MEMORANDUM TO:  G. F. Kemper  
State Highway Engineer  
Chairman, Research Committee  


Unheated paints (sprayed) and glass beads (drop-on) served well for lines on pavements until two years ago, when the decision was made to convert to quick-dry, heated paints and, thereby, to eliminate the need for traffic cones. Quick-dry paints should not be confused with so-called hot-sprayed, thermoplastic striping material. Hot-sprayed thermoplastic as defined by Special Provision No. 93A is equivalent in thickness to about six, additional coats of paint. Paint costs about $0.02 per coat per linear foot of 4-in. wide line. Hot-spray plastic costs about $0.23 per lineal foot. Hot-sprayed plastic should not be confused with hot-extruded thermoplastic lines which have been or are applied at nominally 1/8-in. thickness and cost somewhat more. Hot-spray lines are specified to be 60 or 90 mils thick. The plastic lines have proven to be economical only in situations where traffic volumes are very high and where frequent re-painting is too dangerous or interferes too much with the flow of traffic. The thicker lines provide a higher perch for glass beads and faster drainage of water; this should enhance rainy, nighttime reflectivity and brightness; beads must be well anchored or socketed into the plastic in order to endure very long. The overall objectives are the same as those which have been cited as attributes of raised markers (Report No. 384, 418, and 425).

Performance histories of hot-extruded lines were reported summarily in 1970 (Report No. 290).

Hot-sprayed plastic lines were applied on the Kentucky Turnpike in 1969 (centerline, skip) and in 1971 (edgelines). The hot-sprayed plastic centerlines were applied on top of any existing or remaining paint lines. The contractor was required to guarantee performance regardless. However, the guarantee was not fully enforced. In the subsequent contract, significant mileage of inner edgeline was found to be poorly reflectorized - that is, beads had not been imbedded in the plastic. The contractor was required to overlay those segments of line. There, contexts in Special Provision 93 regarding cleaning and warranty were supplemented by Special Notes as follows: "... in areas where material is to be applied over existing paint, all loose or flaking paint is to be removed to the satisfaction of the Engineer." A subsequent note stated: "The edgeline shall be placed one (1) inch to three (3) inches from the edge of the roadway." This positioned some of the new line on the existing line and brought into issue the desirability of wire-brushing, chipping, and sandblasting.
Figure A, included as an attachment to this memorandum, shows a centerline situation on the Kentucky Turnpike in March 1975, in which overlaying material was detrimental to either the existing line or the overlay -- it is not clear which. The edgelines appear to be the 1971 application. In Figure B, the edgeline was obviously applied in space available between the existing line and the edge of the pavement.

A survey of May 21, 1971, of the centerline stripes applied on the Kentucky Turnpike by Prismo Corporation on June 18, 1969, was reported as follows:

1. There were 79,200 linear feet of 4-inch wide line per lane, a total of 5,280 stripes.
2. The southbound lane had 953 feet of stripe missing, a total of 1.2%.
3. The northbound lane had 1,676 feet of stripe missing, a total of 2.1%.
4. Under warranty, the total footage to be repaired is 2,609 feet.
5. Generally, the stripes are in good condition and no yellowing has occurred.

The edgelines were applied later in 1971; in November 1971, the entire length of inner edgeline was surveyed with a photometer; a significant footage of line having little reflectivity was defined. The project was not completed until June 1972.

A general survey was made March 7, 1975. The results were as follows:

<table>
<thead>
<tr>
<th></th>
<th>Southbound</th>
<th>Northbound</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left Edgeline</td>
<td>Centerline</td>
</tr>
<tr>
<td></td>
<td>211,200</td>
<td>79,200</td>
</tr>
<tr>
<td>Total Feet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equivalent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feet Missing</td>
<td>4,422</td>
<td>31,728</td>
</tr>
<tr>
<td>Percent</td>
<td>2.1</td>
<td>4.0</td>
</tr>
<tr>
<td>Missing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Apparently, the edgelines had not then been painted over; and the quality of these lines, as observed in daylight, was good. The centerlines were worn. It could not be determined, then, how much over-painting, if any, had taken place in the meantime. There were indications such as shown in Figure C (attached). Indeed, wear at the centerline would be expected to dull the reflectivity of lines in a relatively brief time. Renewal of centerlines for reflectorization is usually needed long before the line is completely worn away. It may be mentioned that the color code for inner edgelines changed during the term of the warranty on the edgelines.

Inspection of lines at the time of application, to assure proper imbedment of beads is essential. Paper or foil can be laid on the pavement ahead of the striper and a portion of line deposited on it -- the specimen of line can then be taken up and examined through a magnifying glass.

In January 1975, the Division of Research was requested to evaluate the performance of lines in downtown Louisville (EHST 3001(2)) and on Taylorsville Road (T3001(48)). Apparently, the performance in the city had been considered justification for subsequent striping projects under TOPICS. Research was not advised of any prior, performance survey reports. The surveys now reported were done in the summer of 1975. The basis of the surveys was visual; attempts to make photometer surveys proved futile. The report now submitted does not fulfill the specific request of the FHWA dated December 26, 1974, and as relayed from Traffic on January 9, 1975. It was not possible to evaluate pavement cleanliness, surface preparation, if any, or application temperature. The performance of Cataphote lines was compared with the performance of Prismo lines in a very general way; it was not possible to identify or explain any peculiar performance.
Preparation of the surface, cleanliness, removal of existing lines, etc., remain contentious requirements of the specifications; likewise, the mention of warranty needs further study and clarification. Any additional costs, such as might arise from specifying sandblasting the surface prior to application of lining material would alter the economic analyses presented in the report.

Respectfully submitted,

Jas. H. Havens
Director of Research

Attachments: Figures A, B, and C
Enclosure
cc's: Research Committee
Evaluation of Thermoplastic Pavement-Striping Materials (Louisville and Jefferson County)

Jerry G. Pigman and Kenneth R. Agent

Division of Research
Kentucky Bureau of Highways
533 South Limestone
Lexington, Kentucky 40508

Study title: Evaluation and Application of Roadway Delineation Techniques

Approximately 1,406,100 linear feet (428,579 m) of hot-sprayed thermoplastic stripe was applied to roadways in Louisville and Jefferson County in the summer of 1973. Visual observations of appearance, durability, and night visibility were conducted according to ASTM D 713-69, the standard method for conducting road service tests on traffic paint. Attempts to conduct photometer measurements of the thermoplastic striping were unsuccessful. Visual observations made during rainy, nighttime conditions were also unsuccessful because very little difference was noticeable among the various sections.

The evaluation showed that the thermoplastic stripes performed considerably better on bituminous concrete pavements than on portland cement concrete pavements. White thermoplastic stripes were generally better than yellow stripes, particularly on portland cement concrete surfaces.

No definite relationship was found between durability of thermoplastic striping and traffic volume for stripes applied to bituminous concrete pavements than on portland cement concrete pavements. The stripes, however, were less durable on the older pavements. On portland cement concrete pavements, the stripes were less durable on high volume roads and older pavements.

An economic analysis of the cost of thermoplastic and paint striping revealed that thermoplastic striping is more economical on the higher volume roads. Volumes required for thermoplastic striping to be more economical than paint striping ranged from 15,000 vehicles per day on a two-lane bituminous concrete pavement (white or yellow stripes) to 120,000 vehicles per day on a six-lane portland cement concrete pavement (yellow stripes). Volumes required for other highway types, pavement type, and line color are also presented.
Research Report
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EVALUATION OF THERMOPLASTIC PAVEMENT-STRIPING MATERIALS

(Louisville and Jefferson County)

KYP-73-48, HPR-PL-1(11), Part III-B

by

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and

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Bureau of Highways
DEPARTMENT OF TRANSPORTATION
Commonwealth of Kentucky

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Bureau of Highways. This report does not constitute a standard, specification, or regulation.

May 1976
INTRODUCTION

Experience with hot-melt thermoplastic striping materials dates back to World War II when the Road Research Laboratory in Great Britain explored various compositions of rosin, mineral oil pigments, and fillers (1). Hot-melt thermoplastics have since become the dominant road-marking medium in Great Britain. Their primary use has been on roads outside of urban areas. Acceptance of thermoplastics in the United States has been inhibited by technical and economical factors concerning application, durability, and reflectivity.

In Kentucky, the use of hot-melt, extruded thermoplastics dates back to the early 1950's. The first hot-melt, sprayed thermoplastic material was used to stripe centerlines of the Kentucky Turnpike in 1969. A study concerning the application and long-range performance of thermoplastic pavement-striping materials was begun by Kentucky in 1962 (2). It was found that the cost of hot-extruded, thermoplastic stripes was disproportionate to the level of service realized in comparison to traffic paint. Line losses of more than one percent per year were considered to be intolerable. Catatherm and Perma-Line types of hot-extruded, thermoplastic stripes were applied. Cumulative expenditures consisted of the initial cost of installation and the annual expenditures for succeeding years. The initial cost of hot-extruded thermoplastics was 39 cents per foot (0.3 m), or 25 times the cost of the control sections with traffic paint.

Concerning the visibility of hot-extruded, thermoplastic stripes applied in 1962, it was concluded that hot-extruded thermoplastics have slightly better visibility than freshly applied paint during both daytime and nighttime. In comparison to newly installed lines, it was found that a slight reduction in the visibility of hot-extruded, thermoplastic stripes occurred after 6 months of service, but no significant reduction occurred after that if the lines remained in place. Visibility of the paint, on the other hand, gradually decreases with age, and repainting is required at intervals of 1 to 3 years -- depending on line location, type of pavement, and traffic volume.

Another conclusion drawn from the 1962 study of hot-extruded thermoplastics was the amount of time and inconvenience to traffic required to install the stripes. The daily production from hot-extruded, thermoplastic machines did not approach the production from paint-striping machines. The time required for hot-extruded, thermoplastic installation exceeded that of paint installation by as much as three times.

A final report on the series of thermoplastic evaluations in Kentucky was submitted in 1970 (3). All materials used in those applications to that time were hot-melt, extruded thermoplastics having a thickness of about 0.125 inches (3.18 mm). Two brands of thermoplastic stripes were compared with conventional paint stripes at nine sites in both rural and urban areas. It was found that the performance of hot-extruded thermoplastics placed on bituminous concrete pavements was superior to that placed on portland cement concrete pavements. Epoxy primers were an aid in providing adherence of thermoplastics to portland cement concrete pavements; however, the epoxies were not capable of penetrating surface laitance. Visibility of the hot-extruded, thermoplastic stripes decreased with age due to accumulation of road scum.

Other research related to evaluations of hot-melt, extruded, thermoplastic stripes include a very thorough study by Tooke (4). Major findings from that study indicated that hot-extruded, thermoplastic stripes must exhibit at least 6.3 times the service life of traffic paint to be competitive in average annual cost. From an economic standpoint, it was found that for most highway usage, development of the wet, night visibility potential would be necessary to justify adoption of hot-extruded, thermoplastic striping.

A report by the Mississippi State Highway Department in 1973 concluded that hot-extruded and hot-sprayed thermoplastics exhibit 10 years service life with very little maintenance when placed on most highways (5). It was recommended that consideration be given to the placement of hot-extruded or hot-sprayed thermoplastic stripes and reflective markers on all roads with 2,000 vehicles per day or higher.

Detailed surveys of 43 state, city, and other agencies by the Bureau of Public Roads in 1969 revealed the following (6):

1) Hot-extruded thermoplastic striping is much more durable on bituminous pavements than on portland cement concrete pavements.
2) Hot-extruded, thermoplastic striping is generally more durable on older concrete pavements than on new concrete.
3) The service life of hot-extruded, thermoplastic striping is related more to snowplow activity than to traffic density. By contrast, the durability of conventional paint striping is related to the volume of traffic.
4) A limiting factor in the economic value of hot-extruded, thermoplastic striping on bituminous pavements is the maintenance-free life of the bituminous surface.
5) Hot-extruded thermoplastics can provide economic benefits exceeding paint striping on bituminous pavements when the traffic density is approximately 6,000 vehicles per lane or greater or on portland cement concrete pavements when the density exceeds 9,000 vehicles per lane.
A study by the Minnesota Department of Highways (7) concluded that hot-extruded thermoplastic striping should not be used as a pavement-marking material on portland cement concrete pavements due to poor adhesion and durability. It was also concluded that hot-extruded thermoplastics can be used economically on bituminous pavements having ADT's per lane ranging from 2,000 to 7,000. The importance of overlay-free life of bituminous pavements with respect to the expected life of hot-extruded thermoplastics was also noted.

Hot-extruded, thermoplastic stripes have been installed and experimentally evaluated by the New York State Department of Public Works (8). After 5 years of observations, it was concluded that hot-extruded thermoplastics were as bright as freshly placed reflectorized paint lines throughout the observations. It was also found that hot-extruded thermoplastic material may be economical when placed on bituminous concrete pavement carrying large volumes of high-speed traffic. After three winters, approximately 85 percent of the hot-extruded thermoplastic was still in place.

Further support of hot-extruded, thermoplastic striping was provided by the Arkansas Department of Highways (9). It was found that the material could be used economically for lane-line markings where traffic volumes exceed 6,000 vehicles per day. Additional justification was offered by considering the safety of striping crews.

An evaluation of hot-extruded thermoplastics by the Washington State Department of Highways revealed that the reflex-reflectivity of thermoplastics was negligible, even for clear, dry, nighttime driving (10). In this respect, it was found to be inferior to conventional beaded paint stripes. However, it was noted that the hot-extruded, thermoplastic material gave a very satisfactory 3-year life, particularly when used in conjunction with raised pavement-markers.

Application of hot-extruded and hot-sprayed thermoplastics in the future will require additional verification of the safety and economic benefits. Initially, it was felt that thermoplastic striping materials would be a major step toward a solution of the rainy, nighttime visibility problem; however, very little evidence is presently available to support this presumption. As a result of the lack of evidence to support either hot-extruded or hot-sprayed thermoplastics as a rainy, nighttime delineation technique, primary emphasis in this report will be on the economic justification of hot-sprayed thermoplastics as a replacement for conventional paint stripes. Hot-sprayed thermoplastic stripes applied to roadways in Louisville and Jefferson County in the summer of 1973 will be the basis for this evaluation. Any further mention of thermoplastics in this report will be in reference to hot-sprayed thermoplastics.

PROCEDURE

Approximately 1,406,100 lineal feet (428,579 m) of hot-sprayed thermoplastic was applied to roadways in Louisville and Jefferson County in the summer of 1973 by Cataphote Corporation. Of the total, 422,000 linear feet (128,625 m) were white line and 984,100 linear feet (299,954 m) were yellow line. A very large percentage of the lines were placed on bituminous concrete pavements and only a limited application on portland cement concrete pavements. Applications included lane lines, centerlines, turn-lane lines, and edgelines. Specifications for the thermoplastic striping are given in APPENDIX A.

An attempt was made to conduct a survey which would represent different traffic volumes on the two types of pavements. This was accomplished by obtaining volume information from the Louisville District Office for the various sections of roadways and determining pavement type during the on-spot evaluations. At the time of inspection, all portland cement concrete pavements with thermoplastic stripes were included in the evaluation to obtain enough data for comparison with thermoplastics on bituminous concrete pavements.

The first step was to conduct visual evaluations according to ASTM D 713-69, the standard method for conducting road service tests on traffic paint. Four observers were available for most of the evaluations. Ratings of appearance, durability, and night visibility were performed. All of the sections (approximately 100) were rated by observing the thermoplastic stripes while standing in the roadway. The sections were determined by dividing the streets according to pavement type, volume, and color of thermoplastic stripe. Close visual inspection of each section was conducted during daylight to determine the durability; appearance was also rated at the same point on the section. The percentage of material remaining on the pavement determined the durability. The appearance was the complete impression conveyed by the stripe. Night visibility of sample sections was rated at a later date by observing the thermoplastic stripes from an automobile.

Attempts to conduct photometer measurements of the thermoplastic striping were unsuccessful. Luminosity of the thermoplastic stripes was not sufficient to determine differences between the various applications. This problem had been encountered before in the measurement of luminosity of regular paint stripes. Visual observations made during rainy, nighttime conditions were also unsuccessful because the little difference was noticed between various sections.
RESULTS

ROAD SERVICE TESTS

The standard method of conducting road service tests on traffic paint was used (ASTM D 713-69). This method involved rating the appearance, durability, and night visibility of the thermoplastic stripes. Results of the road service tests are shown in Table 1. The data indicated that thermoplastics performed better on bituminous concrete than on portland cement concrete surfaces. Also, the white lines performed better than the yellow (particularly on portland cement concrete surfaces). The fact that thermoplastics perform better on bituminous concrete than on portland cement concrete surfaces is well documented. The difference in performance between the white and yellow stripes was surprising. The reason for the poor performance of the yellow stripes could not be determined.

The appearance of the markings remained very good in most instances (Figures 1 and 2). At a few locations, the appearance was rated poor (Figure 3 and 4).

The major problem concerning durability of the markings involved yellow stripes on portland cement concrete pavement where an average of almost 40 percent of the stripe was missing after 2 years (Figure 5). Slightly over 20 percent of yellow stripes on bituminous concrete pavement were missing while slightly less than 20 percent of the white stripes were missing on both bituminous and portland cement concrete pavements. Photographs of stripes with varying degrees of deterioration are given in Figure 6, 7, 8, and 9. A section of roadway with stripes which have maintained good appearance and durability is shown in Figure 10.

The ordering of the night visibility and weighted ratings were identical to the appearance and durability ratings. The white stripe on bituminous concrete pavement was best. The white stripe on portland cement concrete and yellow stripe on bituminous concrete pavements were close in performance, but the yellow stripe on portland cement concrete was definitely inferior.

A common failure of the thermoplastic striping was transverse cracks spaced a few inches (millimeters) apart (Figure 11). This may have been caused by differential expansion between the pavement and the thermoplastic. The cracking did not appear to reduce the effectiveness of the stripes in most cases. Severe cracking in some instances did lead to decreased durability due to chipping of the stripe (Figure 12).

There was a notable reduction in durability of stripes on curved sections of roadway and sections near intersections (Figure 13 and 14). This was due to wear from the high percentage of vehicles crossing the stripe. There was also a reduction in durability when the thermoplastic was placed on rough textured surfaces as shown in Figure 9. Apparently, a proper bond could not be achieved on these surfaces.

Small pieces of thermoplastic material were chipped from the stripes. Photographs of these chips were taken to study bead retention (Figures 15 and 16).

RELATIONSHIPS OF AADT AND PAVEMENT AGE TO DURABILITY

Plots were drawn of AADT and pavement age versus durability of the thermoplastic stripes (Figures 17-24). Separate plots were drawn for white and yellow stripes. The trend lines were obtained using the least squares method.

For stripes placed on bituminous concrete surfaces, no definite relationship was found between AADT and durability. For white stripes, there was a slight increase in durability with increased AADT, but there was a slight decrease in durability for yellow stripes. However, there appeared to be a relationship between pavement age and stripe durability. Durability decreased as the pavement age increased (particularly for yellow stripes). As the various sections were rated, it became obvious there was a definite reduction in durability on the rougher textured surfaces. Usually the older pavements exhibited rough texture. Although performance was best on new surfaces, thermoplastics should not be placed on fresh pavements. A few months may be required for the fresh pavement to cure.

For stripes placed on portland cement concrete surfaces, durability was found to decrease with increased AADT and increased pavement age. The generally poor durability of thermoplastics on portland cement concrete surfaces may have resulted in its exceptionally poor performance on high volume roads. It should be noted that no stripes were placed on new portland cement concrete surfaces. The newest surface was 4 years old. However, past studies have shown that thermoplastic stripes also perform poorly on new portland cement concrete because the surface laitance layer and some curing compounds may interfere with good bonding.
Figure 1. White Thermoplastic Striping which Maintained Good Appearance.
Figure 2. Yellow Thermoplastic Striping which Maintained Good Appearance.

Figure 3. White Thermoplastic Striping with Poor Appearance.
Figure 4. Yellow Thermoplastic Striping with Poor Appearance.

Figure 5. Poor Durability of Yellow Thermoplastic Striping on Portland Cement Concrete Pavement.
Figure 6. Good Durability of White Thermoplastic Striping on Bituminous Concrete Pavement.

Figure 7. Poor Durability of White Thermoplastic Striping on Bituminous Concrete Pavement.
Figure 8. Good Durability of Yellow Thermoplastic Striping on Bituminous Concrete Pavement.

Figure 9. Poor Durability of Yellow Thermoplastic Striping on Rough Bituminous Concrete Pavement.
Figure 10. Section of roadway with stripes which maintained good appearance and durability.

Figure 11. Transverse cracking in thermoplastic striping.
Figure 12. Reduction in Durability Resulting from Transverse Cracking.

Figure 13. Reduction in Durability on Curved Section of Roadway.
Figure 14. Reduction in Durability at Intersection.

Figure 15. Bead Retention in a Sample of White Thermoplastic Striping.
Figure 16. Bead Retention in a Sample of Yellow Thermoplastic Striping.

Figure 17. Durability versus Average Annual Daily Traffic for White Thermoplastic Striping on Bituminous Concrete Pavement.
Figure 18. Durability versus Average Annual Daily Traffic for Yellow Thermoplastic Striping on Bituminous Concrete Pavement.
Figure 19. Durability versus Pavement Age for White Thermoplastic Striping on Bituminous Concrete Pavement.
Figure 20.  Durability versus Pavement Age for Yellow Thermoplastic Striping on Bituminous Concrete Pavement.
Figure 21. Durability versus Average Annual Daily Traffic for White Thermoplastic Striping on Portland Cement Concrete Surface.
Figure 22. Durability versus Average Annual Daily Traffic for Yellow Thermoplastic Striping on Portland Cement Concrete Surface.

Figure 23. Durability versus Pavement Age for White Thermoplastic Striping on Portland Cement Concrete Surface.
THERMOPLASTICS APPLIED BY PRISMO CORPORATION

An evaluation of thermoplastic stripes applied by Prismo Corporation was also conducted (Table 2). The stripes were placed slightly over 2 1/2 years ago in Louisville. This evaluation was carried out to compare the performance of thermoplastics applied by different companies. The Prismo stripes had been applied approximately 6 months before the Cataphote markings. All of the Prismo striping was on bituminous concrete pavement.

There were differences in performance of the two applications. The transverse cracks evident in the Cataphote stripes were not found in the Prismo stripes. Some of the Prismo stripes had small surface holes, but this did not seem to cause any problems (Figure 25). The durability of the Prismo stripes was better than Cataphote's. Ten percent of the Prismo stripes were missing compared to 20 percent of the Cataphote (bituminous concrete pavement). Also, the yellow stripe was not rated any poorer than the white stripe. Since no stripes were present on portland cement concrete surfaces, the difference between white and yellow stripes on portland cement concrete could not be checked.

LIFE EXPECTANCY AND ANNUAL COST OF THERMOPLASTIC STRIPES

The thermoplastic stripes evaluated in this study had been in service for only 2 years. The evaluations showed that the life expectancy of thermoplastic stripe in most cases will be substantially longer than 2 years, the only exception being the yellow stripe on portland cement concrete. Past studies accepted the terminal point of the stripe as being the time when 50 percent or more of the stripe was lost (6). Using this criterion, life of the yellow stripe on portland cement concrete would not be much longer than 2 years. The life of white stripes on portland cement concrete, and all striping on bituminous concrete surfaces, would be much longer. A limiting factor on bituminous concrete surfaces may be patching and resurfacing of the pavement. Maintenance-free life expectancy of bituminous concrete pavements may not exceed 8 to 10 years. An estimate of the life expectancy of the pavement surface is necessary to estimate the annual cost of thermoplastic stripes.

An examination of a section of thermoplastic striping installed approximately 6 years ago on the Kentucky Turnpike was conducted to obtain an estimate of life expectancy. A separate evaluation of that application is presented in APPENDIX B. The section consisted of white thermoplastic on portland cement concrete pavement. The examination showed that the striping was just reaching the end of its effective service life. A life expectancy of 5 years would appear to be a good estimate for white stripes on portland cement concrete pavements. This is in agreement with the finding cited in another report (6). In that report, a curve was drawn which related average thermoplastic life and annual snowfall (Figure 26). The mean annual snowfall at the Lexington weather station for the past 39 years has been 18.5 inches (0.47 m). Entering this
TABLE 2. RESULTS OF ROAD SERVICE TESTS (PRISMO CORPORATION STRIPING)

<table>
<thead>
<tr>
<th>PAVEMENT TYPE</th>
<th>LINE COLOR</th>
<th>AVERAGE RATING</th>
<th>WEIGHTED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>APPEARANCE</td>
<td>DURABILITY</td>
</tr>
<tr>
<td>Bituminous</td>
<td>White</td>
<td>8.7</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>8.7</td>
<td>9.1</td>
</tr>
</tbody>
</table>

*Does not apply since no night visibility ratings were done.

Figure 25. Small Holes Prevalent in Prismo Thermoplastic Striping.
value into Figure 26 yields an average thermoplastic life of 5 years on portland cement concrete pavements and 8 years on bituminous concrete pavements. A life expectancy of 5 years, therefore, was used in the calculations for portland cement concrete pavements (white striping). The evaluations indicated better durability on bituminous concrete pavements. A limiting factor, however, would be the maintenance-free life of bituminous concrete pavement. A value of 8 years was selected. This is identical to the value obtained using Figure 26.

If there was no maintenance cost involved during the life of thermoplastic stripes, the annual cost per linear foot (meter) could be obtained simply by dividing the cost of the stripes in place by the life expectancy. There was a notable loss of durability on curved sections of roadway and sections near crossroads. Therefore, an assumption was made that five percent of the total length would be restriped once during the life of the markings. Since this would involve limited quantities, the price of the restriping was assumed to be 50 percent higher than the original cost. The cost of the thermoplastic striping evaluated in this study was 21.39 cents per linear foot (0.3 m). A more realistic estimate of current prices would be 30 cents per linear foot (0.3 m). This was used in the calculations. There would be an additional 2 cents per linear foot (0.3 m) for maintenance ($0.45/ft times 5 percent). This gives a cost of 32 cents per linear foot (0.3 m). Dividing this by the life expectancy yields an annual cost. The annual cost of thermoplastic striping is given in Table 3.
LIFE EXPECTANCY AND ANNUAL COST OF CONVENTIONAL PAINT STRIPING

The life expectancy of conventional paint striping is directly related to traffic volume. Discussions with district traffic engineers have revealed that the highest volume roads may be striped three times a year and other high volume roads may be striped twice annually. This may be affected by the severity of the weather during the winter months. Nearly all roads are striped at least once a year. The average useful paint life for bituminous concrete and portland cement concrete pavements, developed from a nationwide study, is shown in Figure 27 (6). Traffic volumes on roadways in Kentucky which were known to be striped more than once annually matched the volumes cited in Figure 27.

The annual cost of conventional paint striping was determined by considering the annual striping frequency of various volume roads. The annual, basic paint striping cost per linear foot (meter) was calculated by multiplying the annual striping frequency times the cost of paint striping (2 cents per linear foot (0.3 m)). The additional cost of traffic delay and potential traffic accidents resulting from the striping operation was added to arrive at a total cost (Table 4). The derivation of the formulas used to calculate the delay and accident costs is given in APPENDIX C. The annual cost of paint striping was calculated for two-, four-, and six-lane highways. Plots of the total annual cost of paint striping versus the average daily traffic volume are shown in Figures 28, 29, and 30.

COMPARISON OF COSTS OF THERMOPLASTIC AND CONVENTIONAL PAINT STRIPING

An economic analysis of the cost of thermoplastic and paint striping shows that thermoplastic striping is more economical for the higher volume roads. The volume above which thermoplastic striping is more economical varies with number of lanes, pavement type, and line color (portland cement concrete surfaces only). A comparison of the annual cost of thermoplastic striping (Table 3) and conventional paint striping (Figures 28, 29, and 30) provides the volumes above which thermoplastic striping would be the more economical. These volumes are given in Table 5.
Figure 27. Average Useful Life of Paint Striping as Affected by Traffic Density (Both Bituminous and Portland Cement Concrete Pavement).
### Table 4. Annual Cost of Conventional Paint Stripping (Cents per Linear Foot (0.3 Meter) per Year)

<table>
<thead>
<tr>
<th>Annual Daily Traffic (ADT) per Lane</th>
<th>1,000</th>
<th>2,000</th>
<th>3,000</th>
<th>4,000</th>
<th>5,000</th>
<th>6,000</th>
<th>7,000</th>
<th>8,000</th>
<th>9,000</th>
<th>10,000</th>
<th>11,000</th>
<th>12,000</th>
<th>13,000</th>
<th>14,000</th>
<th>15,000</th>
<th>16,000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost of Traffic Delay (D)</strong></td>
<td>0.92</td>
<td>0.87</td>
<td>0.82</td>
<td>0.77</td>
<td>0.72</td>
<td>0.67</td>
<td>0.62</td>
<td>0.57</td>
<td>0.52</td>
<td>0.47</td>
<td>0.42</td>
<td>0.38</td>
<td>0.34</td>
<td>0.30</td>
<td>0.26</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>Annual Stripping Frequency</strong></td>
<td>0.76</td>
<td>0.70</td>
<td>0.65</td>
<td>0.60</td>
<td>0.55</td>
<td>0.50</td>
<td>0.45</td>
<td>0.40</td>
<td>0.35</td>
<td>0.30</td>
<td>0.25</td>
<td>0.20</td>
<td>0.15</td>
<td>0.10</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td><strong>Annual Base Paint Stripping Cost per Linear Foot (A)</strong></td>
<td>1.52</td>
<td>1.50</td>
<td>1.48</td>
<td>1.46</td>
<td>1.44</td>
<td>1.42</td>
<td>1.40</td>
<td>1.38</td>
<td>1.36</td>
<td>1.34</td>
<td>1.32</td>
<td>1.30</td>
<td>1.28</td>
<td>1.26</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td><strong>Annual Cost of Paint Stripping on a Two-Lane Highway</strong></td>
<td>0.91</td>
<td>0.90</td>
<td>0.90</td>
<td>0.89</td>
<td>0.88</td>
<td>0.87</td>
<td>0.85</td>
<td>0.83</td>
<td>0.82</td>
<td>0.81</td>
<td>0.80</td>
<td>0.79</td>
<td>0.78</td>
<td>0.77</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td><strong>Cost of Potential Traffic Accidents (C)</strong></td>
<td>0.69</td>
<td>0.68</td>
<td>0.68</td>
<td>0.67</td>
<td>0.66</td>
<td>0.65</td>
<td>0.64</td>
<td>0.63</td>
<td>0.62</td>
<td>0.61</td>
<td>0.61</td>
<td>0.61</td>
<td>0.61</td>
<td>0.61</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td><strong>Total Annual Cost (A + B + C)</strong></td>
<td>1.59</td>
<td>1.48</td>
<td>1.46</td>
<td>1.44</td>
<td>1.42</td>
<td>1.40</td>
<td>1.38</td>
<td>1.36</td>
<td>1.34</td>
<td>1.32</td>
<td>1.30</td>
<td>1.28</td>
<td>1.26</td>
<td>1.24</td>
<td>1.22</td>
<td></td>
</tr>
<tr>
<td><strong>Annual Cost of Paint Stripping on a Four-Lane Highway</strong></td>
<td>0.93</td>
<td>0.92</td>
<td>0.92</td>
<td>0.91</td>
<td>0.90</td>
<td>0.89</td>
<td>0.88</td>
<td>0.87</td>
<td>0.86</td>
<td>0.85</td>
<td>0.84</td>
<td>0.83</td>
<td>0.82</td>
<td>0.81</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td><strong>Cost of Potential Traffic Accidents (C)</strong></td>
<td>0.70</td>
<td>0.69</td>
<td>0.69</td>
<td>0.68</td>
<td>0.67</td>
<td>0.66</td>
<td>0.65</td>
<td>0.64</td>
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<td>0.61</td>
<td>0.61</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td><strong>Total Annual Cost (A + B + C)</strong></td>
<td>1.63</td>
<td>1.52</td>
<td>1.50</td>
<td>1.48</td>
<td>1.46</td>
<td>1.44</td>
<td>1.42</td>
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<td>1.36</td>
<td>1.34</td>
<td>1.32</td>
<td>1.30</td>
<td>1.28</td>
<td>1.26</td>
<td></td>
</tr>
</tbody>
</table>

1. Interpolated from Figure 27.
2. Based on 3 coats per lane foot.
3. Calculated from equation developed in APPENDIX C.
4. "L.1 x 10^7 x ADT x annual frequency".
5. Calculated from equation developed in APPENDIX C.
6. "L.1 x 10^7 x ADT x annual stripping frequency."
Figure 28. Annual Cost of Conventional Paint Striping for a Two-Lane Highway versus Average Annual Daily Traffic.
Figure 29. Annual Cost of Conventional Paint Striping for a Four-Lane Highway versus Average Annual Daily Traffic.
Figure 30. Annual Cost of Conventional Paint Striping for a Six-Lane Highway versus Average Annual Daily Traffic.
SUMMARY AND CONCLUSIONS

Results from the evaluation of thermoplastic stripes in Louisville and Jefferson County indicated the following:

1. Thermoplastic striping performed better on bituminous concrete pavements than on portland cement concrete pavements. White thermoplastic lines were generally better than yellow lines (particularly on portland cement concrete surfaces).

2. Appearance of the thermoplastics was rated good in most cases, even though up to 40 percent of the stripe was missing on some of the portland cement concrete sections. Slightly over 20 percent of the yellow stripes on bituminous concrete pavement were missing while slightly less than 20 percent of the white stripes were missing on both pavement types.

3. The ordering of the night visibility and weighted ratings were identical to the appearance and durability ratings. The white stripe on bituminous pavements was best. The white stripe on portland cement concrete and yellow stripe on bituminous concrete pavements were rated only slightly lower, but the yellow stripe on portland cement concrete pavements was definitely inferior.

4. There was a notable reduction in durability of stripes on curved sections of roadway and near intersections. A reduction in durability was also observed when thermoplastics were placed on rough textured surfaces.

5. For thermoplastics applied to bituminous concrete surfaces, no definite relationship was found between durability and AADT. With increasing age of bituminous concrete pavement, it was found that durability of thermoplastic stripes decreased.

6. On portland cement concrete pavements, durability was found to decrease with increased AADT and increased pavement age.

7. On bituminous concrete pavements, durability of Prismo thermoplastic stripes was better than Cataphote.

8. The life expectancy of yellow thermoplastic stripes on portland cement concrete was only 2 years. Life expectancy of white stripe on portland cement concrete and white and yellow stripes on bituminous concrete was substantially longer.

9. Annual costs (cents per linear foot (0.3 m)) of thermoplastic striping were calculated to be 4.0 for white and yellow stripes on bituminous concrete pavements and 6.4 and 10.7 for white and yellow, respectively, on portland cement concrete pavements.

10. An economic analysis of the cost of thermoplastic and paint striping revealed that thermoplastic striping was more economical for the higher volume roads. Volumes required for thermoplastic striping to be more economical than paint striping are presented in Table 5. These volumes range from 15,000 vehicles per day on a two-lane bituminous concrete pavement (white or yellow stripes) to 120,000 vehicles per day on a six-lane portland cement concrete pavement (yellow stripes).
REFERENCES


APPENDIX A

SPECIFICATIONS FOR HOT-SPRAYED THERMOPLASTIC PAVEMENT MARKING
KENTUCKY DEPARTMENT OF HIGHWAYS
SPECIAL PROVISION NO. 93-A
HOT-SPRAYED
THERMOPLASTIC PAVEMENT MARKING

This Special Provision shall be applicable only when indicated in the plans or proposal.

I. DESCRIPTION

The work required hereby shall be performed in conformity with: (1) all applicable requirements of Sections 1 through 9 of the Department's 1965 Standard Specifications for Road and Bridge Construction, (2) the requirements in the plans and/or proposal, and (3) the requirements of this Special Provision.

The work shall consist of furnishing and applying hot-sprayed thermoplastic reflectorized pavement marking materials on pavement surfaces that have been cleaned of all dirt, oil, and other foreign matter that would prevent adherence of the thermoplastic material to the pavement surface. The thermoplastic material shall be applied to provide centerlines, edgelines, and/or gore area lines as specified in the plans or proposal.

This work shall be performed on clean dry pavement surfaces, only when the temperature of the surfaces is above 40°F. The minimum thickness of the lines shall be either 60 mils or 90 mils, as specified in the plans or proposal. When edgelines are being placed on a pavement surface, an interval of 1 foot shall be skipped every 50 feet and left unmarked so that any accumulation of water on the surface during periods of rain can exit through the 1-foot skip in the edgeline.

II. MATERIALS

The thermoplastic material shall be a mixture of resins, glass spheres, and other materials, specifically compounded for traffic markings and which, when properly melted and sprayed onto the road surface, shall result in a highly reflective line of maximum durability.

The material shall not exude fumes which are toxic or injurious to persons or property when it is heated to the temperature range required for application. It shall remain stable when held for 4 hours within this temperature range, or when subjected to 4 reheatings after cooling to ambient temperatures.

The temperature-viscosity characteristics of the plastic material shall remain constant throughout repeated reheatings, and shall show like characteristics from batch to batch. There shall be no obvious change in color of the material as a result of repeated reheatings.

When applied, the resulting marking lines shall be as well defined as spray-painted lines. After application and sufficient cooling time, the material shall show no appreciable deformation or discoloration at any time at pavement surface temperatures between -10°F and +140°F.

The cooling time of the applied material shall not exceed 1 minute at pavement surface temperatures of 90°F or below. Cooling time is defined as the minimum elapsed time, after spraying, when the markings shall have and shall retain the characteristics required, and when traffic will leave no impression or imprint on the applied markings.

Glass spheres as described herein shall be uniformly applied to the surface of the newly applied markings at a minimum rate of 7 1/2 lbs. per 100 square feet of line.

III. SPECIFIC REQUIREMENTS

Color: The color of the thermoplastic lines as installed shall be white or yellow as applicable, free from dirt and all other detrimental materials, uniform in appearance, and without any light or dark deviations from the normal color.

Reflectance: The daylight luminous reflectance of the white material shall be not less than 75% when tested according to ASTM E-97. The yellow shall have a minimum brightness of 45% relative to magnesium oxide and shall be within the green and red tolerance of the color tolerance chart (June 1965) published by the Federal Highway Administration.

Color Fastness: Specimens shall consist of three 5" x 9" properly degreased and slightly acid-etched aluminum panels upon which 4" x 9" applications of the thermoplastic material have been made. The thermoplastic material on the panels shall be of the same thickness that is to be constructed on the pavement. The specimens shall be exposed for 100 hours in Type E apparatus conforming to ASTM E 42-65. After 100 hours of exposure, specimens shall show no perceptible color change when compared visually with unexposed specimens.

Softening Point: The softening point shall be no less than 90°F., when tested according to ASTM E-28.

Indentation Resistance: Hardness shall be measured by a Shore Durometer, Type A-2, as described in ASTM D-2240 except that the durometer and the panel shall be at least 25°C., and a 2 kilogram load applied. After 15 seconds, the reading shall be not less than 55.

Glass Spheres: The glass spheres shall conform to the requirements of the current issue of Special Provision No. 62, Type I Glass Beads.

Sampling and Testing: A certified test report from the manufacturer affirming that the thermoplastic material conforms to all the requirements of this Special Provision will be the basis for initial acceptance of the thermoplastic material. The Department reserves the right to sample and test the material at any time during the duration of the contract, and to reject any material not in conformance with this Special Provision.

The glass spheres will be sampled and tested in accordance with the provisions of the Standard Specifications and the current issue of Special Provision No. 62.

III. APPLICATION REQUIREMENTS

The Contractor shall acceptably clean the existing pavement surface, as approved by the Engineer, prior to beginning application of the thermoplastic material.

All marking of the specified lines with the thermoplastic material shall be performed by a spraying process using equipment of sufficient size and capability to insure smooth straight applications. The widths of all the specified lines and the striping patterns will be depicted in the
plans or proposal for the project, and the materials shall be applied at the specified widths and patterns.

All work on the project shall be performed during daylight hours.

The glass spheres shall be applied to the hot-sprayed material in a manner that will embed them in the material to at least 1/2 of their diameter.

The thicknesses of the lines will be determined from the quantity of thermoplastic material used. In addition, spot checks of the wet and dry film thicknesses will be made as deemed necessary by the Engineer.

The Contractor shall remove from the project and shall dispose of all empty material containers and any other debris resulting from the striping operations.

IV. WARRANTY

Upon completion of a project, the Contractor shall provide the Department with the normal warranty or guaranty that is given as customary trade practice by the manufacturer of the thermoplastic material.

V. ACCEPTANCE

The acceptance of a project constructed in accordance with this special provision will be deferred until 90 days after the completion of the application of the thermoplastic pavement marking material to the entire project.

Final inspection will be made to determine if the constructed markings provide satisfactory appearance both during the day and the night. Every portion of the work which is found to be unsatisfactory upon final inspection shall be replaced by the Contractor at no additional expense to the Department.

VI. MEASUREMENT AND PAYMENT

The total length of satisfactory thermoplastic pavement markings will be measured in linear feet. Payment will be made at the contract unit price per linear foot of either centerline, edgeline, or gore area line, as applicable.

Such payment shall be considered as full and complete compensation for all the work and material required to satisfactorily clean the pavement, to satisfactorily complete all the pavement markings specified in the contract, and to replace any unsatisfactory markings in accordance with this special provision and with the terms of the warranty or guaranty.

APPROVED

J. R. HARIBSON
STATE HIGHWAY ENGINEER
APPENDIX B

EVALUATION OF THERMOPLASTIC STRIPES
ON THE KENTUCKY TURNPIKE
EVALUATION OF THERMOPLASTIC STRIPES ON THE KENTUCKY TURNPIKE

Conventional beaded paint stripes are nearly ineffective on rainy nights - when they are needed most. Numerous methods to improve line visibility have been employed in the past; some are employed presently. The methods include multiple paint applications, grooving the pavement before striping, varying the types and application rates of reflective beads, use of raised pavement-markers and use of hot-melt thermoplastic striping. Most of these methods have a high initial cost which is usually justified on a basis of safety rather than economy.

The use of hot-melt thermoplastic striping materials dates back to the early 1950's. Some formulations were placed in Lexington and Frankfort in 1957 and 1958. Other and more substantial applications followed in 1962 and were reported in February 1970 (Report No. 290). All materials used in those applications were hot-extruded thermoplastic having a thickness of about 0.125 inches (3.2 mm). The first hot-melt sprayed material was used to stripe the centerlines of the Kentucky Turnpike in 1969 and the edgelines of the same pavement in 1971. The thickness of sprayed thermoplastic stripes could be easily adjusted, since it is not extruded from a die; it was approximately 0.09 inches (2.3 mm) for the Turnpike applications.

On March 7, 1975, a comprehensive survey was made of the thermoplastic stripes applied by Prismo Corporation on the Kentucky Turnpike. The results are listed in the following table:

<table>
<thead>
<tr>
<th>SOUTHBOUND</th>
<th>NORTHBOUND</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LEFT EDGELINE</td>
</tr>
<tr>
<td>Total Feet (m)</td>
<td>211,200</td>
</tr>
<tr>
<td>Applied</td>
<td>(64,374)</td>
</tr>
<tr>
<td>Equivalent Feet (m) Missing</td>
<td>4,422</td>
</tr>
<tr>
<td>Percent Missing</td>
<td>2.1</td>
</tr>
</tbody>
</table>

The centerline stripes were applied in June 1969 and surveyed in May 1971. Edgeline stripes were applied in September 1971. Strip-chart recordings of the reflectivity of edgelines indicated some deficiencies, and some corrective restriping followed thereafter. The edgelines were accepted on June 18, 1972.

The above table reveals that the extent of damage incurred on the centerline was far more extensive than that on the edgeline. It was adjudged that centerline damage could be attributed primarily to traffic, especially in the area of interchanges where wear was excessive. There was some restriping done on the centerline with both thermoplastic and paint.

Edgeline damage was adjudged to be attributed mostly to snowplow blades and not to wear or loss of adhesion. More wear was noticed in the area of superelevated curves and outside or right edgelines. This could be due to the fact that the raised median prevented traffic and snowplows from close contact with the left or inside edgelines.

There was some pitting and peeling on the remaining lines, but in general, there was good adhesion and appearance.
APPENDIX C

DERIVATION OF TRAFFIC DELAY AND ACCIDENT COST EQUATIONS
DERIVATION OF TRAFFIC DELAY AND ACCIDENT COST EQUATIONS

One benefit which should be estimated when considering use of thermoplastic stripes is the savings in traffic delay and accident costs resulting from the reduction in striping frequency. There have not been any definitive studies on this subject. The derivations of the equations, therefore, was based on various assumptions. The procedures used to develop the equations were based on an article by Chaiken [6]. Several modifications were made in the assumptions used in that study.

COST OF TRAFFIC DELAY

With the usage of quick-dry paint, the speed of paint striping has markedly increased. A rate of striping of 5 miles (8 kilometers) of stripe per hour was used. It would, therefore, take 12 minutes for each mile (1.6 km) of striping. It was also estimated that, during this time, the average speed of vehicles on a typical highway would be reduced from 55 mph (25 m/s) to 30 mph (13 m/s). This would result in a delay of 0.16 minutes for each passing vehicle for each mile (1.6 km) of striping.

Calculating the delay time in terms of linear feet (meters) of actual stripe yields a delay time of $3 \times 10^{-5}$ minutes per vehicle per linear foot (0.3 m) of stripe.

Most paint striping is done during off-peak daylight hours. Under such conditions, hourly one-directional traffic on urban sections of an interstate highway has been shown to represent 2.6 percent of the total average annual daily traffic [6]. Therefore, the total delay (in hours) for all vehicles per linear foot (0.3 m) of striping becomes $1.3 \times 10^{-6}$ x AADT.

A value of time cost in terms of dollars per vehicle-hour was given in a 1970 report as $3.50 for passenger cars and $4.47 for commercial vehicles [11]. Using the consumer price index to convert to 1975 dollars gives a cost of $4.80 for passenger cars and $6.12 for commercial vehicles. Assuming five percent of the total volume were commercial vehicles yields a cost of $4.87 per vehicle-hour. Using this cost, the total delay (in hours) was converted to $6.3 \times 10^{-5}$ x AADT cents per linear foot (0.3 m) of striping. Multiplying this figure by the annual striping frequency gives the annual delay cost.

COST OF ACCIDENT POTENTIAL

The cost of increased accident potential created by paint striping was very difficult to quantify. There have not been any studies that would relate an increase in the accident experience to striping operations. Therefore, the derivation of this equation was entirely based on theory. An increase in speed variance of individual vehicles from the average traffic speed contributes to an increased accident involvement. That is, a decreased uniformity of speeds increases the accident potential. During a paint striping operation, the speed variance would increase, resulting in an increased accident potential. The article by Chaiken [6] estimated that the involvement rate in the vicinity of a striping operation may be increased by ten times the involvement rate during normal traffic operations. This was based on a table which related involvement rate to deviation from mean speed on interstate highways [12]. Including all types of highways would reduce this number, since the maximum speed variance would be on the interstates. A factor of five was chosen for this study.

The average accident rate for the total rural highway system in Kentucky is approximately 200 accidents per 100 million vehicle miles (MVM) (161 million vehicles kilometers (MVK)) [13]. Thus, an additional involvement rate of 800 accidents per 100 MVM (161 MVK) results from paint striping. Using accident cost data from a previous report [14], a direct cost of $2,275 was calculated for the average accident (updated to 1975 costs).

As stated previously, each mile (kilometer) of the striping operation would be a problem area for 12 minutes. The volume during this period would be 0.0052 of the AADT. The potential accident costs per linear foot (0.3 m) of striping per year become $1.8 \times 10^{-5}$ x AADT x annual striping frequency.