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MINIMUM RETROREFLECTIVITY FOR PAVEMENT MARKINGS BY DRIVER'S STATIC TEST RESPONSE

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Abstract: During night times, drivers are highly dependent on road marking retroreflectivity for delineation. Technically speaking, retroreflectivity, which equals to luminance, means the amount of light ray that entered glass beads and reflected to drivers. It has been recommended that the retroreflectivity is evaluated, monitored and controlled at implementation stage or during maintenance. For this reason, the minimum retroreflectivity is postulated based on regulations such as "Polices' Manual on Traffic Safety" and "Manual on Roads" in Korea. This study focuses on the drivers' responses for the minimum retroreflectivity. Subjective evaluations by 49 subjects and quantitative measurements of pavement marking samples especially manufactured with various ranges of retroreflecivity were made in KHC Test Road. The effects of color and material retroreflectivity range were considered. After completion of the experiment, the minimum in-service level, 130~140 mcd/m^2/lux for white markings and 100~110 mcd/m^2/lux for yellow markings, from a driver's point of view was established.

Key Words: Pavement Marking, Retroreflectivity, White Line, Yellow Line, Roadmarking

1. INTRODUCTION

1.1 Background

Pavement markings such as edge lines, skip lines and centerlines are the most widely utilized traffic control devices to provide drivers with passing information, directional information and the location of the road edge. Lateral lane position of a vehicle during nighttime is generally maintained by the driver through peripheral visual cues obtained from pavement markings and the road edge at relatively short distances. Directional and passing decisions made by the driver are usually based on visual information obtained by eye fixations on pavement marking, most often the right-edge line, at relatively long distances ahead of the vehicle.

Visibility plays an important role in nighttime accidents and fatalities. The major components in providing proper nighttime visibility of pavement markings are the headlights, the pavement-marking retroreflectivity, and the driver's visual capacities. Pavement-marking retroreflectivity provides adequate visibility at long distances to allow a driver enough time to acquire and process the navigational information. However, retroreflectivity values of pavement marking gradually decrease over time owing to mainly traffic wear and environment.

It is important to replace the pavement marking prior to the time when they no longer meet the needs of the nighttime driver; A important concern is when the pavement marking should be replace, rather than whether. To maintain nighttime visibility, pavement markings should be maintained by the responsible highway agencies. The ways to determine the appropriate level of retroreflectivity needed by nighttime drivers and replacement timing are not proposed; only standard geometries were proposed.

1.2 Literature Review

There are the existence of a wide variety of information and investigative research on the topic of pavement markings. Significant researches have been conducted owing to growing interest in the retroreflectivity of pavement markings. This can be linked to the fact that the FHWA has a congressional mandate to determine the minimum levels of retroreflectivity that will best service the driving public's needs and still be practical from a funding and maintenance point of view.

Graham, J.R. *et al.* (1996) conducted a low-beam nighttime field study to determine subjective pavement marking retroreflectivity requirements for older observers. A total of 65 subjects ranging in age from 20 to 89 were used in the study. The evaluators traveled as passengers through a 30-km-long test course containing 24 pavement marking treatment locations. The subjects rated their perception of pavement marking adequacy by circling the appropriate multiple-choice category at each treatment site. The results of the field evaluation indicated that more than 85 percent of the older subjects aged 60 years and above rated marking retroreflectance of 100mcd/ m^2/lux as adequate or more than adequate.

Zwahlen, H.T. *et al.* (1997) investigated the spatial driver eye scanning behavior and driving speeds along four rural two-lane road test sites under low-beam illumination conditions at night. The aim was to test the hypothesis that drivers do adjust their spatial eye scanning behavior and their driving speeds as a function of pavement marking visibility. They recommended the minimum levels of retroreflectivity by speed class for roads with and without RRPM's (Raised Pavement Markers).

Zwahlen, H.T. *et al.* (1999) also found that, using CARVE (Computer Aided Road Marking Visibility Evaluator), there was a significant difference in the subjective rating of retroreflectivity of the pavement marking between older and young drivers.

The Minnesota DOT (Loetterle, F. E. *et al.*, 1999) established a minimum threshold value of retroreflectivity by Driver's ratings. During Study participants drove automobiles with headlight on low beam over a course comprised of two-lane state and county roads at night, they subjectively rated the visibility of the white edge lines and yellow centerlines. On the basis of data collected using mobile retroreflectometer, Mndot recommended 120mcd/m^2/lux as the minimum threshold value of retroreflectivity.

A study by Lee, J.T. *et al.* (1998) directly showed the relationship between pavement markings retroreflectivity and crashes were conducted by. The study, however, failed to establish a correlation between nighttime crashes and level of retroreflectivity. Nasser, A.A *et al.* (2002) established a crash-based minimum retroreflectivity threshold of 150 mcd/m^2/lux using Mirolux 12, a 15-meter geometry retroreflectometer when traffic safety is the primary concern.

2. RESEARCH APPROACH

2.1 Research Purpose

The objective of the this research was to develop a threshold value of retroreflectivity, above which drivers would consider a pavement marking acceptable and below which drivers would consider the pavement marking unacceptable. The experiment described here was to obtain the visibility of pavement markings by subjects. In the static test, drivers viewed different pavement markings at a fixed set of distances from a stationary vehicle to assess minimum brightness for pavement marking detection.

Pavement marking samples were especially manufactured before the experiment to ensure the uniformity of a wide range of material retroreflectivity. Both quantitative measurements of pavement marking samples and subjective evaluations by 49 subjects were conducted during the static test. The effects of color, white and yellow, and material retroreflectivity ranging from 40mcd/m^2/lux to 200mcd/m^2/lux were considered. After completion of the experiment, the minimum in-service level from a driver's point of view was established.

2.2 Preparation for Experiment

The field experiments were conducted in dry weather during September and October 2003 between 7 p.m. and 12 p.m. It took one month to manufacture pavement-marking samples in the factory, one week to install them in experimental site and two weeks to conduct field experiments.

A total of 49 subjects, 33 male and 16 female, ranging in age from 20 to 62 years and having normal or corrected to normal vision participated in the experiment. When this experiments was being planed, older subjects having poor visibility were intended to assemble, which was difficult because experiments terminated later at night than expected. The mean age of the subjects was 39.3 years, and the median age was 36 years. The subjects were paid $50 for their involvement in the experiment. Table 1 shows the subjects by age group and gender of the subjects.

Table 1. Number of Subjects by Age and Gender

Age Group	Male	Female	Total
20 ~ 29	10	3	13
30 ~ 39	16	0	16
40 ~ 49	4	1	5
50 ~ 59	3	11	14
60 ~ 68	0	1	1
Total	33	16	**49**

Two college students were hired to act as assistants during experimental period and six college students were hired to install samples on road surface of experimental site for three days before beginning the experiment. Two researchers form Highway & Transportation Technology Institute participated in the experiment. Two of them acted as interviewers who rode with the subjects as they drove the course. Third acted as a supervisor, explaining the method of experiment.

This experiment was conducted using two 2002 EF SONATA. There is little difference in the intensity of illumination between two cars when measured using an illuminometer. The headlights and windscreen were cleaned before beginning experiment and driving mirrors were folded to eliminate the effect of headlights emitted from rear vehicles. Each car was fitted with radio for the purpose of communication.

Figure 1. Experimental Vehicles and Measuring Intensity of Illumination

Two types of the pavement marking samples with retroreflectivity value ranging from 40mcd/m^2/lux to 200mcd/m^2/lux were specially manufactured in the factory. One type was 15cm wide, 3m long and white color; another type was 15cm wide, 5m long and yellow color.
The LTL-X, a 30-meter geometry retroreflector, is placed directly over the pavement marking sample to be measured. The reading is taken, and then the retroreflectometer is moved 8~12 inches to another position on the pavement marking sample. The procedure is repeated fifteen times, and the readings are recorded and averaged for each pavement marking sample.
An error was made during the manufacturing of the samples. Among hundreds of samples manufactured, measuring the retroreflectivity value of them using the retroreflectometer, only one hundred twenty white and seventy yellow samples having low deviation in luminance were selected for experiments.
White and yellow samples were individually classified into fifty classes; one class consists of three samples in white and two in yellow, according to their retroreflectivity values.
A total of 30 sections, 15 white sections and 15 yellow sections, were installed at intervals of 300 meter long.

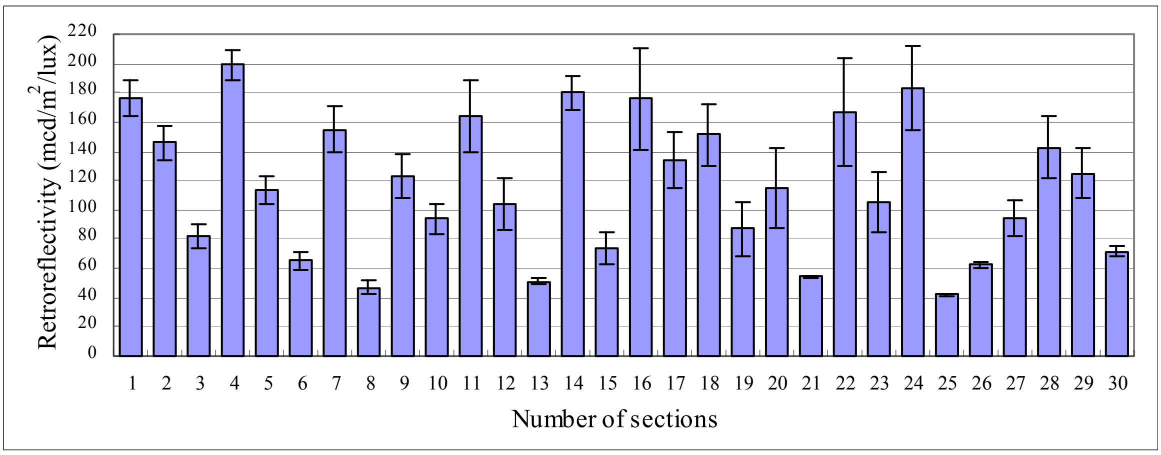

Figure 2. Wide Range of Material Retroreflectivity

Figure 3. Installing Samples on Experimental Sites

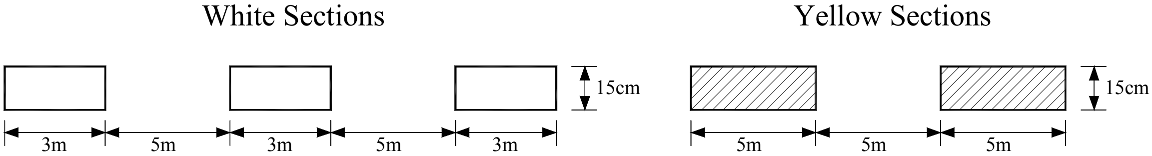

Figure 4. Constitution of Sections

The experiment was conducted on Korea Highway Corporation Test Road, which is about 11.7m wide (2 lanes), 7.7km long and located on the Jungbu inland Expressway. The KHC Test Road, the first full-scale pavement test road in Asia, was constructed from April 1997 to December 2002, including both concrete and asphalt pavement sections. (25 concrete sections, 15 asphalt sections)
It was suspected that the presence of other vehicle might affect subject performance causing distraction included glare and other vehicle interference. The KHC Test Road had not opened to traffic; it was regarded as a suitable site to experiment. Various kinds of pavement marking materials had been installed in the KHC Test Road to monitor luminance of those under traffic loads and environmental changes. The existing lanes were so bright that subjects would be accustomed to high brightness on the experiment. Thus, the existing lanes were covered with tapes to prevent subjects from seeing it.

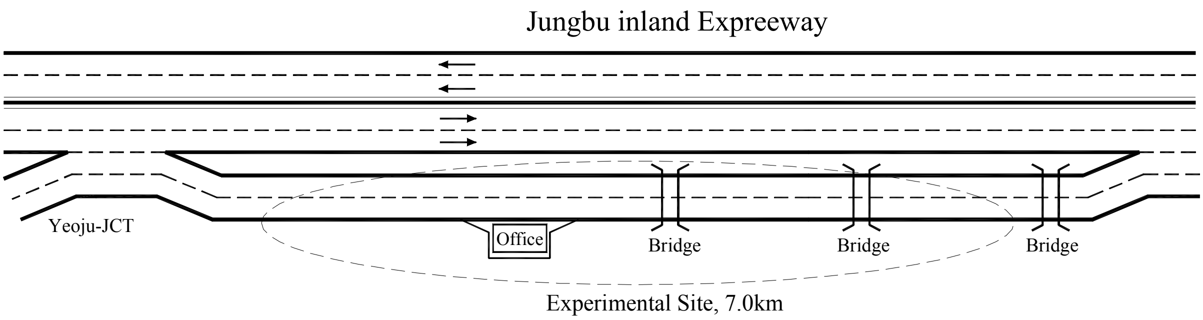

Figure 5. Experimental Sites

2.3 Methodology

Each subject was assembled at office in KHC Test Road and explained the details of the experiment. In turn, they were escorted to the experimental vehicle; seated in the driver seat. One assistant seated in the right-front passenger seat, and one interviewer seated in the right-rear passenger seat to use a penlight for the purpose of recording of subjects' reply without

interfering with them.
First the subject was given the proper instructions and then asked to adjust the driver's seat.
For each run, the subject was instructed to line up the experimental car in the one driving lane that was assigned by the experimental design. Subjects were told to accelerate the car to a speed of about 20 to 30 kph and to hold this speed. During the course of the experiment, the experimental vehicle was driven in both eastbound and the westbound directions. Driven in eastbound directions, subjects evaluated the yellow pavement marking samples and in westbound directions, the white ones. Opposing traffic was rare - if any, the experimental car was stopped - and no vehicles were followed. Low-beam headlights were used at all times. it took about 40 minutes for one subject to conduct the experiment.
During static experimental run, the subject stopped the car at stop line, which had been indicated on the curb in front of each section using adhesive tapes. A distance of 30 meter was selected for viewing because the new geometry, called '30 meter geometry', represents 30 meter viewing. Subjects were asked to grade the brightness of the pavement marking samples according to the selected grading scale. (A: Excellent, B: Very good, C: Acceptable, D: Not acceptable, and, F: Completely unacceptable)

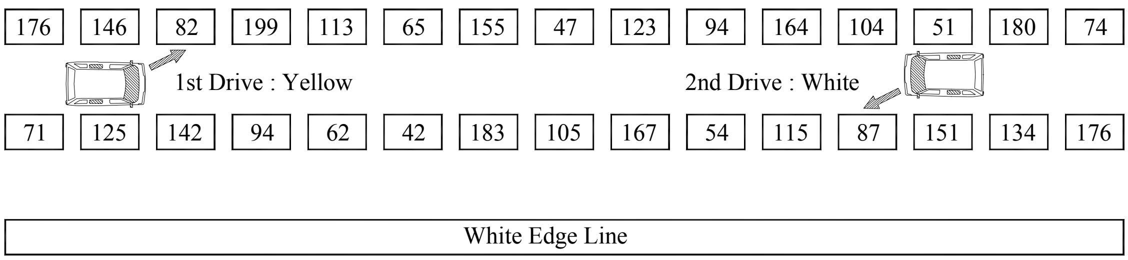

Figure 6. Experimental Method

3. DATA ANALYSIS

After completion of the static test, the correlation between the measured retroreflectivity values of pavement marking samples and the mean values of the ratings was analyzed. Rating scores were made by assigning numerical values on the ratings evaluated by study participants (A=5, B=4, C=3, D=2, F=1) to simplify computations. The mean value of the ratings evaluated by study participants for each pavement marking section was calculated by computing the average of rating scores. Table 2 shows mean value of the ratings for each pavement marking section.
For each section, the ratings were combined so that a rating of A, B, or C was considered acceptable and a rating of D or F was considered unacceptable. For this analysis, an overall score of acceptable was assigned to a pavement marking if 90 percent or more of the participants rating that marking gave it a score of acceptable.
Figure 7 shows the percentage of subjects rating each section as satisfactory (A, B, C) and a scatter plot of the pavement marking retroreflectivity against their corresponding acceptability ratings. The x-axis is the average measured retroreflectivity values for the 15 pavement marking sections of white and yellow color respectively.
This plot shows a well-defined break point; Retroreflectance values greater than 134mcd/m^2/lux for white and 104mcd/m^2/lux for yellow were rated as satisfactory by more than 90 percent of the subjects.

Table 2. Subject's Ratings

Section No.	Mean Ratings	Standard Deviation	Standard Error	Section No.	Mean Ratings	Standard Deviation	Standard Error
1	3.48	0.89	0.13	16	3.88	0.66	0.09
2	3.55	0.82	0.12	17	3.49	0.79	0.11
3	3.02	0.90	0.13	18	3.61	0.80	0.11
4	3.94	0.75	0.11	19	2.71	0.93	0.13
5	3.98	0.69	0.10	20	2.88	0.94	0.13
6	2.46	0.84	0.12	21	1.92	0.85	0.12
7	3.71	0.73	0.11	22	3.61	0.78	0.11
8	2.21	0.82	0.12	23	2.88	0.87	0.12
9	3.77	0.71	0.10	24	3.65	0.72	0.10
10	3.06	0.85	0.12	25	1.02	0.14	0.02
11	3.85	0.74	0.11	26	1.39	0.60	0.09
12	3.27	0.70	0.10	27	2.10	0.84	0.12
13	2.46	0.79	0.11	28	3.27	0.78	0.11
14	3.92	0.61	0.09	29	2.63	0.72	0.12
15	2.71	0.76	0.11	30	1.92	0.85	0.12

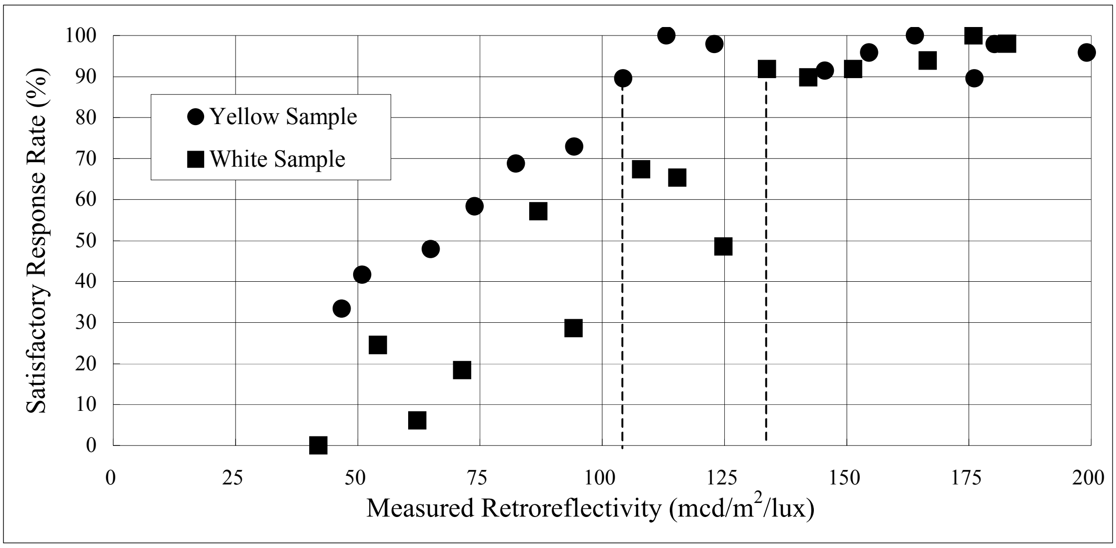

Figure 7. Retroreflectivity Against Percent Acceptable

There is a non-linear relationship in correlation between the measured retroreflectivity values of pavement marking samples and the mean values of the ratings by participants. Figure 8 shows the regression curve in which average retroreflectivity versus average subjective rating has been plotted for each pavement marking section, where X is the retroreflectance (mcd/m^2/lux) and Y is the average subjective rating.

Curvilinear regression yielded a polynomial function of 3th order as the best fit with a coefficient of determination of 0.91 for white, and 0.88 for yellow, respectively. This suggested a strong correlation between the measured retroreflectivity and night visibility ratings by participants.

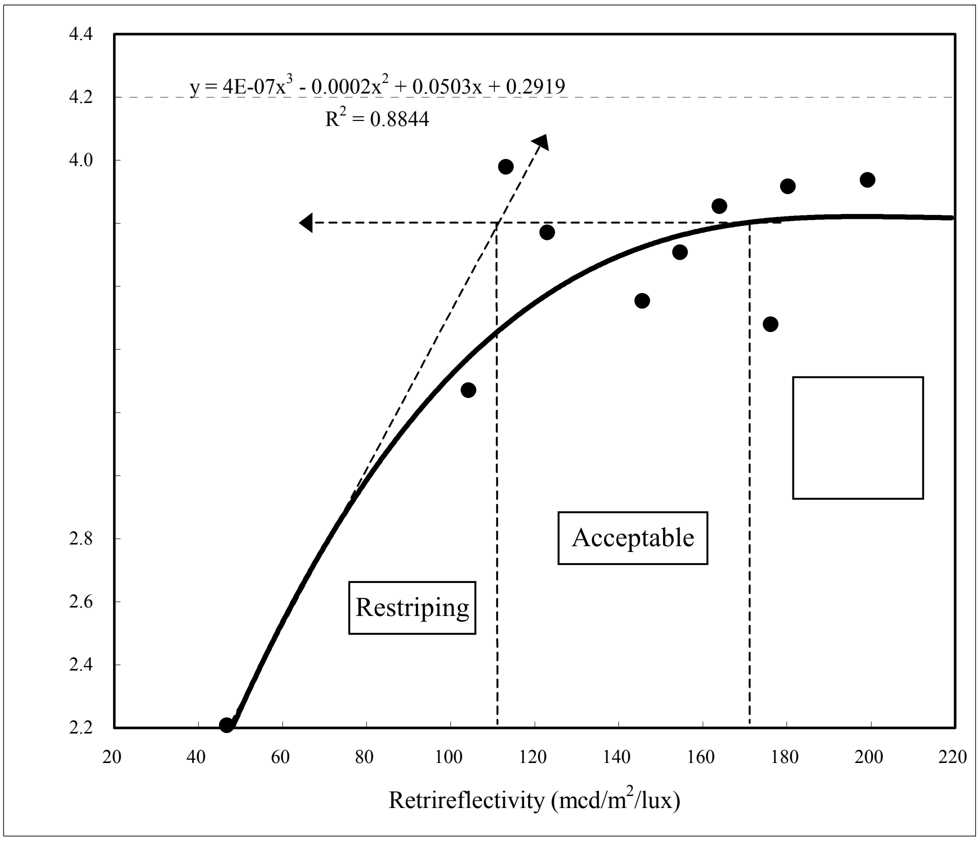

Figure 8(a). Curvilinear Regression for Yellow Markings

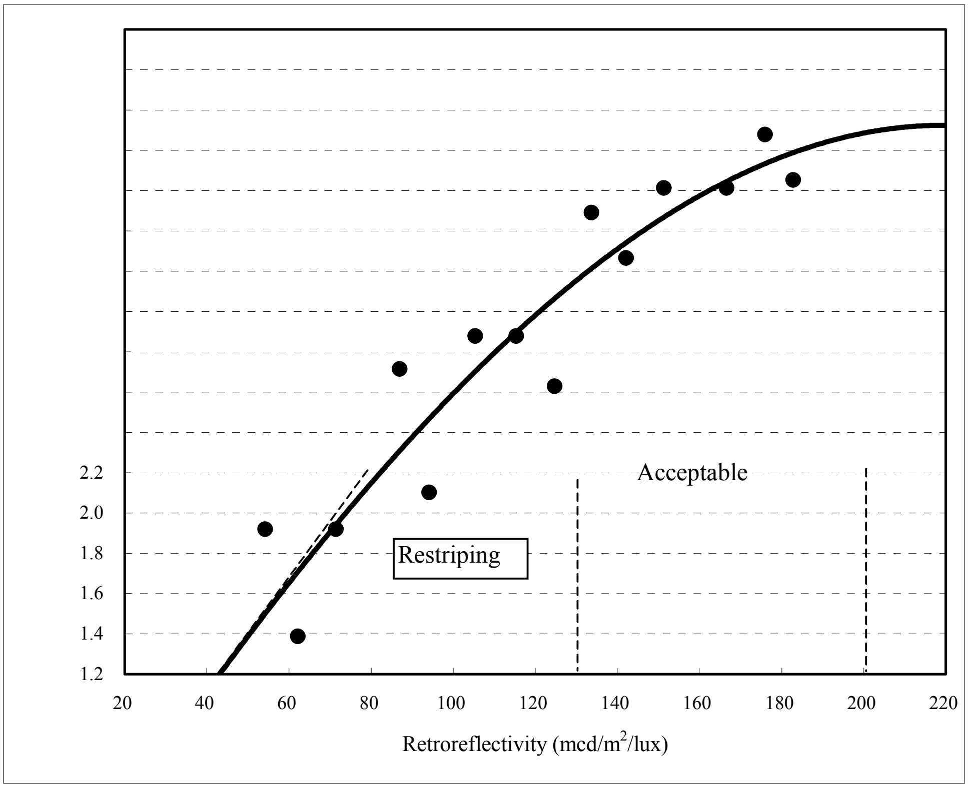

Figure 8(b). Curvilinear Regression for White Markings

The slope of the curve is initially high and rapidly tapers off until the slope is almost zero, which means the existence of break point to satisfy subjects. The interpretation of this relationship is that levels of satisfaction reported by raters improve significantly as the retroreflectivity of the markings increases from zero to 110 mcd/m^2/lux for yellow markings and zero to 140 mcd/m^2/lux for white markings.
As the retroreflectivity of the markings increases from 110 to 170 mcd/m^2/lux for yellow markings and 140 to 200 mcd/m^2/lux for white markings, there is still an increase in drivers' satisfaction, but the amount of increase per unit of increase in retroreflectivity of the markings is not large. Above 170 mcd/m^2/lux for yellow markings and 200 mcd/m^2/lux for white markings, there is little increase of drivers' satisfaction.
These observations suggest that concentrating resource on repainting pavement markings with retroreflectivity below 110 mcd/m^2/lux for yellow and 140 mcd/m^2/lux for white would achieve a greater relative increase in drivers' satisfaction than repainting pavement markings with retroreflectivity above those.

Of the 49 Participants, the ratio of women and man was 1:2. Statistical analysis revealed that there was no significant variation in the rating of retroreflectivity by gender for any other of the pavement marking sections.
Grouping participants into two classes by age, third-one of the subjects were 50 years of age and older. Appliers above the age of 70 were excluded from the sample of subjects because of concerns for safety; the field test was performed in the dead of night.

Table 3. Interim Visibility Indices

Color	Age	Equation	Retroreflectivity (mcd/m^2/lux)										
			100	110	120	130	140	150	160	170	180	190	200
Yellow	>50	Y=0.16X0.60	3	3	3	3	3	3	3	3	**4**	4	4
	<50	Y=0.75X0.33	3	**4**	4	4	4	4	4	4	4	4	4
	All	Y=0.52X0.39	3	3	3	3	**4**	4	4	4	4	4	4
White	>50	Y=0.03X0.93	2	2	3	3	3	3	3	**4**	4	4	4
	<50	Y=0.07X0.80	3	3	3	3	**4**	4	4	4	4	5	5
	All	Y=0.06X0.82	3	3	3	3	3	**4**	4	4	4	4	5

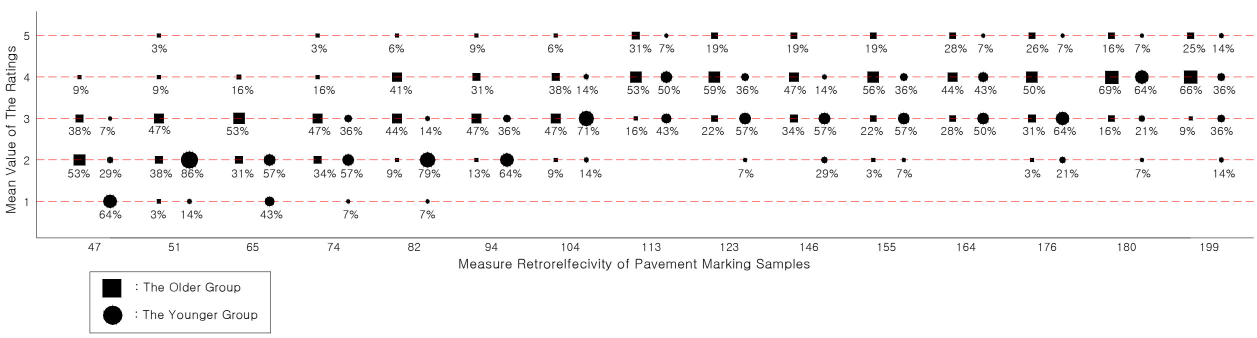

Figure 9. Rating Variations for White Pavement Marking

Table 3 shows the interim visibility indices developed and a trial application for retroreflectivity levels ranging from 100~200 mcd/m^2/lux and Figure 9 shows that subject

ratings of the younger and the older respectively for white pavement marking sections.
In rating the visibility of pavement markings, a significant difference was objected. The older group rated the pavement markings lower than one or more of the younger group; i.e., the older group had more difficulty following pavement markings. For the older group, pavement markings at intersections were the most important item, followed by the number of left –turn lanes, concrete guides, and intersection lighting.
The satisfaction level of not only road markings but also other items such as geometry, signing, and safety facilities may drop in the future owing to the increasing numbers and percentages of older driver with age-related diminished capabilities

4. CONCLUSIONS

The following conclusion were reached based on the data collected in this study

There is an apparent correlation between the readings taken by the retroreflectometer and the rating scores provided by the study participants
From the curvilinear regression curve approach and acceptability versus unacceptability percentile chart and the visibility distance, the threshold value of acceptability versus unacceptability appeared to be 130~140 mcd/m^2/lux for white markings and 90~110 mcd/m^2/lux for yellow markings.
However, it should not be considered as a recommended minimum value because of some factors having an effect on retroreflectivity.
First, Participants represent a relatively young population. In this research, a significant difference was objected by ages. It is likely that older drivers, operating in real-world situation, would require a higher value.
Secondly, the experiment was carried out under dry conditions in the field. In the wet condition, pavement markings can scarcely seen by drivers.
Thirdly, the motor vehicles in service today have different lighting systems, which affect the amount of light reflected in the direction of the source relative to the amount of light provided by the sources. The reflected light from roadway markings available to a driver’s eyes may vary from vehicle to vehicle.
In summary, it is likely that a higher minimum retroreflectivity value may be recommended after regarding the effect of ages, road conditions and headlight systems.

REFERENCE

Freedman, M. (1988) Noticeability Requirements for delineation on Non-Illuminated Highway. **Report No. FHWA -RD-88-028, Federal Highway Administration,** Washington, D.C.

Graham, J.R., j.K. Harrold and L.E. King. (1996) Pavement Marking Retroreflectivity Requirements for Older Drivers. **Transportation Research Record, No. 1529**, 65-70.

Graham, J.R. and L.E. King. (1991) Retroreflectivity Requirements for Pavement Markings. **Transportation Research Record, No. 1316**, 18-23.

Kalchbrenner, J. (1989) Large Glass Breads for Pavement Marking, **Transportation**

Research Record, No. 1230, 28-36.

Lee, J.T., T.L. Maleck. and W.C. Taylor (1998) Analysis of the Correlation between Pavement Marking Visibility and Nighttime Accidents **Transportation Research Board 77th Annual meeting, Washington,** D.C., January 1998.

Loetterle, F.E., R.A. Beck, and J. Carlson. (1999) Public Perception of Pavement Marking Brightness. **Transportation Research Board 78th Annual meeting,** Washington, D.C., January 1999.

Miglets, J., Graham, J.R, K.M. Bauer and D.W. Harwood. (1999) Field Surveys of Pavement Marking Retroreflectivity. **Transportation Research Record, No. 1657**, 71-78.

Nasser, A.A. (2002) Establishing a Crash-based Retroreflectivity Threshold. **Transportation Research Board 81th Annual meeting,** Washington, D.C., January 2002.

Zwahlen, H.T. and T. Schnell. (1997) Drive Eye Scanning Behavior at Night as a function of Pavement Marking Configuration **Transportation Research Board 76th Annual meeting,** Washington, D.C., January 1997.

Zwahlen, H.T. and T. Schnell. (2000) Minimum In-Service Retroreflectivity of Pavement Marking. **Transportation Research Board 79th Annual meeting,** Washington, D.C., January 2000.