Auburn University

IR-92-01

DETERMINING THE LONGEVITY AND SERVICE LIFE OF PAVEMENT MARKING MATERIALS

Prepared by

Brian L. Bowman, Ph.D., P.E.
Raghu R. Kowshik
Srikanth Konda

Highway Research Center
Harbert Engineering Center
Auburn University, Alabama 36849-5337

January 1992

Determining The Longevity and Service Life of Pavement Marking Materials

Final Report

Prepared by:

Brian L. Bowman, Ph.D., P.E.
Raghu R. Kowshik
Srikanth Konda
Highway Research Center
238 Harbert Engineering
Auburn University, AL 36849

Date: January 8, 1992

EXECUTIVE SUMMARY

The longevity of pavement marking material has a direct impact on the cost of maintenance and user safety. The estimated cost of marking streets and highways in the U.S. each year is approximately $475 million. This is a significant investment representing not only a large monetary effort, but also an extensive allocation of manpower and application equipment. Adequate pavement markings are, however, one of the highest payoff, lowest cost operational improvements that can be made to streets and highways. The FHWA Pavement Marking Demonstration Program of the 1970's demonstrated that improved transverse and longline pavement markings were effective in improving motorist safety. The improvement in safety was determined to be especially prevalent during nighttime and low visibility conditions when the pavement markings serve to delineate the required vehicle paths. The desirable delineation effect of pavement markings is accomplished by the principles of retroreflectivity.

Glass beads have been used to make pavement markings reflective for approximately 50 years. Glass beads, if properly embedded in a striping material, have the ability to collect incident light and reflect part of that light back to its source. The performance of the glass beads is dependent upon their embedment depth, size and environmental conditions.

During periods of adverse weather, small glass beads often become submerged in a film of water. Light from headlights bounces off this water surface and is lost. The retroreflective capabilities of beads that function well when the roadway is dry are significantly reduced during rainy or foggy conditions. One solution to the wet night visibility problem is to use larger glass beads with diameters sufficiently large to extend the bead surface above the water film. The larger beads are thereby capable of reflecting vehicle headlights thus making them more visible to the driver during

adverse weather conditions. Until recently, however, the marking materials used and the technology of the bead construction were not sufficiently advanced to provide an acceptable service life. The extended durability of new marking materials, their greater thickness and recent enhancements to the glass bead surface to improve adhesion have resulted in the ability to use larger glass beads than was possible in the past.

The purpose of this project was to determine if the new marking materials and glass bead technology have advanced sufficiently to provide a cost effective method of increasing wet night visibility. The project was conducted by synthesizing the available literature, obtaining the results of State demonstration projects and conducting a survey of State highway departments and material manufacturers.

SUMMARY OF FINDINGS

- The State of New Jersey evaluated the large glass beads manufactured by Potters Industries (VISIBEADS) and epoxy paint @ 20 mils in place of standard glass beads and standard traffic paint. Three different bead configurations were used in the evaluation: single drop, large beads only; double drop, mixture of large and standard beads; and standard beads only. The results of the photometric and visual tests revealed that the large glass beads did produce much brighter lines in wet night conditions than the standard glass beads did in both the single and dual drop applications. It was also concluded that the cost difference between large glass bead and standard beads was relatively low compared to the amount of increased wet night visibility offered by the large glass beads. The study recommended that large glass beads be used wherever the State installed epoxy pavement markings.

- The State of North Carolina investigated the visibility of eight pavement marking materials for both wet and dry conditions. Test markings were placed on three highways and their performance recorded for a period of eighteen months. Field measurements included periodic recording of retroreflectivity and percentage of missing material. An added part of this study evaluated epoxy markings with large glass beads (VISIBEADS). The lines were viewed from an automobile driven at 60 miles per hour and the greatest distance that the markings were visible was estimated from the travel time required to reach the marking after initial sighting. All evaluations were made at night under wet conditions. Visibility distances were also estimated in similar fashion for the adjacent sections of epoxy markings with regular glass beads. The larger glass beads offered improved nighttime visibility during wet conditions. In each instance the visibility distance for the VISIBEAD lines was greater by a factor of two or more than that for the adjacent standard bead lines.
- Potters Industries conducted the initial research which has resulted in the modern large bead technology. This technology tailors the bead coating and size to the type and dried thickness of the pavement marking material used. Large beads designed for use with chlorinated rubber paint pavement markings will be of a different size and possess a different exterior coating than those beads which are designed for epoxy based markings.
- Experience with large beads indicates that they become an integral part of the wearing surface and actually extend pavement marking life in high traffic areas. Since the effective service life of pavement markings is,

however, dependent upon more variables than traffic wear the planned service life of markings with large beads should be considered as equal to that of standard beads with the same marking material.

- Large beads even when worn by traffic and abraded by dirt provide greater retroflectivity values than new standard beads.
- Because the service life of large bead markings is dependent upon the life of the marking material itself, it may be more cost effective to use it with durable binders. For example, the applied cost of paint with large beads is estimated to be $0.08 per foot while the large beads with thermoplastic is $0.28 per foot. Since paint and thermoplastic, applied to asphalt, have approximate service lives of one and five years respectively, the annual cost of large beads with paint is $0.08 per foot and with thermoplastic is $0.06 per foot.
- Much of the research on large bead effectiveness and service life is based on the experience of States with climatic conditions which are drastically different from that of Alabama. This research has demonstrated that the large beads are effective in increasing retroreflectivity of pavement markings during wet-night conditions. It is not known with certainty how the high pavement temperatures and other climatic conditions indigenous to Alabama will affect the service life of markings with large beads.
- It would be advantageous for Alabama to field test large beads on rural sections of roadway that are experiencing a relatively large number of wet-night accidents. The proper selection of the test segments will enable the determination of not only the service life of large beads in

Alabama on different pavement types, but also the expected accident reduction benefits.

- A major manufacturer of large beads provides technical assistance in State testing programs provided the State purchases a truck load of the beads necessary for an extensive test. This assistance includes supervising the field application, modifying the States bead application equipment for large beads and restoring the equipment to its original configuration.

Table of Contents

1. INTRODUCTION

The longevity of pavement marking material has a direct impact on the cost of maintenance and user safety. The estimated cost of marking streets and highways in the U.S. each year is approximately $475 million. This cost consists of about $380 million for materials with the remaining $95 million expended on their application. the estimated quantity of marking materials consists of:

- 40 million gallons of traffic paint.
- 200 million pounds of glass traffic beads.
- Thousands of tons of thermoplastic materials.
- $55 million worth of other materials such as preformed tapes, raised pavement markers, polyesters, epoxies and adhesives.

This is a significant amount of material representing not only a large monetary effort, but also an extensive allocation of manpower and application equipment. Adequate pavement markings are, however, one of the highest payoff, lowest cost operational improvements that can be made to streets and highways. The FHWA Pavement Marking Demonstration Program of the 1970's demonstrated that improved transverse and longline pavement markings were effective in improving motorist safety. The improvement in safety was determined to be especially prevalent during nighttime and low visibility conditions when the pavement markings serve to delineate the required vehicle paths. The desirable delineation effect of pavement markings is accomplished by the principles of retroreflectivity.

Glass beads have been used to make pavement markings reflective for approximately 50 years. Glass beads, if properly embedded in a striping material, have the ability to collect incident light and reflect part of that light back to its source. It is this ability that makes spherical glass particles ideally suited in making pavement markings visible at night.

The performance of the glass beads is dependent upon their embedment depth, size and environmental conditions. Research conducted during the late 1960's indicated that the optimum embedment of the glass beads was 60 percent of the bead diametric. It was also noted that during periods of adverse weather, the small glass beads often became submerged in a film of water. Light from headlights bounced off this water surface and was lost. It was concluded that the retroreflective capabilities of beads that functioned well when the roadway was dry were significantly reduced during rainy or foggy conditions. In addition, the type of marking material, which serves as a binder for the beads, had different effective service lives in their ability to hold the beads in place and thus retaining their retroreflective properties.

Many changes have occurred in the pavement marking industry in the past 20 years; especially in the availability of polymeric non-shrink binders as durable striping materials. In addition to the advent of non-shrink polymeric binders, there has been the development of good water based paints with higher solids content than typical alkyd paint. Alkyd paints have also changed to comply with the requirement for short no-track time, affecting the final film thickness. The extended durability of these films, their greater thickness and recent enhancements to the glass bead surface to improve adhesion have resulted in the ability to use larger glass beads than was possible in the past.

The advantage of larger glass beads is that they break through the water film on the road surface, thereby reflecting the headlights and making the road markings more visible to the driver during adverse weather conditions. In addition, the use of large beads in conjunction with the enhanced binding properties and increased thickness of the new marking materials has the potential to provide increased effective service life.

Background

The primary purpose of this literature review is to identify recent and ongoing research into the night-time wet surface effectiveness, cost and service life of various pavement marking types. A 1952 study by Pocock and Rhodes [16] is an early effort that was referenced by many subsequent studies. The study investigated the principles of glass bead reflectorization and studied the effects of application procedures, bead gradations and refractive index of the beads on retroreflectivity. This study indicated that an advantage of using smaller beads is they provide greater reflective area per pound than large beads. The study, however, failed to consider the lower wet-night reflectivity resulting from the smaller beads being submerged by a film of water.

Dale [2], in a 1967 NCHRP report, investigated methods of improving roadway delineation under both wet and dry conditions. Emphasis was placed on the effectiveness of a silicone based surface layer. The silicone treatment resulted in a reduction in the clogging of bead-dispensing equipment as well as reducing the incidence of bead over-embedment into the pavement marking material. The study also determined that the optimum depth of bead embedment ranged from 55 to 60 percent of the bead diameter. Smaller embedment depths resulted in the premature loss of adhesion between the bead and binder while larger depths resulted in the loss of retroreflective efficiency. Glass bead sizes larger than those currently being used, were suggested as a way of overcoming the problem of loss of reflectivity during the wet pavement conditions. However, it was also pointed out that the thickness of paint film would need to be increased in order to provide the necessary binding depth for the glass beads.

In a subsequent publication [3], Dale questioned the appropriateness of bead gradation used for drop-on application. Dale concluded that the use of various bead sizes in a constant thickness of paint results in a small percentage of the beads providing efficient retroreflectivity. The rationale behind the use of a gradation of mixed sizes is that pavement marking paint gradually fails by abrasion. As the paint is worn away, smaller beads are continually being exposed thus providing sustained retroreflectivity. However, it was noted that paint often does not fail by abrasion, but instead chips away. In this case, a smaller quantity of larger-sized beads would give higher retroreflectivity at a considerable overall cost saving over that available from a larger quantity of various bead sizes. Dale also stated that recent developments in the types of pavement marking types had not resulted in changes in applied bead size.

A 1973 NCHRP synthesis study [13] evaluated various pavement marking materials and how the various methods of application affect their serviceability. Considerable attention was given to the selection of the paint-bead system. The authors discussed the difficulty in deciding the optimum bead gradation due to the wide variation in environmental conditions, application methods and control of materials. The theoretical considerations of film thickness and bead size must be adapted to the reality of stripe application and to the uncertainties of weather and of material control. In addition, the drying rate of the paint film affects the rate of bead settlement and hence their embedment depth. The results of a survey indicated that North Carolina and Ohio preferred the use of premixed beads in the paint due to the convenience of use and uniform distribution of beads in the paint film. However, 80 percent of State agencies used drop-on bead application due to the advantages of lower nozzle wear, faster drying and the decreased need for paint agitation. The survey determined that the predominant bead gradation used by the states was 30 to 80 mesh.

Holman [10], in 1971, reported on Alabama's experience during a national experimental program using traffic marking beads. Alabama used drop-on beads of gradation between U.S. Sieve #30 and #80, and premixed beads of gradations between U.S. Sieve #40 and #230. Test sections were installed at two locations in Montgomery, and monitored periodically for night visibility. It was concluded that test sections with high drop-on bead application rates had good night visibility but low durability as compared to premixed-bead sections.

A 1975 OECD Road Research report [15] summarized experience with road marking and delineation materials and devices. The report indicated conditions and factors that should be considered in the selection of appropriate materials for various circumstances. An embedment of approximately 60 percent of the bead diameter for optimum retention and reflectivity with a bead gradation of between #40 and #80 mesh (between 0.42 and 0.177 mm) were suggested.

Ohio [6] substituted Visibeads (manufactured by Potters Industries) for standard-sized glass striping beads in a large glass bead testing project over a wide range of traffic volumes, roadway geometrics, and pavement conditions. Preliminary results indicated that average reflectivities were well above the minimum acceptable levels. Joint sealing and snowplowing were identified as two major causes of reflectivity loss. It was estimated that 25 to 30% of the pavement markings were damaged by snowplowing, and another 5 to 10% by joint sealing.

Gillis [9] reported on a 1975 study by the Minnesota Department of Transportation that was conducted to evaluate epoxy, polyester, and thermoplastic resins as pavement marking materials. This project also developed a spray-on epoxy/glass bead system appropriate for both bituminous and concrete pavements. The study demonstrated that epoxy markings provide adequate delineation, for both day and night conditions, during an approximate two year period following installation. It was also found that epoxy provided better reflectivity compared to both paint and thermoplastic markings.

Fullerton [8], in the FHWA handbook on Roadway Delineation Practices, discussed delineation concepts, current practices, and introduced promising future techniques. This study reported that 85 percent of the State highway agencies used a bead gradation of #20 to #80 mesh.

McGrath [12], reporting on a Durable Pavement Marking Materials Workshop, summarized presentations on the evaluation of six durable pavement markings materials. Beads with a gradation of #20 to #80 sieve were used in thermoplastic markings which provided excellent reflectivity on asphalt after two years, but resulted in poor reflectivity on concrete due to bond failure. Preformed materials performed satisfactorily for four years, epoxy for two years, polyester for up to eight years, and epoflex performed exceptionally well even with high traffic volumes and warm climates. No specific information was given regarding traffic marking paint.

Dale [4], in an NCHRP Synthesis Report summarized pavement marking needs, different types of pavement marking materials, and various methods of preparing the pavement surface prior to marking. This study investigated two types of paints (solvent-borne and water-borne), thermoplastics, thermosets (polyester and epoxy), and marking tapes. The cost-effectiveness of the different pavement marking types is discussed and life-expectancy curves provided for marking on both bituminous and concrete pavements.

O'Brien [14] performed a laboratory investigation of the embedment characteristics of drop-on moisture-proofed and uncoated glass beads and their associated retroreflectivity in combination with various types of hot applied thermoplastic markings. He concluded that moisture-proofed drop-on beads give excellent retroflectivity. The study also concluded that the retroreflectivity of the standard bead gradation was enhanced by increasing the proportion of the larger-sized beads.

Kalchbrenner [11], in a 1989 publication described a comprehensive test of large glass beads in pavement markings conducted by Potters Industries. Demonstration projects were set-up in 25 States, encompassing seven geographical areas. A variety of binders, road types, geographical areas, pavement types, and application methods were investigated in this study. The laboratory tests concluded that the optimum bead size for good wet night reflectivity ranged from #10 to #20 mesh, depending on the binder. The field test and demonstration projects showed that larger glass beads provided significantly superior retroreflectivity compared to standard bead sizes, for a variety of binders- thin film as well as thick film. This study also suggested bead gradation specifications for single as well as dual-drop marking systems.

Hartman [19] reported on an effort by Research Derivatives to develop a more accurate technique for delivering drop-on beads to reflectorize pavement marking paint. The technique ensures that the beads and paint land together even at variable speeds, reducing bead loss.

Mendola [20] conducted a study for the New Jersey Department of Transportation to evaluate the retroreflectivity performance of Visibeads in Epoxy paint at 20 mil thickness. This study involved comparative photometric and visual tests between large glass beads in Epoxy paint and in standard beads in standard traffic paint. The tests concluded that large beads produced significantly higher retroreflectivity over standard beads and that the cost difference between large and standard beads is relatively low when compared to the increase in wet night visibility.

King and Graham [21] evaluated the visibility of eight pavement marking materials for the State of North Carolina. The study also evaluated epoxy markings reflectorized with large glass beads and concluded that the larger beads improved the wet-night visibility of the markings by a factor of two or more than that for adjacent standard bead lines.

Griffin [22] conducted a study for the Colorado Department of Highways to review the performance of pavement marking materials. This study concluded that the Visibeads manufactured by Potters Industries met the specifications of the Department, but was susceptible to bead loss due to snowplowing operations on mountain roadways.

A 1989 Better Roads Survey [23] reported on the pavement marking types preferred by highway departments and some of the problems experienced with them. This survey did report favorably on the performance of Visibeads during wet weather.

DeJaiffe [5], Schwab and Capelle [17], Bryden et al [1], Ethen and Woltman [7] and Van Gorkum [18], addressed the need for wet night delineation and different methods or instruments to measure the retroflectivity of markings. These studies did not, however, go into any detail on bead gradations for pavement markings.

<u>Project Objective and Scope</u>

The advent of new binding materials and the recognition of nighttime wet pavement retroreflectivity problems has resulted in efforts by researchers, material manufacturers, and governmental agencies to identify the most advantageous pavement marking types. This report contains the results of a literature review and state-of-the-practice survey conducted with the objectives of:

1) Determining if larger glass bead sizes are effective in increasing wet pavement rectroreflectivity.

2) Determining the combination of pavement marker/binder and glass bead types which provide the longest effective service life.

3) Developing quantitative comparisons, including cost effectiveness on the retroreflectivity levels and service lives between small bead and large bead pavement markings.

2. PAVEMENT MARKING TYPES

Prior studies have demonstrated that in addition to the durability of the binder itself, its effective service life is determined by the ability of the binder to retain the retroreflective material. Determining the most appropriate binder, therefore, requires consideration of the type of application (i.e. long line or transverse), glass bead retention ability, traffic volumes, pavement surface type, and total cost over its service life. This section of the report categorizes available information on the predominant binder types. The advantages, disadvantages and costs contained in this section were identified in a 1981 FHWA report [12] on durable pavement marking materials.

Traffic Paint

Traffic paints have been the most widely used pavement marking material since their introduction in the early 1920's. Paints are classified by drying time: instant dry (less than 30 seconds), quick-dry (30 to 120 seconds), fast-dry (two to seven minutes), and conventional (over seven minutes). Traffic paints are comprised of a paint vehicle (alkyd, modified alkyd, chlorinated rubber, or water-base), a solvent, a pigment, and glass beads. The drying time is determined by a paint's specific ingredients.

Durability

The durability of marking materials is dependent upon material composition, weather, application purpose, traffic density, and the type and condition of the application surface. If the pavement marking paint is being reapplied and the existing markings are not adhering well, or if the new paint has a solvent which acts as a paint remover, then applications over existing markings will not be successful. Bonding problems common to both Portland Cement Concrete (PCC) and asphalt are caused by surface contamination and the moisture content of the substrate. The use of water-soluble solvents and high temperatures can sometimes counteract problems related to moisture, but a paint's ability to penetrate surface dirt and oil depends on its composition and the length of time it remains wet before turning viscous. Solvents that require prolonged contact can soften the pavement surface and cause "bleeding", resulting in discoloration of the paint. Although this tendency is reduced by using fast drying paints on asphalt surfaces, adhesion can be adversely affected if solvents evaporate too rapidly and trap air between the paint and the pavement, a problem known as "bridging".

Reflectivity

Paints provide good visibility under dry conditions, but tend to be obscured by water films.

Advantages

The relatively low initial cost, well-established technology, ease of installation and readily available application equipment ensures continued widespread use of traffic paints. They provide good dry-night visibility, a choice of drying times, and are relatively safe to handle. The reduced drying time reduces labor costs and decreases traffic delays and potential accidents related to installation.

Disadvantages

Paints have the shortest life of all marking materials and offer poor wet-night visibility. Year-round delineation with one annual application is difficult to achieve in severe winter climates, particularly on high volume roadways. Paints with accelerated drying times also require more expensive striping equipment and cleaner pavement surfaces for successful adhesion and durability than their longer drying counterparts.

Range of Costs (1981 Costs)

Paint materials cost approximately $5 to $10/gallon ($1.31 to $2.63/liter) and installation costs range from $0.30 to $0.60/ft ($0.09 to $0.18/m) for a 15-mil, 4-in. (10.2 cm) line. While the cost per installed foot for traffic paint is reasonable, the apparent cost savings are often lost due to the required frequency of application.

Thermoplastics

Hot-applied thermoplastics are thick pavement marking materials consisting of a resin binder, reflective glass beads, coloring agents, and an inorganic filler. Proportioned and mixed in a factory, thermoplastics can be transported to job sites as solid slabs and blocks, or as granular powder. The performance of a thermoplastic material is affected by its particular composition. Most commercial thermoplastics today use a blend of synthetic hydrocarbon resins, although alkyds may become more widespread as the price difference decreases.

Durability

Southern States have reported an average thermoplastic service life of ten years. Some thermoplastic markings were observed to last the life of the pavement while other applications did not last one year under heavy traffic in northern climates. Thermoplastic durability is considerably better on asphalt than on concrete pavement. The most common foes to durability in northern climates are abrasion, shaving, and bond failure. Abrasion and shaving are caused principally by snow and ice removal equipment. Since these failures are not inherent in the material, the apparent solutions are to change plowing procedures or to use a thinner marking material. Bond failure, on the other hand, results from improper installation (low temperature or dirty, oily, or cold pavement) and is common on concrete. On asphalt, abrasion is related to the volume of traffic and the incidence of abrasive materials and studded tires. Poor performance of longitudinal markings is usually attributable to dirty or deteriorating pavement present at application.

Reflectivity

Thermoplastics form a relatively durable reflectorized marking. Its initial appearance is generally excellent and reflectivity is sustained throughout service life. Delineation is often good even after two winter seasons. The reflectivity of thermoplastics is generally equivalent to beaded paint, but has greater visibility during rain. The crucial factor in its effectiveness is the application rate of beads, although reflectivity can be diminished by dirt build-up and plow damage. In a study conducted by the Texas Transportation Institute, reflectivity (on skip lines, with or without primer) was excellent on asphalt after two years, but was negligible on concrete because of bond failure.

Advantages

Thermoplastics are capable of providing long lasting pavement markings with good night visibility when requirements are met for proper equipment, composition, and installation. Thermoplastics have an advantage over paints where year-round painting is not possible and where wet-night visibility is important.

Disadvantages

Thermoplastics are a poor choice for transverse lines in areas with high volumes of traffic and for longitudinal lines where turning traffic is common. Because of their thickness, thermoplastic markings are not suitable in severe winter conditions due to their susceptibility to snowplow damage. Successful performance depends on following specific application instructions very carefully.

Range of Costs (1981 Costs)

The cost of thermoplastics, using the 1979-80 contract price paid by New York DOT of $0.40/ft ($1.22/m) for a 4-inch (10.2 cm) line, is five to ten times higher than paint because of material and installation costs.

<u>Preformed Materials</u>

Preformed pavement markings are retroreflective films comprising high quality plastics, pigments, and glass beads. The beads are uniformly distributed throughout the film and form a firmly bonded layer on the surface. These materials are purchased in rolls and applied to the surface either by pressure or by the application of heat to the material.

Durability

A study conducted by the Kentucky Department of Transportation [12] reported a four-year average useful life for preformed materials, although manufacturers will guarantee only two years for inlaid and one year for overlaid markings in snowbelt regions. After two years, preformed markings in Virginia [12] had retained satisfactory appearance and had satisfactory service life at 1) several urban intersections; 2) section of an interstate highway where the tapes had been applied during resurfacing; and 3) on a highway of 25,000 AADT and a high volume of turning traffic. For evaluation purposes, the Research Council of the Virginia Department of Highways and Transportation placed transverse lines across one lane with a volume of more than 15,000 vehicles and determined that the preformed markings held up well. State officials consider three years to be a conservative estimate for preformed materials and have predicted an eight-year life for at least one area.

The durability of preformed tapes and pavement messages primarily dependent on pavement condition and the number of pieces used. Durability is poor on old and deteriorating pavements, especially concrete. Furthermore, since these materials can slide or shift, enhanced performance is obtained by minimizing the pieces of preformed tape.

Reflectivity

Preformed tapes have been rated as five or six times brighter than paint when first placed and still brighter than new paint even when worn. A Kentucky study reported that preformed materials lost their reflectivity in less than one year [12]. This contradicts comparative visual evaluations conducted in Virginia. The Virginia study determined that some brands of preformed markings which were highly reflective when new, dropped in brightness slightly as the top beads wore off, but increased again after the surface wore and the inside beads were exposed. Other brands had consistent reflectivity.

Advantages

A summary of the advantages of preformed marking materials is presented below:

- Its durability eliminates annual or semiannual maintenance even in snowbelt regions.
- Installation is simple, safe, and clean (no paint spills or tracing).
- Their appearance and initial retroreflective qualities are rated five or six times better than paint.
- Preformed tapes meet all requirements for color and conform to the "Manual on Uniform Traffic Control Devices for Streets and Highways" (MUTCD).
- Preformed tapes conform to the surface and adhere well, especially when laid on new pavements.
- They are easy to repair because pieces adhere well to each other.
- They eliminate the need for major traffic disruption during installation (transverse markings can be placed while traffic is waiting during the red signal); and
- They can often be installed using construction funds--with Federal participation--rather than maintenance funds.

Disadvantages

The major disadvantage of preformed markings appears to be loss of reflectivity, although in some brands the reflectivity seems to increase slightly after wear as the premixed beads below the surface appear. Also, under heavy turning traffic, the markings have a tendency to move. Other disadvantages noted by the Kentucky study are related to poor pavement conditions and installation practices (e.g., when a primer is required but not used). Preformed markings installed during cold weather may not adhere well.

Range of Costs (1981 Costs)

The use of preformed tapes for lane lines is too new to have produced good benefit-cost statistics. However, the latest nationwide cost figures range from $0.54 to $0.80/ft ($1.65 to $2.44/m). Virginia currently pays $0.60/ft ($1.83/m) for a 4-inch (10.2 cm) line and expects the price to continue decreasing. Based only on the cost of materials and installation, State officials have estimated that the preformed tape placed on a section of interstate highway must last approximately eight years to offset the cost of traffic paint. Although cost has been reported as a disadvantage for preformed markings, it depends on what other marking system it is being compared with and if such considerations as installation time, ease in installation, availability of application equipment, the need for priming, as well as maintenance, adhesion, distortion and skid resistance have been included.

<u>Epoxy</u>

Epoxy is a 100 percent solid, two-component, chemically-reacted system. It is both safe to handle and apply since it has no solvents to evaporate, and uses low heat. Epoxy is abrasion resistant, durable and adheres well on both asphalt as well as concrete.

Durability

Epoxy's durability has proved "Good to excellent" based on several tests in Minnesota. In one test, epoxy lasted over one year on high AADT systems as compared to conventional traffic paint (3 months or less), and was effective even five years later. At present, durability for three years has been proved on low AADT systems. Failures occur when pavement surface conditions are poor, when larger volumes of crossing or weaving traffic exists and when the requirements for application or quality control of the product have not been followed properly. Failures associated with epoxy are most likely to be one of the following:

- Chipping, whether slight, moderate, or total, is caused by surface contamination or poor temperature control and can be apparent within days.
- Color change is caused by lack of pressure control, improper mixing, or improper bead application.
- Wheel tracking results from incorrect bead application.

Reflectivity

Under low to medium AADT conditions, epoxy's retroreflectivity is excellent when new and still acceptable after three years. Although daytime delineation has been found to drop after two years, nighttime delineation was more than adequate after three northern winters. Based on actual reflectivity readings, the Minnesota DOT found that epoxy outlasted other durable marking materials.

Table 1. Service Life Comparison (in days)

AADT	Epoxy	Paint	Thermoplastic	Polyester
5,000	730 d.	365 d.	180 d.	NA
5-15,000	730 d.	180 d.	180 d.	365 d.
70,000	365 d.	90 d.	180 d.	NA

Advantages

Epoxy is safe to handle and apply, has good color and bead retention (best when placed in 15 mils), excellent retroreflectivity, good abrasion resistance and good adhesion on both asphalt and concrete. Epoxy can be applied on damp pavement, achieves instant no track and is applied like paints. In addition, epoxies:

- Provide an effective 12-month traffic delineation system (through the winter).

- Increase safety since application exposes striping crews to traffic only once instead of numerous times in the same period.

- Requires less energy and equipment to apply than paint in order to service the same number of miles.

Disadvantages

The majority of the disadvantages associated with epoxy are related to installation procedures and equipment. These disadvantages are:

- The material is unforgiving-- there is no room for sloppy, inattentive, or careless workmanship.

- Control of the pressure and volume for the pumping system is critical; with present formulation, the material's temperature control during application is also critical.

- Placement in urban, low speed situations must be protected to prevent tracking.

- Special equipment is required, although not as much as thermoplastics require.

- Placement and drying times are slow.

Range of Costs (1981 Costs)

The initial cost of epoxy is six times higher than for paint [12], although an extended service life results in favorable cost comparison. Based on a four-year projected cost study under various traffic volume situations, the Minnesota DOT found that an application of epoxy (15 mils) outlasted applications of paint, thermoplastic, and polyester materials by factors of two to eight. Application of epoxy at four to 10 mils thicknesses further justify its favorable comparison with these materials. New epoxy formulations and redesign of equipment in the future are expected to reduce costs. Although outdated, the following are recent bid prices for epoxy:

Minnesota (500,000 feet [166,667 m] applied):	$0.28/ft ($0.85/m) edge line $0.30/ft ($0.91/m) skip line
Arizona (130,000 feet [43,444m] applied):	$0.30/ft ($0.91/m) edge line

Polyester

Polyester is a thermosetting durable material consisting of two components, a resin and a catalyst. The resin resembles standard traffic paint, and the catalyst is usually an organic peroxide (methyl ethyl ketone peroxide - MEKP). MEKP must be handled with care as it can cause burns and its fumes are dangerous. Polyester has a long drying time, and can be applied over old paint.

Durability

A summary report prepared for the FHWA states that one application of polyester lines rated equally in color with painted lines after three years, although the paint had been applied three times [12]. In another study the summary states that the polyester line on a highway with 20,000 AADT appeared grayer in color than paint during the daytime but was superior at night and reached the end of its useful life after eight years. Based on experience in Ohio, the following service life can be expected when polyester is applied on good bituminous pavement:

- 3 - 4 years, center line, up to 10,000 AADT
- 1 year, center line, up to 10,000 AADT with heavy trucks and curves
- 3 - 4 years, lane line, up to 24,000 AADT

Polyester has been successful when used for center lines and lane lines and has few reported problems when applied over old paint. Currently, Ohio is not using polyester on its concrete pavements because of adhesion problems. Tests show that polyester lines applied at thicknesses of 7-1/2 mils and 15 mils are equally durable.

The biggest problem for polyester markings is abrasion. In addition, bond failures can occur if polyester is applied over an emulsion seal as well as from tracking, poor weather conditions, an oily asphalt mix, an inexperienced crew, or poor equipment. The "Swiss cheese" effect, which occurs on oily asphalt if polyester material is applied too soon after paving, can be avoided either by waiting approximately two weeks after paving is completed or by striping first with fast-dry paints.

Reflectivity

Using 15-mils wet thickness and 16 to 20 pounds of standard drop-on beads per gallon (1.9 to 2.4 kilograms per liter), polyester material provided good reflectivity in one three-year study, and provided superior reflectivity in another study for eight years. As Ohio expands its use, it continues to find that polyester provides excellent reflectivity.

Advantages

In addition to performing consistently well for more than three years, polyester material does not require more care than standard traffic paint or a minimum application temperature for the pavement. It is low in cost and can be applied over old paint.

Disadvantages

There are several disadvantages associated with the use of polyester: its poor performance on concrete, bond failures due to abrasion (related to improper application procedures), and its lengthy drying time. Also, since the correct mix ratio does not stabilize immediately, some time must be allotted for this before each striping session begins. Equipment can be troublesome, particularly the plumbing for the catalyst if an air-atomized system is used; the catalyst itself requires cautious handling and the use of protective goggles and gloves. For best results, the air temperature must be 50°F (10C), ambient, and application must wait for two weeks after paving, unless a primer is applied first.

Range of Costs (1981 Costs)

The following bid prices for polyester markings (including materials) demonstrate a cost variability [12].

	1980	1979
Center line:	$289/mi	$632/mi
Lane Line:	$266/mi	$258/mi
Channel line (8 in.):	$0.62/ft	$0.85/ft

Polyester compares with other durable materials (per foot) as follows:

	Polyester	Fast-Dry Paints	Epoxy
Edge line:	$0.12	$0.03	NA
Lane line:	$0.15	$0.04	$0.40
Center line:	$0.20	$0.05	$0.50

The Ohio DOT spent approximately $7,000 to convert an older hot-line paint striper to apply polyester; a similar one was manufactured for $8,000. It was also able to convert an existing hot-line hand striper for approximately $1,300.

Epoflex

Epoflex is an epoxy thermoplastic material consisting of a binder (60 percent solid and 40 percent liquid resins), pigment, a calcium carbonate filler, and an amount of premixed glass beads that provide continuous reflectivity as the material wears.

Durability

In field trials on both asphalt and concrete pavements in California, Colorado, Minnesota, and Texas, epoflex has provided very satisfactory durability [12]. In most cases, it is many times more durable than paints and at least twice as good under the most severe conditions in which it was tested-- 27,000 AADT with a high volume of trucks and studded tire use. Epoflex that was applied over existing paint stood up as well as that on bare pavement. The following conclusions about epoflex's service life were based on these tests:

- The service life of epoflex is equivalent to ten applications of paint on concrete and asphalt pavements in warm climates (no snowplowing), under both moderate and heavy traffic conditions.

- The service life of epoflex on asphalt is twice its life on concrete in cold climates and with moderate traffic conditions.

The FHWA contends that epoflex may become an excellent replacement for conventional traffic paints in almost any type of situation.

Reflectivity

On a commuter route in Los Angeles (42,000 AADT), epoflex demonstrated excellent bead retention and no discernible wear after two years, while similar applications of traffic paint showed very clear signs of deterioration. After a year in Minnesota, which included a severe winter, epoflex was still providing very satisfactory day and night delineation and visibility. Glass beads are dropped on during application to provide initial reflectivity while the premixed beads ensure its continuance. Specially treated beads, which are more resistant to chemicals, provide better bead retention.

Advantages

The major advantages of epoflex are its no track time (less than five seconds), lack of volatile components, low cost and simplicity of formulation. It provides an extended service life and good reflectivity on both asphalt and concrete and can be applied at temperatures down to freezing.

Disadvantages

Based on limited field experience, epoflex has three major disadvantages: its high installation temperature, its incompatibility with existing striping equipment, and the required precise timing of drop-on bead application.

Range of Costs (1981 Costs)

Epoflex is comparable to the low cost of traffic paint. Epoflex costs approximately $7/gal as compared to $4/gal for traffic paint. A 4-inch line of epoflex at 15-mils thickness costs $0.22/ft which is $0.005/ft more than paint applied at 10-mils dry. Since epoflex has twice the service life of paint in cold climates, however, it actually costs less in the long run. The cost of producing epoflex from raw materials is expected to decrease due to the simplicity of manufacture. Although the cost of converting stripers designed for paint can be significant, epoflex's service life under almost any condition is expected to rapidly amortize this cost over a short time.

3. COMPARATIVE APPLICATION COST

An inherent problem that restricted the wide spread use of large bead sizes was the relationship between the embedded bead depth and bead retention. The early pavement marking materials did not have sufficient solids to permit an acceptable drying rate while simultaneously enabling a diametric embedment rate of 60 percent. The result was that if sufficient marking material was applied to firmly hold the large bead in place then it took too long to dry. Advances in two pavement marking areas have resulted in the ability to use large bead sizes.

The first of these areas is in the pavement marking materials themselves. New materials, different application systems and enhancements to the old marking types have resulted in the ability to apply thicker layers of material. The high quantity of solids result in greater dry thickness with acceptable drying times. The second area of advancement is in the bead manufacture. Potter Industries conducted considerable research on bead technology and has devised a system of large bead size and bead coatings which are optimal for each type of binding material. The result is beads that are tailor manufactured for a particular type of pavement marking material.

Since the size and bead coating varies in accord with the type of pavement marking material used, there exists a variation in applied cost. Accompanying this variation in cost is the variation in service life due to the durability of the pavement marking material. While there have been claims that the larger bead sizes become part of the wearing surface and thus increase pavement marking life, it is generally true that pavement markings with layer beads will not last longer than pavement markings with regular bead sizes. The increased cost of large beads coupled with the limited life of paints results in paints not being a cost-efficient medium for large beads. A possible exception to this would be in areas of high precipitation that are experiencing a relatively large number of accidents attributable to poor nighttime delineation. Even in this instance, however, the agency would experience increased cost efficiency by the use of a more durable binder than paint.

Table 2 and Table 3 present the comparable costs developed by the New Jersey Department of Transportation for durable binders with different bead sizes [20].

Table 2.

COMPARATIVE ANALYSIS OF PAVEMENT MARKING SYSTEM COSTS

Marking Systems	Applied Cost $/Mile	Applied Cost $/Foot	Expected Life In Years	Annual Cost $/Mile	Annual Cost $/Foot
Epoxy: 15 Mils					
Visibead™ SD	$1,288.00	$.23	3	$408.00	$.08
Visibead™ DD	$1,088.00	$.21	3	$363.00	$.07
Standard Beads	$950.00	$.18	3	$317.00	$.06
Epoxy: 20 Mils					
Visibead™ SD	$1,357.00	$.26	3	$452.00	$.09
Visibead™ DD	$1,220.00	$.23	3	$407.00	$.08
Standard Beads	$1,082.00	$.21	3	$361.00	$.07
Thermoplastic: 60 Mils					
Visibead™ DD	$872.00	$.17	4	$218.00	$.04
Standard Beads	$702.00	$.13	4	$176.00	$.03
Thermoplastic: 90 Mils					
Visibead™ DD	$1,490.00	$.28	5	$298.00	$.06
Standard Beads	$1,320.00	$.25	5	$264.00	$.05
Polyester: 15 Mils					
Visibead™ SD	$685.00	$.13	3	$228.00	$.04
Visibead™ DD	$548.00	$.10	3	$183.00	$.04
Standard Beads	$396.00	$.08	3	$132.00	$.03

SD = Single Drop
DD = Double Drop

Notes*

Standard Beads At $0.15/pound, Visibead™ at $0.85/pound.
Visibead™ single drop = 24 lbs/gal in epoxy and polyester
Visibead™ double drop = 12 lbs/gal Visibead plus 12 lbs./gal standard beads in epoxy and polyester
Visibeads™ double drop in thermoplastic = 12 lbs./sq. ft. of Visibeads™ plus 12 lbs./sq. ft. standard beads
Standard beads = 24 lbs/gal in 15 and 20 mil epoxy
Standard beads = 18 lbs/gal in 15 mil polyester
Standard beads = 12 lbs/sq. ft. in 60 and 90 mil thermoplastic

Table 3.

(All figures as per Potters Industries)

EPOXY Striping Costs

Cost of binder per gallon	$25.00
Cost of standard beads per pound	$.15
Cost of Visibeads™ per pound	$.85
Line width in inches	4
Applied cost: std. line ($/lineal foot)	$.18

	Standard	Single	Double
Thickness of binder (mils)	15	15	15
Quantity of beads (lbs./gal.)	24	0	12
Quantity of Visibeads (lbs./gal.)	0	24	12
Service life (years)	3	3	3

	Quantity Per 1 mile	Unit price	Cost per 1 mile
STANDARD			
Binder	16.33	$25.00	$408.25
Std. beads	391.92	$.15	$58.79
Visibeads	0	$.85	$.00
TOTAL PER LINE MILE			$457.04
TOTAL PER LINEAL FOOT			*$.09*
SINGLE DROP			
Binder	16.33	$25.00	$408.25
Std. beads	0	$.15	.00
Visibeads	391.92	$.85	$333.13
TOTAL PER LINE MILE			$741.38
TOTAL PER LINEAL FOOT			*$.14*
DOUBLE DROP			
Binder	16.33	$.25	$408.25
Std. beads	195.96	$.15	$29.39
Visibeads	195.96	$.85	$166.57
TOTAL PER LINE MILE			$ 604.21
TOTAL PER LINEAL FOOT			*$.11*

(Typical Lab. Equip. & Proc. costs = $483.00/mile)

	Application Cost		Annual Cost	
	Per Mile	Per foot	Per mile	Per foot
Standard	$950.40	$.18	$316.80	$.60
Single Drop	$1,224.74	$.23	$408.25	$.08
Double drop	$1,087.57	$.21	$362.52	$.07

(Based on 3 year service life)

4. STATE OF THE ART SURVEY SUMMARY

A review of the literature indicates that considerable effort has been expended in determining which type of pavement marking material has the most cost effective service life. As expected, this service life is dependent upon the application procedures, material components, surface type, traffic intensity and environmental conditions. While some of the studies addressed larger bead sizes for increasing wet night retroflectivity specific information about the performance of particular bead size and pavement marking material combinations was scarce. A recent study conducted by SASHTO, portions of which are contained in appendix B, obtained information on cost, pavement marking type and bead application rates. The survey did not, however, obtain information on the service life and associated life cycle costs of various combinations of bead size and pavement marking types.

A survey was conducted as part of this project to determine the experience of southern States in the use of different glass bead sizes in various types of pavement marking materials. Emphasis was placed on the use of large bead sizes. The survey was mailed to southern State highway agencies, agencies known to have conducted large bead research through the literature review and paint and bead manufacturers. A sample of the survey instrument is presented as appendix C and summarized below.

<u>What types of marking materials has your agency used, at least on an experimental basis?</u>

Material	% of Agencies Employing It
Paint	100
Thermoplastics	80
Preformed markings	80
Epoxy	90
Polyester	40
Epoflex	50

Paint

Thirty percent of the agencies that used paint used both water-based and alkyd-based paints; 30% used alkyd based paints only, while 40% did not specify the type of paint. Eighty percent of the responding agencies employed paints for both long-line and transverse markings; 10% used paint only for transverse markings, while 10% used paints only for long-lines on both asphalt as well as concrete pavements.

Thermoplastics

Eighty percent of the agencies used thermoplastics at least on an experimental basis. Forty percent used thermoplastics for both long-line and transverse markings, 30% on asphalt pavements alone and 10% on an experimental basis alone.

Preformed Material

Eighty percent of the responding agencies used preformed material on both asphalt and concrete pavements. Seventy percent used preformed material for both long-line and transverse markings, and the remaining 10% used preformed material only for transverse markings.

Epoxy

Ninety percent of the responding agencies employed epoxy markings on their roadways. Seventy percent used it for long-line and transverse markings, 10% used it on concrete pavements alone, and 10% used epoxy for long-lines on asphalt pavements alone.

Polyester

Forty percent of the responding agencies used polyester for pavement markings. Ten percent used it for long-line and transverse markings on both asphalt as well as concrete, 10% only for long-lines on both asphalt as well as concrete and the remaining 20% used polyester for long-lines on asphalt alone.

Epoflex

Fifty percent of the responses indicated usage of epoflex. Ten percent of the agencies applied epoflex for long-line and transverse markings on both asphalt as well as concrete, 20% for long-lines on both asphalt and concrete, and the remaining 10% for long-line and transverse markings on asphalt alone.

<u>What types of pavement marking material and reapplication schedule is currently used by your agency?</u>

Paint

All of the agencies reported use of paint as a marking material. Of these, 20% used water-based paints with a reapplication schedule ranging from six to 12 months. Seventy percent did not specify the paint base used. They had a reapplication every 12 months for long-lines on asphalt, six to 48 months for transverse markings on asphalt, six to 12 months for long-lines on concrete, and six to 48 months for transverse markings on concrete. Ten percent of the agencies used alkyd-based paint with a reapplication schedule of six months for long-line and transverse markings on both asphalt and concrete pavements.

Thermoplastics

Thermoplastics were used by ten percent of the agencies for long-line and transverse markings on both asphalt as well as concrete with a reapplication every three years. A further ten percent used thermoplastics for long-lines on both asphalt and concrete with reapplication once a year, while ten percent used thermoplastics for long-lines on asphalt with reapplication every five years, and for transverse markings on asphalt with reapplication every three to four years. Twenty percent of the agencies reported use of thermoplastics, ten percent without specifying a reapplication schedule and ten percent having let out the maintenance to contract.

Preformed Materials

Thirty percent of the agencies responding used preformed materials for long-lines and transverse markings on both asphalt and concrete pavements with reapplication every two t five years, ten percent of the agencies used preformed materials for transverse markings on both asphalt and concrete with reapplication every three years, and 20% used preformed markings for long-lines on asphalt and concrete with reapplication every two to eight years on asphalt and one to five years on concrete. A further ten percent used preformed materials for long-line and transverse markings on concrete but let out the maintenance to contract.

Epoxy

Fifty percent of the agencies responding used epoxy for long-line and transverse markings on both asphalt and concrete with reapplication every two to five years, 20% used epoxy for long-lines on asphalt and concrete with reapplication every two to four years, and ten percent used epoxy for long-lines on asphalt reapplying every two and a half years. Ten percent of the agencies employed epoxy on new construction projects.

Polyester

Ten percent of the agencies used polyester for long-lines on both asphalt and concrete with a reapplication every two years. The remaining 30% applied polyester for long-lines on asphalt with reapplication every 6 months to two years.

Epoflex

Half of the agencies that used epoflex, 30% used epoflex for long-lines on asphalt with the prevalent conclusion that the material was unsuitable for pavement marking. The remaining 20% either did not indicate the type/area of use or reported that the maintenance of the markings was let out to contract.

Please indicate any special problems that have been encountered by your agency in the use of different marking materials.

Paint

Seventy percent of the agencies reported encountering problems with paint. Thirty percent noted that paints had a poor service life, ten percent reported the unavailability of large quantities of chlorinated rubber, ten percent said that the slow drying of paints led to damage claims, while ten percent indicated that the paint markings faded when use for long-lines on asphalt pavements. A further ten percent indicated that paints performed as expected with only localized problems occurring.

Thermoplastics

Fifty percent of the responding agencies reported problems with thermoplastic markings. Ten percent reported adhesion problems with long-line and transverse markings on both asphalt as well as concrete. This problem was attributed to the pavement condition and method of application. Snow plow damage to long-line and transverse markings on asphalt as well as poor adhesion for long-lines on concrete pavements were reported as problems by ten percent of the agencies. Ten percent reported bond failure of long-lines on asphalt due to snow plowing while another ten percent reported cracks in long-lines on asphalt and bond failure of transverse markings on concrete due to snow plowing. A final ten percent indicated that thermoplastics had a poor service life on concrete pavements.

Preformed Materials

A large portion, 70%, of the responding agencies encountered problems with the use of preformed materials as pavement markings. Ten percent reported problems with adhesion and shifting of long-lines and transverse markings on both asphalt and concrete pavements, ten percent reported shifting of long-lines and another ten percent reported shifting of transverse markings on asphalt. Ten percent of the agencies indicated encountering retention problems and snow plow damage to markings placed on concrete. Another 20% reported loss of retroreflectivity on both asphalt and concrete, with a final ten percent reporting peeling and adhesion problems at crosswalks.

Epoxy

Seventy percent of the responding agencies reported encountering problems with the use of epoxy as a pavement marking material. The majority of these were concerned with discoloration, yellowing or graying, of the white epoxy markings. Thirty percent reported a yellowing/graying of long-lines on asphalt, ten percent noted graying of long-line and transverse markings on concrete, while another ten percent reported fading and discoloration of long-lines on concrete. dead spots (sunken beads) were reported by ten percent of the agencies. This problem was remedied by using larger beads, but this in turn led to mixing problems. A final ten percent of the agencies reported some early adhesion problems on both asphalt as well as concrete, but were generally satisfied with the performance of epoxy as a marking material.

Polyester

Half of the agencies employing polyester reported problems with its use. The long drying time of long-lines on asphalt and concrete and the short service life of long-lines on asphalt were the two principal problems encountered with the use of polyester.

Epoflex

Forty percent of the agencies reported adhesion problems and a short service life of epoflex. Of these, ten percent reported adhesion inadequacies of long-line and transverse markings on both asphalt and concrete, and another ten percent reported total failure within one year of long-lines on asphalt and concrete. A final 20%

indicated adhesion problems and a poor service life of epoflex of long-lines on asphalt.

What size glass beads does your agency predominantly use?

Bead sizes predominantly used range from U.S. sieve #20 to #200. Only ten percent of the responding agencies reported a predominant usage of large glass beads. A typical bead gradation is given below:

U.S. Sieve	% Percent Passing
#20	100
#30	75-100
#50	15-40
#100	1-10
#200	0-2

What is the type of application (drop-on or premix) and application rate of beads employed?

The predominant application rate of drop-on, standard sized beads reported was 6 pounds/gallon of paint and 20-25 pounds/gallon of epoxy. Ten percent of the agencies reported a drop-on bead application rate for Visibeads of 22 pounds/gallon of paint, and a mix of 12 pounds of standard beads and 15 pounds of Visibeads/gallon of epoxy using drop-on application.

Is any specific bead treatment used?

Specific bead treatments for moisture proofing and adhesion were reported by forty percent of the agencies. Twenty percent employed moisture proofing treatments, ten percent used adhesion coatings for beads in epoxy and flotation beads in thermoplastics. A final ten percent applied a saline coating for paint beads.

Indicate if your agency has tried any large glass beads, the type of marking material and the performance.

All the responding agencies had experience with the use of large glass beads, at least on an experimental basis. Ten percent used glass beads of sizes 16-50 at an application rate of 12 pounds/100 sq.ft. of 120 mil thick thermoplastic. The remaining 90% of the agencies employed large glass beads of sizes 12-50 on Epoxy at 15-20 mil thickness. Ninety percent of the agencies found the retroreflectivity level of the large glass beads to be satisfactory, and the remaining ten percent were still evaluating it.

What do you consider as being the most effective combination of marking material and glass bead size for the following?

Eighty percent of the responding agencies provided information on marking material and glass bead combination. epoxy markings were used by forty percent for long-lines and by 30% for transverse markings in urban and rural areas. Thermoplastics were used by 30% for long-lines and for transverse markings, by 20% in urban areas. The glass beads mainly employed for epoxy were Visibeads of sizes 14-20, a mixture of standard and large beads for thermoplastics while standard sized beads were used with paints.

5. SUMMARY OF FINDINGS

The results of the literature review, the state-of-the practice survey and contacts with pavement marking experts are summarized below.

- The State of New Jersey evaluated the large glass beads manufactured by Potters Industries (VISIBEADS) and epoxy paint @ 20 mils in place of standard glass beads and standard traffic paint [20]. Three different bead configurations were used in the evaluation: single drop, large beads only; double drop, mixture of large and standard beads; and standard beads only. The results of the photometric and visual tests revealed that the large glass beads did produce much brighter lines in wet night conditions than the standard glass beads did in both the single and dual drop applications. It was also concluded that the cost difference between large glass bead and standard beads was relatively low compared to the amount of increased wet night visibility offered by the large glass beads. The study recommended that large glass beads be used wherever the State installed epoxy pavement markings.
- The State of North Carolina investigated the visibility of eight pavement marking materials for both wet and dry conditions [21]. Test markings were placed on three highways and their performance recorded for a period of eighteen months. Field measurements included periodic recording of retroreflectivity and percentage of missing material. An added part of this study evaluated epoxy markings with large glass beads (VISIBEADS). The lines were viewed from an automobile driven at 60 miles per hour and the greatest distance that the markings were visible was estimated from the travel time required to reach the marking after initial sighting. All evaluations were made at night under wet

conditions. Visibility distances were also estimated in similar fashion for the adjacent sections of epoxy markings with regular glass beads. The larger glass beads offered improved nighttime visibility during wet conditions. In each instance the visibility distance for the VISIBEAD lines was greater by a factor of two or more than that for the adjacent standard bead lines.

- Potters Industries conducted the initial research which has resulted in the modern large bead technology. This technology tailors the bead coating and size to the type and dried thickness of the pavement marking material used. Large beads designed for use with chlorinated rubber paint pavement markings will be of a different size and possess a different exterior coating than those beads which are designed for epoxy based markings.
- Experience with large beads indicates that they become an integral part of the wearing surface and actually extend pavement marking life in high traffic areas. Since the effective service life of pavement markings is, however, dependent upon more variables than traffic wear the planned service life of markings with large beads should be considered as equal to that of standard beads with the same marking material.
- Large beads even when worn by traffic and abraded by dirt provide greater retroflectivity values than new standard beads.
- Because the service life of large bead markings is dependent upon the life of the marking material itself, it is more cost effective to use it with durable binders. For example, the applied cost of paint with large beads is estimated to be $0.08 per foot while the large beads with thermoplastic is $0.28 per foot. Since paint and thermoplastic have approximate

service lives of one and five years respectively, the annual cost of large beads with paint is $0.08 per foot and with thermoplastic is $0.06 per foot.

6. RECOMMENDED FUTURE RESEARCH

- Much of the research on large bead effectiveness and service life is based on the experience of States with climatic conditions which are drastically different from that of Alabama. This research has demonstrated that the large beads are effective in increasing retroreflectivity of pavement markings during wet-night conditions. It is not known with certainty how the high pavement temperatures and other climatic conditions indigenous to Alabama will affect the service life of markings with large beads.
- It would be advantageous for Alabama to field test large beads on rural sections of roadway that are experiencing a relatively large number of wet-night accidents. The proper selection of the test segments will enable the determination of not only the service life of large beads in Alabama on different pavement types, but also the expected accident reduction benefits. The literature review did not identify any studies which attempted to quantify the accident benefits of large bead application.
- A major manufacturer of large beads provides technical assistance in State testing programs provided the State purchases a truck load of the beads necessary for an extensive test. This assistance includes supervising the field application, modifying the States bead application equipment for large beads and restoring the equipment to its original configuration. The only cost incurred by the State would be that incurred for selecting and evaluating the test segments and the incremental difference between the purchase price of a truck load of large and standard bead sizes. Considering a truck load to be 44,000 pounds, the

price difference between a load of large beads (@ $0.60/lb) and that of standard beads ($0.184/lb) would be $18,304.00. This quantity of large beads would be sufficient for approximately 230 miles two-way of long and skip line application for an incremental cost increase of $0.15 per foot over standard bead application. The prevention of one fatality or 1.4 personal injuries over that 230 mile segment would make the installation of large beads a cost effective countermeasure.

REFERENCES

1. Bryden, J.E., et al., "Reflectivity and Durability of Epoxy Pavement Markings," Transportation Research Record 1086, Transportation Research Board, Washington, D.C., 1986.

2. Dale, John M., "Development of Improved Pavement Marking Material - Laboratory Phase," John M. Dale, NCHRP #45, Highway Research Board, 1967.

3. Dale, John M., "Traffic Marking Beads - Are the Gradations Right?", John M. Dale, Better Roads, Park Ridge, IL., Vol. 39, No. 1, January 1969.

4. Dale, John M., "Pavement Markings: Materials and Application for Extended Service Life," NCHRP Synthesis of Highway Practice #138, TRB, Washington, D.C., June 1988.

5. DeJaiffe, Robert, "Measuring Wet-Night Delineation Reflectivity," Transportation Research Record 1149, Transportation Research Board, Washington, D.C., 1987.

6. DePaulo, Donald, C., "Ohio Tests Large Glass Striping Beads," Better Roads, Park Ridge, IL., Vol. 60, No. 4, April 1990.

7. Ethen, J.L., and Woltman, H.L., "Minimum Retroreflectance for Night Time Visibility of Pavement Markings," Transportation Research Record 1093, Transportation Research Board, Washington, D.C., 1986.

8. Fullerton, I.J., Roadway Delineation Practices Handbook, FHWA-IP-81-5, Federal Highway Administration, Washington, D.C., 1981.

9. Gillis, Henry J., "Durable Pavement Marking Materials," Transportation Research Record 762, Transportation Research Board, Washington, D.C., 1980.

10. Holman, F.L., "Glass Beads for Traffic Marking Paint," Alabama Highway Research, HPR Report #55, Alabama Highway Research, July 1971.

11. Kalchbrenner, James, "Large Glass Beads for Pavement Markings," Transportation Research Record 1230, Transportation Research Board, Washington, D.C., 1989.

12. McGrath, Marcia, A., Durable Pavement Marking Materials Workshop, FHWA-TS-81-221, Federal Highway Administration, Washington, D.C., 1981.

13. "Pavement Traffic Marking: Materials and Application Affecting Serviceability," NCHRP Synthesis of Highway Practice 17, Highway Research Board, Washington, D.C., 1973.

14. O'Brien, Jim, "Embedment and Retroreflectivity of Drop-On Glass Spheres in Thermoplastic Markings," Transportation Research Record 1230, Transportation Research Board, Washington, D.C., 1989.

15. "Road Marking and Delineation," OECD Road Research Group Report, February 1975.

16. Pocock, B.W., and Rhodes, C.D., "Principles of Glass Bead Reflectorization," Highway Research Bulletin #57, Highway Research Board, Washington, D.C., 1952.

17. Schwab, Richard N. and Capella, Donald G., "Is Delineation Needed?", Public Roads, Washington, D.C., Vol. 43, No. 3, December 1979.

18. Van Gorkum, F., "Night-Time Visibility of Seven Road-Marking Materials," Traffic Engineering and Control, London, UK, Vol 25, No. 4, April 1984.

19. Hartman, W.H., "How to Match Striping Paint and Beads", Better Roads, Park Ridge, IL., Vol. 61, No. 1, January 1991.

20. Mendola, A.A., "Comparative Study of the Performance and Cost Effectiveness of Large Glass Beads and NJDOT Standard Glass Beads in Epoxy Traffic Paint", New Jersey Department of Transportation, Final Report, September 1990.

21. King, L. Ellis and Graham, Johnny R., "Evaluation of Pavement Marking Materials for Wet Night Conditions", FHWA/NC/89-003, Department of Civil Engineering, The University of North Carolina at Charlotte, October 1989.

22. Griffin, Richard G., "Pavement Marking Materials", Report No. CDOH-DTD-R-90-4, Colorado Department of Highways, July 1990.

23. "Striping and Marking: What Works Best", Better Roads, Park Ridge, IL., Vol. 59, No. 4, December 1989.

APPENDIX A

APPENDIX A - ANNOTATED BIBLIOGRAPHY

1. **Bryden, James E., et al., "Reflectivity and Durability of Epoxy Pavement Markings", Transportation Research Record 1086, Transportation Research Board, Washington, D.C., 1986.**

Epoxy pavement markings in New York were surveyed to determine their durability and reflectivity after up to six years of service. Study sites were identified by searching NYS DOT records to identify locations where epoxy markings were applied. Sixteen projects were identified, involving four contractors and three suppliers. A total of 145 samples were taken at these projects. Durability was rated as "good", "fair", or "poor" based on a subjective evaluation. Reflectivity was measured with a reflectometer patterned after one built by the Michigan Department of State Highways and Transportation. The instrument is equipped with a photocell and an internal light source and can provide a digital readout from examining a few inches of line.

Most projects appeared to be in good condition, however, some were performing poorly. No trends relating performance to the striping contractor or supplier were identified. More samples will be needed to identify the causes of the marking failures.

2. **Dale, John M., "Development of Improved Pavement Marking Material - Laboratory Phase", NCHRP #45, Highway Research Board, Washington, D.C., 1967.**

The objective of this project was to study ways of improving delineation of roadways under wet and dry conditions by either improving techniques that use existing materials or developing new materials and techniques. The material presented regarding glass bead use in pavement markings is summarized below.

Physical Nature of Glass Beads. The effectiveness of glass beads is greatly reduced by their hydroscopic nature. This property leads to problems with clogging of bead-dispensing apparatus as well as over-embedment of beads into the pavement markings. A solution to this problem was silicone treatment of glass beads. Experiments were conducted to determine the duration of effectiveness of the treatment in the actual roadway environment.

Gradation of Beads. Typical gradation specifications for drop-on glass beads are presented, both for paint as well as for thermoplastic. Specifications for premixed glass beads call for a mixed gradation of beads of a smaller size than are called for in the drop-on application.

Retroreflective Characteristics of Glass Beads. Retroreflection is a function of bead embedment, binder orientation with the light source, mixed bead sizes in a constant-thickness binder, refractive index and shape. As well, the retroreflection is also a function of the thickness of water film submerging the beads. Experiments were performed to illustrate the above variables' effects on retroreflection.

Interpretation of Results. The optimum depth bead embedment for maximum retroreflection was found to range from 55 to 60 percent of the vertical height of the bead. Beads embedded to less than half of their vertical height in ordinary binders have insufficient mechanical embedment to prevent them from being dislodged under traffic.

Currently, the gradation being employed is that passing a No. 30 sieve and retained on a No. 50 sieve, giving an average diameter of approximately 17 mils. Paint application film thickness at the time of this study ranged from 16 to 20 mils. It was suggested that the use of larger bead sizes could counteract the submerging effect of water films on wet days. However, the use of larger beads necessitates that the film thickness of wet paint be correspondingly increased. Application thickness of thermoplastic marking materials at approximately 125 mils provides the opportunity to use larger bead sizes.

3. **Dale, John M., "Traffic Marking Beads - Are the Gradations Right?", Better Roads, Park Ridge, IL, Vol. 39, No. 1, January, 1969.**

The gradation specifications for glass beads used in reflectorizing traffic-marking materials are in large measure the gradations obtained in the bead-manufacturing processes and have an interesting, but not fully appreciated relationship to their performance requirements. This paper examines the relationship above and gives a description of previous literature related to this topic and provides some interpretation of the work. This paper considers 'drop-on' beads exclusively with the following findings.

(1) With the majority of the glass beads submerged in the paint, the predominant thought is that traffic marking paint fails by abrasion, and sooner or later all of the glass beads will become exposed and active. In actuality, this occurs only in very exceptional circumstances.

(2) Glass-bead gradations have remained almost unchanged since the 1940's. However, there has been great change in paints since then. since the performance of glass beads is necessarily linked to the performance of the paint or binder, a change in the type of paint and its performance should imply a change in bead gradations.

(3) There is variation in the method of application of the drop-on beads, although similar bead-gradations exist between states-- one state drops beads onto a wet-paint film thickness of 0.015 inches, while another drops beads onto a wet-paint film thickness of 0.020 inches.

(4) Bead gradations used are based on the fact that paint fails by abrasion. Yet large amounts of traffic paints are known to fail by chipping and flaking away. The ASTM has in fact developed a standard method entitled "Evaluating Degree of Resistance of Traffic Paint to Chipping" (D913-51).

(5) On all but the smoothest textured pavements surfaces, the paint and beads on the uppermost protruding pieces of aggregate experience wear, whereas the bulk of the markings and beads lie in the valleys between the large pieces of aggregate. Here they are never exposed to wear.

(6) To keep it simple, most authorities apply the same paint at the same thickness to city streets, curbs, gore areas, expressways, etc. To keep it simple, they also apply the same bead gradation at all these locations. How efficient and how economical this proves to be is another question.

(7) It was seen that the use of a gradation of mixed sizes in a constant thickness of paint results in only a very small percentage of the beads operating efficiently on application. If the material does not fail by abrasion, a lesser quantity of properly sized beads, though more costly per unit of weight, would give more retroreflection at a considerable overall cost savings.

4. Dale, John M., "Pavement Markings: Materials and Application for Extended Service Life", <u>NCHRP Synthesis of Highway Practice #138</u>, Transportation Research Board, Washington, D.C., June 1988.

This report describes the need for markings, preparation of the pavement surface, and the various types of paint, thermoplastics, and raised markers in current use. The material relevant to the use of glass beads in various types of pavement markings-- paints, thermoplastics, thermosets, and tapes is discussed below.

<u>Solvent Boner Paint</u>. This paint contains approximately 25% by volume

of pigment, extender, and filler. As well, 25% binder and 50% solvent are added. The favored pigments are titanium dioxide for white and lead chromate for the yellow paints. The binder portion of paint is actually a combination of as many as 10 ingredients.

Water-Borne Paint. California has developed a performance specification for water-borne paint. Water proof glass beads are used in this paint. California has concluded that water-borne paints (1) are proven alternatives to solvent-borne paints, (2) may be applied hot or cold depending on equipment and weather conditions, (3) provide service life equal to or better than solvent-borne paints, and (4) provide bead retention superior to solvent-borne paints.

Bead Gradations for Drop-on Application:

Sieve		Openings	%Passing
Std.	Alt	(in.)	by Weight
600 µm	30	0.0234	100
250 µm	60	0.0098	40-70
180 µm	80	0.0070	15-35
106 µm	140	0.0041	0-5

Beads < 106 µm size are normally used as premix materials. However, some studies have questioned the gradation of the beads used.

Thermoplastics. Thermoplastic marking materials are a mixture of resins, glass beads, pigments, and fillers. A typical composition is as follows:

Materials	% by Weight
Resin	18
Glass Beads	25
Pigment & Filler	57

Thermoplastic marking costs on the order of five to six times more than paint. However, thermoplastic marking applied at 60 to 120 mils (1.5-3 mm) in thickness project more easily through submerging water films and drain water more rapidly than thin film markings such as paint. Epoflex, a thermoplastic epoxy marking material developed in the last 1970's, is a faster-setting, durable, low profile marking material having the following formulation:

	Parts by Weight	
Material	Yellow	White
Solid epoxy resin	30	30
Liquid epoxy resin	20	20
Titanium Oxide(ASTM D476 Type II)	---	10
Lead Chromate	9.3	---
$CaCO_3$ (ASTMD 1199)	10	10
Premix Beads (ASTM 2205 Type I)	14	14

Drop-on, gradation-type traffic-marking beads are gravity dispensed onto the top of the molten epoflex immediately behind the spray gun, where they embed themselves to just below their horizontal axis.

Thermosets. Thermosetting materials have two different components that are brought together and a chemical reaction takes place that liberates heat.

The two types of thermosetting materials considered here are polyester and epoxy.

Polyester. Much of the original development and testing of polyester materials was done by the Ohio DOT and the Glidden Company during the 1970's. Polyester pavement-marking materials are applied at a wet film thickness of approximately 0.4 mm and, because they contain no solvent, the hardened line retains its thickness. Glass beads of the type applied to conventional traffic paint at loadings of 12 lb/gal are applied to the polyester materials.

Epoxy. Much of the developmental work on two-component, thermosetting epoxy pavement-marking materials was done by Minnesota DOT and the H.B. Fuller Company during the 1970's. The epoxy marking materials are applied to Portland Cement Concrete and asphaltic concrete pavements with success.

Tapes. Tapes are fabricated as roll-sheet stock or cut-out legends in a factory. They are primarily manufactured using polyvinyl chloride resin binders that are complemented in formulations with pigment, filler, and glass beads, used both in the premix and surface embedded forms. There are two types of marking materials with the following specifications:

	Type I	Type II
Thickness	90 mil	60 mil
Composition (% by weight)		
Resins	40	20
Pigments & Filler	38	30
Glass Spheres	14	33

Cost Effectiveness. With the exception of two-component internally mixed epoxy marking materials, almost all other pavement marking materials have been observed to fail more rapidly on PCC pavements than on asphaltic-concrete pavements. The primary reason for this is the loss of adhesion.

5. **DeJaiffe, Robert, "Measuring Wet-Night Delineation Reflectivity", Transportation Research Record 1149, Transportation Research Board, Washington, D.C., 1987.**

Approximately 54 percent of fatal crashes occur at night; 14 percent occur when the road is wet. Pavement markings can lose their reflectivity, and visibility on dark rainy nights, when drivers actively look to them for guidance. Much research has been devoted to the issue of wet-night visibility. Potter's Industries Inc. (377 Route 17, Hasbrouck Heights, NJ, 07604) has been involved in numerous efforts to demonstrate the wet-night visibility effectiveness of various striping systems, particularly those using large glass beads. Rain, fog, and darkness can obscure vital visual communication from the road. Reflectorized pavement markings provide drivers with information about the roadway. Accurate measurement of reflectivity to obtain quantitative comparisons for research purposes is a problem. This paper describes two methods that have been used and the ways in which their deficiencies led to the development of a laser-illuminated retroreflectometer.

The two methods described are the Boppard System and Wood Research Center. The Boppard System uses luxmeter and telephotometer to measure reflectivity in artificially generated rain while the Wood Research Center uses a telephotomultiplier that can be adjusted to simulate the driver's visual perspective. However, quantitative and reproducible field measurements are not obtained. The laser reflectometer is able to measure retroreflectivity in real world tests and it can reject ambient light, reads luminance from the target ares, and can be used in adverse environmental conditions. The need for both wet reflective systems and methods for measuring their performance has been noted in the report "Visual Aspects of Road Markings," from the Commission International De L'Eclairage.

6. **DePaulo, Donald, C., "Ohio Tests Large Glass Striping Beads", Better Roads, Park Ridge, IL, Vol. 60, No. 4, April 1990.**

The Ohio Turnpike Commission, recognizing the fact that wet weather reflectivity at night is a serious problem, substituted standard-sized glass striping beads with Visibeads, made by Potters Industries, along the highway. Potters' Visibeads are three to four times larger than standard glass beads and are treated with a specialized coating to improve the embedment and adherence. Interviews conducted with the motoring public on a rainy night shortly after the project's completion yielded extremely favorable comments. The comparative cost for Visibeads was approximately 400% more per pound than that of the standard glass beads.

Polyester paint was used in the striping project, and the anticipated service life was two years. Sixteen test areas were established and readings taken every four months. The test areas represent a wide range of volumes and roadway geometrics, as well as pavement conditions. Nine readings were taken of both the white and yellow line at each location with a Mirolux Reflectometer. At the time this report was written, only four sets of data had been obtained, but all average reflectivities were above the acceptable level. In an 11 month period, the average reflectance decreased from 280 milli-candelas per square meter to 205 milli-candelas per square meter, with well over half of this drop occurring within the first three months following installation. There was more loss of reflectivity in areas of higher traffic volumes and in areas which were recently resurfaced, there was less loss of reflectivity than in areas which were in need of resurfacing.

The two major causes to which the loss of reflectivity are attributed are joint sealing and snowplowing. The author estimated that 25 to 80% of the pavement markings along the length of the turnpike had been damaged and the level of reflectance lowered because of plow damage, with perhaps 5 to 10% of the markings being damaged by joint sealing. With regard to the 40% of the area in which the reflectance level has been reduced, the line was still there and remained much more visible than a fast-dry paint line with standard beads would have been under similar conditions.

7. **Ethen, J.L., and Woltman, H.L., "Minimum Retroreflectance for Night Time Visibility of Pavement Markings", Transportation Research Record 1093, Transportation Research Board, Washington, D.C. 1986.**

Many studies have addressed questions related to pavement markings; few, however, have dealt with the subject of minimum and generally acceptable retroreflectance values for night-time visibility. Three studies that dealt with this subject were found, and they agreed closely on minimum and acceptable values, that is 100 and 300 mcd/m^2/1x respectively. Minimum retroreflectance depends on the retroreflective quality of the painted line, the quality of headlamp illuminance, the contrast between the line and the immediately adjacent road surface, and the presence or absence of roadway lighting. This paper describes an experiment using markings with a broad range of retroreflectance on a level tangent roadway of weathered asphaltic concrete. A subjective rating system was employed, and the results correlated well with those of other studies. The values of minimum and acceptable retroreflectance may be useful in establishing acceptance and service criteria for pavement markings.

8. **I.J. Fullerton, Roadway Delineation Practices Handbook, FHWA-IP-81-5, Federal Highway Administration, Washington, D.C., 1981.**

This handbook provides fundamental concepts of delineation, current practices, and promising new techniques of the future. The handbook was developed using the experience of state, county and city agencies and also summarizes future directions and developments as reported by research. The report states that the amount of light reflected by glass beads is a function of three factors: refractive index; bead shape, size and surface characteristics; and the number of beads present and exposed to light rays.

Refractive Index. Commonly, beads used in traffic paint have an RI of 1.50. There are some 1.65 beads used in thermoplastic and 1.90 beads used for airport markings. Each RI bead has a different density; the higher the RI the higher the density. However, despite the increased brightness gained with the higher RI, most state and local highway agencies use 1.50 RI beads. Some do use a mixture of 1.50 and 1.65 beads on highways, and a few supplement the 1.50 beads with 1.90 RI beads.

Bead Size or Gradation. The standard gradation range used by 85% of the State highway agencies is 20 to 80 mesh. Some evidence suggests that uniform, smaller-sized beads (40 to 80 mesh) produce a brighter, more durable marking. However, this is not true under wet-pavement conditions.

Flotation Beads. These are preferred by a number of agencies because of their superior embedment. Flotation beads are especially effective with a smaller, more uniform bead gradation and wet paint thickness of 11 mils. This may however require more frequent restriping and result in lower wet-night visibility.

Application Techniques. Drop-on application of beads is the most commonly used technique. Smaller size beads are generally used in premix paint to avoid the bead settling problem in paint storage. Agencies using premix paint also apply drop-on beads (1 or 2 lbs/gal) to provide immediate reflectivity.

Volume of Beads Used. The optimum amount of beads to be applied depends on paint thickness, size of beads, expected service life of marking, and the type of application and equipment. The normal application is 6 lbs/gal, but 4 lbs/gal has been reported to be effective.

9. **Gillis, Henry J., "Durable Pavement Marking Materials", Transportation Research Record 762, Transportation Research Board, Washington, D.C., 1980.**

The purposes of this project were to evaluate epoxy, polyester and thermoplastic resins as pavement marking materials and to develop and evaluate a spray-on epoxy/glass bead system appropriate for both bituminous and concrete pavements. The study was conducted by the Minnesota Department of Transportation between 1975 and 1978 and was divided into two phases. During the first phase, in 1975 and 1976, 140 miles of epoxy skip line of varying film thickness and bead type was placed on high volume roadways in the Minneapolis area. Forty miles of polyester skip line was placed in 1976 to compare with the epoxy type. In the second phase, during 1977 and 1978, approximately 230 miles of thermoplastic and 150 miles of epoxy were placed statewide.

Phase I. One of the primary purposes of this phase was to develop and fabricate a fully production-capable machine to be used for heating, metering, mixing and spraying the two-component epoxy. In areas where the traffic volume was heavy, glass beads were poured on the epoxy stripe in an attempt to eliminate tracking of the epoxy. This worked so well that a free-fall system capable of flooding the epoxy stripes with glass beads at a rate of 20 to 25 lb/gal was developed. Three different types of beads were evaluated for reflectivity effectiveness. The Minnesota DOT specification beads reached the minimum acceptable reflectivity level within nine months after placement, while floating glass beads reached this level within 10.5 months. Chemically moisture-proofed beads were found to be acceptable for a period of approximately 14 months.

Observations showed that the epoxy provided adequate delineation in day and night conditions for 24 months following installation. During wet weather at night, the shiny enamel surface of the epoxy serves as a mirror and reflects the overhead lighting and the taillights of the vehicle ahead, serving to amplify the delineation system. Phase I concluded that

- Epoxy has better reflectivity than conventional traffic paint 60.6 percent of the time.
- Paint has better reflectivity than epoxy 32 percent of the time.
- The reflectivity of paint is below the minimum acceptable level 51.7 percent of the time.
- No form of delineation exists 18.2 percent of the time when conventional traffic paints are used. Because of severe winter conditions, it was not possible to repaint the lines when such a point was reached.

Phase II. During this phase, bisymmetric glass beads were used on thermoplastic striping and chemically moisture-proofed beads were used on the two-component epoxy-resin system developed in the first phase of the study.

Retroreflectivity readings were taken of test sections, with a failure being recorded for readings less than 30 percent of standard Minnesota DOT ERMA. The thermoplastic striping had a higher failure rate because it was either worn off or plowed off the pavement surface or because of the glass beads were removed and sheared off by snowplows as a result of the greater thickness of the material (30 mils). The epoxy failed due to adhesion problems caused by contamination of the pavement surface.

Material	No. of Test Sections	No. of Months	Percent Failure
Thermoplastic	44	6	93
		12	77
		18	86
Epoxy	51	6	24
	25	12	8
	25	18	16

10. Holman, F.L., "Glass Beads for Traffic Marking Paint", HPR Report #55, Alabama Highway Research, Montgomery, AL, July 1971.

This report describes a study of glass beads in traffic marking paint done in Alabama under the "Traffic Marking Beads - National Experimental and Evaluation Program." The study included "premixed" beads as well as "drop-on" beads. In addition, a limited study of the effect of cleaning a new bituminous surface prior to painting was included.

Materials. The reflective "drop-on" glass beads used were in accordance with the "Proposed specifications for Reflective Glass Beads, Special Grade." Under this specification, beads with a refractive index of 1.50 and the gradation below were used.

Sieve	Total % Passing
30	100
40	90 - 100
80	0 - 10

The reflectorized white paint with premixed glass beads was in accordance with the Alabama Highway Department's Standard Specifications for Highways and Bridges. Under these specifications, a minimum of 4.20 lb/gal and a maximum of 4.90 lb/gal of beads were to be used, and the beads were to be of the following gradation.

Sieve	Minimum	Maximum
Retained #40		0
Passing #40 - Retained #60	0	5
Passing #60 - Retained #70	0	12
Passing #70 - Retained #80	0	15
Passing #80 - Retained #230	58	90
Passing #230	0	10

Test sections of centerline striping were installed on South Boulevard and the Atlanta Highway (US 80) in Montgomery. The roadways were subjected to traffic of approximately 26,000 vpd and 23,000 vpd for the two locations, respectively. The test sections on South Boulevard were on a newly placed bituminous surface, while those on the Atlanta Highway were on a six lane concrete pavement which was about 8 years old. The stripes were periodically rated visually for appearance, durability, and night visibility on a scale of 0 to 10. The following conclusions were reached.

1. Test sections with very high "drop-on" bead application rates (9.9 and 17.4 lb/gal) had good night visibility but rated low in appearance and durability.

2. Early in the study, the paints with "drop-on" beads generally were rated the highest in durability. However, in the later stages, the test sections with premixed beads and no "drop-on" beads improved in standing.

3. Premixed beads with 2.2 lb/gal of "drop-on" beads and ordinary paints with 5.2 lb/gal of "drop-on" beads showed the best overall performance for asphalt pavements.

4. Premixed beads with 2.2 lb/gal of "drop-on" beads showed the best overall performance for concrete pavements.

11. **Kalchbrenner, James, "Large Glass Beads for Pavement Markings", Transportation Research Record 1230, Transportation Research Board, Washington, D.C., 1989.**

There have been many changes in the pavement marking industry in the past 20 years, particularly in the use of polymeric non-shrink binders (epoxy, polyester) as durable striping materials. It has become apparent that as striping line durability and wet line thickness increased, glass bead characteristics had to change. The extended durability of these films has shown the need for bead surface treatments that improve bead adherence to the binders. A need for larger-diameter glass beads is described, which also fits the theoretical requirement of bead embedment and binder thickness for optimum reflectivity.

Larger Glass Bead Development. Potters Industries experimented with larger glass bead sizes both in the laboratory and at a field test site in New Jersey in 1984. The laboratory tests under wet-night conditions indicated that larger glass bead sizes provided retroreflectivity levels three to four times higher than the minimum visibility requirements in rainfall rates up to one-half inch/hr.--a level twice that considered to be heavy precipitation. When the rain stops, the large-bead pavement marking recover quickly to extremely high retroreflectivity values.

After different beads sizes had been tested, it was determined that properly embedded beads within the size range of 10 to 20 mesh, depending on binder, could overcome the water film effect and reflect light back even in rainfall rates of one-half inch/hr. Initial field trails with large beads were conducted in West Milford, NJ. Both thin film materials of less than 20 mils (epoxy, polyester), as well as thick film materials (thermoplastics, etc.) were used in order to optimize bead binder systems. Variations in binder-film thickness, bead size, and bead surface treatments were evaluated for reflectivity, durability, and wet pavement/night-time performance.

Field Performance. During the three years prior to this report, Potters Industries worked together with State and local jurisdictions across the U.S. to demonstrate the effectiveness of the large-bead system. Demonstrations using existing durable binders were initiated in seven geographic areas covering 25 states. The trials involved a variety of binders, road types, geographical areas, pavements types, and marking applications.

Discussion of Results. The performance of larger beads is demonstrated to be significantly superior to that of smaller (standard) bead sizes for a variety of binders-thin film (epoxy, polyester) as well as thick film (thermoplastics. Gradation specifications are suggested for single and dual-drop marking systems.

12. McGrath, Marcia, A., Durable Pavement Marking Materials Workshop, FHWA-TS-81-221, Federal Highway Administration, Washington, D.C., 1981.

This publication summarized presentations on the evaluations of six durable pavement marking materials as reported at 1981 workshops. Pertinent information of each marking materials is given below.

Paints. No specific information is given regarding glass bead size and positioning.

Thermoplastics. The New York DOT now allows either alkyd of hydrocarbon resins, but specifies a minimum 17 percent binder content, plus 20 percent minimum glass beads, and a maximum 49 percent calcium carbonate and other fillers. A minimum RI of 1.50 is required for the glass beads, whether they are premixed or drop-ons. The beads are graded from a #20 to a #80 sieve and must have a moisture-proof coating. Southern states have reported average service lives to ten years for thermoplastics. Reflectivity is generally equivalent to beaded paint, but holds the advantage during rain. In a study conducted by the Texas Transportation Institute, reflectivity was excellent on asphalt after two years, but was negligible on concrete because of bond failure.

Preformed Materials. The State of Virginia specifies a minimum of 20 percent glass beads, by weight, with two percent on the surface and an RI of 1.50. A study conducted by Kentucky DOT reported a four year average useful life for preformed materials, although in snowbelt regions, manufacturers will guarantee only two years for inlaid and one year for overlaid markings.

Epoxy. A free-fall glass bead dispenser, which actually places all the beads on the surface of the epoxy stripe, is necessary to achieve "instant no track." Standard bead guns in a series of two or three will not do. Epoxy markings were found to have an average effective service life of two years on roadways with an ADT less than 15,000 vpd and one year on roadways with an

ADT of approximately 70,000 vpd, according to the Minnesota DOT.

Polyester. Glass beads are applied under pressure at a minimum rate of 15 pounds per gallon of polyester. Based on experience in Ohio, when applied on good bituminous pavement, polyester can be expected to have an effective service life of three to four years as a center line on roadways with an ADT of 10,000 vpd, or one year if there is a large percentage of heavy trucks and many curves. As a lane line, polyester will last three to four years on roadways with an ADT up to 24,000 vpd. Using 15 mils wet thickness and 16 to 20 pounds of standard drop-on beads per gallon, polyester material provided good reflectivity in one three year study; it has provided superior reflectivity for eight years.

Epoflex. Glass beads are dropped on during application to provide initial reflectivity while the premixed beads ensure its continuance. Specially treated beads, which are more resistant to chemicals, provide better bead retention. The service life is equivalent to ten applications of paint on concrete and asphalt pavements in warm climates under both moderate and heavy traffic conditions. In Los Angeles, epoflex demonstrated excellent bead retention and no discernible wear after two years on a commuter route with an average ADT of 42,000 vpd.

13. Pavement Traffic Marking: Materials and application Affecting Serviceability, NCHRP Synthesis of Highway Practice 17, Highway Research Board, Washington, D.C., 1973.

The theoretical considerations of film thickness and bead size must be adapted to the reality of the operations of strip application and to the uncertainties of weather and control of materials. Also, the rate of drying of the paint film affects the rate of settlement of the beads into the paint film. Because the methods and time of failure of the paint-bead system is not predetermined, it is difficult to choose the optimum bead gradation or to decide whether beads should be well distributed in the paint film or concentrated on its surface.

North Carolina and Ohio are presently large users of premix paint. Three or four pounds of fine-gradation beads per gallon of paint are generally premixed with the paint and two pounds of coarser beads per gallon are dropped on the wet paint line. Convenience of use and better distribution of the beads in the paint film are North Carolina's chief reasons for use of premix. Some 80 percent of state agencies use nonbeaded paint, however, because of the advantages of less nozzle wear, faster drying, and less paint agitation necessary. Instead, a drop-on system is used. A wet paint thickness of 15 mils and five pounds of beads per gallon of paint have been the most prevalent rates of materials application. Colorado changes from six pounds per gallon of 20 to 200 mesh non-floating beads to four pounds per gallon of 30 to 80 mesh floating beads, and reported superior brilliance and durability. A number of other states have decreased their wet paint thickness and the amount of beads applied.

There has been much discussion indicating that the gradation of the beads affects the brilliance of the stripe and that one gradation is superior to another. Because of the many factors, most of which are not economically controllable in the actual striping operation, a number of proposed bead gradation changes are not practical. When gravity-applied floating beads are used on unskinned paint film, it is possible to capitalize on a narrow range of bead sizes. However, floating beads lose this advantage if pneumatically applied and forced into the paint film.

When nonfloating beads are dropped on an unskinned paint film, the large beads sink first, followed by successively smaller beads. Fortunately, for better reflectivity, a great number of the small or intermediate sized beads interfere with the settlement of the larger beads and some of the larger beads remain partially embedded for immediate reflectivity. Greatest reflectivity to the driver's eye results when 40 to 45 percent of the volume of each bead is exposed to the light rays of the automobile headlights.

14. O'Brien, Jim, "Embedment and Retroreflectivity of Drop-On Glass Spheres in Thermoplastic Markings", Transportation Research Record 1230, Transportation Research Board, Washington, D.C., 1989.

In this paper the embedment characteristics of drop-on moisture proofed and uncoated glass spheres and their subsequent retroreflectivity are discussed. The above properties were evaluated subjectively in various types of hot-applied thermoplastic traffic markings by illuminating test panels in a dark room. It was found that, in all of the hot-applied thermoplastic traffic marking types tested, uncoated drop-on spheres were generally over-embedded because of positive wetting of the spheres by the thermoplastic traffic marking, and their retroreflectivity varied.

The use of moisture proofed drop-on spheres in various thermoplastic traffic marking types resulted in optimal bead embedment with subsequent excellent retroreflectivity. The optimal rate of glass sphere application in all of the thermoplastic marking types was found to be ten pounds of moisture-proofed glass spheres per 100 sq. ft. This rate enhanced retroreflectivity, bead embedment, and coverage.

It was concluded that the retroreflectivity of the standard gradation of glass spheres may be enhanced in all of the thermoplastic types by increasing the percentage of spheres retained on U.S. Sieves 30, 40, and 50 and by increasing the overall rounds from 70 percent to 80 percent.

15. **"Road Marking and Delineation", OECD Road Research Report, February 1975.**

This report summarizes the experience gained with road marking and delineation materials and devices. The advantages and drawbacks, as well as the specific properties of pavement markings, raised markers and delineators, and of the various materials used are evaluated. The report indicates the conditions and factors to be considered in the selection of suitable systems and materials for any given circumstance. The material relevant to glass bead retroreflectivity is summarized below.

1. Depth of embedment (the bead should be embedded to approximately 60% of its vertical height for optimum reflection). This depth also gives good bead retention properties in the binder.

2. The refractive index of bead material should be as high as possible. However, studies have shown that beads with higher RI's of up to 1.9 do not give significantly better reflectivity from the driver's point of view compared to beads of RI of 1.5. However, high RI glass beads are not suitable from a durability point of view, as the durability diminishes with increasing refractive index.

3. A rate of application should be utilized such that beads do not optically interfere with one another and should be spaced to allow water films to drain from the exposed surface.

4. The grading of beads is also important. Beads which are too small tend to be submerged in the marking film while large beads would not have sufficient embedment to be retained under traffic. It is considered that the gradation of beads should be between ASTM No. 40 (0.42 mm) and No. 80 (0.177 mm) mesh.

5. The life span of markings is largely determined by the thickness, type of marking, and traffic volume. Deterioration of the marking is also caused by mechanical stresses or climatic effects. Finally, the wear resistance is dependent on the type and amount of binder present in the material, the type of pigments and the thickness of application.

6. Adhesion between the marking material and substrate is dependent on good bonding at the marking/pavement interface. Adhesion problems are

associated more with concrete than with bituminous pavements. The presence of curing compounds, the tendency of water to migrate to the surface, etc., are some of the situations whereby pavement marking failure occurs due to poor adhesion on concrete pavements. Failure on bituminous pavement is less common, but may occur on newly laid areas due to the presence of excess bituminous binders on the surface, and on older surfaces due to the polishing of aggregates.

7. Factors considered in providing specifications for glass beads are: refractive index of the glass, bead size distribution, percentage of defects, chemical resistance to $CaCl_2$, water, etc., and water-repellent characteristics.

8. No unanimity exists as to the preferred bead size distribution. countries have three categories of glass bead: for mixed-in beads for paint, for drop-on beads, and for thermoplastics.

Mixed in Beads:

France, US. - Diameters from 60 to 200 μ
Belgium, Netherlands - Diameters up to 420 μ

Thermoplastics:

U.K. - 400 to 1,600 μ
Belgium - 150 to 850 μ
ASTM (U.S.) - 180 to 420 μ

Spray-on Beads:

Specifications vary.

9. Several studies have been conducted with the aim of improving visibility in wet weather. They include a) dressing wit 8/12 mm grains before marking, in order to obtain a granular surface standing clear of the water film; b) use of large glass beads (6 mm ϕ) c) use of grains (4/8 mm) precoated with a binder containing microbeads.

10. Other studies were aimed at improving the effectiveness of the application process by using floating beads. An example of this type of study, "Reflective Traffic Bead Study-Final Report", May, 1970, was conducted by the Colorado Department of Highways.

16. Pocock, B.W. and Rhodes, C.C., "Principles of Glass Bead Reflectorization", Highway Research Bulletin #57, Highway Research Board, Washington, D.C., 1952.

The density of a glass bead is of interest for three reasons: 1) it determines the relative amount of reflective surface furnished per pound of beads of a given size; 2) it affects application procedures through its effect on the sedimentation rate of beads in paint; and 3) it is related closely to the refractive index, which increases as the density increases. Silica and boric oxide are the lowest in density, followed by the oxides of aluminum, sodium, potassium, magnesium, iron, calcium, zinc, barium, and lead.

Effect of Refractive Index on Distribution of Reflected Light. When light is incident on an interface of two transparent media, part of the light will be reflected from the surface of the second medium, part will be transmitted, and the remainder will be absorbed. The proportion of light reflected at the boundary surface can be determined from the equation:

$$R = 0.5\ [(\sin^2(i\text{-}f)/\sin^2(i+r)] + [(\tan^2(i\text{-}r)/(\tan^2(i+r)]$$

where

R = fraction of incident light reflected

i = angle of incidence

r = angle of refraction

When one medium is air, the reflection at normal incidence is:

$$R = (n-1)^2/(n+1)^2$$

where

n = ratio of the refractive index of the second material to that of the first

An increase in the refractive index of glass from 1.50 to 2.00 will result in a tripling of the percentage of reflected light at normal incidence, from around 4% to approximately 12%. Maximum efficiency in the conservation of reflected light is achieved when this index is about 1.90 which brings parallel rays to an approximate focus at the rear surface of the bead.

Interrelation of Beads and Paint in Reflex Refraction. When a beam of light strikes the interface between a glass bead and the vehicle in which the finely divided paint pigment particles are suspended, the portion of light reflected is determined by the refraction indices of the glass and vehicle. the remainder, with some loss by absorption, is transmitted through the vehicle to the pigment particles where some of it is absorbed, some transmitted and the balance diffusely reflected. The amount of light reflected by the pigment particles is a function of their refractive index in relation to that of the vehicle, and the amount transmitted through them depends on their absorption characteristics.

Glass Bead Gradations. There are several advantages to the use of beads of smaller maximum size. Other things equal, the projected reflecting area per pound of beads is greatly increased as the average diameter is decreased. Since beads are sold by weight, which is proportional to volume, a dollar will buy more reflection in the smaller beads. Pound for pound, small beads maintain useful reflection longer because of their greater surface to mass ratio. In addition, smaller beads can be more easily premixed with the paint, will reduce drying time and the effect of relative humidity on drying time, and will lower the loss by rebound when bead-paint mixtures are sprayed on the pavement. The percentage of irregular and fragmentary particles is also noticeably lower in beads of smaller size.

Principles of application. Beads mixed in traffic-marking paint and subjected to the usual pressures of spray application will undergo considerable loss through rebound from the pavement surface if they are larger than No. 60 sieve opening (0.0098 inch). For beads with a refractive index of around 2.0, the efficiency of light return becomes very small under the conditions of illumination ordinarily encountered in driving, when the beads are embedded to a depth of half their diameters. Where beads are embedded less than 50 percent, the vertical aperture for reflex reflection is correspondingly greater, but this advantage is offset to some extent by the likelihood of poor bead retention. At the small angles of illumination usually involved, beads have to be embedded only slightly over 50 percent to lose the property of reflex reflection altogether. To prevent beads which are in direct alignment with the light source from partially eclipsing each other, the following critical separation distance should be used:

		Critical Separation Distance	
Bead Diameter (in.)	Corresponding Sieve	At 500 Feet (in.)	At 50 Feet (in.)
0.0165	40	1.55	0.16
0.0117	50	1.10	0.12
0.0059	100	0.55	0.06

17. Schwab, Richard N. and Capella, Donald G., "Is Delineation Needed?", Public Roads, Vol. 43, No. 3, Washington, D.C., December 1979.

Delineation provides guidance and regulatory or warning information to a driver. Delineation shows the motorist the proper path to follow. This article compares three delineation treatments-stripes, raised pavement markers, and post mounted delineators. Where, when, and how much delineation is required for safe and effective driving is discussed. The research involved a driving simulator that used computer-generated images projected on a screen in front of a real vehicle passenger compartment. Color identification under daytime and night-time illumination was also studied.

Striping reduced accidents approximately 30 percent. A mixture of 50% white pigment to 50% yellow pigment, by weight, will not decrease color identification. The traffic performance study found little difference in driver performance for a 1:3 strip-to-gap ratio in dry weather and in wet weather. Raised pavement markers are cost beneficial at an ADT volume of 3,000 vpd. Accident analysis studies showed that when painted centerlines are replaced with raised pavement markers, there was reduction of approximately 0.50 accidents per million veh-miles (acc/mvm). Post-marked delineators are effective at night and in adverse weather. Performance improved significantly with the use of postmounted delineators on horizontal curves. If safety is the only benefit considered, this treatment is cost beneficial for ADT volumes exceeding 1,000 vpd. A reduction of one acc/mvm was demonstrated.

18. Van Gorkum, F. "Night-Time Visibility of Seven Road-Marking Materials", <u>Traffic Engineering and Control</u>, Vol. 25, No. 4, London, UK, April, 1984.

Roadway markings made of paint of thermoplast (thermoplastic material) become virtually invisible in wet-weather conditions. In addition, thermoplast lines, which are typically 3 mm thick, can create a hazard by trapping a layer of water on the inside of the lane. To address these problems, a study group in the Netherlands tested seven types of pavement markings:

1. Marginal line made of traffic paint.
2. Marginal line made of thermoplastic material and with drainage grooves provided at 0.5 meter intervals.
3. Marginal thermoplast line with vertical ribs (the "Ribbelreflex" line)
4. Marginal thermoplast line with rolled-in grooves at 0.1 meter intervals.
5. RPM reflector with three bioconvey lenses (type A).
6. RPM with 21 small bioconvey reflective lenses (type B).
7. RPM with corner-cube reflectors (type C).

A 300 meter sample of each type of line was painted on a test section of roadway. Each of the RMP types was tested by placing them 10 meters apart on a line 0.2 meters to the right of the right-hand marginal line. The test markings were evaluated using a luminance meter and a subjective observation. Optical measurements were repeated at 41, 112, 175, 308, 469, and 659 days after installation to determine the effects of deterioration and wear. Traffic volumes at the sites were also recorded. Visibility distances for each type of marker were found under wet and dry conditions. The following conclusions were reached.

1. Adding a vertical profile to roadway lines or using reflectors substantially improves night-time visibility.
2. Road marking can be assumed to have reached the end of their useful service life after 22 months and 2 million vehicle passes.
3. Thermoplast markings improve after being worn by weather and traffic action (because pigment is removed from the glass beads).
4. Vertically-profiled thermoplast markings were superior to painted lines, but inferior to RPMs.
5. RPMs have best visibility immediately after installation.
6. RPMs are the most degraded by traffic and weather of all the markings studied.

19. "How to Match Striping Paint and Beads", Better Roads, Vol. 61, No. 1, Park Ridge, IL, January 1991.

W. Herbert Hartman, President of Research Derivatives, noted that the loss of beds during road marking is very costly in terms of the budget for road and highway marking. Making the beads land over the wet paint without overshoot and waste is a complicated problem involving the science of ballistics, because these two components are of different texture, mass, size and shape.

The usual approach followed is setting the guns some distance apart. However, this method will provide bead coincidence only at one speed of travel-the speed at which the forward motion carries paint exactly the required amount of distance ahead of the bead release so that the paint release will catch up with the beads that were dropped earlier. At any other rate of travel, there will be overshoot or undershoot of bead landings with respect to paint.

Most bead landing errors can be compensated by providing fixed-time delay before the paint starts after the onset of the bead release. This permits the beads to start their flight early so that their longer flight time will end shortly after the paint is released and the two will land together on the pavement.

This technique is developed by "Research Derivatives" has been compared to a conveyor belt. Anything loaded on the belt will be carried to the end intact. It will drop off the end at the conclusion of the travel time. Event times may be much smaller than the delay times required for bead and paint coincidence. The Research Derivatives' method insures that the beads land with the paint, even at variable speeds.

20. Mendola, Angelo A., <u>Comparative Study of the Performance and Cost Effectiveness of Large Glass Beads and NJDOT Standard Glass Beads in Epoxy Traffic Paint</u>, New Jersey Department of Transportation, Final Report, September 1990.

The State of New Jersey evaluated the large glass beads manufactured by Potters Industries (VISIBEADS) and epoxy paint @ 20 mils in place of standard glass beads and standard traffic paint. Three different bead configurations were used in the evaluation: single drop, large beads only; double drop, mixture of large and standard beads; and standard beads only. Photometric as well as visual criteria were used in the evaluation. The evaluation was conducted over a period of two years with readings being taken every three months. Photographs were taken during various rainy conditions from the drivers perspective.

The results of the photometric and visual tests revealed that the large glass beads did produce much brighter lines in wet night conditions than the standard glass beads did in both the single and dual drop applications. It was also concluded that the cost difference between large glass bead and standard beads was relatively low compared to the amount of increased wet night visibility offered by the large glass beads. The study recommended that large glass beads be used wherever the State of New Jersey installs epoxy pavement marking.

21. King, L. Ellis and Graham, Johnny R., Evaluation of Pavement Marking Materials for Wet Night Conditions, FHWA/NC/89-003, Department of Civil Engineering, The University of North Carolina at Charlotte, October 1989.

The State of North Carolina investigated the visibility of eight pavement marking materials for both wet and dry conditions. Test markings were placed on three highways and their performance recorded for a period of eighteen months. Field measurements included periodic recording of retroreflectivity and percentage of missing material. An added part of this study evaluated Epoxy markings with large glass beads.

The method for evaluating these markings in the field was highly subjective. The lines were viewed from an automobile driven at 60 miles per hour and the greatest distance that the markings were visible was estimated from the travel time required to reach the marking after initial sighting. All evaluations were made at night under wet conditions. Field measurements include periodic recording of retroreflectivity and percentage of missing material. Visibility distances were also estimated in similar fashion for the adjacent sections of epoxy markings with regular glass beads.

The larger glass beads offered improved nighttime visibility during wet

conditions. In each instance the visibility distance for the VISIBEAD lines was greater by a factor of two or more than that for the adjacent standard bead lines.

22. **Griffin, Richard G., Pavement Marking Materials, Report No. CDOH-DTD-R-90-4, Colorado Department of Highways, July 1990.**

This study was conducted to review and evaluate the performance of pavement marking materials in Colorado. The materials evaluated include preformed plastic, extruded thermoplastic, epoxy paint, standard alkyd traffic paint, and fast dry alkyd traffic paint, applied on both asphalt and concrete.

CDOH research has shown that uniform and smaller gradations of the Type 2 flotation beads create a brighter stripe even at an application rate of only four pounds per gallon. The larger beads, epoxy breads, have the potential to protrude above the paint surface and may improve the retroreflectivity on wet pavements. The Potters Industries PE-115 beads are one of the glass beads that meet the standard specifications. It was reported that they provide proper embedment when used with epoxy with a 15-mil dry film thickness. The specific problem in Colorado, where hard silica based aggregates and snow plowing down to bare pavement are employed to maximize safety during snowy and icy conditions, is loss of large beads from pavement markings. The larger beads are reported to maintain proper embedment and aid in wet night time visibility, but may be susceptible to damage on mountain roadways. This report concludes that 100% solids epoxy paint is durable marking material both on asphalt and concrete and thermoplastic is not recommended on concrete pavement.

23. **"Striping and Marking: What Works Best?", Better Roads, Vol. 59, No. 4, Park Ridge, IL, December 1989.**

This article is a summary of a survey conducted by Better Roads' editors. This survey had 200 responses from all 50 states. 32.3% of the respondents reported that paint worked best in their departments, 30.2% preferred preformed tape, and 28.1% favored thermoplastics. If budgets allowed, most of the maintenance engineers said they would use thermoplastics. For crosswalks, pedestrian crossings, and arrows, more than 60% of respondents preferred preformed tape. Most of the respondents preferred 3M's 5730 tape. Thermoplastics evoked mixed reactions from highway engineers. Thermoplastics were said to get brittle in cold weather, and thus got plowed out by snow removal equipment. Some of the maintenance engineers believe Desantis Coatings, Inc. produces quality paint and some expressed doubts about the performance of paint during rainy and winter seasons. When using glass beads to reflectorize paints, it is important to have the correct mix. If the quantity of beads isn't enough, it seems to keep the stripe from drying as fast as it should. The paint reacts with oil or tar on the road and turns the stripe black which also doesn't reflect. However, Potters Industries' VISIBEADS are larger and they provide more reflective surface, hence they reflect well even in wet weather.

APPENDIX B

17-Jul-91

Appendix B

SASHTO PAVEMENT MARKING INFORMATION

* footnote

TABLE 1
PAINT

Feature	Alabama	Arkansas	Florida	Georgia	Kentucky	Louisiana	Mississippi	North Carolina	South Carolina	Tennessee	Virginia	W. Virginia
Type	Waterborne & Solventborne	Chlorinated Polyolefin	Alkyd	Alkyd	Alkyd or *K1 Chlor. Rubber	Alkyd & Water Base	Waterborne	Alkyd	Alkyd	Alkyd	Alkyd & Waterborne	Alkyd
Type of Specification	Performance *A1	Formulation	Formulation and Performance	Formulation	Performance	Formulation	Formulation and Performance	Formulation	Formulation	Formulation	Performance Some Spec.	Performance
Application Rate	15-18 mils *A2	15 mil	15 mil	15 mil	15 mil	15 mil	15 mil	15 mil	15 mil	15 mil	15 mil	15 mil
Application Temperature	125-135 F 140 F at Nozzle	120 F	150 F	80 F	120 F	Alkyd - 180 F WB - 130 F	150-170 F	130-160 F	180 F quick 135 F slow	140-170 F	None	130-170 F
Dry Time	1-24 min. *A3	3 min. max.	20 sec to 3 min	10-15 Min.	90 Seconds	3 min.	3 min. max.	2-4 Min.	20 Sec.; 3 Min.	60 Seconds	60 Seconds	60 Seconds
Minimum Air Temperature	40 F	NA	40 F	50 F	50 F	40 F	40 F	40 F			50 F Surf. temp.	50 F
Current State Supplier	Safety Coatings	Centerline Industries	Baltimore Paint	Linear Dynamics	Linear Dynamics Balt. Paint *K2	Centerline Industries	Centerline Industries	NC Correction Enterprises	Prismo So. Paint Co.	Prison Industries	*V1	Ennis & Linear Dynamics
Cost per/ft. for a 4" Line	State 3.5 cents Cont. 4.6 cents	State 2.7 cents Cont. 11 cents	State 3 cents Cont. 7 cents	8 cents for a 5" Line Width	5 cents	3 cents	5 cents	State 5 cents Cont. .09 -.20	State 3-5 cents Cont. 10 cents	2.5 cents Maint. Cont.	1.3 - 1.9 cents *V2	Cont. 2.5 cents

Appendix B

SASHTO PAVEMENT MARKING INFORMATION

TABLE 2 - THERMOPLASTIC

* footnote

Feature	Alabama	Arkansas	Florida	Georgia	Kentucky	Louisiana	Mississippi	North Carolina	South Carolina	Tennessee	Virginia	W. Virginia
Type	Alkyd and Hydrocarbon	Alkyd or Hydrocarbon	Alkyd (State) Hydro. (Cont.)	Hydrocarbon	Alkyd and Hydrocarbon	Hydrocarbon	Alkyd and Hydrocarbon	Alkyd and Hydrocarbon	Hydrocarbon	Hydrocarbon	Alkyd and Hydrocarbon	Alkyd and Hydrocarbon
Application Method	Extruded or Hot Spray	Extruded or Hot Spray *B1	Extruded or Hot Spray	Hot Spray	Extruded	St. Hot Spray Cont. Extruded	Extruded, Hot Spray & Ribbon	Extruded or Hot Spray	Extruded or Hot Spray	Extruded	Extruded and Hot Spray	Extruded or Hot Spray
Where Used AC PCC Other	 Yes Yes 2Lanes ADT>3000 All multi-Lane *A4	 Yes Yes	 Yes No All EL, LL & CL	 Yes Yes Interstate Other ADT	 Yes No	 Yes Yes EL, LL & CL All ADT	 Yes Yes EL, LL & CL ADT > 2000	 Yes Yes Interstate Other ADT	 Yes No	 Yes No EL, LL & CL ADT	 Yes No EL, LL & CL	
Application Rate EL, LL & CL	90 mil LL, CL 60 mil EL	90 mil	60 mil EL 90 mil LL	60 mil EL 90 mil LL	90 mil	90 mil	60 mil EL 90 mil LL 120 mil detail	90 mil EL 120 mil LL & CL	90 mil EL, LL & CL 125 mil other	90 mil	90 mil + 5	60 mil spray 90 mil extruded
Application Temp. Recommended Temp. 400-440 F AC 425-440 F PCC	As Specified by Manufacturer	As Specified by Manufacturer	As Specified by Manufacturer	415 F	400-440 F	400-450 F	375-440 F	400-440 F (AC) 425-440 F (PCC)	380-420 F	420-440 F	As Specified by Manufacturer Min. 400 F	As Specified by Manufacturer
Minimum Air Temperature	50 F	50 F	40 F	40 F	60 F	50 F	Pavement Temp 50 F	50 F 40F New Asphalt	55 F	50 F	50 F Surf. Temp.	50 F
Current State Supplier	Pave-Mark	N/A	Cataphote Pave-Mark Swarco, Intermak	Pave-Mark	N/A	Pave-Mark	Cataphote & Linear Dynamics	N/A	N/A	Cataphote Pave-Mark Swarco	Intermak Corp.	NA
Is State Equipped to Place Thermo.	Special marking *A5	No	No	Yes	No	Yes	No	Hand lines only	No	No	Yes Hydrocarbon	No
Cost per/ft. for a 4" Line	15 cents EL 17.5 cents CL	33 cents	20 cents	20 cents	20 cents	40 cents	23 cents	35 cents	20 cents	27 cents	12 cents State forces	

Appendix B

SASHTO PAVEMENT MARKING INFORMATION

TABLE 3
PERMANENT PREFORMED TAPES

* footnote

Feature	Alabama	Arkansas	Florida	Georgia	Kentucky	Louisiana	Mississippi	North Carolina	South Carolina	Tennessee	Virginia	W. Virginia
Uses	Stop Bars Ped. Crossings Transverse line	Stop Bars Ped. Crossings Long lines	Transverse Lines	Stop Bars Ped. Crossings	Concrete Interstate Urban areas	Stop bars Crosswalks EL, LL & CL	Bridge decks Special project Transverse Line	Bridge Decks Intersections	Stop Bars Ped. Crossings Arrow messages	Long. Lines on PCC and AC Pvt.	Stop bars Crosswalks EL, LL & CL	Speciality Markings
Cost per/ft for a 4" Line	0.65-1.40 ST. Cont. 1.15	State 89 cents Cont. $1.10			$1.70	.30 - A320 .70 - 3M	State 67 cents Cont. $1.75	$1.96		$1.09	$1.30	56 cents
Products Used	Stamark 5730, 6330, 5760, A320, A350	Cata-Tile Prismo 3M Stamark	Cata-Tile *F1 Stamark No. 5730 & 5731	No	3M Stamark Pliant Polymer A350 & A351	3M 5730 A320	3M Stamark *M1 3M Detour Grade	3M Stamark Pliant Polymer 350	Linear Dynamics 3M, Volare Cataphote	3M Stamark Flex-O-Lite Prismo Plastix	3M, Cata-Tile Linear Dynamics Seibulite *V3	3M Linear Dynamics

OTHER PRODUCTS USED

Other Products	Epoflex Spotflex		Metromark Thermopolyester		Polyester Paint			2-Part Epoxy		Epoxy Polyester	Epoxy Lightweight paint	Premark preformed thermoplastic

Appendix B

* footnote

TABLE 4 - Reflective Pavement Markers

Feature	Alabama	Arkansas	Florida	Georgia	Kentucky	Louisiana	Mississippi	North Carolina	South Carolina	Tennessee	Virginia	W. Virginia
Raised RPM Bid Price Cost/Foot for 80 Foot Spacing	$2.23 State $3.50 Cont. 4.4 cents	$1.45 State $4.74 Cont. 6 cents	$2.44 State $3.25 Cont. 5 cents	$1.85 2 cents	N/A	$4.00 5 cents	$3.50 - $4.50 5 cents	$4.00 5 cents	$4.00 5 cents	$6.62 8 cents	Don't use execpt in Va. Beach	$2.00
Use Recessed Markers	No	No	Experimental	No	No	No	No	No	Yes	Quit Recessing	Yes	No
Dim. of Groove	N/A	N/A	24" L. 1/2" D.		N/A	N/A	N/A	N/A	48" L. 3/4" D.	N/A	48" L, 0.65" D	N/A
Placement of RPM in Groove	N/A	N/A	Middle of Groove		N/A	N/A	N/A	N/A	Rear of Groove	N/A	4" from rear of groove	N/A
Recessed RPM Bid Price and Cost/Foot	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$12.00 15 cents/foot for 80' spac.	N/A	$12.50 - 27.00 *V4	N/A
Use Snowplowable Markers?	No	Yes	No	No	Yes	No	No	Yes	No	Yes	Yes	Yes
Snowplowable Marker Bid Price	N/A	$28.53	N/A	N/A	$17.00	N/A	N/A	$28.00	N/A	$27.98	$30.00	$25.00
Use Non-Reflective Markers?	Yes	Yes	Yes	Few	No	Some	No	No	No	No	No	Yes
Products Used	Several *A6	Stimsonite 948	Cata-Guide Ray-O-Lite Stimsonite *F2	Stimsonite 948	Ray-O-Lite Stimsonite 66, 88, 911, & 947	Ray-O-Lite Stimsonite	Ray-O-Lite Stimsonite 88 & 911a	Cata-Guide Stimsonite 911, 944, & 948	Stimsonite 911 & 948	Ray-O-Lite Stimsonite 911 & 948	Stimsonite 911, 944, 948 96, LP96	Ferro Stimsonite
RPM Spacing	80' & 40' *A7	80' Rural 40' Urban	40'	80' *G1	80' 4-Lane 40' 2-Lane	40'	80' Rural 40' Urban	80' and 40' *N1	40' ML Urb. 80' Other	80'	80' 20' on ramps	80'
Longitudinal Location	Middle of Gap	Middle of Gap	Middle of Gap	1-2' Ahead of Lane Line	Middle of Gap	Middle of Gap	Middle of Gap	Middle of Gap	6" Behind lane line	2' in Front of Lane Line	Middle of Gap	Middle of Gap
Transverse Loc.	On Line		On Line *F3	4" Offset Line	2" Offset Joint	2" Offset	On Line	2" Offset Line	N/A		N/A	N/A

17-Jul-91

Appendix B

SASHTO PAVEMENT MARKING INFORMATION

TABLE 5

BEADS

* footnote

Feature	Alabama	Arkansas	Florida	Georgia	Kentucky	Louisiana	Mississippi	North Carolina	South Carolina	Tennessee	Virginia	W. Virginia
RI #	1.5 - 1.6	1.5 - 1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Pounds per Gallon of Paint	6 *A8	6	6	6	4 - 6	6	6	6 *N2	6	6	6	6
% of mix weight in Thermoplastic	29-52%	30-50%	30%	25%	30-40%	30-40%	35%	30%	30 - 40%	30 - 40%	25%	20 - 35%
Drop on Appl. Rate on Thermo. lbs./100 sq. ft.	6 *A9	8	10	14	4	10	5	7	12	5	7	10
Current State Supplier	Cataphote	Cataphote Flex-O-Lite	Cataphote	Potters	Cataphote	Cataphote	Cataphote	Potters	Cataphote	Flex-O-Lite	Potters Northeastern	Flex-O-Lite
Cost per Pound	18.4 cents	14 cents	18 cents	17.8 cents	19 cents	18 cents	19 cents	19 CENTS		16.84 cents	18 cents	17 cents

ADHESIVES

Products Used	Bituminous *A10	Epoxy and Bituminous	Epoxy and Bituminous	Bituminous	Epoxy	Epoxy and Bituminous	Bituminous *M2	Epoxy Bit. (Temp.)	Epoxy and Bituminous	Bituminous	Manu. rec. or AASHTO M237	Epoxy and Bituminous

Appendix B

SASHTO PAVEMENT MARKING INFORMATION

TABLE 6
GENERAL

* footnote

Feature	Alabama	Arkansas	Florida	Georgia	Kentucky	Louisiana	Mississippi	North Carolina	South Carolina	Tennessee	Virginia	W. Virginia
Retroreflectometer	MIROLUX 12	MIROLUX 12	MIROLUX 12	MIROLUX 12	MIROLUX 12	Ecolux	Ecolux & MIROLUX 12	MIROLUX 12	No	MIROLUX	MIROLUX	MIROLUX
Line Width	4"	4"	6"	5" *G2	4"	4"	4"	4"	4"	4"	4"	4"
Line Spacing	10' LL 30' Gap *A5	10' Lane Line 30' Gap	10' Lane Line 30' Gap *F5	10' Lane Line 30' Gap	10' Lane Line 30' Gap	10' Lane Line 30' Gap	10' Lane Line 30' Gap	10' Lane Line 30' Gap	10' Lane Line 30' Gap	10' Lane line 30' Gap	10' Lane line 30' Gap	10' Lane line 30' Gap
Location of Edge Line	Edge of Pavement		2" From Edge of Pavement	2-4" From Edge of Pavement	1-3" From Edge of Pavement	2-4" From edge of pavement	2" From edge of pavement	2" From edge of pavement	2" From edge of pavement		Varies	Not Specified
Approved Products List	Yes	Yes Some products	Yes Some products	No	Yes	Yes	Yes	No	Yes Preformed tapes	No	Yes	Yes
Initial Markings Placed By?	State and Contractor	State and Contractor	State - paint Cont. - thermo	94% State	State (Paint) Cont. (Other)	Contractor	Contractor	Contractor 90%	Contractor on Fed. Projects State - Paint	Contractor	State and Contractor	State or Contractor
Replacement Mrks. Placed By?	State	State	State	State	State (Paint) Cont. (Other)	State	State	State (Paint) Cont. (Thermo.)	State (Paint) Cont. (Thermo.)	State and Contractor	State and Contractor	State or Contractor
Acceptance Waiting Period	No	No	45 days for markers	No	90 Days on Thermoplastic	No	No	180 Days	180 Days	No	No	None
State Contact	Lynn Wolfe 205-242-6276	Tony Sullivan 501-569-2661	Larry Smith 904-372-5304	Jerry Gossett 404-363-7625	Lonnie Yates 502-564-3730	Francis Becnel 504-925-5719	Bobby Moseley 601-359-1145	Jimmy Lynch 919-733-3915	Terry Rawls 803-737-1500	Naaman Harper 615-350-4106	Tom Neal 804-737-7731	Dennis King 304-348-3402

Appendix B

SASHTO PAVEMENT MARKING INFORMATION

TABLE 7
COST OF MATERIALS

Feature	Alabama	Arkansas	Florida	Georgia	Kentucky	Louisiana	Mississippi	North Carolina	South Carolina	Tennessee	Virginia	W. Virginia
Paint Cost/Foot for a 4 inch Line	State 2.5 cents Cont. 4.6 cents	State 2.7 cents Cont. 11 cents	State 3 cents Cont. 7 cents	8 cents for a 5" line	5 cents	3 cents	5 cents	State 5 cents Cont. 12 cents		2.5 cents Maintenance contract	1.3 - 1.9 cents	Cont. 2.5 cents
Thermoplastic Cost/Foot for a 4 inch Line	15 cents EL 17.5 cents CL	33 cents	16 cents	20 cents	20 cents	40 cents	23 cents	31 cents	20 cents	27 cents	6.5 cents	N/A
Raised RPM Bid Price and Cost/Foot for 80 Foot Spacing	State $2.23 Cont. $3.50 4.4 cents	State $1.45 Cont. $4.74 6 cents	State $2.44 Cont. $3.25 5 cents	$1.85 2 cents	N/A	$4.00 5 cents	$3.50 - 4.50 5 cents	$9.00	$4.00 5 cents	$5.49 7 cents	N/A	$1.00 - 15.00
Recessed RPM Bid Price and Cost/Foot	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$12.00 15 cents/foot for 80' spac.	N/A	$12.50 - 27.00 *V4	N/A
Snowplowable Marker Bid Price	N/A	$28.53	N/A	N/A	$17.00	N/A	N/A	$28.00	N/A	N/A	$30.00	$25.00
Preformed Tape Cost per 4" Line	0.65 - 1.40	State $.89/ft. Cont. $1.10/ft.			$1.70/foot	70 cents	State $.67/ft. Cont. $1.75/ft.	$1.90/foot		$1.09/foot	$1.30/foot	56 cents
Beads Cost per Pound	18.4 cents	14 cents	18 cents	17.8 cents	19 cents	16 cents	19 cents	17.3 cents		16.84 cents	18 cents	17 cents

Appendix B

SASHTO PAVEMENT MARKING INFORMATION

TABLE 8

WORK ZONES

* footnote

Feature	Alabama	Arkansas	Florida	Georgia	Kentucky	Louisiana	Mississippi	North Carolina	South Carolina	Tennessee	Virginia	W. Virginia
Line Spacing	8' & 10' LL on 40' cent.	4' Lane line 36' Gap	10' Lane L. *F6 30' Gap (Paint)	4' Lane Line Gap	*K3	10'L/30'G 4'L/40'G *L1	10' Lane 30' G. High ADT *M3	10' Lane Line 30' Gap	10' Lane Line 30' Gap	10' Lane Line 30' Gap	10' Lane Line 30' Gap	10' Lane Line 30' Gap
Products Used	Temporary tape & tape			Flexolite 3M Detour grade								
RPM Spacing	80' Passing zone, 40' no passing zone	40'		80' >5 deg. curve 40'	Temp. 5 ft. Perm. 20-40 ft. on Detours		80' Rural 40' Urban	20-40 foot	40' if used		10' 5' in transitions	
Products Used				Stimsonite 948								

AREAS OF CONCERN

	Alabama	Arkansas	Florida	Georgia	Kentucky	Louisiana	Mississippi	North Carolina	South Carolina	Tennessee	Virginia	W. Virginia
	Retention of RPM's on roadway surface Bead retention on paint for nighttime reflectivity Reliable method of rating paint markings Use of SASHTO RTF data *A12	Temporary tape on PCC Waterbased paint MUTCD requirements for temporary striping	Lack of DOT unified policy Quality control of Products Traffic and work zones RPM's staying on pavement surface	Short RPM life Pmt. marking eradication New product evaluation	Cost of snowplowable markers Work zone safety Wet weather visibility Striping late in year	Markings staying on PCC Temp. markings Work zone safety Wet weather visibility	Temp. markings in const. zones Maintenance of pmt. markings Thermoplastic adhering to PCC Wet weather visibility Reflectivity & Durability of RPM's	Markings staying on PCC Need to combine research of Various States Work zone standards Appearance of temp. pmt. markings	Thermo. on PCC pavement RPM maintenance Lead in yellow paint Eradication of temp. markings	Wider lines Removal of lines in const. zones Maintaining markings on PCC Wet weather visibility Need more RPM's	Disposal of paint Durability of temporary markings	Work zone safety Wet weather visibility

Appendix B

TABLE 9

FOOT NOTES

A1 - The retroreflectivity values from the 12th month of the testing period of the SASHTO RTF are converted to a scale of 10 by dividing the 12th month value by the highest initial reading made of each deck and then multiplying the value b 10. The retroflectivity values, durability and appearance values are then averaged for each test deck. An R value is computed using the following formula: R = (10.3 X Appearnce) + (0.3 X durability) + (0.4 X retroflectivity). Products that have an R value greater than 5.0 are put on the approved products list.

A2 - 18 gals/mi on smooth textured pavements and 22 gals/mi on rough textured pavements.

A3 - According to performance on SASHTO RTF for no track dry time, ASTM D711.

A4 - Also used on RR grade crossings and high volume urban roadways.

A5 - State is equipped to place markings/legends and lane lines of short length.

A6 - Highway Ceramics; Permark P7, P19, P7-CV; Ray-O-Lite; STimsonite 88, 911, 948; Pactec 28; 3M 240, 380.

A7 - 80' in passing zones and 40' in no passing zones.

A8 - Top dressing of 2 to 2.4 lbs/gal; 4.4 lbs/mi for 4" stripe; 117 lb/mi for 4" stripe wiout premixed beads.

A9 - 88 lbs/mi for 4" solid stripe.

A10 - Crafco Hot Applied Flexible Marker Adhesive (34270); Stimsonite Bituminous Adhesive (2202031); Renco Bituminous Marker Adhesive; Marker Grip Pavement Bituminous Adhesive

A11 - 10 foot lane line with 30 foot gap in ruaral areas and 15 foot lane line with 25 foot gap in urban areas.

A12 - A12 - A12 - Application of SASHTO RTF data and projecting service life of pavement markings from SASHTO RTF test data.

B1 - Extruded only after 1/1/93.

F1 - Approved Products: Seibulite (5012), 60 mil-white Cata-Tile R-60, white and yellow Prismo HR90, white and yellow Prismo HR60, yellow Stamark 5730, 5731, and 350.

F2 - Stimsonite 88, 911 & 948.

F3 - When maintenance replaces the RPM they place them in the middle of the gap and offset them 1" from the path of the line./wir

F4 - Thermoplastic: all suppliers. Epoxy: Stimsonite Standard Set, Magna 38 and 38-IR, DuPont Modified Acrylic, E-Bond 1240/41 and 1242/43, Futura Bonds, DHS Epoxy 1242/43, Tuf-Top. Adhesive Pads: Stimsonite 88-SS, Ferro Asphalt Adhesive Pad, Ray-O-Lite Adhesive Pad.

F5 - On light colored pavements use a 10' white stripe followed by a 10' black stripe followed by a 20' gap.

F6 - Preformed Tape: 2' lane line on 20' C-C's.

G1 - At least 3 RPM's must be visible at all times to the driver. 120' vs. 80'

G2 - Specifications require a 4 inch line width, but State applies a 5 inch line width.

K1 - State selects paint based on performance and supplier can submit either alkyd or chlorinated rubber.

K2 - Linear Dynamics supplies white and Baltimore Paint supplies yellow.

K3 - 4 foot lane lines on 80 foot C-C's for multi-lane roadways and 4 foot lane lines on 40' C-C's for 2-lane roadways.

L1 - More than 14 days, 10' lane lines and 30' gap. Less than 14 days, 4' lane line and 40' gap.

M1 - 3M Diamond Grade Stamark (Model 350); 3M Bisymmetric Tape (Model 5750)/fs

M2 - Bituminous adhesive approved products list: (1) Crafco's Flexible and Standard Adhesive' (2) Stimsonite's Bituminous Adhesive, (3) Renco's Standard Adhesive, (4) Pave-Mark's Standard Adhesive.

M3 - Low ADT: 4' lane line on 40' centers.

N1 - Speed limit >40mph use 80' C-C; Speed limit <40 use 40' C-C.

N2 - When mixed in paint: 3 1/2 lbs. mixed in, 2 1/2 lbs. dropped on per gallon of paint.

V1 - Douglas Chemical, Waterbase white & yellow; Centerline Industries, Alkyd white; Baltimore Paint, Alkyd yellow.

V2 - WB white 1.4 cents; WB yellow 1.9 cents; Alkyd white 1.3 cents; Alkyd yellow 1.7 cents.

V3 - 3M, 320, 321, 350, 351, 5730, 5731, 5750; Catatile; Linear Dynamics HR60; Seibulite MM.

V4 - Asphalt, 1-way $12.50, 2-way $17.00; PCC, 1-way $17.50, 2-way $27.00.

APPENDIX C

State-of-the-Practice Survey

1. How many miles of roadway is your agency responsible for maintaining?

2. What types of pavement marking materials has your agency used, at least on an experimental basis?

Material Type	Surface Type and Application			
	Asphalt		Concrete	
	long lines	transverse	long lines	transverse
Paints(water based/alkyd etc.)				
Thermoplastics				
Preformed Markings				
Epoxy				
Polyester				
Epoflex				

3. What types of pavement marking material and reapplication schedule(time in months before reapplication is necessary) is currently used by your agency?

Material Type	Surface Type, Application and Reapplication Schedule			
	Asphalt		Concrete	
	long lines	transverse	long lines	transverse
Paints				
Thermoplastics				
Preformed Markings				
Epoxy				
Polyester				
Epoflex				

4. Please indicate any special problems that have been encountered by your agency in the use of following. (e.g. poor service-life, adhesion, checking, shifting etc.)

Material Type	Surface Type and Application			
	Asphalt		Concrete	
	long lines	transverse	long lines	transverse
Paints				
Thermoplastics				
Preformed Markings				
Epoxy				
Polyester				
Epoflex				

5. What size glass beads does your agency predominantly use?

6. What is the type of application(drop-on or premix) and application rate of beads employed?

7. Is any specific bead treatment(e.g. adhesion promoter, surfactants) used?

8. Indicate if your agency has tried any large glass beads, the type of marking material and the performance.

Bead Size	Material		Rectroreflectivity		
			Performance		
	type	application thickness	Satisfied	Unsatisfied	Serviceable

9. What do you consider as being the most cost effective combination of marking material and glass bead size for the following?

Area/line type	Material Type	Bead Size
URBAN		
long line		
transverse		
RURAL		
long line		
transverse		

10. Are you aware of any study performed by your agency to determine the effectiveness and durability of different marking material types and large bead size?

____ Yes Please provide a copy of study.

____ No

11. Would you like to receive a summary of the survey results? ____ Yes ____ No.

Thank you for your assistance. Please mail(or FAX) completed surveys by September 12,

1991 to:

Brian L. Bowman, Ph.D., P.E.
238 Harbert Engineering Center
Department of Civil Engineering
Auburn University
Auburn, Alabama 36849-5337

Telephone: (205) 844-6262
FAX: (205) 844-2672