Research Report
UKTRP-87-10

EVALUATION AND APPLICATION OF ROADWAY MARKING MATERIALS

by

Kenneth R. Agent
Research Engineer

and

Jerry G. Pigman
Research Engineer

May 1987

COMMONWEALTH OF KENTUCKY
TRANSPORTATION CABINET
FRANKFORT, KENTUCKY 40622

C. LESLIE DAWSON
SECRETARY
AND
COMMISSIONER OF HIGHWAYS

WALLACE G. WILKINSON
GOVERNOR

January 8, 1988

Mr. Robert E. Johnson
Division Administrator
Federal Highway Administration
330 West Broadway
Frankfort, KY 40602-0536

SUBJECT: Implementation Statement
UKTRP 87-10
Evaluation and Application of
Roadway Marking Materials

Dear Mr. Johnson:

As a result of the information contained in the subject study, the Department of Highways has developed a new Pavement Marking Policy.

This Pavement Marking Policy has been submitted to your office and was approved with minor changes September 22, 1987. This policy revision is in the process of being included in the Department's Traffic Division Guidance Manual.

Sincerely,

R. K. Capito, P. E.
State Highway Engineer

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Kentucky Transportation Research Program
College of Engineering
University of Kentucky
Lexington, Kentucky

in cooperation with
Transportation Cabinet
Commonwealth of Kentucky

and

Federal Highway Administration
US Department of Transportation

May 1987

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UKTRP-87-10		

4. Title and Subtitle Evaluation and Application of Roadway Marking Materials	5. Report Date May 1987 6. Performing Organization Code
7. Author(s) K. R. Agent and J. G. Pigman	8. Performing Organization Report No. UKTRP-87-10
9. Performing Organization Name and Address Kentucky Transportation Research Program College of Engineering University of Kentucky Lexington, Kentucky 40506-0043	10. Work Unit No. (TRAIS) 11. Contract or Grant No. KYHPR-84-93
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet State Office Building Frankfort, Kentucky 40622	13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes
Study Title: Evaluation and Application of Roadway Delineation Techniques

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

Three different areas of roadway delineation were included in this study. These areas were:

1. Lane delineation materials,
2. crosswalk delineation materials, and
3. snowplowable markers.

Evaluation of lane delineation materials revealed that expanded use was warranted for polyester paint and extruded thermoplastic. The alkyd-resin extruded thermoplastic material was determined to be the most cost-effective material for crosswalk and stopbar installations. Durability and reflectivity results show that Stimsonite 96 markers have performed effectively as snowplowable markers while the recessed markers have performed effectively except on certain interstate locations.

17. Key Words	18. Distribution Statement
Lane Delineation, Crosswalk, Stopbar, Snowplowable Marker, Polyester Paint, Epoxy Paint, Preformed Tape, EPOFLEX, Extruded Thermoplastic	Unclassified with Kentucky Transportation Cabinet approval

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	46	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

This report was prepared with the guidance of the following members of the Study Advisory Committee:

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EXECUTIVE SUMMARY

Three different areas of roadway delineation were included in this study:

1. lane delineation materials,
2. crosswalk and stopbar materials, and
3. snowplowable markers.

The evaluation has shown that expanded use is warranted for polyester paint and extruded thermoplastic. Whether polyester paint can be used on high-volume roadways or portland cement concrete pavements still must be determined. Both alkyd-resin and hydrocarbon-resin extruded thermoplastics have performed well on the interstate open-graded pavement installations. There have been no data that would favor one type over the other. Use of either polyester paint or extruded thermoplastic would involve contracting since the Kentucky Transportation Cabinet does not have the necessary equipment for placement of those materials. The high cost of the preformed tapes would preclude widespread use when compared with the cost and performance of extruded thermoplastic. No further use of the 100-percent solid epoxy, EPOFLEX, or solvent epoxy paint is recommended until such time that additional testing proves problems have been resolved.

The alkyd-resin extruded thermoplastic material was the most cost-effective material for crosswalk and stopbar installations. Installations of this material could be made either by contract or with Kentucky Transportation Cabinet personnel if the necessary equipment were obtained. Preformed tapes should be used in isolated instances where a stopbar or crosswalk is needed and it is not practical to use the thermoplastic equipment. Preformed tapes also may be used on portland cement concrete pavements until it can be shown that thermoplastic material will consistently have the required durability on this pavement type.

Durability and reflectivity results show that Stimsonite 96 markers have performed effectively as snowplowable markers. The recessed markers also have performed effectively except on certain interstate locations. The use of recessed markers should be limited to four-lane highways constructed to high geometric standards with the Stimsonite 96 markers installed on the majority of highways. Recessed markers should also not be used at locations having high truck volumes until its durability at such locations can be proven. Stimsonite 948 markers instead of Stimsonite 947 markers should be used in future installations. The Stimsonite 948 marker has revisions to improve durability. Use of this marker will require a 5-inch groove instead of the 4-1/2-inch groove. Consideration also should be given to using bitumen to place the marker in place of epoxy. The four-lane portion of the parkway system appears to be a good example for the application of recessed markers.

INTRODUCTION

Delineation is defined as the act of representing, portraying, or describing graphically or verbally. Roadway delineation involves describing the roadway environment to the driver. There are alternate methods of providing necessary guidance to the motorist. Delineation must be provided during daytime, nighttime, and adverse weather conditions. This study involved the use of delineation techniques for roadway surfaces.

Three different areas of roadway delineation were included in this study.

1. lane delineation materials,
2. crosswalk and stopbar materials, and
3. snowplowable markers.

Each of these areas were the subject of interim reports (1, 2, 3). This report summarizes data collected since the interim reports and recommends future use of the various materials that were evaluated.

INSTALLATIONS

LANE DELINEATION MATERIALS

Various types of lane delineation materials that were evaluated were placed under several contracts. Following is a brief description of the ten materials included in the analyses:

100-percent solid epoxy paint

This material is a two-component, chemically-reacted system that is 100 percent solids. The two parts are mixed by pumps on the striping equipment. The existing stripe was removed prior to placing the epoxy. Line thickness was 15 mils wet and dry. A no-track time of 10 minutes was specified and cones were used for protection. Beads were applied at about 23 pounds per gallon for reflectivity and as a means to prevent tracking. Two types of epoxy paints were used. They were manufactured by Polycarb and Prismo.

Four separate installations involving solid epoxy paint were placed in the summer of 1982 by three separate contractors. Three contracts involved lane marking on state-maintained streets in three major metropolitan areas: Fayette County, Jefferson County, and the northern Kentucky counties of Boone, Kenton, and Campbell. Another contract involved pavement markings at various narrow bridge locations throughout the eastern portion of Kentucky.

Over seven million linear feet of solid epoxy paint were applied under the four contracts. Contract costs varied from 24.3 to 25.6 cents per linear foot. Those prices were midway of the typica price range of 20 to 30 cents per linear foot. The contracts specified that at least 65 percent of the pavement be exposed prior to application, which required removing the old painted line. The old line was typically ground for removal. On the Fayette County project, an effort was made to remove all existing paint, resulting in the removal of a portion of the pavement. The epoxy line was therefore placed slightly below the surface of the unlined pavement, which had an adverse effect when moisture was present.

As previously noted, a large quantity of beads were placed on the stripe. That reduced the no-track time and also increased reflectivity. Beads were applied using either a free-fall dispenser or by pressure through bead guns.

Polyester paints

This material is a two-component, thermosetting material consisting of a resin and a catalyst. Two separate systems and guns are required on the striper. A minimum thickness of 16 mils was specified. The wet and dry thicknesses were approximately the same. A pressure-regulated air jet was used to remove debris from the pavement in advance of the spray guns. Glass beads were applied by pressure at a rate of 15 to 20 pounds per gallon. Air temperature was specified to be above 40 degrees Fahrenheit. No-track time was 8 to 12 minutes on a normal sunny day; therefore, line protection was required. Two types of polyester paints were used. They were manufactured by Glidden-Durkee and Baltimore Paint.

Polyester paint was first used in Jefferson County in the summer of 1982 and the project was completed at a contract price of 7.4 cents per linear foot. That price was the lowest of any of the durable materials. Under the same contract, work has been conducted each year in which resurfaced roads were striped and the original roads were restriped. Three layers were placed at some locations.

In 1986, large-scale installations of polyester paint were placed in two highway districts. Approximately 3.6 million linear feet were installed at a cost of 6.5 cents per linear foot.

Extruded thermoplastic

Hot-applied thermoplastics are thick pavement marking materials consisting of resin binder, reflective glass beads, coloring agents, and inorganic filler. The extruded thermoplastic was placed at a thickness of 90 mils using a die. A maximum drying time of 15 minutes was specified. The thermoplastic material was manufactured by Pave-Mark. The original installations, placed at narrow bridge locations, used a hydrocarbon-resin material while two small test installations used an alkyd-resin material.

One project involving hydrocarbon-resin extruded thermoplastic was completed in the summer of 1982. The project involved pavement markings at narrow bridge locations throughout the western portion of the state. Slightly over one million linear feet of centerline and edge line were placed at a cost of 47 cents per linear foot. The unit price was high due to excessive travel necessary between various bridge locations. The material was extruded through a die and then beads were sprayed onto the material. Two additional small sections of alkyd-resin extruded thermoplastic were placed in Lexington in the spring of 1985 using a small striping apparatus.

Large-scale installations of both alkyd-resin and hydrocarbon-resin extruded thermoplastic were placed in 1986 on interstate highways having open-graded asphalt surfaces. Approximately 5.0 million linear feet of 4-inch and 76 thousand feet of 8-inch line were placed with the installations divided between the alkyd and hydrocarbon materials. The cost for the 4-inch line varied from 19 to 22 cents per linear foot for the alkyd-resin and from 18 to 20 cents per linear foot for the hydrocarbon-resin. The cost for the 8-inch line varied from 48 to 55 cents per linear foot for the alkyd-resin and from 38 to 50 cents per linear foot for the hydrcarbon-resin.

3M Stamark tape (Series 5730)

This is a preformed tape or a retroreflective film consisting of plastic material, pigments, and glass beads. It is manufactured by 3M. Beads are distributed throughout the film and form a layer bonded on the surface. The thickness is 60 mils. Tape was overlayed onto existing pavements. According to the manufacturer, this tape is a highly durable, conformable, and moderately reflective marking designed for use as words and symbols, lane lines, edge lines, and channelizing lines on newly resurfaced roads.

A project involving 3M Stamark Series 5730 tape as lane delineation was completed in Jefferson County in the summer of 1982. The contract unit price per linear foot was $0.98 for yellow and $1.10 for white 4-inch lines.

3M bysymmetric tape (Series 5750)

This is a preformed tape having a metal-foil backing, a pigmented surface layer, and 1.75 refractive index beads. It is manufactured by 3M. Thickness is about 25 mils. Tape was overlayed onto existing pavements. According to the manufacturer, this tape is a highly reflective and moderately durable marking material designed primarily for use on streets having lower traffic volumes and free rolling traffic.

This tape was placed as a lane line along a few blocks of one street in Lexington in September 1982. The street has an ADT of slightly over 20,000. A typical price per linear foot of 4-inch stripe would be in the range of 50 to 60 cents.

EPOFLEX

This is an epoxy thermoplastic material consisting of binder, pigment, calcium carbonate filler, and premixed glass beads. The material is sprayed at a temperature not to exceed 460 degrees Fahrenheit and at a thickness of 20 mils, which is also the dry-film thickness. Beads are applied at a rate of about 4 to 6 pounds per gallon dropped on and 2 pounds per gallon mixed, giving a total of 6 to 8 pounds per gallon. No coning is necessary since no-track time is less than 5 seconds. The EPOFLEX was manufactured by Pave-Mark.

The first installation evaluated was placed in Indiana in the summer of 1983. Indiana awarded contracts totaling over one million linear feet at costs ranging from 14 to 17 cents per linear foot. A second installation of a revised material was placed on the Jefferson Freeway in

October 1985 as part of a demonstration project.

Solvent epoxy paints

Epoxy paints use two-component epoxy mixed with a reaction-blocking solvent. In the presence of solvent, the mixture remains liquid up to 10 days. When sprayed at 15 mils wet, it dries to about 10 mils. About 6 pounds of pressure-applied beads per gallon of paint are typically used. At a temperature of 75 degrees Fahrenheit, it has a no-track time of 3 to 5 minutes. Solvent epoxy paints manufactured by Saf-T-Mark, Prismo, and Polycarb were used.

This marking material has been used in several states, but not in Kentucky. An inspection was made of an installation in Indiana. In the summer of 1983, three projects, involving about 1.7 million linear feet of this material, were completed at a cost ranging from about 9 to 13 cents per linear foot.

Chlorinated-rubber traffic paint

This typical traffic paint includes paint binder and solvent as well as pigment and glass beads. The paint is applied at 15 mils wet, which dries to about 8 mils. Pressure-applied beads are applied at a rate of 4 pounds per gallon of paint. Chlorinated-rubber resins were used. The paint was manufactured by Ennis Paint Company.

The Kentucky Department of Highways used a chlorinated-rubber based traffic paint for the 1982 striping season and that was included in the evaluation. Beads were applied under pressure at a rate of about 4 pounds per gallon. The bead gun was aimed so that paint and beads hit the pavement surface at about the same time. That procedure was used to obtain proper bead embedment.

Alkyd traffic paint

This is another typical traffic paint, as the chlorinated-rubber paint, which includes paint binder and solvent as well as pigment and beads. This is the type of traffic paint typically used in Kentucky. The paint is applied at 15 mils wet, which dries to about 8 mils. Beads are pressure applied at a rate of 4 pounds per gallon of paint. Alkyd resins were used. The paint was manufactured by DeSantis Coatings Incorporated.

An alkyd traffic paint was used by the Kentucky Department of Highways for the 1985 striping season and also was included in the evaluation. Placement was the same as for the chlorinated-rubber paint.

3M Stamark pliant polymer tape (Series A350)

This is a preformed tape consisting of polymeric materials and pigments with glass beads incorporated into the base cross-sectioned area as well as embeded into the patterned surface to provide immediate and retained retroreflective performance. The thickness is 60 mils. It is manufactured by 3M. It is designed for use as lane lines, edge lines, channelizing lines, and gore markings. The tape has a field performance provision providing that the manufacturer will replace any material that fails to retain a minimum reflectance value or fails due to loss of adhesion or complete wear through for a period of 48 months from the date of installation. This material was placed on I-65 in Jefferson County in 1986 at a contract price of $1.15 per foot for a 4-inch stripe.

CROSSWALK AND STOPBAR MATERIALS

Three separate contracts were awarded initially for installation of experimental marking materials. A summary of costs and quantities of the various installation contracts is presented in Table 1. The installations consisted of 6-inch crosswalks and 24-inch stopbars. Bid prices were in terms of cost per linear foot. The preformed tape contracts in Northern Kentucky and Louisville and the first hydrocarbon-resin thermoplastic contract in Lexington were installed as part of the Pavement Marking Demonstration Program. The two small alkyd-resin and the second hydrocarbon-resin thermoplastic contracts were let by the Lexington-Fayette Urban County Government. The two alkyd-resin thermoplastic contracts installed in 1986 in Lexington and Louisville were let by the Kentucky Department of Highways.

The contract in Boone, Campbell, and Kenton Counties (Northern Kentucky) specified a preformed plastic material (tape) that had a thickness of 90 mils. The material was a cold-plastic tape manufactured by Prismo. The original contract in Jefferson County specified a preformed plastic material (tape) that had a thickness of 60 mils. The material used was the Stamark tape (Series 5730) manufactured by 3M. The contracts in Fayette County and the second contract in Jefferson County specified a thermoplastic striping material conforming to AASHTO Specification Designation M 249-79. The material was placed at a thickness of 90 mils and involved extruding either hydrocarbon-resin or alkyd-resin thermoplastic material. The first hydrocarbon-resin and the two small alkyd-resin materials were supplied by Pave-Mark. Materials for the small hydrocarbon-resin contract and the two 1986 alkyd-resin contracts were supplied by Cataphote.

The three original contracts, which were part of the Pavement Marking Demonstration Program, and the small hydrocarbon-resin thermoplastic contract in Lexington were completed in September 1983. The second and smaller Prismo tape contract was placed in September 1984. The first small alkyd-resin thermoplastic contract was placed in November 1984 and the second was placed in September 1985. The last two large alkyd-resin contracts in Louisville and Lexington were installed in the summer and fall of 1986.

Over 268,000 linear feet of 6-inch crosswalks were installed with about 134,000 linear feet of preformed tape and about 134,000 linear feet of thermplastic material being placed (of the thermoplastic material, about 111,000 linear feet used an alkyd-resin material). Over 97,000 linear feet of 24-inch stopbars were installed with about 47,000 linear feet of preformed tape and about 50,000 feet of thermoplastic material placed (of the thermoplastic material, about 33,000 linear feet used an alkyd-resin material).

Costs of the two types of preformed tapes were similar, but the cost of the extruded thermoplastic stripe was substantially lower. The cost of the alkyd-resin thermoplastic was slightly higher than that of the hydrocarbon-resin material. Weighted costs (considering unit costs and quantities) for the material indicated costs for the 6-inch crosswalk were $2.45 per foot for the preformed tapes compared to $1.02 per foot for the hydrocarbon and $0.81 per foot for the alkyd thermoplastics. The weighted costs for the 24-inch stopbar were $7.16 per foot for the preformed tapes compared to $2.29 per foot for the hydrocarbon thermoplastics and $3.20 per foot for the alkyd thermoplastic. This shows costs of the preformed tapes were two to three times that of the thermoplastic material.

SNOWPLOWABLE MARKERS

Summaries of snowplowable marker contracts are presented in Tables 2 and 3. As shown in Table 2, five contracts had been awarded through 1986 for the installation of recessed markers for a total of about 129,000 markers over almost 1,000 miles. The first recessed markers were placed in September 1984. The cost of sawing grooves varied from $4.44 to $5.79 per groove and the cost per marker varied from $1.82 to $2.50 for a total installed unit cost of $6.26 to $9.00. The weighted total installed unit cost considering all contracts was $7.39.

As shown in Table 3, eight contracts have been awarded through 1986 for the installation of Stimsonite 96 markers for a total of about 509,000 markers over approximately 3,700 miles. The first Stimsonite 96 markers were installed in October 1984. The installed unit costs have ranged from $15.49 to $19.20. The weighted unit cost considering all contracts was $17.28.

Current specifications for the markers are contained in Special Provision No. 74C(85) of the Kentucky Department of Highways (3). The recessed marker consisted of a 48-inch long groove having a width of 4-1/2 inches and a constant depth of 1/2 inch. The marker was placed at the downstream end of the groove except on downhill grades where it could be moved up a few inches from the end to allow water to pool behind the marker. The Stimsonite 947 low-profile marker was placed in the groove using epoxy. A straightedge was placed across the groove during placement of the marker so that the top of the installed marker was flush with the pavement surface. Specifications required that markers extending above the pavement surface or those more than 1/8 inch below the pavement surface be removed and replaced with correctly installed markers.

The Stimsonite 96 marker consisted of a cast-iron housing having the same reflective unit used in the recessed marker. A specially designed concrete saw was used to cut the pavement to recess the marker and then the sawed area was partially filled with epoxy and the marker was placed. The marker is designed so that the snowplow blade rides over the tapered housing and does not contact the reflector. The housing has a low-profile 6-degree slope and 7/16-inch maximum height to reduce the effect of the snowplow blade.

The two types of snowplowable markers were installed on different types of roadways. The recessed markers were installed only on multilane highways, primarily interstates. This allowed the markers to be placed at the back of the groove. Also, the roadway geometrics for those roadways are better than for two-lane highways. These factors allow for optimum viewing of the recessed markers. The Stimsonite 96 markers were installed almost completely on two-lane roadways. Most of the installations were in rural areas.

EVALUATION PROCEDURES

LANE DELINEATION MATERIALS

Data collection included three areas: 1) durability, 2) reflectivity, and 3) appearance. The method of conducting road service tests as described in ANSI/ASTM D 713-69 was used as a guide. This standard describes the rating of traffic paint in terms of appearance, durability, and nighttime visibility. Both daytime and nighttime photographs were obtained to document the durability, reflectivity, and appearance evaluations.

Durability and appearance of the various materials were evaluated visually. The durability evaluation related to the ability of the material to remain on the surface. The appearance evaluation dealt with color of the white or yellow lines as compared to their original color and as compared to a desirable color. Reflectivity readings were obtained using a portable retroreflectometer (PRR). Nighttime observations also were conducted.

The PRR used until late 1986 was constructed in house. A PRR was then purchased (the Mirolux 12) and used for data collection after that date. In early 1987, the Mirolux 12 was adapted so that measurements were in terms of millicandelas per square foot per footcandle.

CROSSWALK AND STOPBAR MATERIALS

The same procedure was used as with lane delineation materials in that data were collected to evaluate durability, reflectivity, and appearance. Durabilities of the materials were evaluated by periodic visual observations. Evaluations considered the percentage of material remaining on the pavement. There was a 90-day proving period following completion of placement of the marking materials placed as part of the Pavement Marking Demonstration Program. Inspections were conducted by Kentucky Transportation Cabinet personnel and repairs were required at locations at which more than 10 percent of the material failed. Data obtained during the proving periods were used for initial durability information and periodic visual inspections were conducted thereafter. Reflectivity readings were obtained using the PRR. Nighttime observations also were conducted. The contract specified that the material be white, and the retention of this color was rated for the appearance evaluation.

ANSI/ASTM D 713-69 was used as a guide in conducting each service test. Daytime and nighttime photographs were obtained to document durability, reflectivity, and appearance.

SNOWPLOWABLE MARKERS

The evaluation consisted of 1) detailed and nighttime inspections of both types of markers and 2) before-and-after accident analyses for those installed in 1984. The detailed inspection involved closely inspecting for damage and proper installation (especially the recessed markers). Twenty recessed marker locations and 30 Stimsonite 96 locations were included in the detailed inspections. Listings of those locations are included in the interim report (3). Twenty-five markers were inspected at each location so that a total of 500 recessed markers and 750 Stimsonite 96 markers were included in the detailed inspection. For the recessed markers, installation data concerning groove length, groove depth, distance from the top of the marker to the pavement surface, and marker placement were obtained along with information concerning lens damage. For the Stimsonite 96 markers, damage to the lens, marker, housing, and pavement were examined along with the installation of the marker.

Nighttime inspections involved driving sections of roadway and counting each marker lens by category based on the percentage of the lens visible. Listings of the roadways inspected are contained in the interim report (3). About 12,000 recessed markers and 14,600 Stimsonite 96 markers were included in the survey.

Three inspections were performed. The first was in the summer and fall of 1985, the second was in the spring and summer of 1986, and the third was in the spring of 1987. This allowed each section to have either two or three winters in use so that all markers had been snowplowed.

To have two years of before and after accident data available, only sections of roadway that had markers installed in 1984 were included in the accident analysis. Two years of after data (1985 and 1986) were compared to two years of before data (1982 and 1983). A total of 122 miles of recessed markers and 565 miles of Stimsonite 96 markers was used in the analysis. Changes in total accidents, nighttime accidents, and wet-nighttime accidents were analyzed. Sections of similar types of highways where no markers were installed were selected as a control to compare to the sections where snowplowable markers were installed.

RESULTS

LANE DELINEATION MATERIALS

Following is a discussion of the results of the evaluations, individually, for the various lane delineation marking materials. Typical prices, in terms of installed cost per linear foot of a 4-inch line, for the various materials are given in Table 4. These prices were based upon discussions with various highway agency officials and company representatives as well as data contained in the literature and contract prices. A summary of the portable retroreflectometer (PRR) data obtained using the original PRR is given in Table 5. Measurements are presented by year. The measurements were obtained several times during the year (except in 1986 when only one measurement was obtained) and averaged. Data obtained with the Mirolux 12 PRR in 1987 are given in Table 6. Data given in Table 5 have no units while data in Table 6 are in terms of millicandelas per square foot per footcandle.

100-Percent Solid Epoxy Paint

As noted previously, the three projects involving this material were placed in 1982 and all had been restriped with regular traffic paint by

1986. No additional data were collected after that reported in the interim report.

As shown by PRR measurements listed in Table 5, the initial reflectivity was good compared to the other materials and was maintained as well as any other material in areas where durability was not a problem. After approximately four years in service, the reflectivity remained fairly adequate. This was revealed through nighttime observations and PRR measurements. However, all but a few locations were restriped with traffic paint after approximately three years in service due to durability problems.

Varying levels of durability problems were experienced on each of the three solid epoxy contracts. All problems were attributed to improper mixing of the two epoxy components. The problem was related to not controlling pressure on the pumps on the striping equipment. This was first noticed and documented as being serious in the northern Kentucky area. The first evidence of a problem was a brown discoloration on the stripe. This discoloration appeared at regular intervals along the stripe, which corresponded to the cycle of the pump that was not properly proportioning the two components. Spots became darker as the material softened. Eventually, the dark (soft) portion of the line wore off. The sensitive nature of this problem was observed in instances where two solid yellow lines were placed side by side, and one line experienced the durability problem while the other did not.

A 90-day proving period was specified in the contracts. Any 2,000-foot section that experienced more than 10 percent failure was to be replaced. The only replacement required was part of the northern Kentucky installation, although durability problems were observed on the Jefferson County project during the 90-day proving period. Several miles of epoxy lines were replaced in northern Kentucky in 1983. One problem observed at some of the replacement lcoations was a lack of bond between the new and old stripe. This was probably related to poor adhesion of the remaining old stripe to the pavement. After a couple of years, the replaced lines showed the same durability problems as the original lines. The replaced lines were then painted over at the same time as the lines.

Stripes placed as part of the Fayette County project presented less severe problems initially. No problems were detected during the 90-day proving period and no significant problem was noted during the first year. Inspections after two years of service indicated some sections were developing discolorations, which was evident much earlier on the other projects. After almost three years in service, the durability problems increased to the point that the lines were painted over.

Problems also were observed in the appearance of the solid epoxy lines, specifically the white lines. The daytime appearance of the markings was good immediately after placement. The yellow line generally retained a good appearance. However, the yellow was not as bright as that provided by typical traffic paint. Also, the white line was not as bright as typical traffic paint and had a dull or gray appearance. The grayish color of the white line was more of a problem on portland cement concrete where the color of the line blended with the pavement surface.

Polyester Paint

Data have been collected on polyester paint applications in Jefferson County since 1982 and on the Kentucky Department of Highways (DOH) installations placed in 1986. The PRR measurements listed in Tables 5 and 6, as well as nighttime observations, showed the white material maintained reflectivity better than the yellow. The yellow stripes were typically subject to more wear since they were used as centerline while the white material generally was used as edge line. The white material was used as lane lines at some of the installations. After almost one year in service, the reflectivity of the lane lines at locations having 12-foot lanes was similar to that for edge lines while a reduction in reflectivity was noted for narrow lane widths.

No significant durability problems were experienced when the polyester paint was placed over pavement or old paint. The only durability problems noted were at some locations in Jefferson County where new polyester was placed over old polyester paint. The new paint did not adhere well to the old paint. This was related to a formulation problem that was resolved in later restriping installations.

The Jefferson County and most of the Kentucky DOH markings were placed on low-volume asphalt pavements. However, some of the Kentucky DOH markings were placed on high-volume roadways having an average daily traffic of over 20,000 with one section of road with portland cement concrete (PCC). No durability problems have been noted on either the high-volume or PCC pavements after almost one year in service.

While polyester paint generally did not appear as bright in color as typical white or yellow traffic paint, its daytime appearance was adequate. Again, the only appearance problem was related to the formulation used when restriping over old polyester at some Jefferson County locations. When the formulation was originally changed, solvent was added so it would dry quicker and would not chip. This problem was solved, but the paint remained tacky, allowing it to become contaminated with dirt, resulting in off-color lines. This problem was solved by using another formulation from a different paint manufacturer. The Kentucky DOH projects have not involved striping over old polyester lines and no problems with appearance have been noted.

Extruded Thermoplastic

Both hydrocarbon-resin and alkyd-resin extruded thermoplastic materials have been installed. As shown in Table 5, for the 1982 installations at narrow bridge locations, the white lines maintained reflectivity fairly well while yellow lines suffered an early loss in reflectivity. The increase in PRR readings for the yellow lines may have resulted from exposing some of the beads that were embedded in the material. Other agencies have reported that reflectivity is low after loss of the surface beads but then increases after the embedded beads are exposed.

The surface of the yellow lines contained numerous small holes. The holes may have resulted either from placing the material at an excessive temperature, which allowed surface beads to sink into the material, or from moisture on the pavement at the time of installation.

The durability of the 1982 installations was good. Almost all of the material was placed on bituminous pavements because of the reported durability problem on portland cement concrete. The lines maintained their original color and appearance quite well. The small holes in the surface of the yellow line did not adversely affect appearance when viewed from a distance of over a few feet.

A small test section of alkyd-resin material was placed in Lexington in 1985. The durability and appearance of the lines placed on asphalt pavements have remained good. The PRR data included in Table 5 show high initial reflectivity measurements for the small alkyd-resin thermoplastic installation in Lexington. Data show that reflectivity was maintained. This material was placed on both bituminous and portland cement concrete pavements. A primer was applied to the pavement before application on the concrete pavement. No durability problems have been noted on the bituminous pavement; but some durability problems have been experienced on the portland cement concrete pavement. The problem appears to be related to a loss of bond between the material and the pavement.

In 1986, large installations of both alkyd-resin and hydrocarbon-resin extruded thermoplastic were placed on interstate highways having open-graded asphalt surfaces. High reflectivity measurements, especially for the white material, are shown in Table 6. No durability problems were experienced in the first year after installation. The appearance of the material also has remained good. Performance of those installations on open-graded surfaces will be monitored further with an evaluation report due in 1988.

3M Stamark Tape (Series 5730)

A project involving 3M Stamark (Series 5730) tape as lane delineation was completed in Jefferson County in the summer of 1982. PRR measurements presented in Table 5 show the Stamark tape had a very high initial reflectivity, but that level of reflectivity was not maintained. PRR data in Table 6 show the low reflectivity for the yellow tape.

There were no problems with durability or appearance of the Stamark tape. After five years in service, the lines remained intact on both portland cement concrete and asphaltic concrete pavements and maintained their color. While this material provides a good daytime line, the level of nighttime delineation (especially noted for the yellow line) was not maintained as well.

3M Bisymmetric Tape (Series 5750)

PRR measurements (shown in Table 5) indicated this tape had the highest initial reflectivity of any material. After one year, its reflectivity remained high, but dropped dramatically after the second year to approximately the level of the Stamark Series 5730 tape. The roadways were restriped after the tape had been in service for about two years.

Durability and appearance of this tape were satisfactory. The tape was placed on both portland cement concrete and asphaltic concrete pavements and exhibited good durability on both.

EPOFLEX

The epoxy thermoplastic (EPOFLEX) material has been used in several states in the past few years and initial inspections were made of installations in Indiana. In the summer of 1983, Indiana awarded contracts totaling over one million linear feet at costs ranging from 14 to 17 cents per linear foot in three highway districts. PRR measurements (shown in Table 5) were obtained in 1983 and then one year later. Reflectivity of this material, especially the yellow, was not as high initially as other materials. Measurements after about one year in service showed that the reflectivity had been reduced to low levels. Significant durability problems were experienced after less than one year in service.

Failures similar to those observed in Indiana were noted in other states. Changes in the EPOFLEX formulation were then made. In October 1985, a test section of a revised epoxy thermoplastic material was placed on the Jefferson Freeway in Jefferson County. This test section was part of Federal Highway Administration Demonstration Project No. 60 to evaluate the modified EPOFLEX material. The material was placed on portland cement concrete pavement. After 18 months in service, durability problems have been observed. The durability problem appears to be related to a failure in adhesion between the EPOFLEX and the pavement. This lack of bond in some areas was first noted a few months after installation. An estimate was made that approximately 40 percent of the material had been lost after the 18-month period. The appearance of the remaining material compared well to regular traffic paint. Initial reflectivity was similar to that of regular traffic paint, which is logical since a similar amount of beads were dropped, and the reflectivity was adquately maintained over this 18-month period. The evaluation will be reported as part of the Demonstration Project.

Solvent Epoxy

As shown in Table 5, PRR measurements obtained a few weeks after placement indicated very low reflectivity. A close inspection revealed the beads were originally embedded properly but had been lost. The bead pockets were clearly visible. No additional inspections were conducted because of bead retention failure.

Chlorinated Rubber Traffic Paint

PRR measurements listed in Table 5 indicated the initial reflectivity was relatively high but had decreased dramatically after about one year in service. Test sections were restriped after one year in service, so no additional data were available. No durability or appearance problems were experienced during the one-year period.

Alkyd Traffic Paint

PRR measurements, shown in Table 5, at several locations in Lexington indicated the initial reflectivity to be below that recorded for the chlorinated rubber but, after one year, measurements had decreased to a similar level. The sections were restriped after about one year in service. No durability or appearance problems were experienced during the one-year period.

Alkyd traffic paint also was used as the control for the EPOFLEX installations on the Jefferson Freeway. The PRR measurements obtained after 18 months listed in Table 6 show that reflectivity was maintained at a relatively low level. Observations at night revealed the edge lines were adequate while the lane lines were poor. The durability and appearance of the lines were good.

3M Stamark Pliant Polymer Tape (Series A 350)

The first-year evaluation of this tape at the I-65 location has indicated no problems. Durability and appearance have been good, and reflectivity is at a high level (as shown in Table 6).

CROSSWALK AND STOPBAR MATERIALS

Durability of Preformed Tape

All preformed tape installations were placed as part of the Pavement Marking Demonstration Program and were subject to the 90-day proving period. Failures were noted in both Jefferson County (3M Stamark Series 5730) and northern Kentucky (two installations of Prismo tape).

The number of feet of tape replaced at each intersection was documented for the Jefferson County installations. Repairs consisted of patching portions of the crosswalk or stopbar that were damaged. Occasionally, the entire line would be replaced. Overall, 16 percent of the total length of stopbars and 18 percent of the total length of crosswalks were replaced. Nearly all intersections received some repair work. The percentage of intersections having crosswalks where either minor or major repairs were made to the crosswalks (92 percent) was higher than the corresponding percentage for stopbars (65 percent). A large percentage of this material was replaced in 1986 with alkyd-resin thermoplastic.

For the first Northern Kentucky contract, failure of the entire intersection was evaluated and repairs were made when it was judged that more than 10 percent of the material in the intersection had failed. The determination was made that 52 percent of the intersections had over a 10 percent failure. Repairs generally consisted of patching the damaged areas as was done in Jefferson County. An estimate by a Transportation Cabinet engineer was that, overall, approximately 25 to 30 percent of the material failed during the 90-day proving period.

Inspections during the 90-day proving period of the second Northern Kentucky contract (Prismo tape) resulted in identification of numerous durability problems. Extensive corrective work was performed, but durability problems continued. The recommendation was made by Kentucky Department of Highways' personnel that the project be accepted at a reduced price since acceptable performance could not be obtained for a 90-day proving period. A problem noted at locations in this second contract involved the loss of large sections of tape due to failure of proper bond at the pavement interface.

Periodic inspections have been made at the original locations for about a 43-month period after installation. A durability problem for the Jefferson County installation, using Stamark tape, has existed from the start at locations where there were high-volume turning movements. Another problem noted was that in the center of the lane, where oil drips from vehicles, there were bond failures between the tape and the pavement. Significant problems were not detected at all locations. Where there were no significant turning movements, the tape was not worn through to the pavement in the wheel paths. Performance was best at the lower volume suburban locations.

Several durability problems were noted with the Prismo material placed under both contracts. Replaced sections of tape experienced the same problem as the original installation. As with the Stamark tape, the Prismo tape experienced problems at locations having high turning volumes. An additional problem involved slippage of the tape, especially at downhill locations, but also at level locations. The Prismo tape has a thickness of 90 mils compared to 60 mils for the Stamark tape, which may account for this problem. When this slippage occurred, the adhesive would remain in its original position while the tape layer would slide forward so there was a problem of delamination. The problem noted with the Stamark tape, a bond failure where oil dripped onto the tape, was not detected to the same degree, although it was noted at some locations. The tape performed generally well at several locations. Wear in the wheel paths through the tape layer down to the adhesive was noted during the inspection after 30 months in service and was common after 43 months in service.

The second Prismo contract experienced more durability problems than the first. The most significant problem was a major loss of material due to a lack of adequate bond between the tape and the pavement. Large sections of tape were missing.

Durability of Thermoplastic Material

The first hydrocarbon-resin contract was part of the Pavement Marking Demonstration Program and subject to the 90-day proving period. Inspections during this period did not reveal problems. The major durability problem was wear in the wheel path. This wear was not observed at the lower volume locations. The amount of wear varied substantially at locations having similar volumes. However, it appears that this type of wear will occur after exposure to approximately five million vehicles per lane (using one-fourth of the total average daily traffic on a four-lane highway to represent traffic per lane). This type of wear was experienced first on crosswalks where a high volume of vehicles were turning. The stopbars and crosswalks still functioned satisfactorily with wear in the wheel paths. However, some markings were painted over in early 1986 after about 30 months in service. There also was a durability problem relating to lack of bond between the material and the pavement where the pavement was portland cement concrete.

The second and much smaller hydrocarbon-resin contract was the only thermoplastic contract that experienced durability problems. The material sustained wear in the wheel paths as well as minor chipping after only a few months in service. The problem may have been related to the fact the material was softer than that used in the other hydrocarbon-resin thermoplastic contract (wheel imprints were visible, especially in areas where oil was present). An inspection after over three years in service revealed that about two-thirds of this material was still in place and still performing its function.

The first alkyd-resin thermoplastic material applied on the small Lexington contract has been in service about 29 months while the material placed in the second contract has been in place for 19 months. None of the locations have sustained any significant durability problem. There has been some wear at high-volume turning locations, but the durability has typically been good. An inspection in April 1987 revealed that approximately 90 percent of the markings were still in place.

The large alkyd-resin contracts were installed in Lexington and Louisville in 1986. The Lexington contract replaced the hydrocarbon-resin lines placed in the 1983 contract. Since an alkyd-resin was replacing a hydrocarbon-resin material, the old line was removed. In future installations, where the alkyd-resin material is placed over an old alkyd line, it will not be necessary to remove the old line. After almost one year in service, no durability problems have been noted with the alkyd-resin materials placed in Lexington and Louisville. Almost 100 percent of the markings are still in place. Some of the markings in this contract were placed on portland cement concrete pavement. No durability problems have been experienced to date at these locations.

Reflectivity of Preformed Tape

Measurements of reflectivity were obtained using a portable retro-reflectometer at several intervals after installation of the various materials. Measurements were obtained at approximately 10 intersections for each contract, except the second hydrocarbon-resin thermoplastic contract where measurements were obtained at five intersections. Averages of measurements at the various intersections are listed in Table 7 for the original PRR and Table 8 for the 1986 data using the Mirolux 12 PRR.

Data in Table 7 show that the Prismo and Stamark tapes and the first hydrocarbon-resin thermoplastic contract had very similar levels of reflectivity. Reflectivity declined substantially at those loations in the first year in service. Measurements verified nighttime observations. Reflectivity measurements of about 100, which was classified as low, within one year indicate that none of the materials exhibited good long-term reflectivity characteristics. However, the intersections at which the materials were placed were almost always in areas having roadway lighting, so loss of reflectivity would not be as critical. Reflectivity of the second hydrocarbon-resin installation remained slightly better than that placed under the first contract. This is probably related to the lower traffic volumes at the intersections at which the second hydrocarbon-resin material was placed. The highest reflectivity readings shown in Table 7 were obtained for material placed in the two alkyd-resin projects. The higher initial readings would probably be related to the quantity of drop-on beads applied. Also, initial measurements were made within a month of installations rather than a few months thereafter. There is a large loss in reflectivity during the first few months as the beads on the surface are lost. This may be noted in the substantial decrease in their readings for materials placed in the second alkyd-resin contrct between October 1985 and

April 1986.

Data in Table 8 show the reflectivity measurements obtained with the Mirolux 12 PRR in April 1987. Reflectivity measurements for both the hydrocarbon-resin and alkyd-resin material were in the range of 140 to 160 millicandelas per square foot per footcandle. This was found for material in the range of one to four years in service. The reflectivity probably remained at this level due to embedded beads becoming exposed with wear. Nighttime observations revealed the reflectivity to be adequate, especially since most of the installations were in areas having lighting. The reflectivity measurements for the tapes were lower than those for the thermoplastic.

Appearance

As part of the visual inspection, the overall appearance of the material was noted. This generally involved rating the appearance of crosswalks when viewed at a distance of at least 10 feet. The color of the material, as compared to the original color, received particular attention. The appearance inspection considered only the material remaining and was not directly related to durability.

Both the 3M Stamark and Prismo preformed tapes maintained their appearance and original color with no significant problems. The material that remained did not discolor to a great extent.

While the overall appearance of thermoplastic stopbars and crosswalks was satisfactory, a discoloration of the hydrocarbon-resin material was noted between the wheel paths. This was the result of stains from oil dropped from vehicles. This problem was worse at high-volume turning locations. Also, when the thermoplastic material was viewed closely, it could be seen that some of this material was covered with small potholes. This may have been the result of the application temperature being too high or from moisture in the pavement. If the temperature was too high, it would have allowed the beads to sink too far into the material and contribute to loss of reflectivity. However, the small holes were not obvious from over a few feet away and did not adversely affect appearance.

Inspections of the alkyd-resin thermoplastic stopbars and crosswalks revealed that they maintained their appearance without the discoloration problem between the wheel paths associated with the hydrocarbon-resin material. The alkyd material is chemically incompatible with grease and oil drippings while the hydrocarbon material reacted with the oil and grease, darkening the material. The latest inspection in April 1987 revealed minor discoloration between the wheel paths for the alkyd-resin material, but not as noted for the hydrocarbon-resin material.

SNOWPLOWABLE MARKERS

Detailed Inspections of Recessed Markers

Detailed inspections were conducted at 20 recessed marker locations. Twenty-five markers were inspected at each location providing a total of 500 markers included in this part of the survey.

The initial inspection included several measurements relating to installation. The results are summarized in Table 9. The average groove length at all locations was 50 inches compared to the 48-inch groove designated in the specifications. The average groove length, by location, varied from 47 inches at two locations to a maximum of 55 inches. About 60 percent of all grooves measured were within plus or minus 2 inches of the 48-inch standard and about 83 percent were within plus or minus 4 inches. The shortest groove measured was 40 inches and the longest was 61 inches.

As shown in Table 9, the average groove depth was 0.48 inch compared to the 0.5-inch depth designated in the specifications. The average groove depth at the various locations varied from 0.43 to 0.54 inch. About 88 percent of all grooves measured were within plus or minus 1/16 inch of the 1/2 inch specified. The measured groove depth varied from 1/4 inch to 5/8 inch.

A concern in the installation process was placement of the marker such that the top of the marker was flush with the pavement surface. Specifications required that the top of the marker not extend above the pavement surface or be more than 1/8 inch below the surface. As shown in Table 8, only 5.4 percent extended above the pavement and only 2.6 percent were greater than 1/8 inch below the pavement surface.

Specifications also stated that, on downhill grades, the marker should be installed several inches from the end of the groove to reduce water pooling in front of the marker. Measurements indicated that the markers were being placed farther from the end of the groove when placed on a grade.

The groove width was specified to be 4-1/2 inches. Average groove widths varied from 4.3 to 4.5 inches. The average groove width was 4-7/16 inches.

Damage to lens of the recessed marker, as noted in the detailed inspections, are summarized in Table 10 for the 1985, 1986, and 1987 inspection periods. The date of inspection, days in service, and traffic exposure are presented along with the lens damage observed. Damage was classified as either under or over 50 percent of the lens damaged (missing) or where the lens was cracked with none of it missing. This percentage (50 percent) was selected as the point at which the marker lost a substantial amount of its effectiveness. That is, in a replacement program, markers having more than 50 percent of the lens missing should be replaced. As may be noted, only a small percentage of the markers (0.2 percent in 1985, 1.3 percent in 1986, and 2.6 percent in 1987) had more than 50 percent of their lens missing. Markers inspected in 1987 had been in service for an average of 641 days, or close to two years. The average daily traffic (ADT) at those locations was about 14,400. As may be noted, the detailed inspections revealed the recessed markers to be in good condition after almost two years in service. However, it should be noted that only three of the 20 locations were on interstates and durability problems were noted on interstates as documented in the nighttime inspections.

The markers were generally in good condition with minor chipping to the abrasive coating on the lens. The typical damage was usually to the top, with some of the lens damaged. In several instances, while only a small percentage or none of the lenses were damaged, water was allowed to get behind the lenses due to damage to the tops of the markers and those markers' reflectivity was lost. This was evident from the nighttime inspections to be a problem on interstates that had high truck volumes.

A question regarding the recessed markers was whether the grooves would lead to damage to the pavement. No such problem was noted. Even when the groove was placed where the pavement was previously cracked, there was usually no problem. The exception was when the groove was placed on a pavement that was in very poor condition. If the pavement was excessively cracked, sections of the pavement in the groove failed, resulting in loss of the marker in some instances.

There was no problem with pavement failure noted when the groove was placed on a portland cement concrete (PCC) pavement. There was concern that there might be damage since the groove would be close to the pavement joint. The groove was usually placed 1 to 2 inches from the joint; but even when placed next to the joint, no damage was noted.

Another question pertaining to the recessed marker was whether debris would accumulate in the groove. This was not observed to be a problem. Traffic kept the grooves clear of debris.

A major problem observed with the recessed markers during the inspections did not relate to durability. Some inspections were made shortly after substantial rainfalls and collection of water in the groove was noted. If the groove was on an upgrade, water would accumulate away from the marker but, if there was a downgrade, water would tend to cover the marker. The water would be blown out of the groove fairly quickly by the traffic, especially on the high-volume and high-speed interstates having a large percentage of truck traffic. The length of time the water remained in the groove also was related to pavement type. Water remained longest in a groove on a portland cement concrete pavement and shortest on an open-graded asphaltic concrete pavement where it could also drain readily through the pavement.

Detailed Inspections of Stimsonite 96 Markers

Results of the detailed inspections of the Stimsonite 96 markers are summarized in Table 11 for the 1985, 1986, and 1987 inspection periods and by the year the marker was installed (1984 or 1985). As with the recessed marker inspection, the date of inspection, days in service, traffic exposure, and numbers having damaged lens were listed. In addition, the numbers having damaged steel housing and paint on the lens were summarized.

Only one of the 750 markers was observed to have steel housing damage. One marker had been torn from the pavement (probably by a snowplow). Observations of other installations revealed this occurrence to be very rare. The markers appeared to be installed properly, so there should be no damage to the steel housing.

Several lenses were observed to be partially covered with paint. The paint stripers were equipped with a device that allowed the metal marker to be detected, which cut off the paint spray temporarily so the marker would not be painted. This device worked well in almost all instances. The 1986 and 1987 inspections revealed less problem with painted lenses compared to the 1985 inspection. Few additional markers had been painted and the paint had begun to wear from the lenses painted in 1985. The Stimsonite 96 markers were placed with epoxy and, in a very few instances, an excess amount of epoxy was used, allowing it to cover part of the lens.

As with the recessed marker inspections, only a small percentage of the lenses had more than 50 percent missing (3.2 percent in the 1987 inspection compared to 2.6 percent for the recessed marker). The 1987 inspection revealed another 12.7 percent having under 50 percent missing compared to 10.4 percent for the recessed marker. The 1987 inspection revealed another 5.1 percent with a lens cracked compared to 1.2 percent of the recessed markers. As may be noted, while the damage to the Stimsonite 96 marker was not great, there was more damage at the detailed inspection locations than was observed at the recessed marker detailed inspection locations. This difference could be partially explained due to the greater number of days in service of the Stimsonite 96 markers (an average of 737 days compared to 646 days for the recessed markers). However, the average traffic exposure was higher for the recessed marker locations (6.87 million vehicles) than for the Stimsonite 96 locations (3.06 million vehicles) due to the higher average ADT (14,400 at the recessed marker locations and 4,100 at the Stimsonite 96 locations). There would be a higher percentage of truck traffic at the recessed marker locations. Also, since the Stimsonite 96 markers were placed on the narrower two-lane roadways compared to the four-lane, interstate-type highways for the recessed markers, there would be a greater tendency for traffic to run over the Stimstonite 96 marker.

The only wear for most of the Stimsonite 96 markers was the chipping of the abrasive coating of the marker lens. The reflective element in the Stimsonite 96 marker is the same low-profile marker that is placed in the groove. It is attached to the housing with an adhesive pad. The entire marker was not observed to be missing at any of the detailed inspection locations. However, failure of adhesion between the marker pad and housing was noted in a few instances.

Nighttime Inspections of Recessed Marker Installations

Data for the recessed marker nighttime inspections are summarized in Table 12. The numbers of markers surveyed, average days in service, and traffic exposure are listed along with the damage observed. The damage was classified according to the percentage of the lenses damaged. Results of the 1985, 1986, and 1987 inspections are summarized separately as well as the installations made in 1984 and 1985. Considering all data, the percent of markers having 50 percent or more loss in reflective surface was 1.5 percent in the 1985 survey, 3.7 percent in the 1986 survey, and 15.7 percent in the 1987 survey. The percentage having a loss in reflective surface of less than 50 percent of the lens was 2.2 percent in the 1985 survey, 6.6 percent in the 1986 survey, and 6.7 percent in the 1987 survey. Therefore, the nighttime survey revealed that about 22 percent of recessed markers had some loss in the reflective surface after an average of almost two years in service. This percentage was higher than that noted in the detailed survey. One explanation would be the larger traffic exposure at the nighttime inspection locations when the average ADT, weighted to consider the length of each location, was about 21,700. Another explanation would be that damage to only a small portion of the lenses may result in lack of reflectivity to a larger portion of the lenses if water is allowed behind the lenses.

The percentage of recessed markers having damage varied subtantially by location. Of the 12 sections, four were interstates and eight were four-lane, non-interstate highways but about one-half the sample was from interstates. The percent of markers having 50 percent or more loss in reflective surface was 27.9 percent on interstates compared to only 2.8 percent on four-lane, non-interstate highways. This percentage varied at the interstate locations from 58.0 percent on a section of I-64 eastbound between Louisville and Frankfort to 13.8 percent on a section of I-24 eastbound between Paducah and the Western Kentucky Parkway. The percentage of markers that were not visible was 19.1 percent on the interstates compared to only 1.1 percent on the non-interstate highways. The number of days in service and the traffic exposure was higher at some of the non-interstate locations than some of the interstate locations. The difference in performance could be related to the higher traffic speed and the higher percentage of truck traffic on the interstates. Many of the markers that were not visible at night had no significant damage to the lenses. It is possible that, since the recessed markers are installed with the top flush with the pavement, heavy truck tires impacting the top of the marker cracked the marker and moisture may have entered behind the lens, which would destroy its reflectivity.

Observations during the 1987 nighttime inspections indicated the recessed markers to still be providing adequate delineation at the 80-foot spacing on all but certain sections of the interstate highways. Several markers were usually visible (except on the sections of interstate where durability problems were noted) with no fewer than three visible even on hill crests and curves. A problem with reflectivity occurs when there is a very heavy rainfall. At some locations, depending on roadway geometrics, visibility may be limited to one marker and some markers became obscured for a short period of time.

Nighttime Inspections of Stimsonite 96 Installations

A summary of data obtained during the nighttime inspections at the Stimsonite 96 locations is given in Table 13. The same types of data and summaries are presented as for the recessed markers.

Considering all data, the percent of lenses having 50 percent or greater loss of reflective surface was 0.9 percent in the 1985 survey, 1.5 percent in the 1986 survey, and 3.4 percent in the 1987 survey. The percentage having a loss in the reflective surface of less than 50 percent was 1.1 percent in the 1985 survey, 3.8 percent in the 1986 survey, and 3.9 percent in the 1987 survey. The nighttime survey revealed that about 7.3 percent of Stimsonite 96 markers had some loss in the reflective surface after an average of slightly over two years service. The percentage of lenses having a loss of reflectivity was substantially less for the Stimsonite 96 than for the recessed markers. An explanation would be that, even though the Stimsonite 96 locations had been in place longer, the traffic exposure was much higher at the recessed marker locations due to the higher traffic volume (a weighted value considering length of location of 21,700 at the recessed marker locations compared to 4,200 at the

Stimsonite 96 locations). Also, there was a higher percentage of truck traffic at the recessed marker locations (especially the interstate locations).

Observations revealed that the Stimsonite 96 markers placed at a 40-foot spacing provided very good delineation. It appeared that spacing could be increased to 80 feet on tangents but should be maintained at 40 feet on curves.

Accident Analysis

To estimate the effect the snowplowable markers have had on traffic accidents, a before-and-after accident analysis of snowplowable marker installations and control locations was conducted. Results are presented in Table 14. The analysis was limited to locations installed in 1984 so that two years of before and after data could be obtained. Recessed markers were installed on about 122 miles of roadway in 1984 (all on interstate highways). Stimsonite 96 markers were installed on about 566 miles of roadway in 1984. Accident data for 1982 and 1983 were used for the before data and data for 1985 and 1986 were used as the after data. As control sections for the recessed markers, about 71 miles of interstate highways were selected where recessed markers had not been installed before the end of 1986. Approximately 382 miles of highways, similar to the type where Stimsonite 96 markers were placed but where no markers were installed, were selected as control sections for the Stimsonite 96 installations.

In Table 14, total accidents and the percent of all nighttime and wet-nighttime accidents are listed for the Stimsonite 96 marker and recessed marker installations and control sections. The percentages of nighttime and wet-nighttime accidents were used because the total number of accidents increased substantially in 1985 and 1986 compared to 1982 and 1983. Nighttime and wet-nighttime accidents are the types that would be expected to be affected by the installation of snowplowable markers.

The accident data showed a decrease in these types of accidents at the Stimsonite 96 marker and recessed marker locations. There was not such a reduction at the recessed marker control locations. A statistical analysis indicated that, comparing the before and after data, there was a reduction in the percentage of nighttime accidents at the recessed marker and Stimsonite 96 installation locations with a significance level of 0.99 (4). There was also a reduction in the percentage of wet-nighttime accidents at the Stimsonite 96 installation locations with a significance level of 0.99. However, the Stimsonite 96 control locations showed a very similar reduction in the percentage of nighttime and wet-nighttime accidents as the Stimsonite 96 installation locations. Therefore, no statistical accident benefit from the installation of the Stimsonite 96 markers could be documented. The recessed marker control locations did not have the reduction in nighttime accidents found at the recessed marker installation locations.

The types of highways on which the Stimsonite 96 markers are installed were constructed to lower design standards than the highways on which the recessed markers were installed, so the Stimsonite 96 markers have the potential for a greater benefit. The reduction in nighttime accidents was similar while the reduction in wet-nighttime accidents was greater at the Stimsonite 96 than the recessed marker locations. However, for an unknown reason, the Stimsonite 96 control locations also experienced a large reduction in nighttime and wet- nighttime accidents.

SUMMARY

LANE DELINEATION MATERIALS

100-Percent Solid Epoxy Paint

This material had the highest reflectivity of any of the paints. However, durability and appearance problems preclude widespread future use until it is demonstrated that those problems have been resolved. The durability problem was related to equipment problems, specifically improper mixing of the two epoxy components. The major appearance problem was the dull daytime apperance of the line. This material had been used extensively in other states, and the manufacturer of the paint indicated that the two problems have been remedied and the material has been used successfully in other states. Another test installation is warranted using the revised material to determine whether future use of the material is justified.

Polyester Paint

Polyester paint had the lowest price of any of the durable materials. Reflectivity was adequate, although not as good as solid epoxy. Some durability and appearance problems were detected when several applications were made at the Jefferson County locations but were solved by changing the paint formulation. The large-scale installations made by the Kentucky Department of Transportation in 1986 have performed very well in their first year in service. Installations on higher-volume roads (ADT of 20,000 to 30,000) also have performed well. No durability problems have been noted on a small installation on a PCC pavement. The performance of the material should continue to be evaluated to determine its long-term performance on high-volume and PCC pavements.

Extruded Thermoplastic

Both hydrocarbon-resin and alkyd-resin materials have been tested. The original installations involved the use of hydrocarbon-resin material at low-volume, narrow-bridge locations. No durability or appearance problems were noted and initial reflectivity was high but considerable loss in reflectivity was experienced later. Small-scale installations of alkyd-resin material were placed in Lexington and have performed well except for durability problems on PCC pavement.

Large-scale installations of both materials have been placed on open-graded pavements on interstates. The first-year performance has been very good with no durability or appearance problems and with good reflectivity (although the reflectivity of the yellow was substantially lower than the white). Performance on the interstate locations will continue to be monitored as part of another study.

Reflectivity characteristics must continue to be evaluated to determine if its use should be limited to lighted roadways or roadways where it is supplemented with snowplowable markers. The typical price per linear foot for this material for large installations would enhance its use on high-volume roadways but limit its use on low-volume roadways.

3M Stamark Tape (Series 5730)

This was one of the most expensive of all materials evaluated. While there were no durability or appearance problems, reflectivity decreased dramatically. Its cost and poor reflectivity would limit its use to high-volume lighted roadways. The addition of the Series A350 pliant polymer tape would appear to limit the use of this tape.

3M Bysymmetric Tape (Series 5750)

This tape had the highest initial reflectivity of all materials tested. The reflectivity decreased dramatically after two years on a relatively high-volume street. The durability and appearance of this tape were satisifactory. The cost of this tape was substantially less than the Stamark-type tapes and use may be warranted on moderate-volume streets having no lighting.

EPOFLEX

The EPOFLEX installation inspected in Indiana suffered significant durablity problems after less than one year in service. Problems were experienced in several states. A test installation using a modified material was placed in October 1985 in Jefferson County and also experienced durability problems over an 18-month test period. Durability problems related to loss of adhesion were noted. This evaluation will be reported as part of a Demonstration Project.

Solvent Epoxy

The installation inspected had a complete loss of beads within a few weeks after placement. This would probably be related to either a problem with application or formulation. This material has been used successfully in the past in other states, but additional testing would be necessary before it could be used in Kentucky.

Chlorinated-Rubber and Alkyd Traffic Paints

These paints are substantially less expensive than the more durable markings. They provide adequate reflectivity and durability for varying periods based on traffic volumes. In most rural areas, a service life of one year is provided. At high-volume locations, these paints must be restriped at least once each year and should be restriped more than once a year in many instances to maintain adequate reflectivity. Their appearance is very good, having bright white and yellow colors.

3M Stamark Pliant Polymer Tape (Series A350)

Performance has been good during its first year of service. Continued monitoring will be necessary to determine if this material will be cost-effective.

CROSSWALK AND STOPBAR MATERIALS

The durability, reflectivity, and appearance of Prismo and 3M Stamark preformed tapes and hot-extruded thermoplastic (both hydrocarbon-resin and alkyd-resin) were evaluated as marking material for stopbars and crosswalks.

Costs of the two preformed tapes were similar but were two to three times the cost of the thermoplastic material. The cost of the alkyd-resin thermoplastic material was slightly higher than that of the hydrocarbon-resin material.

Both preformed tapes experienced initial durability problems with a substantial amount of the material being replaced in the 90-day proving period. The replaced material sustained similar problems. The Stamark tape had significant durability problems in areas of high-volume turning movements as well as in the area between wheel paths. The Prismo tape had durability problems relating to 1) loss of large sections of tape due to a lack of proper bond between the tape and the pavement and 2) delamination of the tape layer from the adhesive.

The thermoplastic material did not experience those durability problems. It was noted that there was signficant wear in the wheel paths after exposure to approximately five million vehicles per lane (using one-fourth of the total average daily traffic on a four-lane highway to represent the traffic per lane).

All materials sustained a significant loss in reflectivity, but since there was typically roadway lighting present, nighttime delineation was adequate. The highest reflectivity measurements were obtained for the alkyd-resin thermoplastic material, but readings decreased substantially after a few months.

Both preformed tapes maintained their appearance fairly well as did the alkyd-resin thermoplastic material. The hydrocarbon-resin thermoplastic material sustained some discoloration between the wheel paths, especially in turning lanes, due to oil staining.

SNOWPLOWABLE MARKERS

Contracts for the installation of about 129,000 recessed markers over almost 1,000 miles and about 509,000 Stimsonite 96 markers over approximately 3,700 miles had been awarded through the end of 1986. Total installed unit costs ranged from $6.26 to $9.00 for the recessed markers and from $15.39 to $19.20 for the Stimsonite 96 markers.

Inspections of installations of both types of markers revealed they were installed properly. Specifically, for the recessed marker, the groove length, depth, width, marker placement, and distance from the pavement surface to the top of the marker were checked and found to meet specifications in most instances.

After an average of almost two years service, the detailed inspections revealed about 2.6 percent of the recessed markers had over 50 percent lens damage while another 10.4 percent had under 50 percent damage and another 1.2 percent had the lens cracked.

After an average of two years in service, the detailed inspections revealed 3.2 percent of the Stimsonite 96 markers had over 50 percent lens damage while another 12.7 percent had under 50 percent damage and another 5.1 percent had the lens cracked.

No problem was detected relative to dirt accumulation in the groove used for the recessed marker. Traffic kept the groove free of debris. The groove that was installed for placement of the recessed marker was not observed to cause damage to the pavement.

The paint-skipping device used in conjunction with the Stimsonite 96 markers was noted to work properly in all but a few instances.

For both the recessed markers and Stimsonite 96 markers, chipping of the abrasive coating of the marker lens was noted, but this did not cause any durability problem or loss in reflectivity.

After an average of about two years in service, the nighttime inspections revealed 15.7 percent of the recessed markers had over 50 percent loss of the reflective surface while another 6.7 percent had under 50 percent loss. There was a much higher percentage having over 50 percent loss of the reflective surface at interstate locations (27.9 percent) compared to four-lane, non-interstate highways (2.8 percent). The nighttime inspections revealed that the recessed markers provided adequate delineation at the 80-foot spacing on all but certain sections of interstate highways. The problem experienced on the interstate highways may be related to the high truck volume.

A major problem with the recessed markers concerned the accumulation of water in the groove for short periods of time during periods of heavy rainfall. This would limit visibility to only one or two markers or, depending on the roadway geometry, the recessed marker could be obscured by the water.

After an average of two years service, the nighttime inspections indicated 3.4 percent of the Stimsonite 96 markers had over 50 percent loss of the reflective surface while another 3.9 percent had under 50 percent loss. The nighttime inspections revealed that the 40-foot spacing used for the Stimsonite 96 markers provided very good delineation and could be increased to an 80-foot spacing on tangents; however, the 40-foot spacings should be maintained on horizontal curves.

An accident analysis at locations where recessed markers were installed revealed that, compared to control locations, there were reductions in the percentage of all nighttime and wet-nighttime accidents. There was also a large reduction in the percentage of these accidents at Stimsonite 96 locations, but a similar reduction was found at the Stimsonite 96 control locations.

IMPLEMENTATION

LANE DELINEATION MATERIALS

The evaluation has shown that expanded use is warranted for polyester paint and extruded thermoplastic. The limited experience to date has shown polyester paint to be performing satisfactorily on both high-volume roadways and PCC pavements. However, there has been no evidence that it will have long-term success on PCC pavements (especially old PCC pavements). Durability problems have been experienced on PCC pavements in other states and no large-scale installations on PCC pavements should be placed until further research is conducted. As shown in Table 15, even if use was limited to lower-volume bituminous pavements, polyester paint could be used on a very high number of miles. Almost 80 percent of the total mileage included on the statewide roadway volume file has an ADT under 3,500 and over 90 percent of Kentucky's highways have bituminous surfaces.

Both alkyd-resin and hydrocarbon-resin extruded thermoplastic have performed well on the interstate open-graded pavement installations. There have been no data that would favor one type over the other. Use of either polyester paint or extruded thermoplastic would involve contracting since the Kentucky Transportation Cabinet does not have the necessary equipment. The cost of the extruded thermoplastic would limit its use to high-volume roadways. Experience has not established that it may be used successfully on PCC pavements.

The high cost of the preformed tapes would generally preclude widespread use when compared with the cost and performance of extruded thermoplastic. The bysymmetric tape had a cost substantially less than the other preformed tapes and its performance could warrant consideration on moderate volume roadways having no lighting. No further use of the 100-percent solid epoxy, EPOFLEX, or solvent epoxy paint is recommended until such time additional testing proves that problems have been resolved.

There is a need to continue to monitor the large installations of polyester paint and hydrocarbon-resin and alkyd-resin extruded thermoplastics placed in 1986. There is also a need to monitor and evaluate 1) any new installations of previously tested materials, such as 100-percent solid epoxy, that have been altered since placed as part of this evaluation and 2) installations of marking materials not previously tested, such as water-based traffic paint.

CROSSWALK AND STOPBAR MATERIALS

The alkyd-resin extruded thermoplastic material was the most cost-effective material for crosswalk and stopbar installations. Installations of this material could be made either by contract or with Kentucky Transportation Cabinet personnel if the necessary equipment were obtained. After a few years, crosswalks and stopbars must be refurbished to repair wear in the wheel paths. This may be accomplished by adding only the amount of material necessary at any given point to bring the line up to a uniform thickness. Preformed tapes should be used in isolated instances where a stopbar or crosswalk is needed and it is not practical to use the thermoplastic equipment. Preformed tapes also may be used on portland cement concrete pavements until it can be shown that thermoplastic material will consistently have the required durability on this pavement type.

SNOWPLOWABLE MARKERS

The durability and reflectivity results show that the Stimsonite 96 markers have performed effectively as snowplowable markers. The recessed markers also have performed effectively, except on certain interstate locations.

The use of recessed markers should be limited to four-lane highways constructed to high geometric standards with the Stimsonite 96 markers installed on the majority of highways. The recessed markers should not be used at locations having high truck volumes until its durability at such locations can be proven. Any future use of recessed markers should use the Stimsonite 948 marker instead of the Stimsonite 947 marker. The Stimsonite 948 marker has revisions to improve durability. Use of this marker will require a 5-inch groove instead of the 4-1/2 inch groove. Consideration also should be given to using bitumen to place the marker instead of epoxy. The four-lane portion of the parkway system would appear to be a good example for the application of recessed markers. On interstates such as I-65 in Jefferson County, it appears the Stimsonite 96 marker would be more appropriate. Spacing of the Stimsonite 96 markers should be increased from 40 feet to 80 feet on tangents and shallow curves. A spacing of 40 feet should continue to be used on sharp curves. This change in spacing should serve to alert motorists of the change in alignment and insure a minimum number of markers being kept in view. The 40-foot spacing should be used when the design speed of the curve is less than 55 mph. Therefore, the 40-foot spacing should be used on curves having a degree of curvature greater than six degrees. A field procedure for the measurement of horizontal curvature is given in a previous interim report (3).

REFERENCES

1. Agent, K. R. and Pigman, J. G.; "Evaluation of Durable Crosswalk and Stopbar Marking Materials," Research Report UKTRP-86-13, University of Kentucky Transportation Research Program, May 1986.

2. Agent, K. R. and Pigman, J. G.; "Evaluation of Durable Lane Delineation Materials," Research Report UKTRP-86-15, University of Kentucky Transportation Research Program, May 1986.

3. Agent, K. R. and Pigman, J. G.; "Evaluation of Snowplowable Marker Installations," Research Report UKTRP-86-16, University of Kentucky, June 1986.

4. Natrella, M. G.; Experimental Statistics, United States Department of Commerce, National Bureau of Standards Handbook 91, August 1963.

TABLE 1. SUMMARY OF CROSSWALK AND STOPBAR INSTALLATION CONTRACTS*

LOCATION	MATERIAL	YEAR INSTALLED	COST PER FOOT 6-INCH CROSSWALK	COST PER FOOT 24-INCH STOPBAR	QUANTITIES (FEET) 6-INCH CROSSWALK	QUANTITIES (FEET) 24-INCH STOPBAR
Northern Kentucky (Boone, Kenton, and Campbell Counties)	Prismo Preformed Tape	1983	$2.64	$7.54	51,612	15,832
		1984	$2.64	$7.54	12,902	3,957
Louisville (Jefferson County)	3M Stamark Tape	1983	$2.28	$6.89	69,982	27,691
	Hot-Extruded Thermoplastic Alkyd-Resin	1986	$0.84	$3.36	53,678	15,848
Lexington (Fayette County)	Hot-Extruded Thermoplastic Hydrocarbon Resin	1983	$1.05	$2.27	20,616	16,021
		1983	$0.72	$2.86	2,175	484
	Alkyd Resin	1984	$1.15	$3.10	2,301	1,366
		1985	$0.95	$3.60	3,905	1,155
		1986	$0.75	$3.00	53,000	15,000

* Contracts awarded through 1986.

TABLE 2. SUMMARY OF RECESSED MARKER INSTALLATION CONTRACTS*

		GROOVES			
CONTRACT	DATE	CONTRACT NUMBER	UNIT COST	MARKER UNIT COST	INSTALLED UNIT COST
FG3000(17)	6-22-84	30,768	$4.44	$1.92	$6.36
FG3000(18)	6-22-84	34,000	4.44	1.82	6.26
~~PMSOOS(30)~~	~~11-16-84~~	~~19,399~~	~~5.79~~	~~2.50~~	~~8.29~~
IRGOOS(25)	8-23-85	24,989	5.74	2.45	8.19
IRGOOS(32)	5-31-86	20,194	5.50	3.50	9.00

* Contracts awarded through 1986.

TABLE 3. SUMMARY OF STIMSONITE 96 MARKER INSTALLATION CONTRACTS*

		STIMSONITE 96 MARKERS	
CONTRACT	DATE	CONTRACT NUMBER	UNIT COST
FG3000(19)	8-17-84	68,725	$15.54
FG3000(20)	8-17-84	61,322	15.39
FG3000(25)	6-14-85	52,552	17.10
FG3000(28)	6-14-85	49,811	16.00
FG3000(31)	6-14-85	79,069	17.50
F3000(40)	5-31-86	100,320	18.50
F3000(43)	5-31-86	24,456	18.60
F3000(46)	5-31-86	72,323	19.20

* Contracts awarded through 1986.

TABLE 4. TYPICAL PRICES OF MARKING MATERIALS (MATERIALS AND INSTALLATION)

MATERIAL	COST (CENTS PER LINEAR FOOT FOR 4-INCH LINE)
100-Percent Solid Epoxy Paint	20 - 30
Polyester Paint	7 - 12
Extruded Thermoplastic	25 - 35
3M Stamark Tape (Series 5730)	80 - 110
3M Bisymmetric Tape (Series 5750)	50 - 60
3M Pliant Polymer Tape (Series A350)	100 - 150
EPOFLEX	15 - 20
Solvent Epoxy Paint	10 - 15
Chlorinated Rubber Traffic Paint	3 - 5
Alkyd Traffic Paint	3 - 5

TABLE 5. SUMMARY OF ORIGINAL PORTABLE RETROREFLECTOMETER (PRR) DATA FOR LANE DELINEATION MATERIALS

MATERIAL	COLOR	PRR MEASUREMENT 1982	1983	1984	1985	1986
100-Percent Solid Epoxy Paint - Lexington	White	290	190	150	***	***
	Yellow	230	140	140	***	***
- Louisville	White	290	170	160	160	***
	Yellow	240	160	140	140	***
- Northern Kentucky	White	270	180	170	***	***
	Yellow	220	170	160	***	***
Polyester Paint (Jefferson County)	White	250	150	170*	160*	140*
	Yellow	190	90	100*	120*	110*
Extruded Thermoplastic (Narrow Bridge Locations) (Hydrocarbon)	White	290	230	160	140	130
	Yellow	200	80	70	100	90
Extruded Thermoplastic (Lexington) (Alkyd)	White	**	**	**	380	300
	Yellow	**	**	**	210	190
3M Stamark Tape (Series 5730)	White	360	160	130	120	120
	Yellow	280	120	110	90	90
3M Bisymmetric Tape (Series 5750)	White	550	200	130	***	***
EPOFLEX -- Indiana	White	**	180	100	***	***
	Yellow	**	100	80	***	***
EPOFLEX -- Jefferson County	White	**	**	**	240	180
	Yellow	**	**	**	140	130
Solvent Epoxy Paint -- Indiana	Yellow	**	70	**	**	**
Chlorinated-Rubber Traffic Paint	White	210	100	**	**	**
	Yellow	180	80	**	**	**
Alkyd Traffic Paint	White	**	**	**	160	130
	Yellow	**	**	**	110	90

* Measurements increased as a result of additional paint applications.
** No data for this time period.
*** Material painted over.

TABLE 6. SUMMARY OF MIROLUX 12 PRR DATA

MATERIAL	COLOR	MIROLUX 12 DATA*
Polyester Paint (Jefferson County)	White	150
	Yellow	110
Polyester Paint (KYDOT Contract)	White	210
	Yellow	140
Extruded Thermoplastic (Hydrocarbon-Resin) Interstate Locations	White	290
	Yellow	140
Extruded Thermoplastic (Alkyd-Resin)		
Lexington	White	160
Interstate	White	300
	Yellow	170
3M Stamark Tape (Series 5730)	White	140
	Yellow	60
EPOFLEX	White	160
	Yellow	110
Alkyd Traffic Paint	White	120
	Yellow	120
3M Stamark Pliant Polymer Tape (Series A350)	White	330
	Yellow	230

* Measurements in terms of millicandelas per square foot per foot candle. Data were collected in the spring of 1987.

TABLE 7. SUMMARY OF ORIGINAL PORTABLE RETROREFLECTOMETER (PRR) MEASUREMENTS FOR CROSSWALK AND STOPBAR MATERIALS

LOCATION	MATERIAL	INSTALLATION DATE	AVERAGE PRR MEASUREMENTS — DATE: 11-83	7-84	8-84	11-84	2-85	3-85	4-85	10-85	11-85	4-86
Northern Kentucky	Prismo Preformed Tape											
(Boone, Kenton, and	First Contract	9-83	150	100					80		90	90
Campbell Counties)	Second Contract	9-84					100				90	90
Louisville (Jefferson County)	3M Stamark Tape	9-83	130	100					120	110		90
Lexington	Hot-Extruded Thermoplastic											
(Fayette County)	Hydrocarbon Resin											
	First Contract	9-83	130	100					100	80		70
	Second Contract	9-83			140					150		130
	Alkyd Resin											
	First Contract	11-84				250		170		170		140
	Second Contract	9-85								320		130

TABLE 8. SUMMARY OF MIROLUX 12 PRR DATA FOR CROSSWALK AND STOPBAR MATERIALS

MATERIAL	INSTALLATION DATE	MIROLUX 12 DATA*
Extruded Thermoplastic		
Alkyd Resin		
Lexington-First Contract	11-84	160
Second Contract	9-85	150
KYDOT-Lexington	9-86	140
Louisville	9-86	140
Hydrocarbon Resin		
Lexington Contract	9-83	140
3M Stamark Tape (Series 5730)		
Louisville	9-83	90
Prismo Preformed Tape		
Northern Kentucky		
First Contract	9-83	70
Second Contract	9-84	110

* Data collected in April 1987 in units of millicandelas per square foot per footcandle.

TABLE 9. SUMMARY OF INSTALLATION DATA FOR RECESSED MARKERS DETAILED INSPECTIONS

Average Groove Length	50 Inches
Average Groove Depth	0.48 Inch
Average Marker Placement	4 Inches*
Average Groove Width	4.44 Inches

Distance from Pavement Surface to Top of Marker	Number	Percent
-1/8 Inch	3	0.6
-1/16 Inch	24	4.8
Flush	227	45.4
1/16 Inch	157	31.4
1/8 Inch	76	15.2
3/16 Inch	10	2.0
1/4 Inch	3	0.6

* Distance from back of marker to end of groove.

TABLE 10. SUMMARY OF LENSES DAMAGE TO RECESSED MARKERS (DETAILED INSPECTIONS)

LENS DAMAGE	INSPECTION DATE					
	1985*		1986**		1987***	
	NUMBER	PERCENT	NUMBER	PERCENT	NUMBER	PERCENT
Under 50 Percent Damaged	6	1.2	21	4.2	52	10.4
Over 50 Percent Damaged	1	0.2	5	1.0	13	2.6
Lenses Cracked	4	0.8	6	1.2	6	1.2

* Average of 94 days in service and average traffic exposure of 0.91 million vehicles.

** Average of 332 days in service and average traffic exposure of 4.82 million vehicles.

*** Average of 646 days in service and average traffic exposure of 6.81 million vehicles.

TABLE 11. SUMMARY OF DATA FOR STIMSONITE 96 MARKERS DETAILED INSPECTIONS

YEAR INSTALLED	NUMBER OF LOCATIONS	AVERAGE DAYS IN SERVICE	NUMBER OF MARKERS						
			NO PROBLEM	LENSES DAMAGE		LENSES CRACKED	STEEL HOUSING DAMAGE	LENSES PAINTED	
				UNDER 50 PERCENT	50 PERCENT OR MORE			UNDER 50 PERCENT	50 PERCENT OR MORE
1984*	15	330	270	26	4	14	1	54	2
1985*	15	56	359	5	0	0	0	5	0
ALL*	30	193	629	31	4	14	1	59	2
1984**	15	584	271	34	10	22	1	32	1
1985**	15	288	316	26	2	16	0	9	0
ALL**	30	436	587	60	12	38	1	41	1
1984***	15	595	278	50		21	3	19	1
1985***	15	878	261	45		15	1	23	4
ALL***	30	737	539	95	24	38	4	42	5

* Inspections conducted in 1985. Average of 193 days in service and average traffic exposure of 0.80 million vehicles.

** Inspections conducted in 1986. Average of 436 days in service and average traffic exposure of 1.86 million vehicles.

*** Inspections conducted in 1987. Average of 737 days in service and average traffic exposure of 3.06 million vehicles.

TABLE 12. SUMMARY OF DATA FOR RECESSED MARKERS NIGHTTIME INSPECTIONS

YEAR INSTALLED	TOTAL MARKERS SURVEYED	AVERAGE DAYS IN SERVICE	AVERAGE TRAFFIC EXPOSURE (MILLION VEHCILES)	DAMAGE SUMMARY*						PERCENT WITH 50 PERCENT OR GREATER LENS DAMAGE
				NO DAMAGE	NOT VISIBLE	PERCENTAGE OF LENSES DAMAGED				
						UNDER 25	25-49	50-74	75-99	
1984**	3,102	375	5.14	2,913	18	85	29	29	28	2.4
1985**	8,438	140	1.89	8,728	53	53	51	20	33	1.2
ALL**	12,040	180	2.48	11,641	71	138	80	49	61	1.5
1984***	3,102	560	8.13	2,704	47	149	51	28	33	3.5
1985***	8,930	333	7.50	8,136	145	360	108	98	91	3.7
ALL***	12,040	371	7.60	10,930	192	509	159	126	124	3.7
1984****	2,742	879	12.77	2,021	314	126	87	93	101	18.5
1985****	8,827	635	14.11	6,951	884	365	201	213	213	14.8
ALL****	11,569	676	13.89	8,972	1,198	491	288	306	314	15.7

* Number of marker lenses having given damage.
** Inspections conducted in 1985
*** Inspections conducted in 1986.
**** Inspections conducted in 1987.

TABLE 13. SUMMARY OF DATA FOR STIMSONITE 96 NIGHTTIME INSPECTIONS

YEAR INSTALLED	TOTAL MARKERS SURVEYED	AVERAGE DAYS IN SERVICE	AVERAGE TRAFFIC EXPOSURE (MILLION VEHICLES)	DAMAGE SUMMARY* NO DAMAGE	NOT VISIBLE	PERCENTAGE OF LENSES DAMAGED UNDER 25	25-49	50-74	75-99	PERCENT WITH 50 PERCENT OR GREATER LENS DAMAGE
1984**	7,671	390	1.60	14,801	62	176	119	130	54	1.6
1985**	6,926	100	1.44	13,789	15	25	8	11	6	0.2
ALL**	14,597	300	1.54	28,590	75	201	127	141	60	0.9
1984***	7,671	590	2.39	14,206	87	610	200	159	80	2.1
1985***	6,926	300	3.03	13,456	34	239	56	47	20	0.7
ALL***	14,597	490	2.60	27,662	121	849	256	206	100	1.5
1984****	7,556	882	3.62	13,570	194	613	233	300	88	3.9
1985****	6,081	613	5.50	11,696	133	149	57	57	156	2.8
ALL****	13,637	792	4.25	25,266	327	762	290	357	244	3.4

* Number of marker lenses having given damage. Each marker had two lenses.
** Inspections conducted in 1985.
*** Inspections conducted in 1986.
**** Inspections conducted in 1987.

TABLE 14. BEFORE AND AFTER ACCIDENT ANALYSIS AT SNOWPLOWABLE MARKER INSTALLATIONS AND CONTROL LOCATIONS

	BEFORE*	AFTER**	PERCENT CHANGE
Stimsonite 96 Installations			
Total Accidents	1,478	1,743	+18
Percent Total Nighttime Accidents	29	26	-10
Percent Wet-Nighttime Accidents	7.8	5.2	-33
Stimsonite 96 Control Installations			
Total Accidents	847	1,023	+21
Percent Total Nighttime Accidents	29	25	-12
Percent Wet-Nighttime Accidents	7.7	5.3	-31
Recessed Marker Installations			
Total Accidents	319	355	+27
Percent Total Nighttime Accidents	46	39	-15
Percent Wet-Nighttime Accidents	7.2	6.9	-4
Recessed Marker Control Locations			
Total Accidents	294	341	+16
Percent Total Nighttime Accidents	41	40	-3
Percent Wet-Nighttime Accidents	6.8	7.2	+6

* Average of 1982 and 1983 accident data.
** Average of 1985 and 1986 accident data.

TABLE 15. STATEWIDE MILEAGE SUMMARY BY ADT AND SURFACE TYPE

ADT RANGE	TOTAL MILEAGE	PERCENT OF TOTAL	PERCENT HAVING GIVEN SURFACE TYPE		
			BITUMINOUS	PC CONCRETE	OTHER
Under 500	10,459	41.7	92	0	8
500 - 999	4,389	17.5	98	0	2
1,000 - 2,499	4,587	18.3	99	1	0
2,500 - 4,999	2,635	10.5	89	11	0
5,000 - 9,999	1,584	6.3	83	17	0
10,000 - 19,999	846	3.4	66	33	1
20,000 or more	564	2.3	36	64	0