic Control Devices) to include a standard for a minimum level of retroreflectivity that must be maintained for traffic signs and pavement markings which apply to all roads open to public travel" [6]. In order to perform more consistent analysis of retroreflectance and conform to a "minimum level" of retroreflectance, many states have chosen to switch from visual inspection to a more objective, machine-based analysis [5].

Although the MUTCD requires retroreflectance on pavement markings, it has not defined a minimum retroreflectivity requirement. While there exists a standard method for measuring a machine-based retroreflectance (ASTM E 1710), the method may yield varying results for the same marking. This makes converging on a universally accepted minimum retroreflectance difficult. Additionally, the acceptance of a federal minimum retroreflectance would open the government to tort liability for traffic accidents. Thus, a minimum retroreflectance for pavement markings has not yet been established in the U.S..

The current accepted working standard for machine-based retroreflective measurement described in ASTM E 1710 uses a "30 meter geometry" which was initially set by the European Committee for Normalization (CEN) [7]. 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 4). 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.

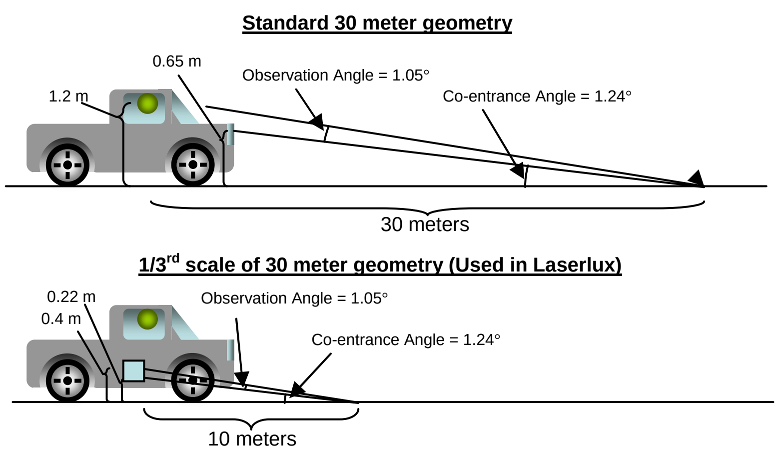

Figure 4. Standard 30 meter geometry and a 1/3rd scale 30 meter geometry

ASTM E 1710 also specifies that the measurement be taken in the direction of travel, that the roadway be dry and clean, and that the retroreflectometer be calibrated nearly every hour with a calibration standard [9]. In order to reduce experimental time, the standard calls for measurement stations whose spacing is based on the length of road and the type of marking.

3. HANDHELD VERSUS MOBILE RETROREFLECTOMETERS

Although nearly all retroreflectometers use the same geometry, there is little consistency in measurements between different instruments (Figure 5). There are also significant errors (approximately 5%) for reproducing results for a given area using a single handheld retroreflectometer. The variation between and among instruments could be due to environmental factors such as humidity, sunlight, or temperature of the device, as well as non-isotropic bead placement on the marking and technique of taking the measurements. Although many of these effects are known to change the readings of retroreflectometers [8], these effects have not been the focus of much study.

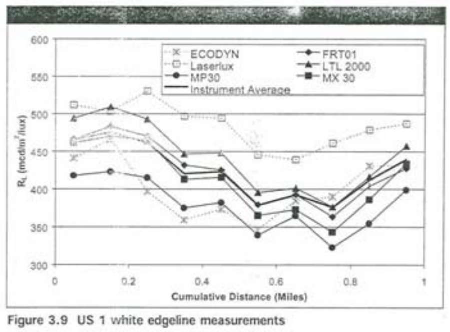

Figure 5. US 1 White edgeline measurements using various retroreflectometers [8]

While MRUs typically have more error in their measurements of pavement markings [8], portable handheld units require maintenance of traffic (MOT) and can be quite tedious for examining large segments of roadway (Figure 6). MRUs have the benefits of reduced safety risks to road workers, faster data acquisition, as well as a reduction in traffic congestion as compared with handheld devices. In some cases, it has been determined that small changes in the positioning of a handheld unit on a marking can produce significantly different readings. This may allow operator bias to influence the measurement of the marking retroreflectivity if only one measurement is to be recorded. A MRU takes many more samples than typically obtained with a handheld unit, and averages the scans, which reduces operator bias, and gives a more reliable reading for a stretch of roadway. Thus MRU’s are considered a supplement to conventional handheld technology and may be a future replacement with further study on reducing their error.

Figure 6. Handheld Retroreflectometer

4. LASERLUX BASED MOBILE RETROREFLECTOMETER

Currently the Laserlux model is the most common type of retroreflectometer employed for mobile analysis (Figure 7). The Laserlux is capable of acquiring retroreflective measurements with errors less than 15% while driving less than 88.5 kilometers per hour (55 miles per hour) [10, 11]. The Laserlux uses a 30 meter geometry and provides a 1.07 meter scan perpendicular to the direction of travel at a distance of 10 meters in front of the device (Figure 4). 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 a rotating mirror mounted inside the device (Figure 8). The retroreflected laser then returns to the Laserlux 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 7. FDOT van with Laserlux attached

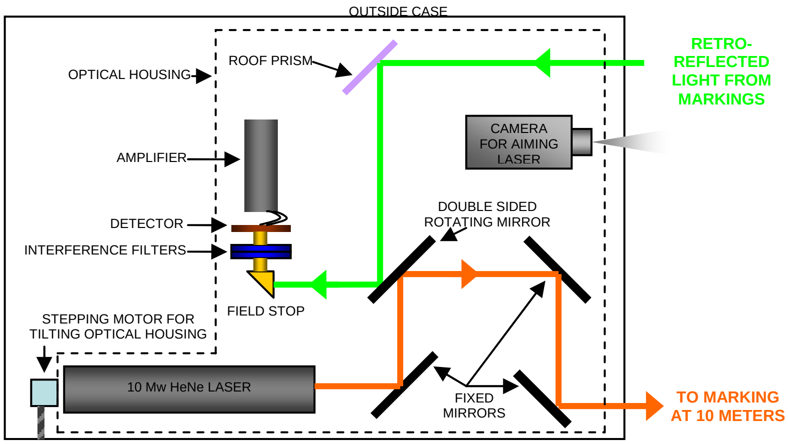

Figure 8. Internal operations of the Laserlux

The Laserlux can be mounted on either side of the vehicle, monitor single, double and broken lines as well as their combinations and incorporates a distance measurement instrument (DMI) accurate to within 0.1 meters per kilometer.

The Laserlux as well as the DMI on the MRU requires calibration. Laserlux calibration is completed by scanning a panel of a known retroreflectance with all equipment and personnel in place for the correct ride height and trajectory for the laser. In order to ensure proper operation, a small section of roadway is typically used for verification with a handheld unit. The DMI is calibrated by driving a known distance and adjusting the instrument accordingly.

4.1 Laserlux Studies

Laserlux based MRU analysis of pavement markings has been used in several studies [6, 11, 12] although the characteristics of its operation were not the subject of these studies. Much of the current knowledge on MRU operational performance is recorded in a study by the Highway Innovative Technology Evaluation Center (HITEC) [8]. It concluded that calibration of the Laserlux had a significant effect on the pavement marking measurement. It was further concluded that the MRU could better reproduce analysis on solid line segments than on broken lines and that the measuring accuracy of the instrument increases with retroreflectivity magnitudes values nearer the middle of the retroreflectivity range limits of the instrument. Another study [13] also found measurements to be possibly 20% lower while in motion than stationary although minimal data was used to make this conclusion.

Unfortunately there is limited information currently available on the Laserlux and the particulars of its operation in literature. Thus in order to provide a better understanding of the operational characteristics of a Laserlux unit, several organizations who own and operate MRUs were contacted for their experiences.

4.2 Previous Experience with Laserlux MRUs

While MRUs may provide a method of more quickly taking inventory or project level analysis of pavement markings, only a few states use them and even fewer own one. They are not typically owned by states due to their price, the level of expertise necessary to ensure consistent results, or the fact that handheld instruments are conventionally used for project acceptance. The results of a limited survey of state transportation agencies regarding the operational characteristics of Laserlux units are summarized below:

A total of 25 Laserlux units have been built with 22 shipped to US destinations. Of those, 20 are known to currently be operational (Table 2). Of these, several organizations were selected to provide an understanding of the operational factors that affect the performance of the MRU. It was found that the primary purpose of using a MRU was to form forecasting models to determine the useful life of pavement markings. This data could then be used to reduce the yearly expenditure for pavement markings as well as to more accurately budget for maintenance. An additional purpose for MRU use was to provide a measure of feedback for pavement marking contractors, which can be used for improving the design and method of application of markings. In some cases, this feedback provided the information necessary for a doubling of initial retroreflectivity.

Due to their needs, level of experience and contractual obligations, each MRU owner typically chose to operate the unit in a unique way by following protocols developed in-house. Typically, a MRU is used for product acceptance, project acceptance, inventory, or a combination of these. The validity of the data the MRU produces and thus its level of use is dependent on the experience of its operators. The range of experience required to identify the significant factors that affect the MRU and operate the system effectively varies between a few days and 5 years, depending on previous training. The influence of these factors on the measurement reduces the accuracy of the data which promotes its use as a survey tool to supplement, rather than replace handheld measurements. In some cases (as at the

Minnesota DOT), more confidence can be placed on MRU results than on measurements taken by handheld retroreflectometers. This exists because of the consistency achieved through experience with using the MRU. Also the MRU collects a greater number of measurements and it is not as influenced by experimenter bias when compared with a handheld unit, which allows the MRU to provide a more representative sample of the retroreflectivity. Although a MRU has the capacity of being an effective tool for measuring retroreflectivity, its operation may be limited due to existing performance specifications which require the use of handheld retroreflectometers because it is an accepted standard.

Due to the number of miles of roadway in any given state and seasonal limitations, most states that own a MRU assess approximately 20% of their roadways. Roadway assessment typically depends on several critical factors chosen through experience with pavement markings in the area, which indicate the severity of deterioration. In one case, 100% of durable (other than painted) pavement markings are assessed since painted markings typically last less than a year.

4.3 Operational System Characteristics

Although the overall impression of the use of MRU's for pavement marking measurements was favorable, there were some overall issues concerning the operation of the MRU. These include the following:

- Ensuring proper calibration (laser aiming, and checking retroreflectivity against a standard) as it is the most critical factor in limiting error
- Using on longer segments since the MRU relies on law of averages to reduce errors from vehicle dynamic effects such as hills, curves and speed
- Having to refuel frequently and not shift any heavy objects in the cabin to eliminate weight imbalances
- Reducing the exposure of the electronics and laser to heat as it causes readings to vary.
- Difficulties with finding a level place to recalibrate in the field
- Not operating the MRU in fog, rain, on salted roads until the first hard rain of the season, and in extreme cold, or heat
- Yearly cleaning and adjusting of the mirrors used to direct the laser

Table 2. MRUs in Operation [14]

Agency	Number of units	How Acquired (when acquired)	Why Purchase or not	When Calibrate	Time necessary to become proficient	Use for Inventory	Use for Project Acceptance	Use for New Products	% coverage of state per year
Minnesota DOT	2	Roadware with QNX Software (Mid 90s)	Pavement Marking Management	DMI-every week, Laserlux-at least 2 times a day, but could be 15	1-2 years	Yes	Yes	No	~20%
Iowa DOT	1	Roadware with QNX Software (late 90s)	Pavement Marking Management	Every 5-10 miles	~2 years	Yes	No	Yes	~20%
Alabama DOT	1	Gamma Scientific with Windows Software (2001)	Pavement Marking Management	N/A	N/A	N/A	N/A	N/A	0% No one to operate
Oregon DOT	1	Roadware with Windows Software (Mid 90s)	Inherited from FHWA	DMI every year and Laserlux every day	~2 hours	Only research based	No	Occasionally for research purposes	Nearly 100% of durable markings
Alaska DOT	1	Roadware with Windows Software (Mid 90s)	Inherited from FHWA	When switch laser to other side of vehicle	Couple of runs	No	No	No	50-60 miles
Utah DOT	1	Roadware with Windows Software (Mid 90s)	Inherited from FHWA	Each time the instrument is used	~1 year	For research only	No	No	20-25%
Washington State DOT	1	Roadware with Windows Software (Mid 90s)	Inherited from FHWA	N/A	N/A	N/A	N/A	N/A	0% No one to operate
North Carolina DOT	0	Contract out	No one to operate the instrument	N/A	N/A	Yes	Yes	Yes	~10%
Michigan DOT	0	Contract out with Michigan State	Complex system to get good results	N/A	N/A	Yes	Yes	Yes	~20%
West Virginia DOT	0	Contract out	Complex system to get good results	N/A	N/A	Yes	N/A	N/A	~15%
Delaware DOT	0	None	Too few miles of roadway	N/A	N/A	N/A	N/A	N/A	N/A
New Jersey DOT	0	None	Repaint every 3 years	N/A	N/A	N/A	N/A	N/A	N/A
BC Traffic Engineering	3	Roadware and Gamma Scientific with Windows Software (Mid to Late 90s)	Pavement Marking Assessments	N/A	2-3 years	N/A	N/A	N/A	N/A
Precision Scan in North Carolina	5	Roadware and Gamma Scientific with Windows Software (Mid to Late 90s and one in 2003)	Pavement Marking Assessments	N/A	N/A	N/A	N/A	N/A	N/A
Private contractor in Utah	1	Gamma Scientific with Windows Software (2004)	Pavement Marking Assessments	N/A	N/A	N/A	N/A	N/A	N/A
Private Contractors in Texas	2	Gamma Scientific with Windows Software (2004)	Pavement Marking Assessments	N/A	N/A	N/A	N/A	N/A	N/A
Michigan State University	1	Roadware with QNX Software (late 90s)	Pavement Marking Assessments	N/A	N/A	N/A	N/A	N/A	N/A

Typical calibration methods of the Laserlux include using a level surface on which to calibrate, ensuring proper inflation of the tires, accurately setting the height of the laserlux above the roadway and length to the calibration panel, and performing the aiming and panel calibration while all equipment and personnel are situated in the vehicle. Laserlux calibration is typically completed several times a day in order to ensure compliance with the 30 meter standard geometry. It also must be noted that the Laserlux typically requires a yearly calibration of the internal components such as the sensor and mirrors to ensure proper operation.

The MRU system includes a distance measuring instrument (DMI) which also requires calibration. This calibration is typically completed at a previously surveyed site about a mile in length and is completed less often than the calibration of the Laserlux. Also, during operation, the MRU is typically run with no less than a half tank of fuel, with a minimum of weight shifts in the cabin and at no faster than 60 miles per hour.

4.4 Potential Sources of Error using a MRU

Through operational experience, effects such as wind, hills, acceleration, weight imbalance, speed, temperature of the Laserlux and others have a significant influence on the measured retroreflection. These effects on the measurement which may far exceed the stated error limits for the instrument may be partially explained through an examination of the operation of the system.

4.4.1 Vehicle Dynamics

Since MRUs acquire retroreflectivity data apart from the material they measure and from a moving reference as opposed to a handheld device, there are several factors that may introduce additional error in the measurement. Unlike the stationary handheld design, a retroreflectometer on a vehicle is subject to pitch, roll and yaw dynamics of the vehicle during driving. This can cause misdirection of the laser and a loss of the standard 30 meter geometry. This is to be expected since there is only a 1.24 degree angle of the laser with the road to keep the 30 meter geometry. Although data averaging may reduce the significance of this effect, it has been shown to have significant effects based on shorter runs, or on runs where one road condition persists such as in wind, on a hill, or change in weight distribution (Figure 9).

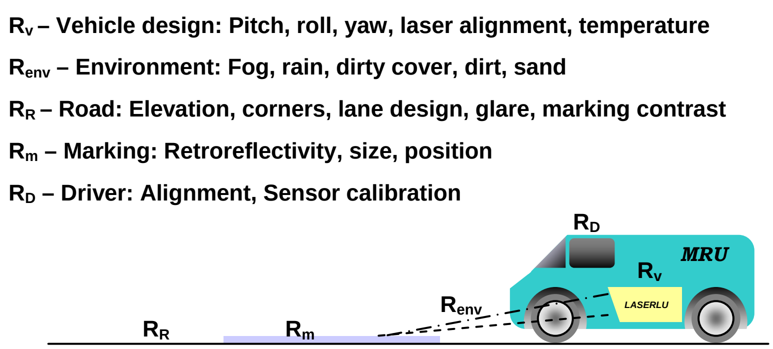

Figure 9. Areas of additional error associated with a MRU

Beyond aiming the laser during calibration and keeping the vehicle steady during driving, the operator must also be sensitive to wheel wander. While the Laserlux unit is designed to scan the roadway, the measured retroreflectance at the edges of the scan may decrease due to the increased angle between the retroreflectance and the sensor.

4.4.2 Environmental Effects

As the Laserlux is placed on the side of a vehicle, it must endure the roadway environment. This includes gravel, dirt and other blinding materials that would reduce the illumination of the road by the laser and the reception of the retroreflected laser by the sensor. Thus care must be taken not only to clean the lens frequently when in operation, but also to protect the lens during transport.

Once the laser beam exits the device, environmental factors such as fog, rain, and road surface conditions, such as dirt and sand on the surface may obscure an otherwise clear view of the marking. Fog acts to scatter the laser light, which reduces the possible retroreflection from the marking. Rain acts similarly as fog, but water on the road creates an additional impediment to measuring retroreflectance. Light is reflected off of the water surface rather than retroreflected back in the direction of the laser (Figure 10). While the effects of fog and rain may be eliminated by operating when weather permits, dirt and sand on the roadway surface should not be considered error, but actual impediments to the effectiveness of the pavement marking.

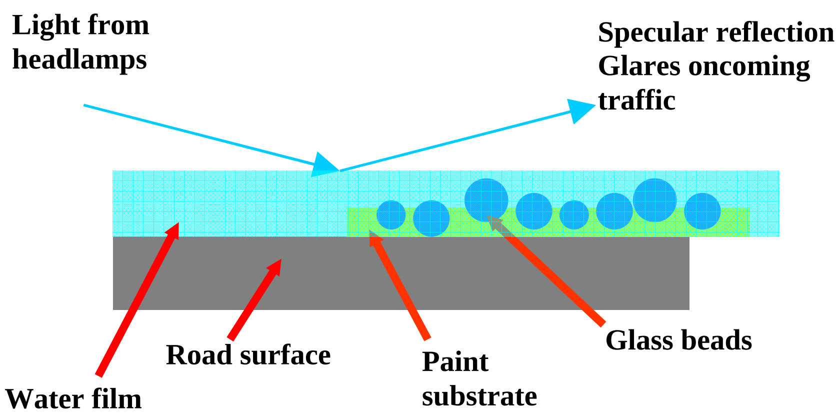

Figure 10. Effect of water film on visibility [15]

4.4.3 Pavement Surface Geometry

Once the laser reaches the road surface, other issues arise. The road may not be completely flat. Elements such as changes in surface elevation, rutting and slope may cause errors because the 30 meter geometry may not be maintained as a result of these factors. There are also lane design changes such as off ramps and corners where the marking may be absent. Other roadway effects such as glare from oncoming vehicles and poor contrast with the surrounding pavement material may also be concerns.

4.4.4 Ambient Light

Once the light from the laser is retroreflected, it must again penetrate the environment to arrive at the sensor. Many handheld units are not calibrated for increased levels of ambient light, thus light filtering may be necessary before proper calibration to ensure accurate operation. The Laserlux provides frequency filters to reduce the effects of the background noise, which may be caused by the sun, or any other light source.

4.4.5 Internal Temperature

Internal temperature is another effect that has been shown to change the output of the Laserlux. The frequency filters used in the system are temperature dependent and thus the heat generated by the laser as well as electronics and environment effects the measurements although there may be other temperature dependent factors as well within the system.

4.5 MRU Updates to Reduce Error

In order to reduce the effect of some of these potential sources of error, several MRU operators have updated their systems. These updates have included reducing vehicle motion during tests and providing a controlled environment for the instrument. Once calibrated, keeping the 30 meter geometry is critical to ensuring accurate measurements. By changing to a stiffer suspension and taking measurements at a slower speed, much of the yaw, pitch and roll of the vehicle in response to the road may be reduced, although this both limits the number of miles that can be assessed and potentially reduces the benefits of safety to the traveling public.

Controlling the operational temperature of the Laserlux is important as well for accuracy. While there are thermoelectric heaters installed on the frequency filters for fast startup, MRU operators have found it critical to install coolers and possibly thermal insulation on especially warm days. Additional measures have been taken by painting portions of the Laserlux system that are black, or dark in color with lighter colors to reduce heat entering the laser and its components. Reductions in temperature within the Laserlux can be made by keeping the system in the shade when parked.

5. CONCLUSIONS

A Laserlux based MRU has been used in several states to provide fast, safe and generally unbiased data on pavement markings. These measurements provide information vital for improving the quality of new pavement markings, reduce costs for assessing a pavement marking inventory, reducing yearly expenditures for marking maintenance and for forecasting future maintenance budgets. Realizing these benefits is based on the limitations of the equipment and the experience of the operators of the measuring device. Although several states own MRUs, there is no real consensus on the best method of operation. Common in all methods is the realization of the necessity for proper calibration and experience in the operation of the equipment. Several MRUs have been mechanically adapted to reduce some of the errors associated with operation, although there is limited information on the long-term merits of these adjustments. Although MRUs have been successfully implemented provide both financial and safety benefits, further study may reduce the possible errors of operation and thus improve the utility of the instrument.

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