In-Service Evaluation of Thermoplastic and Tape Pavement Markings Using a Portable Retroreflectometer

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The use of portable retroreflectometers to evaluate the reflectivity of longitudinal markings such as center lines and edge lines, and special markings such as arrows and symbols is described. Two hand-held retroreflectometers (Ecolux and Mirolux 12) were used in these evaluations. Retroreflectometers measure reflectivity of pavement markings through manual placement on a small section of pavement marking. The Mirolux 12 unit was used for most readings because it is easier to operate and speeds data collection. Two evaluation procedures were used. The first procedure evaluated longitudinal pavement markings and involved selecting a section of pavement markings (usually 1 to 3 mi long), breaking that section down into zones, and taking reflectivity readings within those zones. The second procedure evaluated special markings and involved taking 5 to 10 reflectivity readings for each marking to determine the reflectivity level for each marking. The use of retroreflectometers with these evaluation procedures has proven to be a helpful tool for the traffic engineer in evaluating the nighttime performance of pavement markings. Thermoplastic has been used in North Carolina since the mid-1970s and has long been considered a durable pavement marking; however, objective evaluations of its reflective performance have never been made. An in-service evaluation was performed on nearly 350 mi of thermoplastic long lines using portable retroreflectometers. This evaluation indicated that thermoplastic is both a durable and a reflective pavement marking. Another evaluation raised questions about reflectivity during deck testing of preformed tapes. These questions led to an in-service evaluation of approximately 200 special markings. The evaluation indicated poor reflectivity performance of preformed tapes.

Pavement markings are one of the most important traffic control devices available to road users. These devices serve to regulate, warn, and guide the motorist in the use of highways and streets during the day and night. During darkness and adverse weather conditions the driver's performance depends to a great extent on the reflectivity of the marking and its contrast with the pavement surface (*1*).

Reflectivity is the single most important quality of a pavement marking. The fact that "the nighttime fatality rate in the United States is more than three times the daytime rate" (*2*) indicates the need to provide visual guidance to the road user at night. During the day there are many sources of delineation other than pavement markings to aid the driver in the operation of a vehicle. Some of these sources of delineation include the pavement shoulder, roadside foliage, longitudinal joints, the distant view of the road ahead, and roadside development. During the day drivers appear to rely on features in the distance rather than the road surface for delineation and guidance (*1*).

This is not to say that the daytime appearance of pavement markings is not important. Where markings are used as regulatory or warning devices, such as center lines and railroad symbols, they must be intact and visible to be effective. In most instances, however, if the nighttime reflectivity of a pavement marking is acceptable, its daytime appearance is also acceptable.

Pavement markings are reflective because small glass spheres (beads) are embedded in the marking material. These glass beads act as tiny reflectors that collect light from a vehicle's headlights and reflect a portion of it back to the driver's eyes. Figure 1 shows the vision geometry for a typical driver in a vehicle (*3*). Table 1 gives examples of vision geometry for different vehicle models.

This is a simplification of a complex system. The reflectivity of pavement markings is a function of a number of parameters, including (a) the manufacture and application of the marking material and beads and (b) the physical condition of the road, driver, and vehicle (Kalchbrenner, paper in this Record).

USE OF RETROREFLECTOMETERS

In the United States, the night visibility of pavement markings has been evaluated using human observers under nighttime conditions. Although this has been the "ideal" method for determining the true visual performance of pavement markings, human observation has many drawbacks, including the subjective nature of the evaluators and the need to conduct evaluations after normal working hours (Kalchbrenner, paper in this Record).

Retroreflectometers were developed to provide objective measurements of retroreflectivity of pavement markings and to allow daytime evaluation. A retroreflectometer attempts to simulate—on a reduced scale—the nighttime visibility conditions experienced by a driver. The device generally consists of a box that eliminates ambient light, a light source projected on a known area, a light sensor to measure retroreflected light, and provision for calibrating the instrument on a strong retroreflector.

There are two types of retroreflectometers in use today, coarse-geometry and fine-geometry instruments. A coarse-geometry instrument does not closely simulate the conditions experienced by the driver, whereas a fine-geometry instru-

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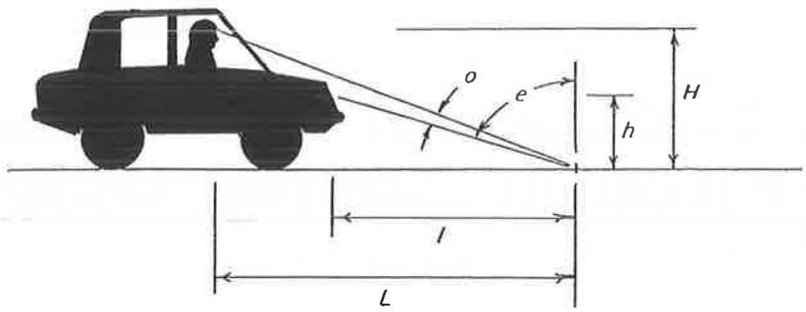

L: distance between driver's eyes and observation point
l: distance between headlights and observation point
H: height of driver's eyes
h: height of headlights
i: incidence angle
e: entrance angle
o: observation angle

FIGURE 1 Driver's vision in a vehicle.

TABLE 1 TYPICAL DRIVER'S VISION GEOMETRY FOR DIFFERENT VEHICLE MODELS (*3*)

Model	H	h	L	l	e	o
Dump Truck International Fleetstar 1910	6'8"	3'8"	64'	58'10"	86.4	2.3
Pickup Truck Dodge Custom 200	5'	3'	56'9"	50'	86.6	1.6
Sedan Chevrolet Impala	4'	2'3"	49'4"	42'	86.9	1.5

ment does. Some coarse-geometry machines would include the Michigan and Virginia Department of Transportation retroreflectometers. Fine-geometry machines would include the Ecolux, Erichsen, Optronik, and Mirolux (*4*).

Three different retroreflectometers were used in gathering reflectivity data in this research: Ecolux, Mirolux–Experimental, and Mirolux 12. These are all fine-geometry instruments, each having an entrance angle of 86.5 degrees and observation angles of 1, 1.5, and 1.5 degrees, respectively.

The Ecolux was used sparingly for in-service evaluations because of its weight and bulkiness. It is approximately 33 in. long and 10 in. wide, and weighs 20 lb. In addition, the Ecolux has a 21-lb battery pack and cable, which requires an additional person to handle it. The Ecolux has an analog scale, which is not difficult to read but does require judgment, and slows down the data-gathering process. The Ecolux reflectivity readings were converted to millicandelas per square meter per lux [(mcd · m^{-2})/lx] using a conversion equation specific to each machine.

In contrast, the Mirolux retroreflectometers are much lighter and easier to use, which resulted in more flexibility and productivity in data gathering. The two units used are hand-held and approximately 18 in. long and 6 in. wide, with an internal rechargeable 12-volt battery pack and a total weight of 14 lb. The read-out is digital and there is a digital battery voltage check. The readings from the two instruments were not the same, and correlation tests were required between the two and between the Ecolux and the two Mirolux retroreflectometers to determine their values. (All the values reported in this paper will be in millicandelas per square meter per lux as measured with an Ecolux retroreflectometer.) The two Mirolux machines were used to gather most of the in-service readings on pavement marking tapes and thermoplastics. In fact, without the Mirolux instruments, the number of in-service readings taken on these projects would not have been possible.

CORRELATION OF RETROREFLECTOMETERS

The two Mirolux retroreflectometers used were different generations of the same instrument. The first unit, the Mirolux–Experimental, was experimental and the second unit was one of the first production models of the Mirolux 12. The readings taken with the Mirolux–Experimental were "machine readings" and could not be converted. However, the Mirolux 12 provided direct readings in millicandelas per square meter per lux. Therefore a correlation test was developed to determine the relationship between these two units so machine readings taken with the Mirolux–Experimental could be converted into equivalent Mirolux 12 readings in the appropriate units.

The correlation test involved taking closely controlled reflectivity readings on different colored sheets of paper, pavement marking tape samples, and painted markings in the field with both instruments. Each instrument was carefully calibrated before readings were taken, using the internal retroreflector, and each instrument was checked using the external test panel of known reflectivity provided with each instrument.

Care was taken to measure the reflectivity in exactly the same location with each instrument. Sixteen different colored sheets of paper were checked, 19 tape samples, and 23 paint locations. These samples gave a good distribution of reflectivity levels from 0 to 989 as measured with the Mirolux 12 unit. Table 2 shows the readings as taken with each instrument for the paper, tape, and paint samples. A linear regression was performed on this data and a straight line was fitted to the data. Figure 2 shows a plot of this data and the equation for the line. A correlation analysis of these data and the straight line indicated that the data closely fit a straight line with a correlation coefficient of $R = 0.996$ and an $R^2 = 0.992$. This analysis enabled the machine readings taken with the Mirolux–Experimental to be converted into Mirolux 12 readings in millicandelas per square meter per lux.

Because the Mirolux 12 retroreflectometer was new, no information was available on how a reading related to the reflective performance of pavement markings, in other words, what the "good" and "bad" reflectivity readings were according to the Mirolux 12. Because some information was available on acceptable levels of reflectivity as measured with an Ecolux reflectometer, reflectivity readings taken with the Mirolux 12 were compared with those from an Ecolux. For this evaluation, an additional correlation test was performed between the Ecolux and Mirolux 12.

This correlation was performed in the same way as the previous correlation test, using paper and tape samples. The correlation test established that a relationship did exist between the readings of these two instruments. Figure 3 shows a plot of Ecolux versus Mirolux 12 readings taken on samples of paper and tape.

ESTABLISHING MINIMUM REFLECTIVITY VALUES

Determining the reflectivity of pavement markings has traditionally been a difficult task for traffic engineers in the United States because of the lack of recognized standards and equipment for making high-speed field evaluations. To the author's knowledge, no uniformly recognized U.S. standards for reflectivity of pavement markings exist.

Reflectivity standards for pavement marking materials are used in other countries, however—most notably in France and Germany. Each country has standards based on reflectivity readings taken with hand-held fine-geometry retroreflectometers manufactured in that country. The French have established an acceptable reflectivity value of 150 $(mcd{\cdot}m^{-2})lx$ as measured with an Ecolux retroreflectometer, and the Germans use a range of values from 150 to 70 SL based on traffic

TABLE 2 REFLECTIVITY READING FOR MIROLUX–EXPERIMENTAL VERSUS MIROLUX 12 ON PAPER, TAPE, AND PAINT SAMPLES

Test Sample	Mirolux Expmntl.	Mirolux 12	Test Samples	Mirolux Expmntl.	Mirolux 12
Paper Samples			Tape Samples		
White	28	32	Prismo Remov.-white	320	477
Ivory	28	30	-yellow	151	217
Very Lt. Blue	26	25	Prismo Inglf.-white	282	415
Lt. Blue	21	20	-yellow	188	276
Dark Blue	27	29	Paint - white	105	152
Lt. Pink	24	24	Paint - white	112	162
Pink	31	34	Paint - white	119	181
Lt. Yellow	31	33	Paint - white	112	175
Medium Yellow	27	28	Paint - white	112	170
Dark Yellow	27	27	Paint - white	108	159
Green	23	23	Paint - white	107	166
Orange	29	33	Paint - white	120	188
Red	26	26	Paint - white	170	243
Black I	9	2	Paint - white	113	156
Black II	11	5	Paint - yellow	72	106
Black plate	5	0	Paint - yellow	70	105
Test Plate-Old	207	309	Paint - yellow	82	135
Test Plate-New	305	453	Paint - yellow	74	110
MM Yellow	117	160	Paint - yellow	69	99
Prismo TR-white	531	777	Paint - yellow	73	108
MM white	220	322	Paint - yellow	51	85
Prismo TNR-white	561	813	Paint - yellow	34	64
-yellow	125	180	Paint - yellow	65	98
Swarolite -white	572	989	Paint - yellow	33	49
-yellow	458	650	Paint - yellow	43	61
Catatyle-yellow	237	351	Paint - yellow	43	61
3M Remov.-white	267	397			
-yellow	372	554			

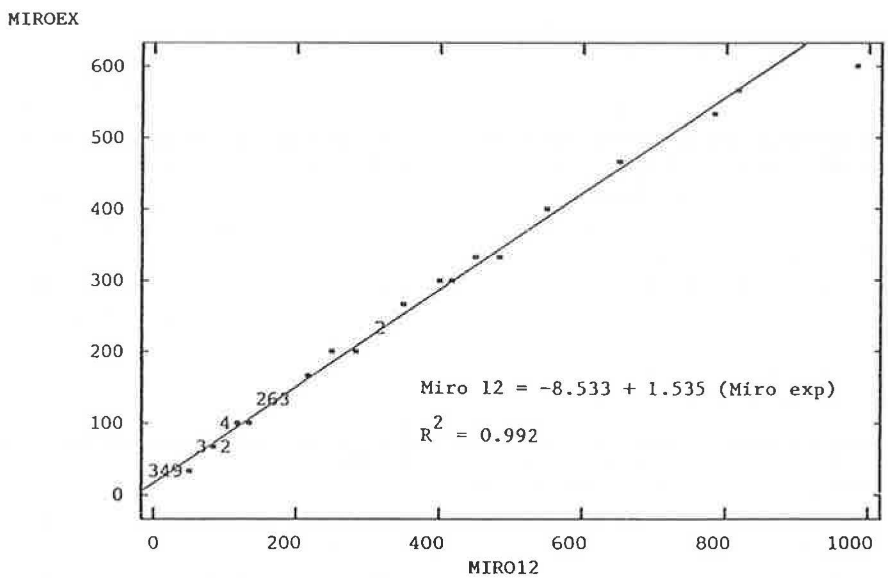

FIGURE 2 Plot of Mirolux–Experimental versus Mirolux 12 readings on laboratory and field samples.

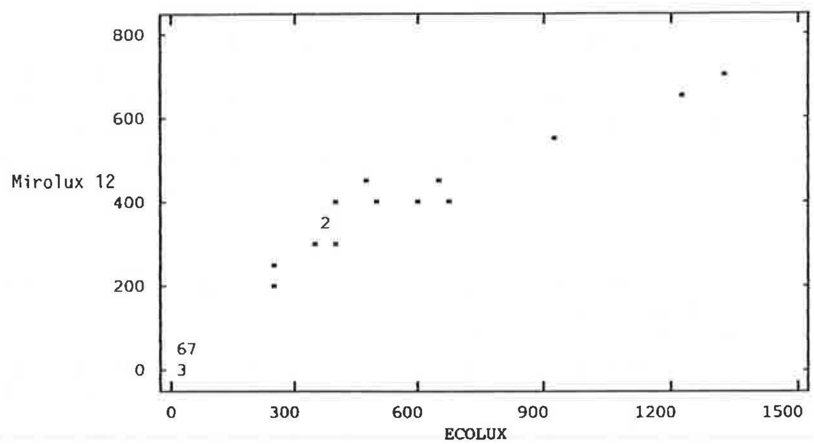

FIGURE 3 Plot of current Mirolux 12 versus Ecolux values on laboratory samples.

conditions as measured with a German-made retroreflectometer (*5*).

Although the United States does not currently have any minimum standards for reflectivity of pavement markings, some research has been performed and discussion is under way. One of the first such studies was an FHWA project by Allen et al. (*6*). Other research includes work done by Ethen and Woltman (*7*). NCHRP Project 4-16—Cost and Service Life of Pavement Markings—is also investigating minimum reflectivity values for markings.

This paper is not intended to establish the minimum acceptable standards for pavement markings in the United States. That task will take much research and discussion. However, if objective reflectivity readings are to be made, some value must be used for comparison of readings.

For this work, the research discussed in the previous paragraph was consulted for information on acceptable levels of reflectivity for pavement markings, and a limited panel evaluation was conducted by the Institute for Transportation Research and Education (ITRE). The panel evaluation was not conclusive. Its scope was limited because funds were limited and only five observers were used to evaluate 13 different markings with different amounts of wear. Even though the panel evaluation was not conclusive, it did aid in the review of previous work in this area and the decision was made to use a value of 100 (mcd·m^{-2})/lx as measured with an Ecolux retroreflectometer as a minimum acceptable value for reflectivity. Therefore all the readings presented in this paper will be Ecolux values.

Again it should be noted that the minimum value used here is not intended to be a standard. Other agencies may choose lower values for markings and some may want a higher level of service and require higher acceptable values. Individual criteria may be chosen until a national standard is adopted.

THERMOPLASTIC LONG-LINE IN-SERVICE EVALUATIONS

Thermoplastic has been used for pavement marking by the North Carolina Department of Transportation (NCDOT) since the mid-1970s. Numerous evaluations have been conducted by the NCDOT on the performance of thermoplastics during this period, but most have been informal or specific to a particular roadway project. The consensus among the NCDOT field traffic engineers has been that thermoplastic is a durable pavement marking material that performs well for several years when installed on asphalt pavements.

The specific number of years of acceptable service varied among engineers but generally ranged from 4 to 6 years. This performance was based primarily on periodic daytime and nighttime visual evaluations by field traffic engineers. Although these evaluations provide useful information on the overall trend in the performance of thermoplastic, problems with this procedure are evident, including lack of standard evaluation procedures, difficulty in measuring reflectivity (nighttime brightness), and the large number of engineers involved in these evaluations. North Carolina has 14 highway division offices with 14 field traffic engineers, all with different perceptions and opinions on the performance needs of pavement markings.

In 1985 the NCDOT Traffic Engineering Branch began a Highway Planning and Research Project on plastic pavement marking materials to determine how well thermoplastic and preformed tape marking materials were performing in North Carolina. The thermoplastic portion of the project focused on the performance of long-line thermoplastic pavement markings. Long-line markings include edge lines, lane lines, center lines, and barrier lines. A variety of projects representing each of North Carolina's geographic regions (mountains, piedmont, and coastal plain) and roadway types was evaluated. The roadway types evaluated included two-lane roadways, multilane undivided roadways, and divided (Interstate-type) roadways. The average daily traffic (ADT) varied from 5,000 to 20,000.

The purpose of the thermoplastic phase of this research project was to determine how well long-line thermoplastic pavement markings perform on different highways across North Carolina and to determine their expected life. To accomplish this purpose, a thorough review was conducted of other research in this area. NCDOT's thermoplastic project information was reviewed, evaluation procedures were developed and tested, and preliminary and final field visits were made to conduct the evaluations.

Research Review

The review covered previous research reports concerning the evaluation and performance of thermoplastic and other pavement marking materials. In total more than two dozen reports and documents were used.

An inventory review was made of all available NCDOT records on thermoplastic pavement marking projects in North Carolina. This review revealed special marking projects dating back to 1976 and long-line projects back to 1978. A complete list of these potential projects was assembled for further investigation and preliminary field visits. The projects were assembled by NCDOT Highway Division, date, county, and project number.

Preliminary Field Visits

A copy of the identified thermoplastic projects in each highway division was sent to each respective NCDOT Highway Division traffic engineer for review and change. Field visits were then arranged with each NCDOT Highway Division traffic engineer to discuss thermoplastic markings, to review the data, and to make field visits to thermoplastic sites.

These visits proved to be a valuable contribution to this project in providing

- Updates and corrections to the list of projects,
- First-hand information about this research project for field personnel,
- A means of learning about the experiences, problems, and opinions of practicing field personnel on the subject of pavement markings, and
- A preliminary review of most of the thermoplastic projects still in service.

These preliminary visits also allowed for a discussion of evaluation procedures and some experimentation with different approaches. A number of nighttime evaluations were conducted on thermoplastic during these visits, first to observe at first hand how well markings were performing at night and second to try different evaluation approaches.

During these visits with the 14 NCDOT Highway Division traffic engineers, one point was repeated—thermoplastic is a durable and effective pavement marking material when used on asphalt. When asked about lifespan of this material, individuals offered responses ranging from 4 years to "until it's resurfaced." There were some negative comments on the performance of the material in heavy snowplow areas and on concrete. In fact, the comments on thermoplastic's performance on concrete were as uniformly negative as the comments on its performance on asphalt were positive. In the final evaluation, only one section of concrete with thermoplastic was found that had not previously been repainted.

Reflectivity Readings and Field Evaluations

Upon conclusion of the preliminary visits, a list of sites for further evaluation was assembled. Of the 1,456 mi of thermoplastic originally identified from traffic engineering records, approximately 800 mi was found to be in place in the field. The remainder of the sections were either resurfaced or painted over. North Carolina had two major resurfacing programs in the 1980s, and many of the sections of Interstate, primary, and urban roadways where thermoplastic was installed in the late 1970s and early 1980s were covered in these programs. Resurfacing is unavoidable in highway work, and despite careful planning pavements can deteriorate more quickly than anticipated. Durable pavement markings are placed on high-volume routes, which are more susceptible to pavement failure and receive a higher level of maintenance.

Resurfacing accounted for the majority of the loss of thermoplastic projects. Over 540 mi of the original projects identified had been resurfaced. In most cases, no information on the condition of these sections at the time of resurfacing was available and in other cases information was not readily available. An evaluation could not be made without information on the condition of the marking at the time of resurfacing. Of the remaining 120 mi of projects, approximately 60 mi had been placed on concrete and repainted within the first 3 years by maintenance forces. Loss of material due to chipping was the major failure of thermoplastic on concrete, according to field contacts. The other 60 mi of thermoplastic placed on asphalt had also been repainted by maintenance forces. Lane lines were the most frequent markings repainted on projects installed in 1981 or before.

Procedures used to evaluate a pavement marking's performance vary substantially among divisions. This was concluded from the field visits with the 14 NCDOT Highway Division traffic engineers and in previous studies with traffic service operations. Some divisions have higher levels of service for pavement markings than others. Without more definitive information on the marking's performance at the time of repainting, its condition at that time remains unknown.

A few general comments can be made concerning these repainted sections of thermoplastic. First, a higher proportion (70 percent) of the sections that had been repainted were in the mountainous and northern piedmont divisions of the state. These divisions experience higher amounts of snow and ice and, according to field observations and contact with field representatives, damage from snowplows. Snow and ice control contributed significantly to a loss of thermoplastic and subsequent repainting.

Second, certain divisions had repainted all thermoplastic markings that were installed before a particular date, possibly indicating a higher level of service than other divisions. This conclusion was based partly on a number of spot reflectivity readings taken on portions of lines not completely retraced, indicating that some of these repainted markings were still providing acceptable levels of reflectivity.

Evaluation Procedures

A number of evaluation procedures were examined for use in this project. Some of these ideas were tested in the preliminary field visits. As in the other evaluations, the three most important factors concerning a pavement marking's performance are appearance, durability, and reflectivity. The appearance and durability evaluations were used in other research projects on thermoplastic and were generally conducted in the daytime from a moving vehicle or from the shoulder of the road. Evaluation of reflectivity was more difficult because it required nighttime visits to each section and then a subjective rating of the condition.

A series of nighttime reviews of thermoplastic markings indicated that useful information could be determined about the reflectivity of pavement marking in this manner. A number of serious problems were encountered with this method, including the need to conduct evaluations after normal working hours and to control evaluation conditions such as oncoming headlights, peripheral lighting, time, and season. Trial measurements were made on pavement markings using an Ecolux retroreflectometer in an attempt to eliminate some of these problems.

The Ecolux eliminated many of the problems encountered in the subjective nighttime evaluations but had problems of its own. The major problem with the Ecolux was that it was not easy to operate under traffic conditions. The Ecolux requires two people to operate—one to hold and read the machine and the other to carry the battery pack and cable. Operating the machine was a laborious task, making extensive use of an Ecolux impossible.

Shortly after these trials with the Ecolux, ITRE was provided with a Mirolux retroreflectometer for testing. The Mirolux solved the task-oriented problems of the Ecolux. The Mirolux was small, light, easy to operate, and proved to be reliable after repeated use. Testing also revealed a direct relationship between its readings and those of the Ecolux. Finally, an objective means of evaluating the reflective quality of pavement markings was available for use in the field. Armed with this new evaluation tool, ITRE began an extensive field evaluation of thermoplastic.

Before field visits were made, the evaluation procedures were finalized and tested. The three areas of evaluation were appearance, durability, and reflectivity.

Appearance

Markings were rated as acceptable or unacceptable using the following definitions. This was an overall rating for the entire section.

Acceptable The intent of the pavement marking to guide, warn, or regulate is clear to the driver from a vehicle operating at normal highway speeds during daylight hours. This is the complete impression conveyed by the marking, including appropriate color (white or yellow).

Unacceptable The intent of the marking to guide, warn, or regulate is not clear to a driver from a vehicle operating at normal highway speeds during daylight hours.

Durability

The durability was evaluated according to the percentage of the material remaining on the pavement. This evaluation was made at the same locations as the reflectivity readings, directly over the marking, using the unaided human eye. Only surface area covered was evaluated. Thickness measurements are not practical without a special instrument, which was unavailable at the time of this evaluation.

Reflectivity

The reflectivity was evaluated using a Mirolux 12 retroreflectometer. Each thermoplastic project was evaluated by taking three sets of reflectivity readings, generally in the first third, the middle third, and the final third of the project. A set of reflectivity readings consisted of at least 18 readings over six skip lines (three readings per skip) and 18 readings distributed evenly over 300 ft of continuous line. This was done for each line (edge line, center line, lane line, or barrier line) in both directions. This procedure was followed for sections approximately 3 mi long. For sections over 3 mi, an additional set of readings was taken at each additional segment up to 3 mi. Readings were taken on randomly selected tangent sections within each of the three zones to allow for comparison between sections and for safety.

The following procedure was used to determine the reflectivity performance for a marking on a project. On a given project, all reflectivity readings for a given marking (i.e., edge line, lane line, or center line) were totaled and then divided by the number of readings to get an average reflectivity value. This reflectivity value could then be used to determine whether the edge line, lane line, or center line met minimum acceptable reflectivity standards.

Site Selection

After the preliminary visits, approximately 800 mi of thermoplastic on 146 pavement marking projects was identified. The decision was made to evaluate thermoplastic sites in all of the 14 NCDOT Highway Divisions. This would give a good distribution of geographic and climate types. Approximately one week was assigned to each division for data collection. The approach was to check as many sites as possible within each division. In 5 of the 14 NCDOT Highway Divisions, all thermoplastic sites were evaluated. In the remaining 9 divisions, approximately half of the thermoplastic sites within each division were evaluated. An attempt was made to evaluate each type of roadway (two-lane, multilane undivided, and multilane divided) within each division.

Results of Thermoplastic In-Service Evaluations

In the final evaluation, approximately 350 road mi of thermoplastic on 60 different projects was evaluated. These projects covered the period from 1979 to 1986. Sections were grouped according to the type of roadway:

- Two-lane,
- Multilane divided, and
- Multilane undivided.

Appearance

With the exception of a few sections of roadway in the coastal region of the state, the appearance evaluation criterion was not the controlling factor in determining the performance of a section of thermoplastic. On these particular sections, the pavement was 7 to 8 years old and contained highly polished aggregate, which gave a pavement color similar to that of concrete. The appearance of these particular markings varied according to the direction of travel and the intensity of sunlight. The end result was that the surface did not provide sufficient contrast with the pavement markings to be effective during all daytime conditions.

Contrast

This study did not have the instrumentation to measure contrast objectively, so it was evaluated subjectively. It is interesting to note that these particular sections had good nighttime reflectivity. Failure due to daytime performance was the exception rather than the rule in these evaluations. In most it was the reflectivity evaluation that controlled the marking performance in this project.

Reflectivity

The importance of reflectivity in the performance of a pavement marking has always been recognized, but an objective evaluation of that performance has been a difficult task. With the use of the Mirolux 12 retroreflectometer, an objective evaluation of reflectivity of thermoplastic projects in North Carolina was performed and shows why thermoplastic pavement markings are so favored by NCDOT field personnel. Results showed that white thermoplastic provided 6 and 8 years of acceptable performance on all types of highway facilities. Yellow markings had not provided comparable results. Less than half of the projects had demonstrated acceptable service after 3 years. The evaluation is based on an acceptable reflectivity value of 100 SL as measured with an Ecolux retroreflectometer. The same value was used on both white and yellow materials. (Yellow is inherently less reflective than white and this may justify a lower level of reflectivity. Experiments in this area were outside the scope of this project, however.) Table 3 gives a summary of the reflectivity performance of the thermoplastic projects evaluated under this project.

Table 3 also shows the number of thermoplastic sections and mileage by year and the percentage (by mileage) that were acceptable (≥ 100) and unacceptable (< 100) as measured with an Ecolux. Table 3 shows that nearly all white thermoplastic markings were found to be acceptable regardless of age. In fact, of the more than 60 projects evaluated, only 2 were found to have white thermoplastic unacceptable because of reflectivity. The performance of yellow thermoplastic was not as good, with more than half of the yellow material failing after less than 6 years of service in both the edge line and center line conditions.

Durability

Information on durability (percent of material remaining) was gathered at the same time as the appearance and reflectivity data. Reflectivity or appearance, or both, were the factors that controlled the failure in all the sections evaluated. However, durability was an integral part of the reason the markings failed. If a marking material loosens from the pavement surface, no reflective material is present to delineate lines.

In the analysis of field data, white thermoplastic markings were rated acceptable according to appearance; reflectivity

TABLE 3 SUMMARY OF THERMOPLASTIC REFLECTIVITY READINGS

TWO-LANE ROADWAYS

YEAR	NUMBER OF SECTIONS	MILES	WHITE EDGE LINE READINGS %>100	WHITE EDGE LINE READINGS %<100	YELLOW CENTER LINE READINGS %>100	YELLOW CENTER LINE READINGS %<100
1979	3	18.0	100	0	44	56
1981	11	38.5	100	0	61	39
1983	1	7.0	100	0	100	0
1984	3	33.0	100	0	88	12

MULTI-LANE DIVIDED ROADWAYS

YEAR	NUMBER OF SECTIONS	MILES	WHITE EDGE LINE %>100	WHITE EDGE LINE %<100	WHITE LANE LINE %>100	WHITE LANE LINE %<100	YELLOW EDGE LINE %>100	YELLOW EDGE LINE %<100
1979	2	14.0	100	0	100	0	43	57
1981	17	84.5	95	4	98	2	39	61
1982	5	33.0	100	0	100	0	36	64
1983	5	32.0	100	0	100	0	37	63
1984	2	9.0	100	0	100	0	100	0
1985	3	21.0	100	0	100	0	100	0
1986	2	17.0	100	0	100	0	100	0

MULTI-LANE UNDIVIDED ROADWAYS

YEAR	NUMBER OF SECTIONS	MILES	WHITE EDGE LINE %>100	WHITE EDGE LINE %<100	WHITE LANE LINE %>100	WHITE LANE LINE %<100	YELLOW BARRIER LINE %>100	YELLOW BARRIER LINE %<100
1981	3	12.0	100	0	100	0	0	100
1985	3	31.0	100	0	90	10	90	10
1986	1	2.0	100	0	100	0	0	100

NOTE: The values shown are Ecolux values [(mcd · m^{-2})/lx].

generally consisted of more than 70 percent of the material remaining. When less than 70 percent of the marking was present, reflectivity was generally at or below the acceptable level and appearance was unacceptable or marginal. For more than 90 percent of the markings evaluated in this project, 75 to 90 percent of the surface area was covered with material. These durability percentages were recorded at the locations of reflectivity readings. (There was not always a relationship between the percentage of material remaining and reflectivity of yellow thermoplastic markings.) As discussed before, yellow materials are inherently less reflective than white materials and, in many cases, more than 70 percent of the marking was in place and the reflectivity level was still below the minimum acceptable level.

Performance on Concrete

Another problem discovered in this evaluation was the poor performance of thermoplastic on concrete. Only one concrete project of approximately 5 mi had thermoplastic markings that had not been repainted. This particular section was multilane divided, with >20,000 ADT, and was approximately 4 years old. It was in excellent condition. All other sections exhibited extensive chipping and loss of material. According to field personnel, each of these sections was restriped with paint within 3 to 4 years after installation. A variety of explanations was presented for these failures, including poor cleaning of curing compound before placement, excessive loss due to snowplow activity, and a lack of sufficient bond to the concrete.

In conclusion, thermoplastic is a durable and reflective pavement marking material when used as a long-line marking on multilane and two-lane roadways with wide lanes. In North Carolina, white thermoplastic is providing acceptable appearance and reflectivity for 6 and 8 years when installed on high-type roadways with traffic volumes up to 20,000 ADT. Yellow thermoplastic is providing a marking life of 3 years under similar roadway conditions. These results are based on an extensive evaluation of reflectivity using objective readings from a portable retroreflectometer.

LONG-LIFE TAPE IN-SERVICE EVALUATIONS

A second part of the 1985 North Carolina Highway Planning and Research Project was an evaluation of pavement marking tapes. This evaluation included test deck testing and in-service testing of different pavement marking tape products. This research covered a 2-year period and provided approximately 20 months of observation time measured from the time of installation. Because long-life tapes are used primarily for special markings such as arrows, school and railroad symbols, stopbars, and crosswalks, one of the in-service tests was to install samples of each long-life tape product in special marking locations. The site selected for this test was in Oxford, N.C. (population 8,000). Oxford's main street was chosen because of on-street parking, signalized intersections, curb and gutter, asphalt pavement, and an ADT of 6,500 to 11,000. The roadway has two lanes with short left-turn lanes at signalized intersections.

Oxford Crosswalk and Stop Bar Tests

Five different long-life pavement marking tape products were installed at the site. At least three samples (approximately 10 ft long) of each of the five products were installed as crosswalks or stop bars, or both. Visual evaluations were made of these samples at 1, 6, 12, and 20 months of service. During these evaluations the markings were analyzed for appearance (acceptable or unacceptable) and durability (percentage of marking remaining). During this 20-month period 5 of the 17 total samples installed failed appearance or durability criteria. At the end of 20 months of service, reflectivity was also evaluated. Five reflectivity readings were taken on each section of crosswalk or stop bar with an Ecolux retroreflectometer. These five readings were then averaged to get a reflectivity value for each sample. Table 4 lists the individual crosswalk and stop bar markings and their average reflectivity readings. Using 100 (mcd$\cdot$m^{-2})/lx as measured with an Ecolux as an acceptable reflectivity level, Table 4 shows that these markings performed poorly in reflectivity. In fact, none of the materials tested met the acceptable level of reflectivity. This test raised questions about the reflectivity performance of pavement marking tapes when used as special markings, which is where most are used.

To determine whether these poor reflectivity results were indicative of the performance of pavement marking tapes in general, an expanded in-service evaluation was conducted on special markings installed by NCDOT maintenance forces in 1985—the same time that test samples were installed. The only long-life pavement marking tape approved for use by NCDOT at that time was 3M Company's Stamark Pliant Polymer® 5730 tape; therefore, it was the only material evaluated.

3M 5730 Long-Life Tape in Special Markings

Approximately 30 projects and locations were identified for evaluation with varying ADTs and traffic conditions. These locations were all in Harnett and Cumberland counties, which are on the coastal plain of North Carolina. A total of 194 individual markings were evaluated. Installation dates were known for all of these markings and all were installed in the summer of 1985. In this evaluation the same criteria for appearance, durability, and reflectivity were used as in the other in-service evaluations.

A variety of special marking types was evaluated, including all types of arrows, railroad crossing symbols, and stop bars at railroad crossings. As in the Oxford study, most of the markings evaluated were acceptable in appearance and durability (approximately 5 percent of the markings evaluated failed due to appearance and durability). Again, reflectivity was the weak point in the performance of these markings. Reflectivity was evaluated using a Mirolux 12 retroreflectometer taking 5 readings per arrow and 10 readings for each railroad symbol. These readings were then averaged to get a reflectivity reading for each marking. Using the 100 SL—as measured with an Ecolux retroreflectometer—as the acceptable value for reflectivity, 74 percent of the markings checked were unacceptable because of reflectivity after only 2 years of service.

Table 5 shows the reflectivity performance by showing the number of special markings evaluated by type and the percentage above and below the 100 SL as measured with an Ecolux retroreflectometer. As the table shows, the only type of special marking that performed reasonably well was the through arrow; however, only 36 percent of those checked were above the 100 SL.

Even if reflectivity values below the established level of 100—as measured with an Ecolux—are used, a significant percentage of the special markings would be unacceptable. Table 6 gives the percentages of each type of special marking that had reflectivity values below 100, 90, 80, and 70 SL.

Because of poor reflectivity readings, it is questionable whether long-life pavement marking tape should be used in special markings except under lighted conditions. Of course, this recommendation is based on an acceptable value of 100

TABLE 4 OXFORD CROSSWALK AND STOP BAR TESTING REFLECTIVITY READINGS AT 20 MONTHS

	Crosswk Locat.1	Crosswk Locat.2	Crosswk Locat.3	StopBar Left Turn 1	StopBar Left Turn 2
A - SEIBULITE "MM"	69	65	67	--	--
B - 3M "STAMARK" 5730	66	59	66	92	--
C - CATA-TILE	58	--	--	80	69
D - PRISMO 60MM	61	56	--	--	75
E - PRISMO 90MM	60	56	--	88	74

NOTE: Reflectivity readings were taken with an Ecolux retroreflectometer. The listed readings are an average of 5 readings per test sample.

A dash (--) indicates that no material was installed at that location.

TABLE 5 REFLECTIVITY READINGS FOR 3M STAMARK® 5730 TAPE USED AS SPECIAL MARKINGS

Special Marking Type	Markings Evaluated	Acceptable Readings≥100 Number	%	Unacceptable Readings <100 Number	%
TURN ARROWS	36	8	22%	28	78%
THROUGH ARROWS	66	24	36%	42	64%
COMBINATION ARROWS	39	1	3%	38	97%
RXR-RAILROAD SYMBOL	33	7	21%	26	79%
--- STOP BAR AT RAILROAD CROSSING	12	1	8%	11	92%
TOTALS	186	41	26%	145	74%

NOTE: The values shown are ecolux values [(mcd · m^{-2})/lx].

Reflectivity readings for all arrows and stop bars at railroad tracks are based on 5 readings for each marking. Railroad symbols are based on 10 readings each.

TABLE 6 PERCENTAGES OF UNACCEPTABLE SPECIAL MARKINGS AT LOWER REFLECTIVITY VALUES

Special Marking Tape	No. of Markings Evaluated	Percentage of Reflectivity Readings (Ecolux) <100	<90	<80	<70
Turn Arrows	36	78%	78%	38%	14%
Through Arrows	66	64	41	20	9
Combination Arrows	39	97	95	62	10
RxR - Railroad Symbols	33	79	70	30	6
---Stop Bar at Railroad Crossing	12	92	75	42	17
TOTALS:	186	74%	64%	37%	14%

(mcd·m^{-2})/lx as measured with an Ecolux retroreflectometer, and lower acceptable values may result in different conclusions. The purpose is to show that a portable retroreflectometer can be used to evaluate the reflectivity performance of pavement markings. Reflectivity has long been recognized as an important part of a pavement marking's performance. Nevertheless, it has been difficult to objectively evaluate the reflective performance of pavement markings because of the subjective nature of nighttime visual evaluations. A portable retroreflectometer makes such an objective analysis possible.

SUMMARY AND CONCLUSIONS

The evaluation of pavement markings for reflectivity under in-service conditions is a difficult task for the traffic engineer. The lack of reflectivity standards and high-speed equipment for making such measurements has resulted in fewer in-service evaluations of pavement marking reflectivity.

Until such standards and high-speed equipment are developed, highway agencies will have to rely on their own capabilities in the evaluation of pavement markings. These might include nighttime visual evaluations and use of the portable handheld retroreflectometers currently available. Highway agencies could establish their own acceptable levels of reflectivity.

A procedure has been presented for using a portable retroreflectometer (Mirolux 12) to evaluate the reflectivity of long lines and special markings. A procedure was presented for taking reflectivity readings under actual field conditions on both types of markings. Information was also provided on the selection of an acceptable level of reflectivity. Two examples were presented in the application of this evaluation procedure, one looking at longline thermoplastic markings and another looking at preformed tape used as special markings.

The thermoplastic evaluation shows that white thermoplastic has been providing acceptable service under a wide range of traffic conditions in North Carolina for 6 and 8 years. Yellow thermoplastic is providing at least 3 years of service and longer in some cases. The special marking evaluation of preformed tape indicated that these materials were not providing an acceptable level of reflectivity after only 2 years of service.

These evaluations were based on an acceptable level of reflectivity of 100 (mcd·m^{-2})/lx as measured with an Ecolux retroreflectometer. This level of reflectivity was based on previous studies in the area of pavement marking reflectivity and a limited panel evaluation.

These examples show that useful information can be derived from this type of evaluation to help the traffic engineer in making decisions concerning pavement marking practices.

ACKNOWLEDGMENT

This study was sponsored by the North Carolina Department of Transportation.

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Publication of this paper sponsored by Committee on Coatings, Signing, and Marking Materials.