NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

17

PAVEMENT TRAFFIC MARKING

MATERIALS AND APPLICATION AFFECTING SERVICEABILITY

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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PAVEMENT TRAFFIC MARKING

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION
OF STATE HIGHWAY OFFICIALS IN COOPERATION
WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- GENERAL MATERIALS
- MAINTENANCE, GENERAL
- CONSTRUCTION AND MAINTENANCE EQUIPMENT
- HIGHWAY SAFETY
- TRAFFIC CONTROL AND OPERATIONS

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1973

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectvity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The study reported herein was undertaken under the aegis of the National Academy of Sciences—National Research Council. The National Cooperative Highway Research Program, under which this study was made, is conducted by the Highway Research Board with the express approval of the Governing Board of the NRC. Such approval indicated that the Board considered that the problems studied in this program are of national significance; that solution of the problems requires scientific or technical competence, and that the resources of NRC are particularly suitable for the oversight of these studies. The institutional responsibilities of the NRC are discharged in the following manner: each specific problem, before it is accepted for study in the program, is approved as appropriate for the NRC by the NCHRP Program Advisory Committee and the Chairman of the Division of Engineering of the National Research Council.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Highway Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices without in fact making specific recommendations as would be found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available concerning those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Highway Research Board

This report should be of special interest to those administrators responsible for traffic engineering, maintenance, materials research and specifications, and traffic operations. The report offers information on policies and practices affecting procurement of materials, equipment and services, types of materials for marking, and methods of application.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem is frequently not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to resolve this situation, a continuing NCHRP project, carried out by the Highway Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems—a synthesis being identified as a composition or combination of separate parts or elements so as to form a whole greater than the sum of the separate parts. Reports from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems. This is the seventeenth report in the series.

In recognition of the safety and operational benefits of both center line and edge marking the 3.8 million miles of the highway system of the United States, highway agencies have attempted to increase the durability and decrease the drying time of traffic paint, as well as to obtain a less expensive paint. Although durability has been improved by better selection of pigments and vehicles, other factors that influence the performance of traffic paint include the substrate, pavement surface preparation, humidity and temperature during and after application, and the application equipment.

The increased operation demands on the highway network have led highway engineers to consider thermoplastic marking materials, raised markers, and rapid-drying traffic paint for achieving minimal interruption to traffic flow. Other considerations include wet-weather and night visibility, climatic resistance, and costs of application and maintenance. The Highway Research Board has attempted in this project to set down those traffic marking practices found to be most effective. The report discusses these practices from the standpoint of serviceability as it is achieved by the appropriate combination of materials, equipment, and application procedures.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from many highway departments and agencies responsible for highway planning, design, construction, operations, and maintenance. A topic advisory panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

As a follow-up, the Board will attempt to evaluate the effectiveness of this synthesis after it has been in the hands of its users for a period of time. Meanwhile, the search for better methods is a continuing activity and should not be diminished. An updating of this document is ultimately intended so as to reflect improvements that may be discovered through research and practice.

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Valuable assistance in the preparation of this synthesis was provided by the Topic Advisory Panel, consisting of J. Travis Brooks, Highway Engineer, Signs and Marking Branch, Traffic Control Systems Division, Office of Traffic Operations, Federal Highway Administration; Bernard Chaiken, Chief, Chemistry and Coatings Group, Materials Division, Office of Research, Federal Highway Administration; Carl F. Crumpton, Assistant Engineer, Planning and Development—Research Division, Research and Materials Laboratory, State Highway Commission of Kansas; J. Robert Doughty, Director, Bureau of Traffic Engineering, Pennsylvania Department of Transportation; Joseph A. Mickes, Assistant Division Engineer—Traffic, Missouri State Highway Commission; and K. K. Moore, Paint Engineer, Materials and Test Division, Texas Highway Department.

A. G. Clary, Engineer of Maintenance, and W. L. Williams, Projects Engineer, both of the Highway Research Board, assisted the Special Projects staff and the Advisory Panel.

Information on current practice was provided by many highway agencies. Their cooperation and assistance were most helpful.

PAVEMENT TRAFFIC MARKING

MATERIALS AND APPLICATION AFFECTING SERVICEABILITY

SUMMARY

The benefits of traffic lane markings or stripes were obvious to highway agencies by the early 1920's. Experiments with a variety of materials and practices have been conducted; however, the painted stripe continues to be the most widely used pavement marking. Development of a better paint at a lower cost has been a continuing goal. The demands for better traffic services have added requirements for public convenience and safety—such as reflectorized paint, faster drying paint, and improved application equipment. Individuals playing a role in making improvements are research, equipment, maintenance, and traffic engineers, together with procurement officials, paint superintendents, and crew foremen.

Organizations that have been active in paint testing and evaluation include AASHO, ASTM, HRB, NCHRP, ITE and the National Advisory Committee on Uniform Traffic Control Devices.

Factors affecting the performance of traffic paint include:

- Paint formulation.
- The substrate.
- Surface preparation.
- Humidity and temperature.
- Application equipment.

The buildup of paint thickness by numerous restripings is a problem. Efforts to remove the old paint and to prepare the pavement for restriping include the use of air blasts, wire brushing, sand blasting, and pretreatment with mineral spirits, linseed oil, or other primers.

Controlling factors in selecting traffic paints are safety and costs. High-volume routes normally require faster drying paints than do low-volume routes. In order to meet varying requirements, some highway agencies have developed specifications for two or more different paints. Drying terms used in this report are as follows:

Instant dry	Less than 30 sec
Quick dry	30 to 120 sec
Fast dry	2 to 7 min
Conventional	Over 7 min

The thickness of paint film in relation to bead size has not been completely resolved. The drying rate of the paint, premix vs drop-on beads, equipment wear, and bead gradation are factors that must be considered. Most agencies now use unbeaded paint and drop on the beads. The wet paint thickness is usually 15 mils (0.38 mm); however, 10 mils (0.25 mm) has been used successfully. Bead rates vary from 4 to 6 lb/gal (0.5 to 0.7 kg/l). Recent surveys indicate that modified alkyd resin is the most favored vehicle and titanium pigments are given preference.

Hot-sprayed and hot-extruded thermoplastic striping materials have several advantages over standard traffic paint. They are both faster drying and longer lasting; however, they cost more and require special application equipment. Increased use and competition among suppliers have helped to reduce the cost of materials.

Cold thermoplastics or preformed plastic tapes have been limited to special applications and have not been considered as satisfactory as hot thermoplastics.

A major advantage of raised markers is their wet night visibility. The biggest disadvantage is their destruction by snowplow blades. Several highway agencies have experimented with "snowplowable" raised markers with limited success. The FHWA has recommended the use of raised reflective markers to supplement or simulate lane lines, especially on Interstate highways having three or more lanes in each direction.

Traffic paint purchases are based on composition or performance specifications. Each method has been considered satisfactory, although more agencies use a composition specification and some use both.

Several agencies have awarded contracts for furnishing and applying pavement markings. A maximum drying time and a guarantee period are usually specified. The guarantee may be a specified time period or a varying time based on the average daily traffic. Contracts have included both traffic paint and thermoplastics.

Striping equipment ranges in size from small single-line machines to large truck-mounted units capable of placing several lines at a single pass. The larger units have high-capacity air compressors and special heaters for heating paint. Several agencies are now using stripers that utilize high fluid pressure paint spray systems.

Although the instant-dry and similar paints do not require the placement of cones or other devices for protection of the line, the striping equipment itself usually requires a protective vehicle in front and at the rear. When cones are required for conventional paints, special setting and pickup equipment is often used.

Paint supply for high-speed, multi-line stripers can be a problem. Drums are generally agitated and handled with special equipment. Crew sizes vary with the size of the operation and the requirement for protecting the wet line.

The management or scheduling of striping operations varies with different agencies. Some use statewide crews to paint primary routes. Others use regional or district crews and stripe an area before moving on. Special traffic conditions in urban areas often restrict the available striping time.

Problems that have not been solved include the following:

- Rapid wearing of stripes by high-volume traffic.
- Adhesion of paint and thermoplastics.
- Cleaning pavement for restriping.
- Preventing buildup of paint layers.
- Evaluation of daylight appearance vs night visibility.
- Increasing production and maintaining quality of work.
- Economic criteria for selection of marking technique.
- Wet night visibility.

CHAPTER ONE

INTRODUCTION

HISTORY

The father of the center traffic line has been identified as Edward Hines, a road commissioner in Wayne County, Mich. (*2*).

In Wisconsin, Frederick Balsley is credited with the application of the first traffic paint stripe in 1921, when a black stripe was hand painted for a one-block length in the middle of University Avenue in Madison. The Highway Commission concluded that the stripe kept traffic on the right side of the road.

The obvious benefits of the center-line stripe were eventually realized and striping spread to many highway agencies. Various materials other than paint were tried. Lines were depressed in portland cement concrete pavement and filled with asphalt. An asphalt stripe covered with white stone was tried on portland cement concrete and on asphaltic concrete. These and other ideas were soon discarded in favor of the painted stripe. However, there was a need for a suitable material that had characteristics different from those of ordinary paint.

Highway agencies in states, counties, and cities soon were studying specifications and experimenting in the laboratory and in the field to develop a traffic marking paint. The problems of applying the paint soon became apparent and equipment manufacturers constructed equipment for hand and truck striping. One of the first hand-powered stripers consisted of a wheelbarrow frame, a 5-gal (19 l)* tank, and a canvas-wrapped solid wooden wheel (Fig. 1). Paint trickled onto the canvas to be applied as the wheel rolled. The first motor-driven paint striper in Wisconsin (Fig. 2) was built about 1923 (*1*). A paint wheel at left rear of the truck marked the center line. The bicycle wheel at right front of the truck was adjusted to ride the pavement edge. A three-wheeled motorcycle on the back of the truck was used to transport the crew between home and work site.

DEVELOPMENT OF TRAFFIC PAINT

In the 50 years of development of pavement traffic marking paint there always has been a desire for a better paint and lower costs. The increase in traffic volume and the demand for better traffic services have added requirements for public convenience and safety (such as reflectorized paint).

As the mileage placed each year increased, there was a need for faster application rates. This focused attention on the drying time and efforts were intensified to formulate a more rapid drying paint. Examination of early traffic paint specifications indicates that almost everything available to a paint manufacturer was tried in one combination or other at some time. The less durable, very slow drying, and needlessly expensive traffic paints were eliminated.

The application of pavement traffic marking materials has developed into a high-speed process on a truck that travels up to 18 mph (29 km/h). This has been necessary because of the steady increase of pavement mileage to be painted and the relatively short season when paint should be applied. This high-speed process has further influenced the materials that are used and has steadily reduced the application cost. This process has developed through a number of compromises and trade-offs. Chief of these trade-offs is the sacrifice of some durability for more rapid drying.

INDIVIDUALS INVOLVED IN PAVEMENT MARKING

Because of the different organization of highway agencies, there are a number of individuals involved in pavement traffic marking. These are the equipment engineer, the materials engineer (including the paint chemist and technicians), the maintenance engineer, the paint superintendent (including the crew foreman), the procurement officer, the research engineer, and the traffic engineer. Each has a distinct responsibility in the over-all task of obtaining durable and effective pavement marking. Police assistance is necessary in some areas to protect the paint stripe, the paint crew, and traffic.

ORGANIZATIONS INVOLVED WITH TRAFFIC MARKING MATERIALS

The American Association of State Highway Officials (AASHO) has considered traffic marking paints for more than 30 years. At one time, several specifications appeared in their Materials Specification Books. In 1971, the Section on Paint of the AASHO Subcommittee on Materials was reactivated to continue studies and to prepare specifications on traffic markings.

The American Society for Testing and Materials (ASTM) Committee DO1 on Paint, Varnish, Lacquer and Related Products has a subcommittee (DO1.44) on Traffic Paints. This subcommittee has working groups on Accelerated Testing of Traffic Paint, Night Visibility of Traffic Paint, Tests for Consistency, Package Stability, and Drying Time of Traffic Paint. ASTM Committee DO4, on Road and Paving Materials, has a subcommittee (DO4.32) on Highway Traffic Marking Materials.

The Highway Research Board (HRB) has a Committee (A2GO2) on Coatings, Signing, and Marking Materials, which, under various other designations (such as Traffic Zone Paint), has existed for more than 30 years. HRB also has another committee (A3AO2) on Traffic Control De-

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* SI equivalents are conversions of U.S. customary units in accordance with Metric Practice Guide, ASTM E 380-70.

Figure 1. Hand-powered striper. (*Wisconsin Dept. of Trans.*).

Figure 2. Early motor-driven striper. (*Wisconsin Dept. of Trans.*).

vices. The National Cooperative Highway Research Program (NCHRP) of the HRB convenes panels to monitor specific pavement marking research.

The Institute of Traffic Engineers, Department 4, Technical Division, is interested in pavement marking materials.

The National Advisory Committee on Uniform Traffic Control Devices (formerly the National Joint Committee on Uniform Traffic Control Devices) prepared the *Manual on Uniform Traffic Control Devices* (MUTCD) *for Streets and Highways* (*3*). This committee is composed of representatives from AASHO, Institute of Traffic Engineers, National Committee on Uniform Traffic Laws and Ordinances, National Association of Counties, and National League of Cities. The MUTCD has been adopted by the Federal Highway Administrator as a National Standard for application on all classes of highways.

CHAPTER TWO

MATERIALS

TRAFFIC PAINT SUMMARY *

Several factors have influenced the materials used in traffic paint. Although an agency's specifications may have remained unchanged, if composition has not been specified, a manufacturer may have used less expensive materials, compounding, and grinding. However, the influence of competition may have worked to improve the quality of the paint.

Highway agencies have attempted to increase the durability and decrease the drying time of the paint, as well as to obtain less expensive paint. In some cases, durability has been improved by better selection of pigments and vehicles.

In addition to the paint formulation, other factors that influence the performance of traffic paint include the substrate, the preparation of the surface, the humidity and temperature during and after application, and the equipment used in the application of the paint and the beads.

Substrate

The two basic substrates for the paint film are portland cement pavement and bituminous pavement. Each of these varies widely in physical composition, surface chemistry, and porosity. It is well documented that most paints perform better on bituminous surfaces than on portland cement concrete. The hostile environment of portland cement concrete has been often discussed. This environment includes alkali carried to the concrete pavement surface and trapped by the paint film, curing compound remaining on the surface, vapor pressure differential between the atmosphere and the pores of the concrete caused by the paint film, and, in some geographic areas, freezing of water under the film.

A different substrate is encountered when a stripe is repainted. This does not entirely remove the effects of the original pavement surface but does introduce another potential problem—that of the effect of the old paint on the new stripe. The buildup of paint thickness by numerous restripings is reported to be causing trouble. Because most pavements are restriped with no real surface preparation, other than removal of debris and an air blast immediately ahead of the spray gun, many contaminants may be present on the substrate.

Thus, a number of variables may affect the adhesion of the paint to the substrate.

Preparation of the Substrate

There have been conflicting reports on the benefits of various methods of substrate preparation. With some paints, use of a pretreatment solution of orthophosphoric acid in water gave better adhesion on concrete pavement. No cost/benefit ratio was given in any of the reports where the treatment improved adhesion.

Sandblasting is an expensive method and a hazard to traffic. Dale (*4*) showed that wire-brushing was the most effective way of cleaning concrete when an epoxy cement was used as an adhesive for a raised marker.

Several states use an air blast immediately ahead of the paint spray and find it effective in blowing off debris and old flaking paint stripes. With some striping equipment this requires additional compressor capacity.

The U.S. Corps of Engineers (*5*) reported improved adhesion of paint to sandblasted concrete with a pretreatment of a 50/50 solution of mineral spirits and linseed oil.

It has been reported that one district of the Texas Highway Department uses a 50/50 solution of mineral spirits and linseed oil to pretreat the concrete several days prior to paint striping. The District Engineer believes that better adhesion is obtained. The solution is available at all Districts in bulk, as it is used primarily to treat all new concrete bridge decks for protection from deicing chemicals.

The maintenance manual of the California Division of

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* See Appendix A for a review of the literature.

Highways recommends use of a primer on all new pavement surfaces. Four to 5 gal of standard traffic paint (no beads) is applied per mile (9 to 12 l/km) of broken stripe to either portland cement concrete or asphaltic concrete. It is allowed to dry on the asphaltic concrete until bleeding stops, but can be covered immediately on portland cement concrete with 7 gal/mile (16 l/km) of standard beaded traffic paint (6 lb of beads per gallon of paint; 0.7 kg/l). Previously, on portland cement concrete the primer could also consist of 15 percent Buna N rubber dissolved in methyl ethyl ketone. Perma-Bond or Pliobond or equal containing 15 percent solids were permitted. Currently, only the standard traffic paint is used for primer and is required to be used on all new pavement surfaces.

Selection of Paint-Bead System

The most efficient and economical system for any pavement and traffic situation can be selected only by making a number of compromises. Materials, equipment, and procedures are available to meet almost any situation. Safety and cost generally are the controlling factors. The selection options for a rural highway with a low average daily traffic (ADT) are different from those for an urban highway with a high ADT. The drying time for the paint, the type of application equipment, and application procedures are among the factors that should be considered.

A number of state highway agencies currently specify two types of traffic paint; several specify three types. As striping equipment is replaced or rebuilt, there is a trend toward using hot paint. Most agencies are providing for use of a moderate-heat paint for better viscosity control and uniformity of stripe. Generally, the changeover is done by districts to avoid mix-ups and to simplify logistics.

The terms indicating drying times are legion. Standard definitions should be established. In this report, the terms used are as given in Table 1.

Several instant dry materials have been used for marking pedestrian lanes where traffic was controlled by a traffic signal. The material was applied during the red interval and traffic drove over the stripes immediately thereafter without pickup. However, in one case the beads were pushed down into the paint and nonuniform reflectivity resulted.

A number of states have used the quick and the fast dry paints with considerable success. High humidity or other weather conditions can make the drying times longer than expected. These paints, available from a number of manufacturers, are relatively new and development of shorter drying times and improved serviceability is expected.

Many organizations have had a long history of successful use of the conventional paints and numerous specifications have been developed for these paints. However, the use of conventional-drying paints is decreasing because the heated or faster-drying paints offer advantages (such as elimination of stripe protection).

The efficacy of the combination of paint film and bead size has been frequently discussed. The theoretical considerations of film thickness and bead size must be adapted to the reality of the operations of stripe 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 method 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.

About 20 percent of the state highway agencies use the "beads-in-paint" (premix) type of traffic paint, supplemented by some "drop-on" beads. Over the years, a number of agencies have changed from the beads-in-paint type to the nonbeaded paint with drop-on beads, although some have started with drop-on beads and changed to premix and then returned to drop-on beads. Many premix users had troubles with equipment, particularly with excessive wear of paint spray-gun nozzles. Settlement of the beads in the paint during storage and handling was an acute problem in the early days. This was partially solved by use of smaller-size beads and suitable suspension agents in the vehicle plus drum rolling equipment and stirring equipment.

North Carolina and Ohio are presently large users of premix paint. Three to 4 lb of fine-gradation beads per gallon (0.4 to 0.5 kg/l) of paint are generally premixed with the paint and 2 lb of coarser beads per gallon (0.2 kg/l) of paint are dropped on the wet paint line. The State Prison Enterprises manufacture the premix paint for North Carolina on order. North Carolina highway officials state that convenience of use and better distribution of the beads in the paint film are their chief reasons for use of premix. Their performance tests on a number of paints, using both premix and drop-on beads, showed better durability for the premix. Bead settlement is not a problem, as their district headquarters are equipped with drum rollers and the paint is seldom stored for an appreciable time.

It appears that the advantages of drop-on beads—less nozzle wear, faster drying, less paint agitation needed—outweigh the advantages of premix. Indeed, about 80 percent of highway agencies use nonbeaded paint and drop on all of the beads. Because drop-on-beads are needed for immediate reflectivity when the premix type is used, it is reasonable to apply all of the beads at one time and eliminate the beads from the paint.

A wet paint thickness of 15 mils (0.38 mm) (16.5 gal/mile of 4-in. solid line) (39 l/km of 100-mm line) and 5 lb of beads per gallon (0.6 kg/l) of paint have been the most prevalent rates of materials application. Kansas has used a 10-mil (0.25-mm) wet film thickness with 4 lb of nonfloating, low-index beads per gallon (0.5 kg/l) since 1969. Colorado reported savings by changing from 6 lb/gal (0.7 kg/l) of 20- to 200-mesh (non-floating) beads to 4 lb/gal (0.5 kg/l) of 30- to 80-mesh floating beads (*23*), as well as superior brilliance and durability with the floating beads. A number of other states have decreased their wet paint thickness and the amount of beads applied. Wyoming reports using a 3- to 5-mil (0.08- to 0.13-mm) dry thickness and 5 lb of beads per gallon (0.6 kg/l) of paint. It is not uncommon to use 10- to 12-mil (0.25- to 0.30-mm) wet thickness for restriping in some states. Restriping is generally based on daytime appearance; however, many miles of satisfactory stripe are repainted because of other restriping nearby.

There has been some research and 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. Thus they are not practical for use with many quick-drying paints.

When nonfloating beads are dropped on an unskinned paint film, the large beads sink first (according to Stokes Law), followed by successively smaller beads. Fortunately, for better reflectivity, a great number of the small or intermediate-size 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. Discussions of bead-paint film geometry have been included in several reports (*6, 7*). The real objective is to attain the theoretical optimum geometry while solving the practical problems of paint and bead application to the many types of irregular and uneven surfaces using paints of widely different drying properties.

When skinning of the paint film results from too fast surface drying, fewer beads will drop into the film and it is then necessary to apply the beads pneumatically immediately following the paint spray. The fast drying may be caused either by use of a heated paint or by high volatility of the solvents in the paint. What size beads remain on top is problematical.

Traffic Paint Formulation

A traffic paint survey completed in 1950 (*8*) indicated that paint formulation was of early interest. Titanium pigments were preferred, followed by zinc oxide, and lithopone. Magnesium silicate was a first choice as an extender pigment. Alkyd resin type was the preferred vehicle, followed by phenolic resin varnish and phenolic varnish dispersion resin type. More recent surveys indicate that the modified alkyd resin is favored by more users than any other type. At least 10 states are using modified alkyd-chlorinated rubber type vehicle and others are investigating it.

New York found that 40 percent of titanium pigment produced a paint that was as durable as their standard paint, which contained 70 percent of titanium dioxide in the pigment portion (*9*).

Paint composition is discussed in reports by Chaiken (*10*) and Frank (*11*). Frank discusses how certain ingredients influence the performance of the paint and beads, and points out that the present methods of measuring and specifying viscosity lead to erroneous conclusions concerning spraying consistency. He attributes this to the inability of the viscosimeters to measure viscosity at the high shear rates encountered during spraying.

TABLE 1

TERMS USED FOR PAINT DRYING TIME

TERM	DRYING TIME
Instant dry	< 30 sec
Quick dry	30 to 120 sec
Fast dry	2 to 7 min
Conventional	> 7 min

Many organizations avoid specifying composition by using a performance specification and by specifying physical properties relating to handling, spraying, and drying. (See Appendix B for a list of specifications for traffic paint and glass spheres.)

SULFUR MARKING MATERIAL

One of the early experimental uses of sulfur for pavement marking was reported by Hancock (*12*). His work indicated that a number of problems existed when sulfur was used as a marking material, but that some promise was indicated. Good durability and bead retention were reported for sulfur in field tests conducted by the manufacturer in several states (*13*). The California Division of Highways (*14*) reported that the sulfur white lines did not comply with the California yellowness index specifications. Other reports indicate that adhesion is a major problem. (See Appendix A for more details.)

THERMOPLASTIC TRAFFIC MARKING MATERIAL

Hot Thermoplastic

Hot thermoplastic striping material includes the hot-extruded type as well as the hot-sprayed type. Each of these solvent-free solids must be heated to a molten state—approximately 425°F (218°C) for most materials—for application. Use of the hot-extruded material has practically doubled since 1965 (*15*). The hot-sprayed material is a more recent development and is generally applied at a lesser thickness.

Thermoplastic striping material has several advantages over standard traffic paint. It is faster drying or setting and longer lasting. These advantages are somewhat offset by its much greater cost and the need for special equipment. Most of it has been applied by specialty contractors. A 1965 national average cost reported by Chaiken (*16*) was $0.327 a linear foot ($1.07/m) of 4-in. (100-mm) stripe. This cost generally represented large contract installations on highways. The cost of traffic paint was reported as $0.022 per linear foot ($0.072/m) of 4-in. stripe.

The Chaiken report is based on questionnaires returned by 52 highway departments, 17 toll road and bridge authorities, and 16 cities and counties. It covers the project and location, ADT, type and age of pavement, snowplow activity, date striped, primer used, thermoplastic used, type of stripe, amount of striping, installation cost per linear foot, amount of stripe lost, useful life, and standard paint striping data for 1965. Chaiken developed a guide for selecting the most economical striping material, either paint or thermoplastic (Fig. 3). Mean annual snowfall in inches is needed to use Figure 3 because snowplow activity greatly affects thermoplastic adhesion. Using the mean annual snowfall from Figure 4, the type of pavement surface, and the actual ADT, one can estimate whether traffic paint or hot-applied thermoplastic would be more economical.

Some of the more recent prices, for both contract and work by state forces, are much lower than the 1965 prices used to prepare Figure 3 and this should be considered when making a choice between thermoplastic marking material and traffic marking paint.

Typical specifications for primers and the thermoplastic materials are also included in Chaiken's report. The majority of organizations were using proprietary materials.

Chaiken concluded that hot-extruded thermoplastic striping is much more durable on bituminous pavements than on portland cement concrete pavements and recommended research in this area:

> Although many such installations have performed well, the greatest deterrent to the wide use of thermoplastic striping is its sporadic, and sometimes unexplained, failure on concrete surfaces. Research to improve this situation should be sharply emphasized. Suggested for such investigations are the following parameters and their contributions to thermoplastic performance on concrete: surface cleaning and preparation, improved primer formulation, rate of primer application and its relation to the age and nature of the concrete surface, time interval between primer and thermoplastic application, and feathering of thermoplastic leading edge and sides to reduce snowplow destruction.

Tooke (*17*) made extensive laboratory tests and field evaluations of known formulations of thermoplastic materials. He made systematic formulation studies and studied the effect of different ingredients and quantities of ingredients on the physical and mechanical properties of the thermoplastics. He also studied the effect of primers on bonding to concrete. He found that epoxy primers were superior to rubber-phenolic primers in improving the bond of thermoplastic to concrete and that priming is essential to good service life. He concluded that a thickness of ⅛ in.

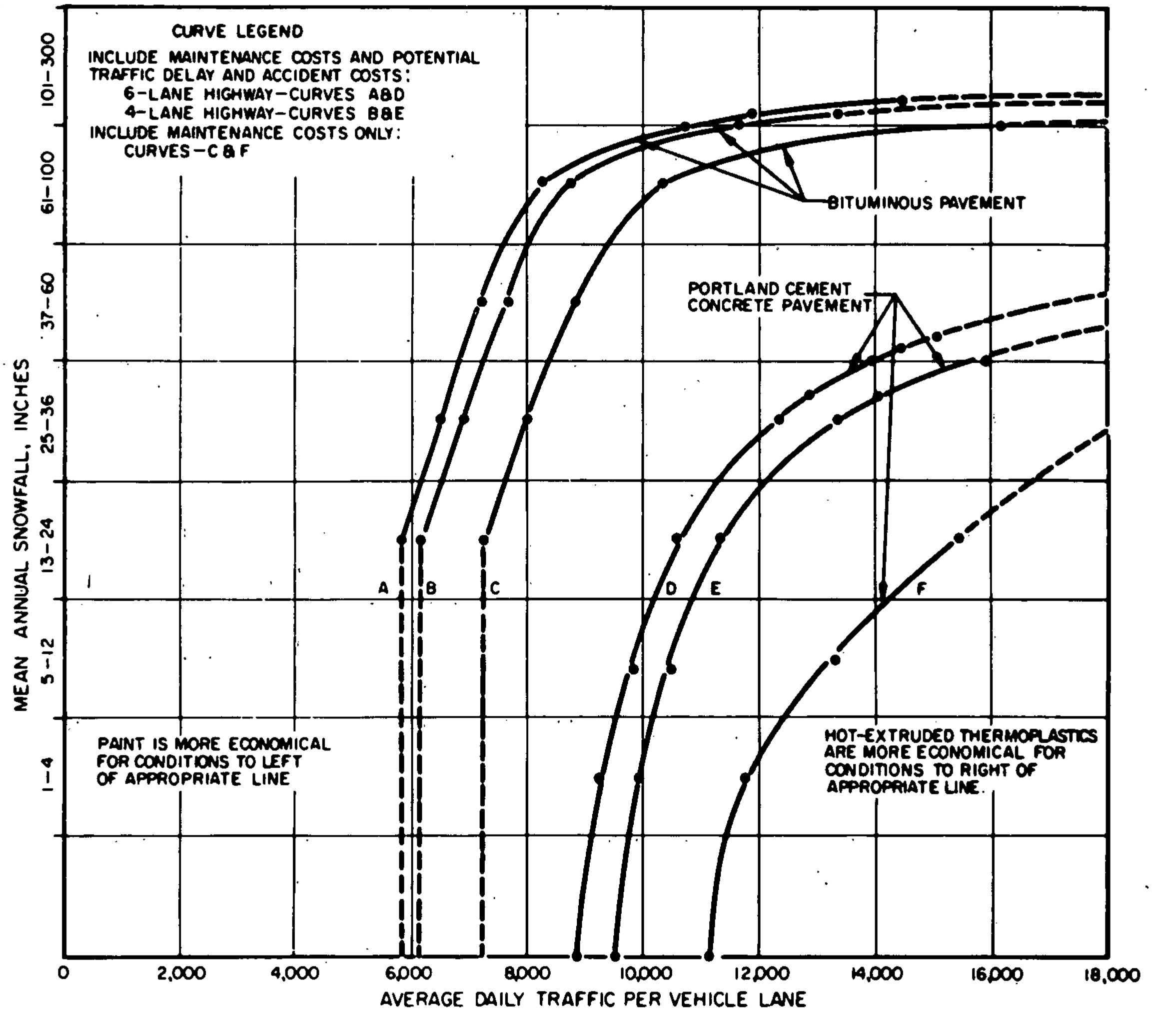

Figure 3. Guide for selecting the most economical striping material, paint or thermoplastic (16).

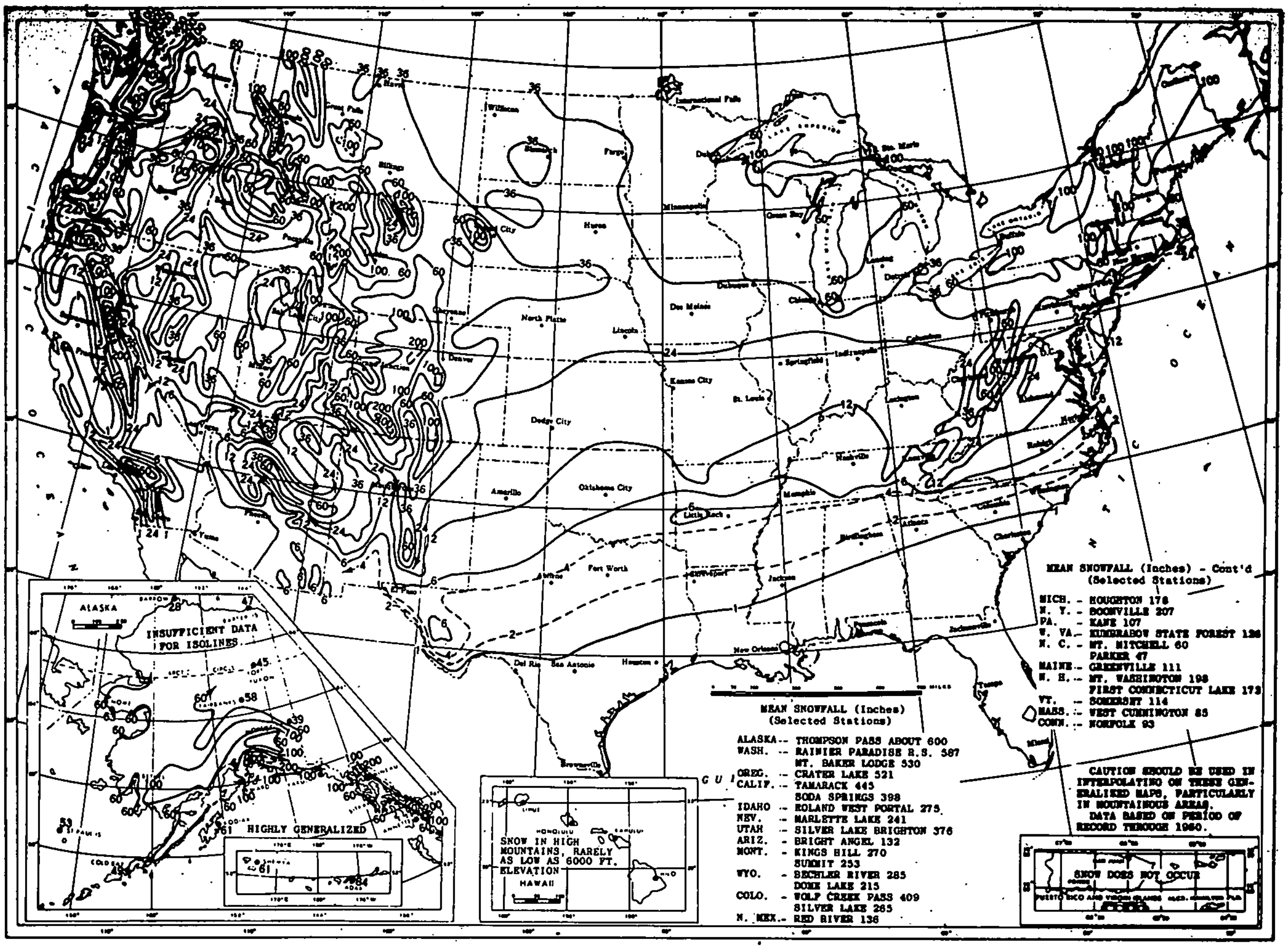

Figure 4. Mean annual snowfall, in inches, in the United States. (Prepared by U. S. Dept. of Commerce, revised 1966).

(3.2 mm) was optimum for thermoplastic stripes in Georgia.

Despite his formulation studies, Tooke presented a specification based on physical properties and performance in the appendix of his report. Also presented were specifications for primers.

The Institute of Traffic Engineers has developed a model specification for thermoplastic marking materials, including a section on road service tests (*30*).

Cold Thermoplastic

Cold thermoplastic stripes, also called preformed plastic stripe or tape, generally consist of a plastic reflectorized or unreflectorized strip coated with a pressure-sensitive adhesive. A paper backing protects the adhesive from sticking when the stripe is in a roll. A primer is required on the pavement with some material. The stripe is applied manually (Fig. 5) or with a machine that removes the protective paper backing as the stripe is rolled or tamped onto the surface of the pavement. Traffic may drive over the stripe immediately after application. These stripes have been used for marking pedestrian crossings and for pavement legends for some time. Little has been used for rural highway pavements.

Another type of cold thermoplastic stripe has been used for temporary markings of detours and for other short-time needs. This type of prefabricated stripe is generally much thinner than those intended as permanent markings.

New York reported on several trial sections installed in 1959 and 1960 (*25*). A conclusion was that the cold thermoplastic was not providing satisfactory service on rural state highways because the stripes were not clearly visible to the motorist unless overhead lighting was provided, and in some cases the stripes were removed by traffic and snowplows in a few months. The plastic stripes did not perform as well as paint lines in the same area.

Arkansas reported that cold thermoplastic tape does not give satisfactory service on portland cement concrete pavement (*26*).

California reported that the plastic tape (3⁄32-in. or 2.4-mm thickness) is not as durable on crosswalks as the hot-extruded thermoplastic traffic stripe (*27*). The lack of adhesion and distortion of the plastic tape under traffic in crosswalks is caused by turning action and rapid acceleration of vehicles. When applied as lane line delineation

Figure 5. Applying cold thermoplastic stripe.

where turning action and acceleration are less pronounced, the cold plastic tape and the hot-extruded thermoplastic stripe are essentially equivalent when both are applied over sandblasted concrete.

However, cold thermoplastic stripes have been used successfully in several cities, especially when rolled into the final pass of new bituminous pavement where good, overhead lighting is provided.

The ITE specification (*30*), noted in the previous section, also covers cold thermoplastic.

Thermo-Applied Pavement Marking Powder

Thermo-applied pavement marking powder, also referred to as thermoplastic striping powder, requires a special striping machine for its application. The powder (or granules) is a dry mixture of pigmented resin granules intermixed with glass beads. The material contains about 15 to 25 percent of titanium dioxide and 30 to 35 percent of glass beads by weight. It must be free flowing when exposed to high humidities (90 percent R.H.) and high ambient air temperature (100°F; 38°C). This ensures that sufficient material will be available for melting and deposition on the pavement at the speed that the machine travels. The material is heated and applied with compressed air.

The material should not be applied on pavement surfaces that have been previously treated with concrete curing compounds, paint, or other material. The surface must be clean and free from foreign materials.

Because the material dries almost instantly, it has an advantage for use on pedestrian crosswalks and busy urban streets. The material cost is about eight to ten times that of traffic paint for the same dry thickness (10 mil; 0.25 mm). Documented cost and performance data have not been found.

RAISED MARKERS

It has long been observed that painted traffic stripes lose their effect when covered by water, as the retro-reflectivity of the beads can disappear. The need for satisfactory wet night visibility has been recognized for some time and has become acute on multilane high-speed freeways. Various types of raised markers have been devised to overcome this deficiency.

California was one of the first to experiment with plain and reflectorized buttons and wedges. Botts pioneered in the development of a ¾-in. (19-mm) high, 4-in. (100-mm) circular button in which epoxy was used. (These were first known as Botts Dots.) In early experimental installations the buttons were used both as supplemental delineation and in lieu of the painted stripe. Some of the experimental work is covered in a 1963 report (*18*). Development of a wedge-shaped marker is included in this report, as well as observations on day and night visibility and overhead lighting. California also developed an epoxy adhesive for the markers. Like many other adhesives this did not set as fast as many conditions required, so they developed a rapid-set adhesive. The latter development is described in another research report (*19*). The rapid-set epoxy adhesive is required whenever the air or pavement temperature falls below 50°F (10°C).

Portland cement concrete raised markers containing glass beads have proven as durable as epoxy or polyester markers. The portland cement matrix wears away very slowly, presenting a new surface and additional beads that provide better visibility than the epoxy or polyester markers.

Israel (*20*) described a study on a 9-mile (14.5-km) length of six-lane freeway in which fully beaded wedges were used in lieu of painted lane lines. With 70 percent glass beads, these markers were relatively difficult to see on white concrete during daylight hours. A study covering two years of operation compared this installation to the adjacent six-lane freeway, which was marked with standard painted traffic stripes. It was found that for this period there were 27 percent less accidents and 61 percent less fatal and injury accidents on the section with the raised markers. Traffic observations indicated some 40 percent less lane changes on the section with the raised markers. Because of the better traffic distribution, the primary reduction in accidents was in the rear-end category. Israel thought that the rumble effect to alert sleepy or indifferent drivers should reduce accidents on any type of road. The reduction in lane changes was also observed in Washington (*21*).

A California report (*22*) describes the different types of raised markers used or experimented with from 1953 to 1968. Less staining of ceramic markers than of plastic types was reported. Both types are included in the specifications. A service life of 20 years is predicted for beaded and nonbeaded polyester or epoxy markers on portland cement concrete pavements (*18*). The much higher coefficient of expansion of epoxy markers with high resin content could be one of the causes of failure on portland cement concrete.

The ceramic markers pit to various degrees depending on the traffic, but are expected to have a service life of ten years. California has two types of ceramic markers in their specifications. One is for use exclusively on portland cement concrete pavement; the other can be used on either portland cement or asphaltic concrete pavement. Raised markers are used only in snow-free areas.

Dale discussed the need and the advantages of improved pavement marking materials (*7*) and the development of formed-in-place reflective pavement marking materials (*4*). In the latter report, he described the development of a prototype machine that was used to clean the pavement, apply an epoxy resin, and drop 19 0.25-in. (6.4-mm) diameter glass beads into the epoxy. The epoxy required about 10 to 20 min to harden. The formed-in-place markers were placed on trial sections in ten states. It was reported that the markers performed well except in areas of snowplow activity. The installed cost of these markers was $0.31 each, compared to other reported costs of $0.65 each. Dale gives tables of estimated costs per mile of combinations of commercial reflectorized markers with painted lines, with nonreflectorized markers, and with thermoplastic traffic lines.

A number of highway departments in nonsnow areas have trial installations of beaded paint stripes supplemented with commercial acrylic cube corner reflective markers. The reflective markers are generally spaced at 80-ft (24-m) intervals in the skip area on tangent sections and at 40-ft (12-m) intervals on curves. The cube corner molded plastic marker has been used in a number of these installations.

Raised traffic markers are damaged or removed by snowplowing. However, use of rubber snowplow blades may reduce the loss of raised markers under certain circumstances (*44*). To overcome the possible damage done by snowplows to the raised traffic marker, a "snowplowable" marker was designed. A reflective unit similar to that used in the standard cube corner marker was incorporated in a hardened steel casting. The casting is set into grooves cut into the pavement and is held in place with an epoxy adhesive. The castings are tapered, in the hope that a snowplow blade will ride up and over the markers without damaging either the blades or the reflective elements mounted in the steel housing. The reflective elements are strips of precision-molded high-strength acrylic plastic.

The Pennsylvania Highway Department began testing the experimental "snowplowable" markers in December 1966. Several field installations were made with various spacings, pavement surfaces, and ADT. The spacing of markers in groups of three, 7½ ft (2.3 m) apart with the groups 65 ft (20 m) apart to fit the 80-ft (24-m) cycle of 15-ft (4.6-m) line and 25-ft (7.6-m) skip space, was abandoned after one year because of complaints from snowplow operators. In general, findings indicate that a 40-ft (12-m) spacing of single markers was adequate. Relatively few of the single markers were removed by the snowplows, but the reflective units could not be maintained because of tire chains, snow tire studs, and other undetermined causes.

New York discontinued their trial installations of "snowplowable" markers due to severe damage by snowplows equipped with tungsten carbide blades. Syracuse, N.Y., installed one-way "snowplowable" markers to delineate flush painted channelization in July 1970. Examination after one winter showed that a number of markers were missing or damaged. There was considerable evidence of two-way plowing—the short ramp of the marker in many cases showed evidence of being struck. Several markers had gouges on the long ramp and there was evidence of cracks in the epoxy in the grooves. The cost of one marker, including installation by city forces, was about $4.25.

NCHRP Report 130 (*24*) shows photographs and describes a number of different markers. Materials, maintenance, costs, and environmental effects are discussed.

The ITE Committee on Raised Pavement Marking sent questionnaires to states and cities in August 1971. The replies to these will be used in a state-of-the-art report on raised pavement markings.

HRB Committee A2GO2 on Coatings, Signing and Marking Materials is currently preparing a report on the materials and quantities used for all marking materials for

FY 1971 by state highway agencies. This report is planned for release in 1973. A preliminary report presented at the 1972 Committee meeting showed a total of about 3.8 million raised markers in service, an increase of about 350 percent since 1962.

The Federal Highway Administration recommends use of raised reflective markers, especially on Interstate highways having three or more lanes in each direction, to supplement or simulate lane lines. Details are set out in Instructional Memorandum 21-3-72.

CHAPTER THREE

PROCUREMENT

PAINT PURCHASING

A 1950 survey of traffic paint users (*8*) indicated that about as many base purchases on a composition specification as on a performance specification. Recent information indicates that most use a composition specification, but many are using both composition and performance specifications.

Proponents of the composition specification believe that this procedure secures the type of paint that has been specified. However, it has been acknowledged that the manufacturing operation may produce an inferior performing paint even though the paint meets the composition specification. Several composition specifications are referred to in Appendix B.

The performance method of purchasing traffic paint requires considerable time between issuance of invitations to submit samples and the actual award of the purchase contract. Generally, the following steps are taken:

1. Invitations are sent to manufacturers to submit samples of each type of paint. These may include specifications for physical properties.
2. Samples are tested in the agency's laboratory for physical and application properties. If application properties are suitable, samples are also placed on pavement in field test sections (Fig. 6). Ratings of the test stripes are made at certain intervals. The road service test is generally conducted in accordance with ASTM Method D 713 or a similar method.
3. Quotations are requested from those manufacturers whose samples complied with specification requirements for physical properties and met the minimum performance requirements in the road service test.
4. The bid prices are analyzed and the cost per unit of length per unit of time of useful life of each paint is determined using each manufacturer's bid price per gallon and test performance ratings. The contract is awarded on the basis of the low cost per unit of length per unit of time of useful life rather than on the low price per gallon of paint.
5. A certificate of analysis is frequently part of the bidding requirements. If required, it is generally furnished with the paint samples.

HRB Committee A2GO2 has prepared an outline or model for procurement based on performance tests (*28*). The Institute of Traffic Engineers has also prepared a model performance specification for paint (*29*) as well as for thermoplastics (*30*). Burch (*31*) was one of the earliest advocates of the performance test and the first to suggest the method of computing the cost per foot per day of useful life. Bollen and Zuick (*32*) discussed the procurement system for one state using performance tests as the basis. Goetz (*33*) suggested use of performance tests rather than composition specifications.

Generally, proponents of the performance specification believe that this system allows the manufacturer to introduce the use of new materials and that the paint is tested in the same environment in which it will be used.

Because performance specifications and composition specifications have been used for more than 20 years by almost equal numbers of users, there appears to be no well established preference or superiority of one type over the other.

Several state highway agencies purchase traffic paint from their state prison industries. In some states this method of purchase is required by law. Little published information is available on the success of these arrangements.

CONTRACT PAVEMENT MARKING

Kelley and Johnson (*34*) reported on several contracts for furnishing and applying pavement markings. Each of the first three contracts in 1966 was for furnishing and applying cold paint on approximately 700,000 ft (213,000 m) of solid and broken lines. The bid price on each contract was $0.0225 per ft ($0.074/m). In May 1968, 26 lane-miles (42 km) of thermoplastic were applied by contract at $0.33 per ft ($1.08/m). In October 1969, an experi-

Figure 6. Applying test stripes.

mental contract for 99,000 ft (30,200 m) of cold-applied reflectorized tape was awarded for $0.37 per ft ($1.21/m). Both installations were required to be guaranteed for two years. The tape did not prove to be satisfactory; although the adhesive was good and the aluminum backing was durable, the binder and beads flaked excessively. The contractor had to replace the tape twice and finally repainted the lines within the period of the contract.

In 1970, Massachusetts prepared a special provision for contract application of fast-dry marking. The reflectorized line was required to dry to a track-free condition in 180 sec or less. Use of protective devices for the wet lines was not permitted; however, protection warning trucks were required. The contractor was required to guarantee the lines for a period of 24 months after the original application. Standards of failure and a procedure for notifying the contractor to replace lines were developed. Installment payments were scheduled throughout the guarantee period. Deductions could be made from the contract payments if pavement marking failures were not replaced within 24 hours after written notification. The bid price for the 24-month guaranteed fast-drying marking was $0.17 per ft ($0.56/m) on one contract and $0.18 per ft ($0.59/m) on another contract.

Florida's latest specification requires a guarantee that varies with average daily traffic (Table 2). The guarantee applies to longitudinal thermoplastic marking only.

Table 3 gives recent costs in several states for contract marking.

TABLE 2

MARKING GUARANTEE REQUIREMENTS (FLORIDA)

ADT (1,000's)	GUARANTEE (MONTHS)
40	12
30–40	18
20–30	24
10–20	30
<10	36

TABLE 3

SOME 1971 COSTS OF CONTRACT MARKING [a]

STATE	MATERIAL	COLOR	QUANTITY (FT)	QUANTITY (M)	COST ($/FT)	COST ($/M)
New Jersey	Traffic paint	White	17,557,414	5,351,500	0.013	0.043
		Yellow	1,337,583	407,695	0.013	0.043
Oklahoma	Thermoplastic	White	225,000	68,580	0.315	1.033
		Yellow	17,000	5,182	0.285	0.935
S. Carolina	Thermoplastic [b]	White	502,134	153,050	0.130	0.427
Dist. of Col.	Thermoplastic	White	96,362	29,371	0.566	1.857
Illinois	Thermoplastic	White	908,626	276,949	0.350	1.148
		Yellow	122,700	37,399	0.350	1.148
Florida [c]	Thermoplastic	White	1,792,481	546,348	0.140	0.459
Arizona	Thermoplastic	White	595,000	181,356	0.120	0.394

[a] From Ref (*15*).
[b] Sprayed.
[c] Combination of contractor-supplied equipment and state forces.

CHAPTER FOUR

EQUIPMENT–PROCEDURES–POLICIES

PAINT STRIPING EQUIPMENT

Two general types of striping machines are in use. One is the small, self-propelled, manually controlled, low-capacity machine (Fig. 7) that can be used for striping crosswalks and other transverse lines. The other is the heavy-duty, multi-line, truck-mounted unit.

The truck-mounted, multi-line, high-production striper is almost always used for longitudinal striping. The truck must be large enough to carry all of the necessary striping equipment and should have sufficient power to maintain a steady speed up grades in order to allow the spray equipment to produce a uniform stripe. The striper truck must be equipped with special warning lights and, if not preceded and followed by protecting trucks, signs to properly warn traffic and to direct proper passing movements. It must be equipped with a device that will enable the driver to follow a series of targets on the pavement or to follow a previously placed line. The device must be retractable so that it can be lifted free of the pavement when the striping operation is discontinued or the device is not in use. A mirror or a bombsight device has been used on some trucks. A current model of striper used to apply heated paint is shown in Figure 8.

Two different methods may be used for supplying the traffic paint to the spray guns. In one, the paint drums are lifted from a supply truck to the striper truck by a hoist and the paint is then pumped directly from the drums to the paint guns. Kansas uses this method, with a valved T in the hose that permits pumping from either of two drums. The Kansas striper is shown in Figure 9. In the other method, paint tanks are located on the striper. These may be filled from drums or tankers by either mechanical pumps or air pressure. In either method, the paint screens that must be used in the lines must be freely accessible so they may be cleaned frequently. Additional screens should be located close to the paint spray guns.

The striper truck should be equipped with an accurate tachometer so that the truck speed is known. A volume meter for each paint supply is a valuable addition to monitor the quantity of paint applied.

Some cleaning solvents are corrosive to certain metals, so it is necessary to ascertain this when selecting equipment. The hoses that connect fixed parts of the paint spray equipment to the movable parts must also be resistant to the cleaning solvent being used and to the solvent used in the paint.

An air pressure system transports the paint to the spray guns at a pressure determined by the quantity of paint to be delivered. It also supplies air at a lower pressure to an air jet at the paint nozzle to atomize the paint. Air also moves the glass beads from the bead tank to the gravity-type bead dispensers. If hot paint is used, the glass beads are pneumatically applied. Air is also used in control valves for the paint guns, etc. Some agencies use an air blast just ahead of the paint gun to blow loose paint chips and other debris from the area being sprayed.

The air supply comes from an air compressor driven by a gasoline or diesel engine. Both of these are mounted on a skid frame that is bolted to the truck bed. Controls should be provided so that the engine power matches the load on the compressor. Protective devices should be provided to shut down the engine in the event of a malfunction.

The air pressure is also connected to the cleaning system, which consists of a tank of paint solvent that can be connected to the paint lines and nozzles by suitable valves. The lines, nozzles, and screens must be cleaned daily after use. The cleaning solvent is returned to a drum on the striper truck.

Figure 7. Small, self-propelled striper.

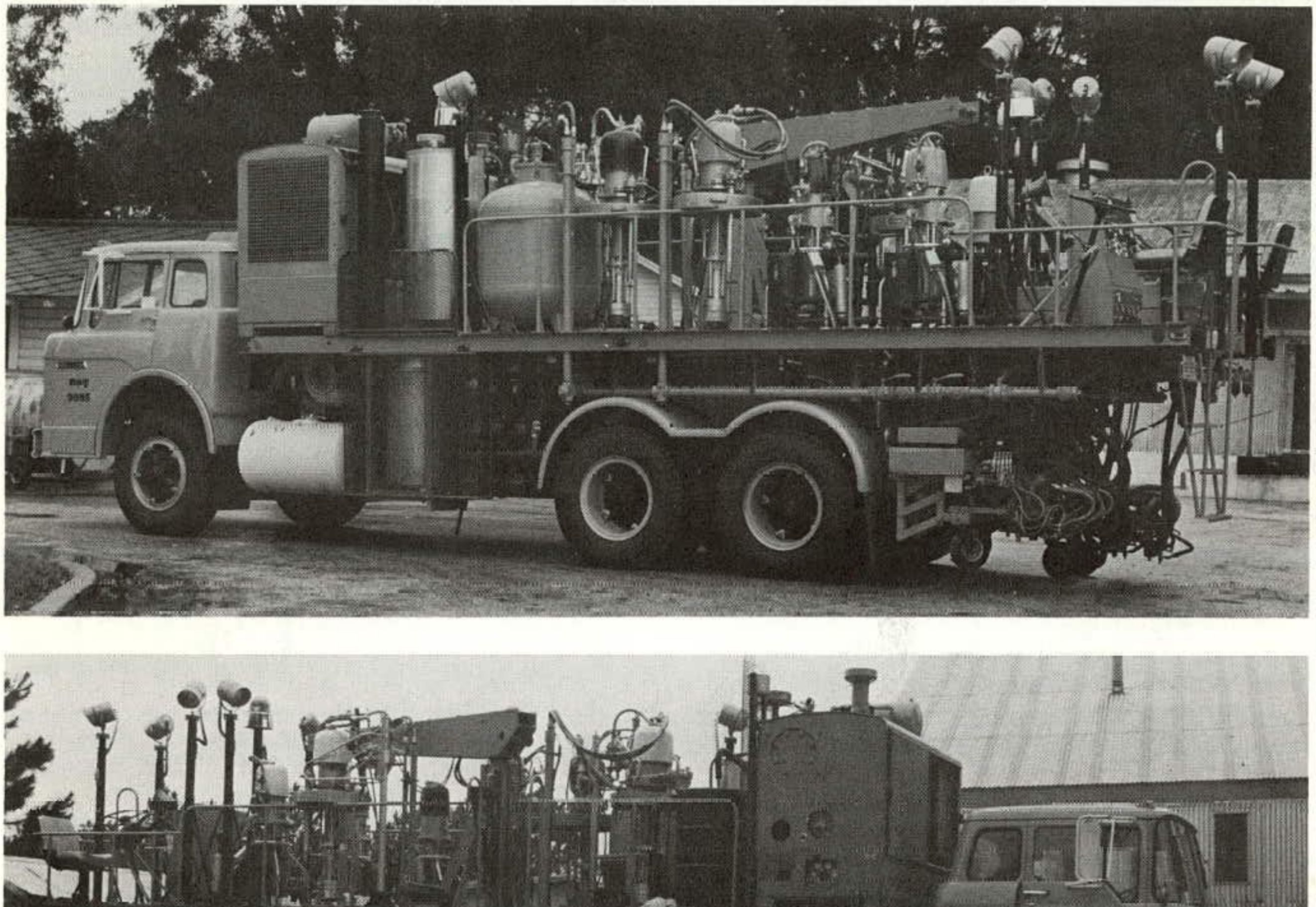

Figure 8. Heated paint striper (Florida).

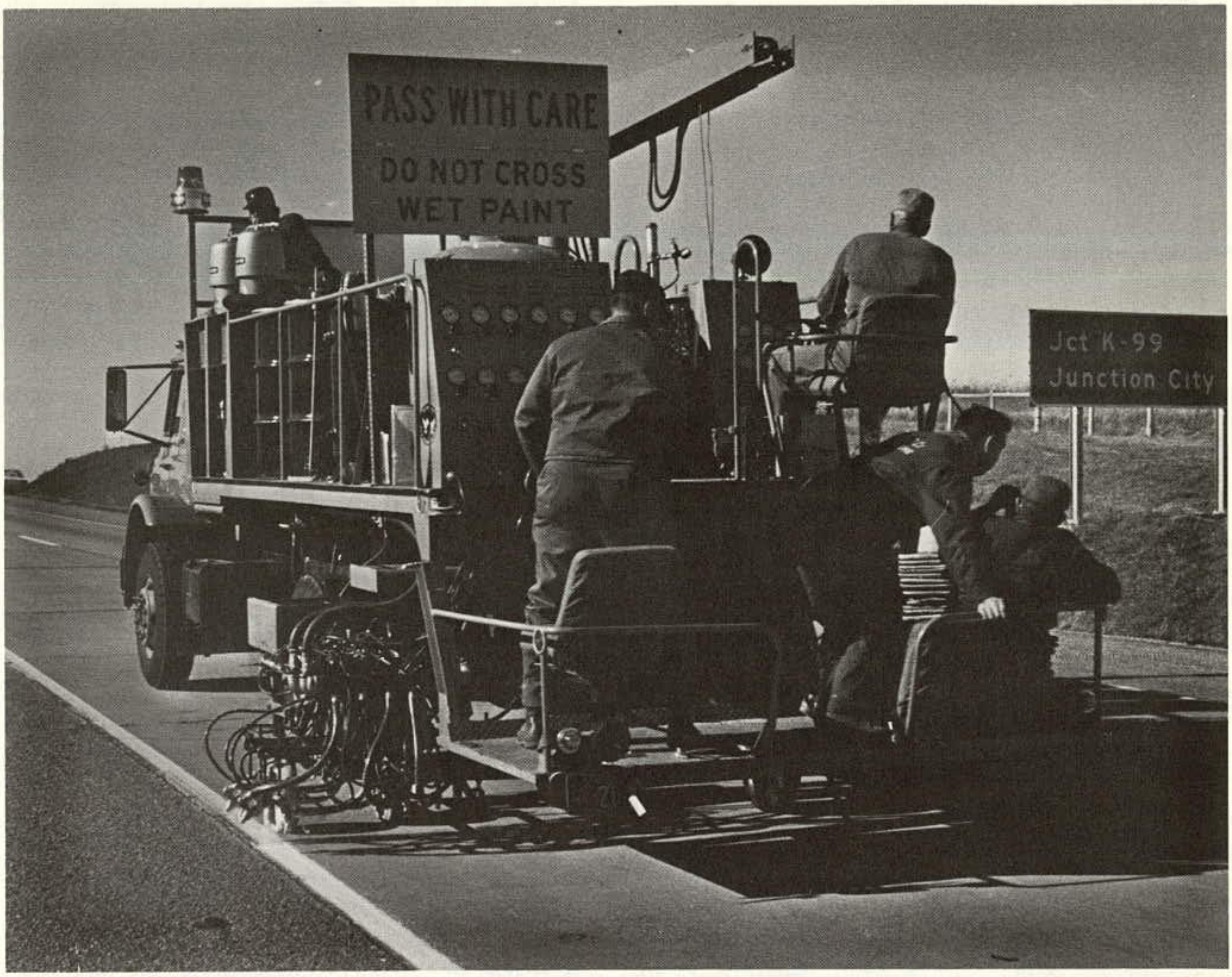

Figure 9. Striping operation.

The paint spray guns and bead dispensers are mounted on carriages underneath the truck bed just behind the rear axle (Fig. 10). The carriages can be moved laterally by the spray gun operator. A positive placement of the carriage is required. If edge lining is done at the same time as center lining, two carriages are needed.

The paint spray guns and bead applicators are synchronized so that the bead applicator starts at the appropriate time after the paint spray gun starts. All spray guns and bead applicators are controlled by an intermittent timer containing a timing mechanism driven by a ground contact wheel.

EQUIPMENT FOR HEATED PAINT

Heating the paint has provided more uniform consistency for spraying under changing temperature conditions. Low heat has been obtained by using a heat exchanger in the paint supply tank. This uses hot water from the truck radiator or from the compressor radiator. If higher temperatures are required, it is necessary to jacket the paint supply lines and to supply hot water to the jackets.

Temperatures above 180°F (82°C) generally require an external heating system to supply heated liquid (a coolant or special fluid) to the heat exchanger and to heat the paint lines. An electrical heating system used in Oregon since 1955 was described by Widdows (*35*). Florida reported using hot paint and described the equipment used (*36, 37*).

Figure 11 shows a traffic situation that requires the use of quick-dry heated paint. A prototype pavement striper for this type of paint has been developed by the Florida Department of Transportation (Fig. 12). It has a compressor located behind the driver and a heat exchanger in the screened area. The operator sits at the control panel in the rear. The forward spray is the striping material; the rear spray is placing beads for immediate reflectivity. The

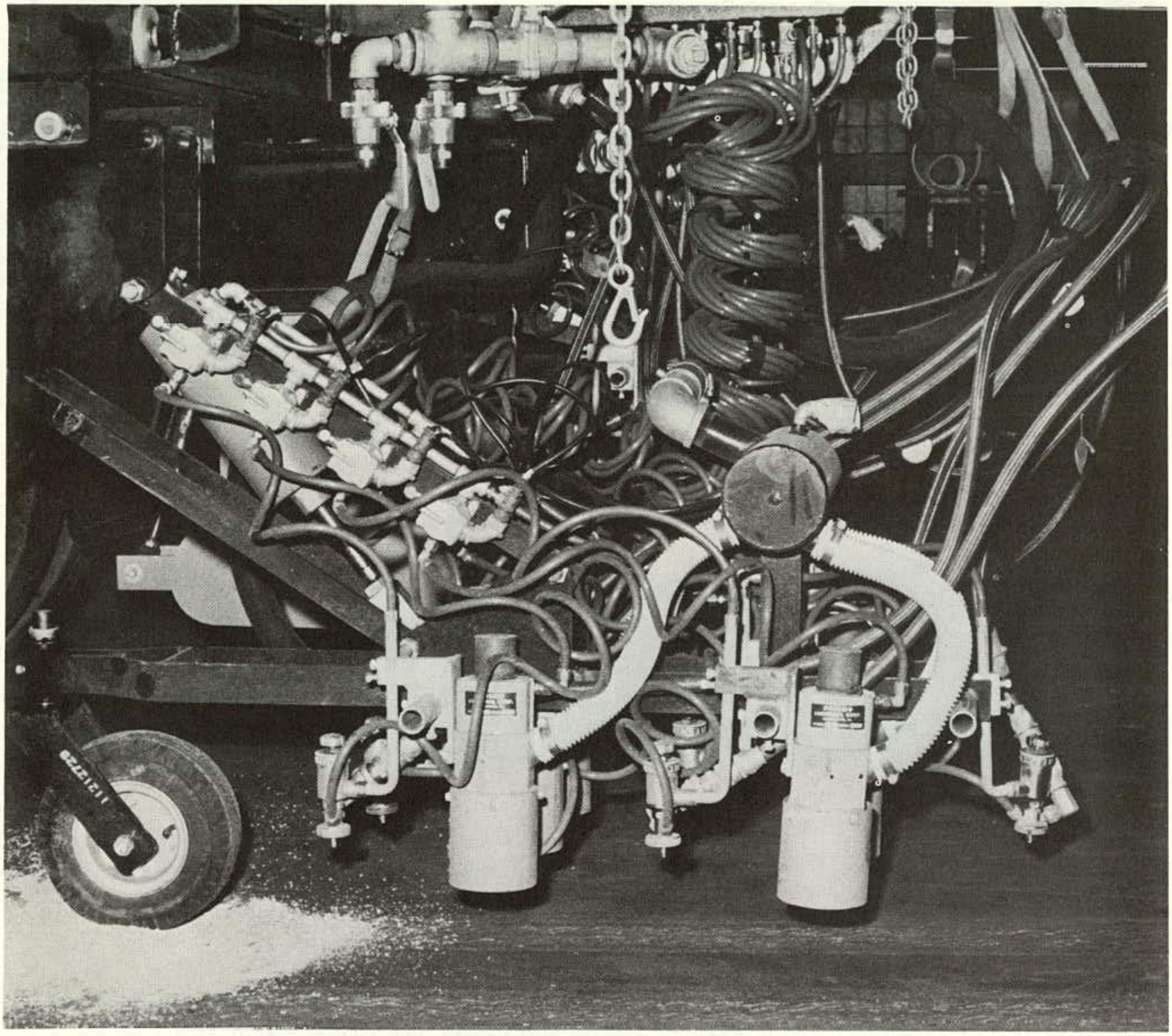

Figure 10. Spray gun carriage mounted underneath truck bed.

equipment is capable of applying material under varying pressures up to 2,000 psi (14,000 kPa) and temperatures up to 350°F (177°C). Figure 8 shows a modern Florida paint striper. It has a million-BTU (293-kW) heater, a 250-cfm (0.12-m^3/sec) compressor, dual steering, and a paint temperature capability of up to 225°F (107°C) while painting three lines. Figure 13 is a rear view of the striper showing dual seats, controls for paint spray operators, and the paint gun carriages under the platform.

A new California striper (Fig. 14) generates heat in a patented device that uses rotational, mechanical energy to heat paint directly without the need for a heat exchanger. Temperature can be controlled to within 1°F (0.6°C) over a range from ambient to 400°F (204°C). The prototype has been tested with various materials and at speeds up to 20 mph (32 km/h). Paint drying time, depending on material, ranges from 6 to 90 sec. Operation is by a two-man crew plus a follow-up truck with warning signs. The machine can stripe from the right or left side (retractable spray guns at center line of tandem axles) or straddling the line (sulky in front of truck). Up to three lines may be applied simultaneously. Another feature of this striper is a multiple-nozzle airless spray gun capable of layer operation; e.g., two thin layers of paint, followed by beads, then another layer of paint and a top course of beads. Because it is not necessary to clear the paint lines and spray guns at the end of a day's work, a full day of striping is possible. This new striper is reported to reduce bead use by 15 percent and paint by 10 percent.

Figure 11. Traffic situation requiring fast-dry heated paint.

HIGH-PRESSURE SPRAYING SYSTEMS

Missouri, North Carolina, and several other states have stripers that utilize a high fluid pressure (1,400-1,800 psi; 9,600-12,400 kPa) paint spray system. No air atomization of the paint is required. Walter (*38*) described such a striper that was constructed in 1966. Wyoming now has three of these units with air motors to drive the high-pressure pumps.

PAINT LINE PROTECTION DEVICES

Although heated paints and some cold-applied quick-drying paints eliminate the need for wet paint line protection with traffic cones or Z bars, agencies that still use the slower-drying cold paint must protect the wet paint lines.

Where paint line protection is required, the striper truck may be equipped either with an apparatus that sets the protection devices (Fig. 15) or with a platform near the ground attached to the rear of the truck so that cones can be placed manually. In some operations, cones are placed from a truck following the striper. Protection devices are usually placed in the skip portion of the wet line.

Machines for picking up traffic cones have been built by many of the state highway departments. Examples of such machines are shown in Figures 16 and 17.

MATERIALS SUPPLY

Materials supply is always a problem for the striping crew. The solution begins with having the material at the right location at the right time. Paint drums are generally handled with a hoist on the striper truck or on the paint supply truck. Hoists also are used to handle glass beads on pallets. Figure 18 shows a materials supply truck. The appropriate sign is hung from the tailgate when the truck is in use (the signs shown are stored on the side of truck).

CREW SIZE

The size of the striper crew varies with the striping operation. If edge lines are applied at the same time as the center line and no-passing lines, two paint spray gun operators are needed on the striper truck. Thus, considering that the striper truck has a driver and assistant, a crew of four men is required. A supply truck with operator is generally required for most operations. If cones are needed, another

Figure 12. Prototype pavement striper. (Florida)

man is required. The crew foreman coordinates the operation and generally follows the striper. The cones must be retrieved by another truck with two or three men. The trucks supporting the paint striper are used for protection of the line if cones are not needed. They follow at about 500-ft (150-m) intervals.

The simplest striping operation requires about five men and two trucks plus the striper truck. Considerable planning and coordination is needed to attain an efficient and low-cost operation. Because the striping operation is seasonal in many states, it is necessary that the crew spend as much time as possible in the actual striping operation when weather permits. This means that the crew should be placing the striping as early in the morning as possible, but not before conditions are suitable. Because of rigid work hours, striping is often started in the morning before the pavement surface has dried.

Good workmanship is often sacrificed because of the constant push for increased production. This appears to be a problem.

GROOVING OF PAVEMENT FOR INCREASED NIGHTTIME VISIBILITY

Utah was one of the first states to experiment with grooving the pavement before application of the traffic stripe (*42*). One-quarter-inch (6-mm) grooves spaced about 1 in. (25 mm) apart were sawed longitudinally in the pavement for a 4-in. (100-mm) width. Drainage grooves were sawed transversely at intervals toward the low side of the pavement. Another installation used grooves sawed transversely across the width of stripe. These were also ¼ in. deep and 1 in. apart. A method was also devised to form the transverse grooves in fresh concrete. Figure 19 shows a mock-up of normal paint stripe, longitudinally grooved stripe, and transversely grooved stripe.

The prepared stripe area is painted with reflectorized paint. Because the sides of the grooves are protected from traffic, the paint should last longer and should be more visible either at night or in daytime during rain, as the

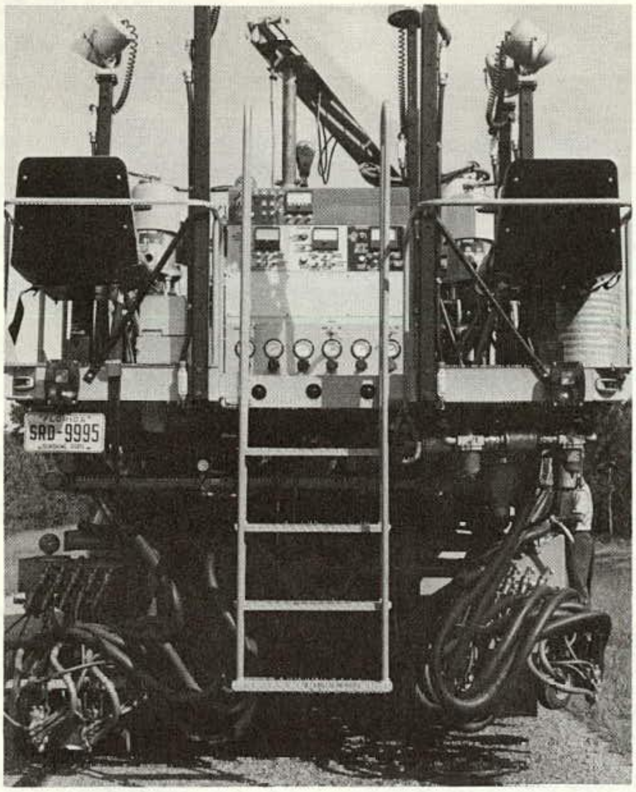

Figure 13. Rear view of striper. (Florida)

grooves should drain the water away. The grooved stripe is believed to have better visibility under wet and dry conditions than the regular stripe. It is also reported that the grooves do not fill up with dirt or water as might be expected.

California, Louisiana, Kentucky, Minnesota, and New York are also experimenting with grooving. However, there are reports that the paint on the top of the grooves is subject to wear and that dirt collects in the bottom, obscuring the paint and making repainting difficult (*43*).

PAINT REMOVAL

There are several occasions (such as construction operations, temporary detours, or reconstruction) that require the removal of paint stripes. Lines have been painted over with black paint or with a liquid asphalt on asphaltic pavement. Missouri reported use of a special machine to remove traffic lines (*39*). This self-propelled machine is powered by a 9-hp (6.7-kW) engine and removes the lines with 92 2½-in. (64-mm) steel cutters mounted on four shafts. The cutters remove the line at the rate of 10 ft per minute (0.05 m/sec) and last about 4 hr of running time. The machine costs about $750 and the cutters about $0.20 each. Unpublished reports from several other agencies were not entirely favorable to removal by grinding. Another machine has been reported that uses a combination of cutting and burning.

A chemical stripper has been tried for removal of painted lines (*40*). The chemical was applied using a steel drum with spigot mounted on a hand-pushed three-wheel cart. After setting for an hour, the chemical and the dissolved paint were flushed from the roadway by a water truck. About 1/16 in. (1.6 mm) of asphalt was also removed by the chemical. A trace of paint was left on the aggregate but two weeks later even this was substantially obliterated, leaving visible a slightly darker and coarser stripe of asphalt. Cost of chemical removal was $0.15 per foot ($0.49/m).

Several states use sandblasting to remove painted traffic stripe. This is considered successful and has been adopted as a standard method in a few states.

REQUIREMENTS AND WARRANTS FOR STRIPING

The *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (*3*) states that center lines are desirable on paved rural highways 16 ft (4.9 m) or more in width with prevailing speeds of greater than 35 mph (56 km/h). Center lines are also desirable on all through highways and other highways with significant traffic vol-

Figure 14. New California striper.

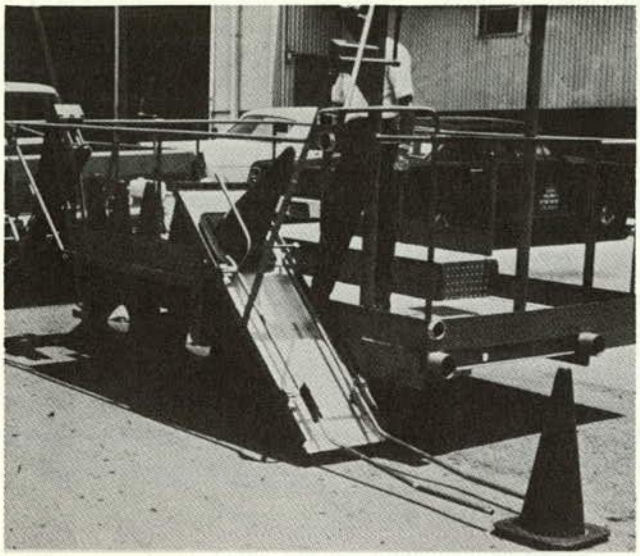

Figure 15. Device for setting cones. (Texas)

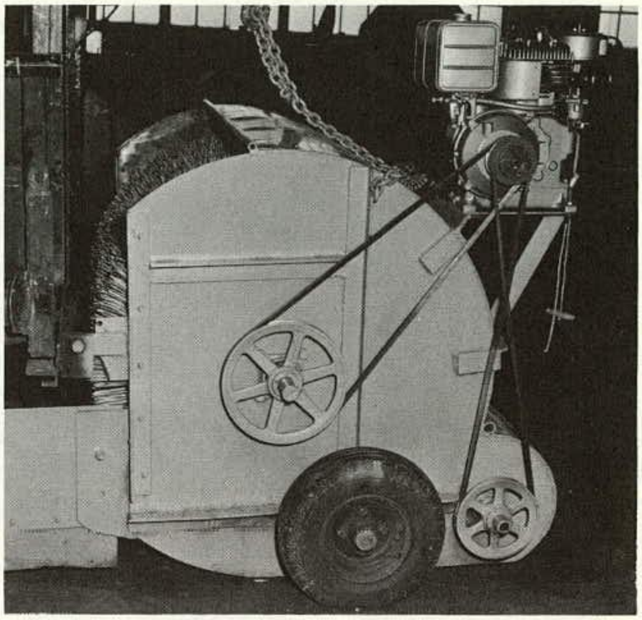

Figure 16. Cone retriever. (Missouri)

umes in residential or business districts and on all undivided pavements of four or more lanes. The actual criteria or warrants vary considerably among the states. In New York and Florida all state highways 18 ft (5.5 m) and wider are marked with center lines. In Missouri all paved highways that have a minimum ADT of 225 are center lined. In Texas all paved highways 18 ft (5.5 m) or wider and having an ADT of 350 or more are center lined. In North Carolina, state law requires that all Interstate, primary, and secondary roads that have an ADT of 200 or more be marked with center lines and edge lines.

The MUTCD requires that edge lines be provided on all Interstate highways and may be used on all others. Edge lining started about 1960 and is thus a much more recent practice than center lining. Many states have not completed their program of edge lining on secondary roads. Florida is placing edge lines on all pavements that are 22 ft (6.7 m) or wider and is also working on the secondary system. Texas may not edge line all of their secondary road pavements. Kansas edge lines all of their primary and secondary road pavements. Missouri has edge lined all of their primary road pavements. Nebraska recently started to edge line their pavements on secondary roads.

The MUTCD states that a normal line width is 4 to 6 in. (100 to 150 mm). Most highway agencies use the 4-in. (100-mm) line for edge and center lines. California and Texas have used a 3-in. (75-mm) edge line. These states report that at 60 mph (100 km/h) it is difficult to differentiate between the 3-in. and the 4-in. lines. However,

Figure 17. Cone retriever. (Texas)

Figure 18. Materials supply truck. (Florida)

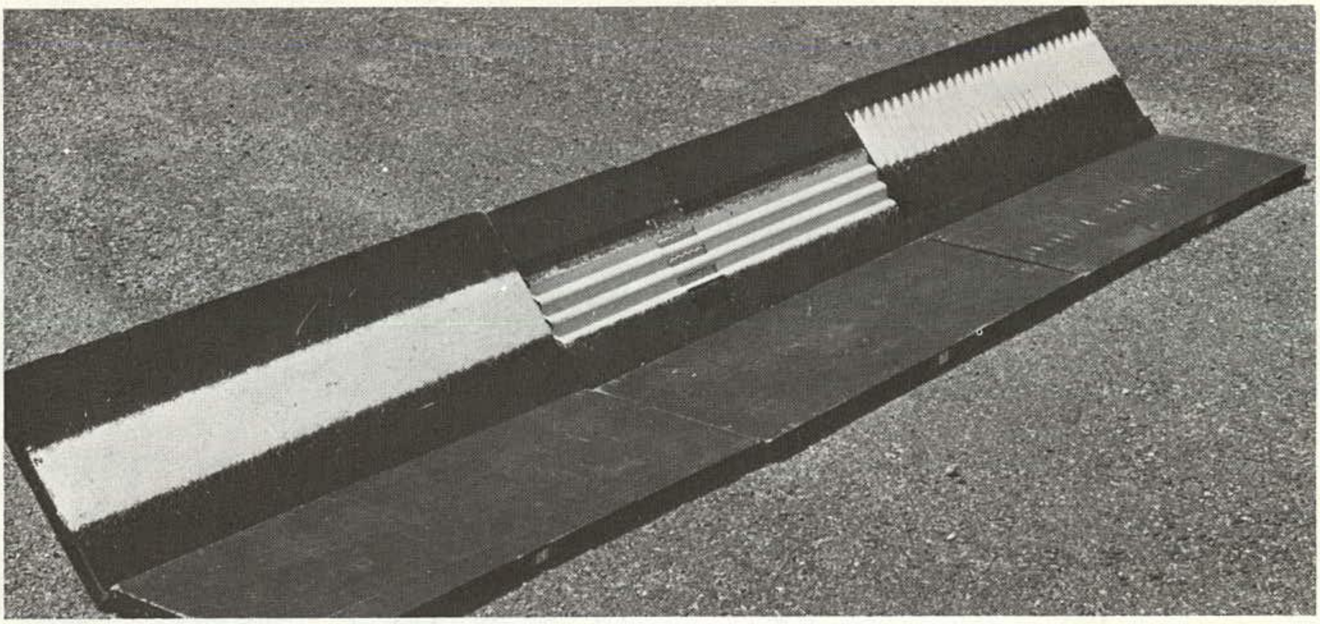

Figure 19. Grooved stripes. (Utah)

3-in. lines are not permitted by MUTCD. All new edge and center lining in Texas will be 4-in. Kansas uses 4-in. edge lines, 5-in. (125-mm) center lines on state systems, and 6-in. on the Interstate system.

The MUTCD defines a broken line as having 15-ft (4.6-m) segments and 25-ft (7.6-m) gaps, with other dimensions in the ratio of 3:5 as permissible. Most agencies follow the 3:5 ratio and the 15-ft segment and 25-ft gap. Kansas uses a 17.5-ft (5.3-m) segment and a 32.5-ft (9.9-m) gap to produce a 50-ft (15.2-m) cycle for convenience in referring to 500-ft (152-m), 1,000-ft (305-m) and 1,500-ft (460-m) lengths for signing or warning devices. California uses a 9-ft (2.7-m) segment and a 15-ft (4.6-m) gap. A recent study (*24*) indicates that the 3:5 ratio may not be necessary and that adoption of a lower ratio would reduce material costs.

Many states place the lane line or the center line over a longitudinal joint in portland cement concrete pavement. Difficulties may be encountered if the joint is filled with a bituminous filler, which may bleed through the stripe or cause the stripe to crack with continuous scaling of the paint along the crack. Some states avoid this by placing the stripe adjacent to the longitudinal joint rather than over it. A number of state highway departments believe that the stripe looks better when it is offset from the pavement joint; however, at least one state was displeased with the appearance.

Paint striping organization is as variable among the states as other operations, such as administration, planning, design, or construction. In most states, procurement is handled by the central headquarters. In a number of smaller highway departments, the striping operation also is directed from the central headquarters.

In most states, the striping operation is directed from the district or division headquarters with crews and equipment from the district. To obtain as much uniformity as possible between divisions, and to avoid public criticism, Missouri designates certain routes as the most important routes (MIR). The MIR center lines are scheduled for completion by July 1. Edge lines, applied next, are completed by August 15. All MIR are restriped again in October. By following this procedure, all MIR in all districts are striped at approximately the same time, which results in more consistent application and appearance.

In some of the smaller highway departments, striping is programmed by routes. An Interstate route would be striped completely throughout the state. Major state routes are likewise striped.

In corridor and tourist states, striping often is programmed so it will interfere least with the seasonal traffic. Because of the many different situations, there appears to be no one system that can be best for all highway departments. Under some conditions, many agencies find it necessary to stripe at night or on Sunday mornings. The general goal appears to be to get the best job done in the safest and most efficient way at the least cost. Many problems arise as an agency tries to reach this goal.

CHAPTER FIVE

PERFORMANCE–EVALUATION–PROBLEMS–RESEARCH AND DEVELOPMENT

CURRENT RESEARCH

Several agencies are currently engaged in research into pavement marking materials. Many of these are identified in Table 4.

FUTURE RESEARCH

The steady increase in traffic volume is making it much more difficult for the painted traffic line to give the desired service. Scaling, abrasion, and accumulation of dirt are the major reasons for restriping, although the type of deterioration varies with the pavement type, climate, paint quality, application rate, and volume of traffic. Mechanically caused damage is becoming more prevalent in the snow areas, due to both close blading for snow removal and snow-tire studs.

One of the greatest needs in the improvement of traffic paints and thermoplastic marking materials is improved adhesion. A more thorough preparation of concrete pavement for the first striping operation, or a pretreatment, may be required. One field study (*41*) showed that some flaking or scaling resulted from failure in the concrete substrate rather than in the paint film.

Considerable restriping is done because of loss of satisfactory daytime appearance. Perhaps the stripe should be cleaned, rather than repainted too frequently. Buildup of the stripe thickness occurs due to repeated striping operations. Increased scaling and possibility of increased physical damage may result from the increased thickness of the paint stripe.

One of the difficult problems is frequently created by the user organization itself. There is generally a continuous urge by the administrators to increase production without a similar and simultaneous admonishment to increase quality of application.

Some of the specific research needs follow.

Application of Materials

A system is needed for the quick determination of the application rate of paint and glass beads during the operation.

Additional research is needed on thin stripes with lower bead application rates for low-ADT roads. Intermittent beading on a stripe should also be investigated.

Paint

There is a need for development of accelerated tests of traffic paint, considering factors such as type of surface, traffic count, and climate in such a manner that test results may be correlated with actual field performance.

Performance test methods that will correlate with field performance are also needed.

Equipment

Electronic controls are needed for longitudinal and lateral accuracy of traffic lines at higher striping speeds.

Research is required to determine the desirability of operating the striper at the same speed as traffic for increased safety.

Raised Markers and Reflectivity Under Wet Conditions

Research should be continued on development of durable raised markers.

The use of an asphalt-sand raised stripe to provide a good foundation for paint and to raise the stripe above the water film should be investigated.

Further study should be made of reflectivity under wet conditions.

Thermoplastics

Additional research is indicated for the type, quantity, and time of application of primers for thermoplastic striping materials.

Substrate

A well-designed research project using new and old concrete pavement is needed to establish the cost/benefit ratio for cleaning and pretreating concrete pavement before the application of traffic marking paint.

Additional research is indicated concerning the lack of or the loss of adhesion of paint and of thermoplastic from its substrate.

Heating of the substrate to promote adhesion of coatings has been successful in several industries. Its benefit should be investigated for thermoplastic striping materials.

Miscellaneous

The feasibility of cleaning paint stripes should be investigated.

Factual information about the type and characteristics of pavement markings needed and wanted by the driver should be developed.

Research is needed to promote uniform stripe protection techniques.

The feasibility of bulk shipping of paint and beads should be investigated.

Economic criteria are needed for selection of a marking technique from among the various systems.

TABLE 4

SUMMARY OF KNOWN RESEARCH ACTIVITIES RELATED TO PAVEMENT TRAFFIC MARKING—MATERIALS AND APPLICATION AFFECTING SERVICEABILITY[a]

RESEARCH PROJECT TITLE	RESEARCH AGENCY	HRIP NO.[b]
Pavement Marking Materials	Minnesota Department of Highways	34 001500
Durability of Traffic Paint on Portland Cement Concrete Pavements	Kentucky Department of Highways	34 007064
Development and Evaluation of Raised Traffic Lane Markers	California Division of Highways	34 007797
Paints for Airfield Marking	Naval Civil Eng. Lab., Port Hueneme	34 040476
Elaboration of a Technique for Measuring Resistance to Wear of Traffic Paints: Correlation Between Laboratory and Field Tests.	Montreal, Quebec (Canada)	34 050612
Materials for Pavement Markings	Rome Technical University (Italy); Inst. of Highways, Railways & Airports	34 061126
Apparatus for Measuring the Reflectivity of Road Marking Materials	Braunschweig Technical Univ. (Germany)	34 061688
Road Marking Materials	Central Road Research Inst. of India	34 063691
Carriageway Marking Materials	Madras Highway Department (India)	34 063758
Measuring the Bond Strength and Resistance to Wear of Paints and Materials for Carriageway Marking	Federal Inst. of Road Research (Germany)	34 064297
Durable Road Marking Materials	State Road Lab. (Netherlands)	34 065897
Friction Characteristics of Road Marker Paints	Hong Kong Public Works Dept.	34 066756
Test Methods for Identifying Qualities of Traffic-Marking Materials	National Road Research Inst. (Sweden)	34 067982
Road Marking Materials	Phys. Plng. & Constr. Res. Nat. Inst. (Ireland)	34 068382
Raised Reflective Lane Markers for Urban Roadways	Louisiana Polytechnic Univ.	34 086209
Wet Night Visibility Study	Georgia Institute of Technology	34 086829
Pavement Marking Materials	New York State Dept. of Transportation	34 089264
An Evaluation of Road Marking Materials	Mississippi State Highway Department	34 206115
Traffic Marking Materials	Indiana State Highway Comm.	34 207610
Floating Beads for Traffic Stripes	New Jersey Department of Transportation	34 208429
Development of Optimum Specifications for Glass Beads in Pavement Markings	Pennsylvania State University	34 218388
Reflective Traffic Bead Study	Colorado Department of Highways	34 219724
Evaluation of Hot-Applied and Fast-Dry Paints on High ADT Roads	Connecticut Department of Transportation	34 219726
Meter to Measure Night Visibility of Reflectorized Traffic Paints	British Columbia Research Council, Vancouver (Canada)	51 050443
Pavement Marking Systems for Improved Wet-Night Visibility Where Snow-plowing is Prevalent	Texas A&M University	51 221164
Raised Reflective Pavement Markings	New Jersey Department of Transportation	53 006043
Grooved Traffic Stripes	California Division of Highways	53 205481
Traffic Marking Beads	Alabama State Highway Department	53 206514
Investigation of Paints and Glass Beads Used in Traffic Delineation Markings	Missouri State Highway Comm.	53 206956

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[a] As of November 1972. [b] Acquisition number assigned by the Highway Research Information Service of the Highway Research Board; HRIP = publication entitled *Highway Research in Progress* (current issue).

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APPENDIX A

REVIEW OF LITERATURE ON TRAFFIC PAINT

PAVEMENT MARKING PAINT

In 1925, Mattimore (*A-1*) described requirements and suggested physical tests for traffic paints. He listed in order the factors he thought were the most important: consistency (freedom from clogging tendencies when applied by mechanical method), spreading rate, hiding power (opacity), drying time, light resistance, visibility (day and night), and durability (resistance to weather and abrasion).

Mattimore concluded that a poor paint had almost as much day visibility as a good one, indicating that brightness of the painted surface was not the governing factor in night visibility as it is in day visibility. Night visibility was a function of the roughness of the surface. The more irregularities there are to reflect the light back in its path, the greater will be the night visibility. Therefore, a grooved or corrugated surface, with the grooves perpendicular to the direction of the beam of light, will furnish the highest night visibility. He used a visibility measuring device that measured the coefficient of reflection of painted surfaces at large angles of incidence and reflection. (The angle of incidence in this case was the angle between a normal to the surface and the rays of light from the automobile headlights, and the angle of reflection was the angle between the normal to the surface and the path of the reflected light beam.)

Mattimore thought that the effect of abrasion was important; however, true conclusions as to actual durability could be arrived at only by testing for resistance to both weather and traffic abrasion.

Another early report on pavement marking paint was made by Stanton in 1931 (*A-2*). He thought that the paint should dry in 30 min or less. This required the use of a lacquer type of paint, which was the most rapid drying paint at that time. Because some vehicle solvents dissolve asphalt, these could not be used in the lacquer. The gums used in the vehicle must be such that, after drying of the paint, they would not leave a brittle residue nor be so soft that they could be easily discolored by dirt, grease, or oil. Stanton made investigations that resulted in the early California standard specifications for traffic paint.

These California specifications required that the paint must pass a severe abrasion test, must dry in 15 to 30 min, have good flow and covering properties, resist cracking under a severe bend test, resist disintegration in water, and must not dissolve the asphalt in the pavement. The paint in the traffic line must also retain its color.

Stanton's report stated that labor was 20 percent of the entire cost of striping and the other 80 percent was the cost of the paint. Practically all lines required renewal between nine months and a year. In exceptionally heavy traffic, the line required renewal in three to six months.

Botts (*A-3*) reported that the lacquer paints did not last as the traffic increased and that the lacquer was discontinued in favor of cheaper conventional-vehicle paints. (California presently uses a modified alkyd chlorinated rubber type of traffic paint.)

The Highway Research Board Committee on Traffic Zone Paint in 1940 conducted a survey of all state highway departments, the District of Columbia, and six cities (*A-4*). Some of the findings were:

> The idea of a complete composition specification still predominates. A few organizations are working on the basis of performance specifications, but experience with them is relatively limited.
>
> . . .
>
> The use of laboratory tests, either in the form of chemical tests to check composition, or laboratory tests to indicate some special service quality, is quite universal.
>
> The use of small-scale road tests has become general.
>
> Very few depend on practical road service alone in judging the quality of traffic paints.
>
> Aside from checking composition by chemical tests, which is quite generally done, at least 14 tests for different properties receive more or less attention in the laboratory. In order of popularity, the most important are: drying time, consistency, bleeding, flexibility, water resistance, hiding power, color stability, spreading qualities, weather and wear resistance, and visibility.
>
> In making road tests, parallel and cross lines are almost equally popular and most organizations put these tests on both concrete and bituminous surfaces. Hand-brush, machine, and spray applications are also almost equally used. Four-inch lines are most popular and the spreading rates most used range from 90 to 175 sq ft per gallon of paint (1/10 to 1/20 mi. per gallon).
>
> Given in order, drying time, wear resistance, visibility, weather resistance, and color stability are the factors generally used in grading road service tests. Of the organizations that report the use of definite rating schedules, the majority give wear resistance first consideration, followed by drying time, visibility, weather resistance, and color stability.
>
> Experience with laboratory wear and weathering tests is not yet very general. However, it is noted that the organizations reporting actual experience with these tests show a marked majority opinion in their favor.

Ashman reported the results of a 1950 survey on traffic paint (*A-5*). The report summarized replies to questionnaires received from 34 states and from 175 manufacturers of traffic paint. The report indicated about a 10 percent increase from 1949 to 1950 in the use of white paint. A great increase in the use of retroreflective road marking was also noted.

For use in white paint, both highway departments and paint manufacturers preferred titanium pigments first, followed by zinc oxide and lithopone. Magnesium silicate was a definite first choice as an extender pigment.

About one-half of each of the two reporting groups preferred alkyd resin-type vehicle and about one-third preferred a phenolic resin varnish type. The phenolic varnish-dispersion resin type was voted as third in preference and copolymer-chlorinated paraffin was fourth.

The highway departments and the manufacturers indicated that improved service life was the paint property requiring greater emphasis in the future. The average normal service life for white paint alone was six months and for white paint with beads was nine months.

Of 163 manufacturers replying to the questions concerning factors relating to the service life of the paint film, 108 indicated that the type of vehicle was the most important, 18 thought that film thickness was the most important, 16 thought that application variables were the most important, and 15 thought that the type of pavement surface was important.

Ashman's survey included information about the basis of traffic paint purchase in 1950. Of the 34 states reporting, 14 had a composition specification, 14 had a performance specification, and some had a combination of the two. Two states purchased solely on a composition basis and six purchased solely on a performance basis. According to the survey, few purchased solely on a cost-per-gallon basis.

One of the early references on pavement marking materials was *HRB Bulletin 57* (*A-6*), which contained 10 papers presented at the January 1952 HRB meeting. It also contained an annotated bibliography with references dating from 1924 to 1951. One of the papers is a good review of paint research developments up to 1951. Another paper was one of the first to describe road tests of traffic paint. A companion article concluded that the accelerated test is a satisfactory method of evaluating service behavior of traffic paints. A traffic engineer presented a paper describing one of the first performance tests of pavement marking materials. He concluded that it was practical to make awards for the purchase of pavement marking materials on the basis of performance, but that additional study and research was needed to develop a more convenient and practical field method for evaluating the performance and characteristics of material.

In 1957, the HRB Committee on Paints and Marking Materials reported on a study of traffic paint specifications (*A-7*), which was based on a questionnaire sent out in 1955 to 48 states, 22 major cities, the District of Columbia, Puerto Rico, and Hawaii. The questionnaire was designed to develop information on the current methods of purchasing traffic paint, with particular emphasis placed on gaining information relative to specifications requiring a road service test. One table summarized the principal features of the 21 different performance specifications returned with the questionnaire. Fifteen of the 48 states indicated that they would not use a performance specification. The report stated that this hesitancy probably stemmed partially from the fact that the states were doubtful that they could be certain that the production material actually furnished would be identical to the samples tested previously. The committee felt that this problem was one of the chief difficulties in developing a reliable performance specification that would give equal protection to both seller and buyer. The report indicated that seven of the 21 agencies then using a performance specification solved this problem by requiring the manufacturer to divulge his formula when he submitted his samples. A few of the agencies using performance specifications used spectrophotometric equipment to compare the test samples and the production material.

The report included an analysis of the performance specifications and suggested elements of a road service (performance) specification.

Almost all of those answering the questionnaire indicated that they normally applied their paint at 16-mil wet thickness, the equivalent of 18 gal per mile of continuous 4-in. stripe. All but one of the states and all but two of the cities reflectorized at least a portion of their stripes. Seventy-five percent of the states and 53 percent of the cities reported that all of their traffic paint was reflectorized.

A report on pavement marking material use (*A-49*) indicated that 12,000,000 gallons of white and yellow paint were used in 1965, an increase of 420 percent over 1950. Much of this increase was attributed to widespread adoption of edgelining. Glass bead use increased by 840 percent because almost all paint was reflectorized in 1965 versus about 50 percent in 1950. Most states were using a composition-type specification, some used a combination specification, and a few used solely a performance-type specification.

In 1964, the HRB Committee on Coatings, Signing and Marking Materials prepared a report entitled "Preparation of Performance-Type Specifications for Reflectorized Pavement Marking Paint" (*A-8*).

The American Society of Testing and Materials' Committee D-1 has a subcommittee, Number 44, that has worked for many years in the preparation of tests for physical characteristics of traffic paints. Appendix C is a list of these tests with their ASTM designations. Among these is a method for conducting road service tests on traffic paints.

The Institute of Traffic Engineers has published "A Model Performance Specification for the Purchase of Pavement Marking Paints (*A-9*) and "A Model Performance Specification for the Purchase of Thermoplastic Pavement Marking Materials" (*A-10*).

The National Association of State Purchasing Officials in 1969 published "Specifications for Traffic Marking Paint" (*A-11*).

These and other association or society publications constitute good sources of background information for specification purposes. A list of specifications is given in Appendix B.

REFLECTORIZED PAVEMENT MARKING PAINT

The first patent applying to retroflection through the use of glass beads was U.S. Patent 1,902,440 issued to Edwin R. Gill in 1933. An annotated bibliography in *HRB Bulletin 57* (*A-6*) includes reports on the use of beads for marking paint dated as early as 1938. A 1943 reference is one of the first that discussed bead embedment. Another reference, from 1947, has this annotation:

> Working closely with manufacturers of paint and glass beads, the [Michigan] Highway Department has adopted a formula of 6 lb of beads per gallon of paint. Tests prove that this mixture is satisfactory for one year of wear on heavily-traveled truck-lines.
>
> Reflectorized paint lasts two to three times as long as ordinary paint. This saving on labor and equipment cost, due to greater durability of the paint, made the total yearly cost very little higher than the total yearly cost for ordinary paint.

Tremper and Minor (*A-46*) reported Washington's experience in 1948:

> Glass beads increase the night visibility of painted traffic stripes to a greater degree than any other available materials. Smaller beads offer advantages in economy and service life over larger sizes formerly used.
>
> Beads were originally applied by gravity to the fresh surface of the stripe. This method, called "over-lay," has been succeeded . . . by a "premix" method in which the beads are mixed with the paint just prior to application. . . . [T]he "fog-coat" method [may be] used as an alternate. In this method, beads placed by over-lay are given a second light application of paint . . .
>
> Data are given on the use of the "premix" and the "fog-coat" methods.

Washington presently uses unbeaded paint with drop-on beads.

In 1949, Lyon and Robinson (*A-13*) conducted an extensive field and laboratory investigation of beaded paint stripes, beads, and paint. Their conclusions were:

> 1. Commercially available reflective beads vary considerably in chemical composition and physical characteristics and the differences are of such magnitude that differences in performance in beaded lines result.
> 2. The effectiveness of beaded paint lines decreases at varying rates as a function of time and traffic volume.
> 3. The presence of foreign materials such as soil, sand and other granular materials on the pavement surface, reduces the service life of a beaded paint stripe.
> 4. Reflectorizing beads should be rated on the basis of a reflectance or perfomance curve which includes enough of the time element to permit evaluation of resistance to weathering and traffic, rather than on the basis of initial reflectance alone.
> 5. Loss of beads from the paint film is an important factor in the diminishing of reflectivity of a beaded line.
> 6. Structural strength is a factor in bead loss.
> 7. Imperfections such as scoring, scratching, etching, pitting and milkiness contribute to lowering of reflective efficiency.
> 8. Chemical stability of the beads is essential to maintenance of reflectance. Deteriorating agents may include moisture, acids, paint film constituents, and ice removal agents.
> 9. Accelerated traffic tests, in the form of transverse lines, are suitable for evaluation of service behavior of reflectorizing beads.
> 10. The Hunter meter is a usable instrument for the measurement of the reflectance of beaded surfaces, its accuracy being limited by the relatively small field of observation.
>
> [Author's note: Because of the extremely small area measured and the lack of repeatability of readings this instrument is now regarded as obsolete for this purpose.]

Indications also listed were:

> 1. Beads graded from coarse to fine seem to result in better maintenance of reflectance than beads of a single size.
> 2. Excessively coarse gradations seem to result in increased bead loss.
> 3. The presence of irregular particles tends to decrease reflectance.

> 4. Bubbles or seeds may contribute to lowering of structural strength and resistance to traffic impact, and hence to reduction of reflectivity of beaded lines.
>
> 5. For the type of field application and binder used in Missouri, a film thickness of approximately 18 mils and a bead application of 5 to 6 pounds per gallon seem to be within the optimum range of maximum efficiency.
>
> 6. Changes in viscosity or other characteristics of the paint may affect the embedment and envelopment of the beads and thus affect the early reflectance and efficiency of the traffic lines.
>
> 7. The thicker paint films tend to reduce bead damage and loss.
>
> 8. With proper techniques, photographic methods may be used to record reflectance comparisons and the progressive deterioration of reflective lines.

Peed (*A-14*), in 1950 and 1951, made laboratory and field tests on a number of reflectorized traffic paints. An accelerated abrasion test using a circular track was included as one of the tests. He reported on the effect of the speed of drying of the paint film on the mechanics of the settlement of the glass beads. Gravity application of beads to a slow-drying paint (32-min drying time; 11.2 gal/mile) resulted in the beads settling in the paint and acting as premixes. A paint with a 14-min drying time (8.2 gal/mile) allowed the same type of beads to be embedded about 50 percent with pillaring of the beads by the paint. A paint with a 10-min drying time did not give the beads an opportunity to become embedded as much as the paint with the 14-min drying time. In spite of this, Peed stated that the adhesion seemed good and there was little loss of beads after 500 hr of accelerated weathering and mild abrasion.

Shelburne, et al. (*A-15*) reported field and laboratory tests of 11 paints in 1952. The field sections were placed in 1949 in accordance with ASTM D 713-46. Transverse lines and a few longitudinal lines were placed. Based on the 18-month study of field performance on eight experimental sections, it was concluded that the ASTM method was satisfactory for evaluating service behavior. Good correlation was found between results of the longitudinal paint lines and the transverse lines. Except for initial readings, reflectance values on longitudinal lines were consistently higher than those on comparable transverse lines.

> The composition, type, shape and size of beads were important factors affecting performance of the beads-on-paint-type lines, particularly as determined from reflectance readings. From the experiments it is indicated that the coarse beads (plus 40-mesh) give high reflectance initially, but this is not maintained over a long period. On the other hand, the fine beads (minus 40-mesh) have lower initial reflectance which is more constant with age. The reflectance of graded beads (coarse and fine) is intermediate.

On the basis of these studies, specifications were developed to purchase the paints that performed best. A maximum drying time of 1 hr was specified at an application thickness of 15 mils. The beads were required to have a Hunter night visibility meter reading of not less than 14 when the beads were applied at a rate of 6 lb/gal on a binder having a wet film thickness of 15 mils.

Pocock and Rhodes (*A-16*) reported in 1952 on the principles of glass-bead reflectorization. They discussed durability versus serviceability and the effect of composition on durability, density, refractive index, crushing strength, and color. They also discussed the effect of refractive index on distribution of reflected light, the interrelation of beads and paint in reflex reflection, compatibility of beads and paint, glass bead gradations, and the effect of imperfections on reflection. They discussed the effect of depth of embedment on reflex reflection, rate of application, and also miscellaneous practical considerations. They showed that an increase in relative humidity increases the drying time of the beaded paint.

A recapitulation of their report is quoted:

> First, all of the properties of glass which significantly affect bead reflectorization are directly related to composition. There is considerable latitude in the selection of desired attributes by proper compounding and processing. The most important factor limiting the range of composition is devitrification, or crystallization, on cooling. The high-silica glasses are, in general, stronger and more durable than the others, but do not have a sufficiently high refractive index for maximum efficiency of reflectorization. It should be possible to produce commercially a glass of satisfactory durability and considerably higher index without undue increase in cost. As a matter of fact, several such products have already appeared on the market.
>
> Second, chemical durability and serviceability are not synonymous terms in defining the qualities of glass beads. Many glasses of relatively poor durability give excellent service. Loss of weight by solution or dulling of surface luster are not infallible criteria of optical performance. Formation of film on some glasses gives noticeable improvement in transmittance and reduction of external reflection, a fact made use of in the present practice of lens coating. Therefore, laboratory results based on loss of luster or weight in extraction or weathering tests may wrongly condemn a perfectly satisfactory glass. Moreover, bead durability should be tied in with the life expectancy of the binder or stripe as a whole. At best, the life of a pavement stripe is relatively short. Chemical durability in a bead, then, is not as significant as serviceability, and optical tests are the most reliable method of evaluating serviceability.
>
> Third, color of the beads is important mostly from the standpoint of possible objectionable modification of the color of the painted stripe. However, a noticeable color of the beads in bulk may be totally imperceptible when they are applied to the paint, and a color specification which is unnecessarily restrictive may hamper the development of glasses superior in other respects.
>
> Fourth, the amount and distribution of reflected light is largely determined by the refractive index of the glass composing the beads and its relation to the index of vehicle and pigments in the paint. The pattern of the returned light (divergence-angle characteristics) depends on the index of the glass. 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. The amount of light specularly reflected from the boundary between paint and bead is a function of the difference in their refractive indices. More particularly, it depends on the difference in index of bead and paint vehicle, since the vehicle completely envelops the pigment particles and light reaching the latter is diffusely reflected.
>
> Fifth, the depth and firmness of embedment of beads in paint depends on compatibility with respect to the ability of the paint to wet the bead surfaces. Thus, paint

> and beads are intimately related in service performance, and the reflectorized stripe should be evaluated as an entity rather than as a combination of independent materials.
>
> Sixth, optimum gradation of beads for maximum usefulness has not been completely determined experimentally. However, experience and the geometry of surface-to-mass ratios definitely indicate the desirability of using beads of smaller maximum size. The principal advantages of using smaller beads are: (1) pound for pound, they present more reflective surface and are retained better; (2) they can be premixed with the paint; (3) they reduce both drying time of the paint and the effect of relative humidity on drying time; (4) they contain a smaller percentage of imperfect particles; and (5) they suffer smaller rebound losses in spray application.
>
> Seventh, the two kinds of imperfections receiving most attention at present are nonroundness and gas inclusions. A large percentage of fragments is detrimental, but it is doubtful whether other nonrounds, such as spheroids, ellipsoids, etc., significantly affect optical performance. Gas inclusions are definitely harmful, because they interfere with reflex reflection and weaken the bead structurally.
>
> Eighth, depth of embedment is an important factor in reflex reflection of pavement marking beads, because at the very small angles of incidence involved, the effective reflex-reflecting zone of the bead is extremely narrow. When the bead is embedded to a depth of half its diameter, the height of the vertical aperture through which light may be received for reflection is approximately the product of the diameter and the sine of the incidence angle, or only a few thousandths of the bead radius. With only a slight increase in depth of embedment (half of the above vertical aperture), reflex reflection is lost altogether. Decreasing the depth of embedment extends the effective zone vertically, but this advantage is offset to some extent by the likelihood of poor bead retention.
>
> Ninth, from an analysis of bead interference in relation to critical separation distances, it appears that some bead economy may be achieved by further experimental study of the problem of application rates.
>
> Finally, experience so far indicates that the use of beads lengthens the life of the painted stripe, and that beaded stripes last longer on bituminous pavements than on concrete.

In 1957, Hastings (*A-12*) called attention to the relation between bead size, bead embedment, and binder film thickness. Although he was discussing application to highway signs, he noted that the immersed portion of the beads displaced a volume of the binder film, which resulted in an increase in binder depth. This may have a bearing on sizes of beads and the thickness of binder film designed for the traffic paint stripe system.

Rhodes reported in 1957 a comparative study of the drop-in and overlay (premix with some beads dropped on) methods of reflectorizing traffic paints (*A-17*). The test sections were placed in October 1954 using two white and yellow paints. Wet film thicknesses of 12, 15, 18, and 21 mils were used for the drop-in applications and corresponding thicknesses of 14.4, 18.0, 21.6, and 25.2 mils for the premix applications. These premix film thicknesses took into account the bulking due to 4 lb of beads per gallon of paint, so that the same amount of binder was present in the corresponding applications by drop-in and premix. In the one case, all 6 lb (per gal) of beads were dropped in; in the other, 4 lb were premixed and the other 2 lb dropped in. Both sets carried the same proportions of beads of the same grading. The gradings of the two types of beads used in the premix method combined to produce the grading used for drop-in.

Rhodes' test showed that drying time increased with increasing film thickness. Except for the lightest application rate, the drying times of stripes reflectorized by the premix method were shorter than those of the corresponding stripes with drop-in beads, and the difference became greater as the film thickness increased. It was also apparent that drying times for these paints became excessive at application rates of more than 16.5 gal/mile. There was little difference in the performance of paints reflectorized by the two methods. In most cases, any observable difference was in favor of the drop-in method when the test stripes were evaluated on the basis of performance over the entire test period. It was found that thicker films gave longer-lasting stripes, but that the life was not increased in proportion to the amount of material used.

Rhodes concluded that it would not be economical to increase the rate of application from the existing 16.5 gal/mile (15 mils) in Michigan; rather, the reverse was indicated. The results of the study definitely pointed to the abandonment of the premix method of reflectorization in favor of the drop-in method of application as the standard method in Michigan. He noted that the methods were practically equal in efficiency and material cost; however, there was considerable difference between them in the cost of operation and equipment maintenance. He mentioned the damage to the paint guns and also the difficulties and extra expense in mixing beads with paint on the job and in keeping the premix paint agitated.

One of the most extensive investigations made in this field was reported by Crumpton and McCaskill covering experimental field and laboratory work conducted in 1967 to 1969 (*A-18, A-19*). The abstract from Report 1 follows:

> One hundred individual test sections, involving over 230 miles of pavement with more than 24,000 individual center line stripes, were included in this study. In addition, 69 miles of continuous edge lines were placed and studied. Paint thickness ranged from 5.4 mils to 20.2 mils. Bead application rates varied from 1.4 to 9.3 pounds per gallon. On the basis of area covered, the beads varied from 0.010 to 0.068 pound per square foot of stripe.
>
> Ninety-nine percent of the stripes were performing satisfactorily at the end of one year. Some of the stripes on asphalt were in test nearly two years and still performing satisfactorily. It has been demonstrated in our tests that thinner paint stripes and lower bead application rates than commonly recommended can be utilized. Our studies show that we can safely reduce our paint thickness to 10 mils and our bead rate to 4 pounds per gallon and have a better reflecting, faster drying, more durable stripe than we have had at 18 mils and 6 pounds of beads per gallon.
>
> Our studies show that in Kansas paint chipping is the major problem of paint loss. Wear or abrasion is a minor problem. There is also minor loss due to snowplow operations, patching, crack filler and joint compound. The service life of the paint stripes is often more dependent upon the surface conditions of the road than upon the thickness of the paint film.

They further state in the preface:

> One strong indication from [earlier] studies was that the medium oil alkyd paint now being used in Kansas was about as durable as any paint we tested under Kansas conditions. Furthermore, the Kansas alkyd paint was more economical, considering both durability and initial cost, than any of the paints we tested. Another indication was that paint loss in Kansas was not due to wear as we so long were led to believe, but that our loss was primarily a matter of paint chipping. Since chipping was probably our greatest means of paint loss, then transverse stripes were of limited value to us in studying paint loss and performance. The transverse stripes may be worn out in the wheel paths, before chipping occurs, but still be in good shape at centerline and on the edges of the pavement where there is little traffic. There were also indications that we could use thinner stripes and less beads and still have satisfactory traffic control lines; furthermore, thin stripes dried faster than thicker ones.

From the two Kansas reports it appears that a gradual change was made in the paint use in that state (Table A-1). 1971 information indicates that they are continuing the application at 10 mils and 4 lb/gal.

The second report of the Kansas study concerned laboratory and detailed field paint stripe examinations. The Summary and Conclusions of this report are quoted:

> This report is presented primarily as a narrative explaining the practical use of several items of laboratory equipment in studying the performance of glass beads in paint. Several aspects of the paint and bead problem were studied utilizing binocular and petrographic microscopes. Wear and abrasion of paint and beads were studied using the California-developed surface abrasion equipment. The texture of road surfaces was measured using cores and linear traverse equipment. The conclusion and results are based on the studies reported herein:
>
> 1. Microscopes are very useful in studying paint and bead problems both in the field and in the laboratory.
>   a. A vertical illuminator attachment on a microscope makes it possible to simulate normal headlight angles to study the performance of various bead sizes and gradations in paint films of differing thicknesses.
>   b. Much of the engineering of glass bead size and gradation to fit the wet film thickness of paint being used or anticipated for use can be done in the laboratory using the microscope techniques described. Our glass bead specifications were changed with such studies as a guide. This has resulted in a lower unit price for beads.
>   c. Microscope studies indicate that internal fractures are more detrimental to light retroreflection than are bubbles, impurities, or nonround beads. Glass fragments and two or more beads stuck together or beads with protruding knobs usually do not reflect light.
> 2. Glass beads in at least some black paints do reflect light.
> 3. New stripes that appear very dull may only be covered by traffic grime and dust. Washing such stripes often reveals a bright stripe under the road grime. This dust problem is greater in cities than in rural areas due to the slower city traffic.
> 4. Kansas presently uses 10 mils (wet) paint with 4.0 lb of drop-on beads per gallon of paint.
> 5. Painting is now faster than before and one crew has placed more than 118 miles of beaded stripes in an 8-hour day.
> 6. This project, which will eventually cost approximately $20,000 in research funds, has saved about $324,209 in paint and bead costs for fiscal years 1969, 1970, and 1971, compared with 1965. In addition, the cost of the materials for many additional miles of edge line painting has been paid for by the implemented changes. This has occurred during a period of otherwise spiraling inflation.
> 7. Savings in storage space, testing, and handling of paint and beads have also occurred.
> 8. A stream of air blown over an old stripe just ahead of the paint striper removes the loosest and most detrimental flakes of old paint and therefore is somewhat effective in increasing paint and bead life. Other attempts to rapidly remove the old paint prior to repainting have been largely negative.

TABLE A-1

PAINT AND BEAD APPLICATION (KANSAS)

YEAR	WET PAINT THICKNESS (MILS)	BEADS (LB/GAL)
Before 1967	18	6
1967	14	5
1968	12	4.5
1969	10	4.5
1970	10	4

During the Kansas paint stripe examinations the thick buildup of old paint was observed in samples of traffic stripe taken to the laboratory. One sample showed seven separate layers of paint. Each of the layers contained many beads that were buried in the paint and never exposed. Kansas was using an 18-mil wet paint film thickness during the entire period of painting represented by the sequence of old paint layers. This study confirmed observations of others that the gradation of the beads is important and that for a given paint thickness there is only one size of bead that will give optimum optical performance.

They reported that the overspray of paint on the beads reduced the reflectivity severely. The overspray was eliminated when the correct spray pressure was used.

Kansas was the first to report mold growth under beads in an 18-month-old stripe. This was not considered a problem because the stripes were generally repainted yearly. Mold was also observed under layers of stripe. This could be a cause for loss of adhesion. This mold growth was observed in a great number of old paint layers from several different locations. The younger upper layers of paint seldom exhibited the mold growth.

The microscope was found to be quite useful in studying the effect that shadows cast by large beads have on the reflection from smaller beads. The shadowing effect is reduced considerably when beads of only one size are used in a paint film of the proper thickness to cover about 60 percent of the diameter of the beads.

In 1966, a study of glass beads for traffic paints was made by Hiss and McCarty (*A-20*). This study was made to compare glass beads currently being specified with more expensive glass beads having a higher index of refraction. The summary of the report is quoted:

> High index of refraction (1.65+) glass beads were field tested to determine if the increased cost of these beads could be justified on the basis of increased light reflectivity during the life of a pavement marking paint line. During the field test, measurements were made on these beads as well as the regular beads used by the state. As a result of photometer readings and bead counts in established test areas on asphaltic and portland cement concrete pavements, the following conclusions are drawn:
>
> 1. Although the high index of refraction beads initially provided greater reflectance on portland cement concrete pavement, after about eight weeks the reflectance had declined to a point where it was difficult to distinguish between the two bead types. This is explained by the fact that the standard beads were better retained by the traffic paint.
> 2. On an asphaltic concrete surface the high index of refraction beads consistently reflected more light than the standard beads. However, the difference was hardly visible even though it could be measured with the photometer. On this pavement, about equal percentages of each bead type were retained by the paint.
> 3. There would be no advantage in specifying high index of refraction beads with the currently used traffic paint since the additional cost of two cents per pound would amount to $46,000 on the 2,300,000 pounds of beads purchased annually.

The light reflected from the beaded paint lines was measured with a photometer each week for a period of 13 weeks. A photographic survey was also made of the two bead types by taking close-up pictures of the beaded lines each week for 12 weeks. Bead retention was determined by counting the number of beads and bead craters in each picture. Visual observations were also made of the nighttime visibility of the stripes. On portland cement concrete about 30 percent of the high index of refraction beads were lost from the stripes in about 90 days, whereas only about 20 percent of the New York standard beads were lost. On asphaltic concrete each type lost about 20 percent of the beads in about 90 days.

In March 1969, Hiss et al. (*A-21*) made an interim report on pavement marking paints. This report contained four parts: an analysis of striping costs; evaluation of paint performance; comparison of paints and special studies of pavement pretreatment; and paint preheating and special pigments.

The conclusions state that in 1963 New York State spent $0.017 per foot to paint traffic stripes. Of this cost, about 36 percent was for paint and 64 percent was for labor, equipment, beads, solvent, and operations. Another cost breakdown showed all materials cost 54 percent, with 46 percent being spent for labor, equipment depreciation, maintenance, and operating costs.

The paints tested were alkyd, modified alkyd-chlorinated rubber, modified alkyd, vinyl-butadiene, epoxy, waterbase, and high-polymer. The white paint giving best performance and costing least was the modified alkyd already in use by New York State, containing 40 percent titanium pigment. The best performing yellow paints were modified alkyds and modified alkyd-chlorinated rubbers. The white modified alkyd paint with 40 percent titanium pigment performed as well as the same paint with 60 percent pigment.

The conclusions state that, in general, neither acid etch nor synthetic rubber primer pretreatments were effective in increasing service life. Even though paint placed over the acid-etched pavement performed slightly better, this difference in performance occurred late, beyond the useful life of the paint.

In the fall of 1966, Colorado started an investigation of a new type of bead that was purported to require only 4 lb/gal of beads in comparison to the usual 6 lb/gal of beads to produce the same reflectance. The tests were continued through 1969 (*A-22, A-23, A-24, A-25*).

After three years of testing and two years of regular use, the following conclusions were made:

> 1. Small, single-size glass beads that float on the surface of traffic marking paint provide better reflectance and are more durable when applied at the rate of 4 lb per gallon of paint than nonfloating-type reflective beads applied at the rate of 6 lb per gallon of paint. [The floating bead is distinguished from the nonfloating bead by its ability to float on a xylol solvent.]
> 2. Floating beads cost approximately $0.02 a pound more than nonfloating beads, but because only two-thirds as many pounds are required, the savings are substantial.
> 3. The superior performance of the small, single-size floating bead is due to: (a) The fact that at 4 lb/gal of paint this bead provides more reflective bodies on the surface of traffic marking paint than mixed-gradation beads provide at 6 lb/gal. [Microscopic examination showed that the floating bead had approximately 2,000 beads per square inch compared with approximately 1,000 beads per square inch for any other bead tested when applied at the rate of 4 lb/gal of paint.] (b) Almost every small floating bead is embedded the proper amount for good reflection. Very few beads settle far below the surface of the paint.
> 4. The estimate of durability of paint stripes in Colorado is primarily a function of the daylight appearance. Stripes are repainted before the nighttime visibility is drastically impaired. Maintenance personnel feel that stripes need to be repainted when the daylight appearance is judged to be in the 4 to 6 region, with 10 being perfect and 0 being totally unsatisfactory. At this time, the nighttime brilliance of the floating beads is usually judged to be in the 7 to 8 class, when initially applied at 4 lb/gal of paint. The brilliance of the nonfloating beads when applied at 6 lb/gal of paint is judged to be in the 4 to 6 region at the time restriping is necessary.
> 5. The photocell device is more sensitive and reliable as a record keeper than the human eye. Graphs of the performance of floating beads compared to nonfloating beads show that after a year's use floating beads still have more nighttime brilliance than nonfloating beads.
> 6. The high performance of the small single-size floating bead must be attributed to both the small size and the floating characteristics. If only one of these characteristics is provided to a sample of beads, the performance of the modified bead is somewhat improved, but not up to the standard of beads having the floating and single-size characteristics.

Colorado also reported that the performance of glass spheres in reflectorized paint stripes can be evaluated by an inexpensive instrument that compares closely to human evaluation (*A-22, A-24, A-25*).

Glass spheres having a refractive index in the range of 1.5 to 1.6 can be satisfactory for reflectorizing painted stripes. It is not necessary to pay a premium price for beads of a higher refractive index.

Loss of reflectance under traffic comes mainly from a chipping off of the paint that holds the beads. Large bead particles (diameter greater than 40-mesh sieve) come loose in the paint matrix, but small spheres are held quite well by the paint, and may even assist in prolonging the life of the painted surface.

Colorado estimates that the purchase of floating beads saved the state approximately $50,000 during the 1967-68 traffic striping season and $36,000 during the 1968-69 season. This saving results from the reduction of the application rate from 6 lb of beads per gallon to 4 lb of beads per gallon of paint.

Dale (*A-26*) emphasized the need for wet reflective materials. He evaluated raised markers and traffic paint at a remote test site with little traffic and free from foreign light sources. The marking materials were evaluated while dry and during a simulated rainfall.

Dale also discussed the role and the characteristics of glass beads in pavement markings. He covered the physical nature of glass beads; gradation of beads; thickness of binders; application rates for glass beads; retroreflection as a function of bead embedment; retroreflection as a function of binder orientation with the light source; retroreflection as a function of mixed bead sizes in a constant-thickness binder; retroreflection as a function of refractive index, shape, and imperfections; and retroreflection characteristics of glass beads when wet. In the last, he distinguished between thin covering films of water, thick submerging films of water, and water film characteristics as a function of bead application density.

Dale discussed marking practices and day and night visibility. Other topics included unbeaded stripes, intermittent black contrast lines, depth of bead embedment, refractive index, direction of application, bead gradation, wet and dry day and night visibility, regular and irregular elevation of the area to be marked, use of large beads, use of small beads in a carrier, and reflectors mounted on posts. In another section he discussed designing the marking system for all-weather visibility. He also called attention to including the pavement surface profile in the design and selection of the marking system. A pavement surface profile recorder was designed and constructed.

Dale's report also discussed the development and field testing of an advanced day-and-night, dry-and-wet marker. The conclusions of the report are quoted as follows:

> 1. A systematic approach to marking pavements is needed wherein one obtains a pavement surface profile of the surface to be marked, qualifies the water film thicknesses to be encountered, and then selects one of several marking systems that will perform under the imposed conditions and provide the lowest cost per mile per day of useful life.
>
> 2. Only under very unusual circumstances, such as when a road surface is extremely rough, or when the area to be marked has been pretreated to present a very rough surface, can conventional paint binders, reflectorized with the current bead gradations, be expected to perform when wet.
>
> 3. Retroreflective materials can perform satisfactorily, even when wet, so long as they are not covered by a layer of water. Raised, reflectorized markers perform in this manner and are very effective. The use of glass beads of a larger diameter or bead-coated granules in thicker binders or improved binders, such as some of the thermoplastic or thermosetting resins that have sufficient mechanical properties to hold these materials under traffic, is another attractive approach to this problem.
>
> 4. Incorporation or placement of retroreflective materials other than in or on surface film markings such as paint, improves the daytime visibility and appearance of surface film markings.
>
> 5. Great benefits are seen from the use of beads that are essentially the same diameter, the diameter selected being one that will result in the beads being embedded in the binder to 55 to 65 percent of their vertical height.
>
> 6. The idea of producing waterproof or water-repellent glass beads is an excellent concept. Unfortunately, the silicone and other available treatments appear to be so short-lived in the field that they are of little practical significance.
>
> 7. The use of glass beads of high refractive index and the use of larger quantities of glass per unit of stripe offer improvements in the field; however, it would appear that, in the immediate future, greater dividends would accrue from the better utilization of glass beads having a low refractive index and costing less through improved bead-gradation specifications and application techniques.
>
> 8. Marking authorities should consider adding equipment, either separate or complementary, to their present marking machines that will allow raised, reflectorized markers to be made at high speed in one operation at the point of application along the lines of the system developed in this program and described in this report.

HEATED PAVEMENT MARKING PAINT

In 1960, Widdows (*A-27*) reported on the use of heated traffic paint in Oregon. It was thought that the use of heated paint would produce more uniform application, speed up the operations, reduce the drying time, provide better adhesion of the paint to the pavement, and lengthen the striping season. A system of paint heating started in the fall of 1955 after a unique pumping and heating apparatus was developed and installed on a paint truck. The heating elements consisted of two 3,000-w elements similar in design to a waffle iron. Current was supplied by a 7½-kva generator. This produced a capacity to heat 65 gal of paint per hour to a temperature of 150-160°F. The heaters were thermostatically controlled and the paint was constantly recirculated to minimize the danger of explosion.

The hot spray striping method made the operation almost a year-round possibility except during wet and extremely cold weather. The application speed was increased by more than 30 percent and the drying time was decreased nearly 50 percent. Using the cold spray, the average striping speed was 6 to 7 mph under adverse conditions; using the hot spray method the application speed was increased to 11 to 12 mph.

The original hot spray striping equipment used a pushcart ahead of the paint truck, which allowed the operator of the pushcart to see the road clearly and to operate the paint sprays and bead applicator. Most of the striping equipment used this pushcart arrangement until 1970. These original stripers have now been replaced with units that have the equipment installed on the truck.

The major change in the heating equipment has been replacement of the two 3,000-w elements in the heater by five 1,500-w elements, or a slight increase in the heating capacity. The paint crew is instructed to use 120°F as the optimum temperature; however, a range of 100°F to 140°F is generally attained. Wet thickness is 12 to 15 mils, and 6 lb of beads are applied per gallon of paint.

The Oregon specification for traffic paint is based on laboratory-measured application characteristics and actual road performance before purchase of the paint. Type I, standard dry, is required to have no pickup at 10 min and no indentation at the end of 30 min. Type II, quick dry, is required to have no pickup at the end of 90 sec and no indentation at the end of 10 min. It is proposed to use only Type II in the future.

Adoption of heated paints by highway departments was relatively slow; however, several companies began offering products for testing. Michigan evaluated a proprietary quick-dry marking material in the Detroit area in 1964 and 1965. Because of the decrease in hazards attending the striping operation, the Office of Maintenance was authorized to use quick-drying traffic paints in high-traffic-volume areas by the most economical method of application. In 1967, they converted one striper to the quick-dry operation by the addition of a heater, recirculators, and a special bead gun. The same year, more extensive testing was done; test stripes showed one paint with very good durability, 2 min or less drying time, and good applicability. In the spring of 1968, Michigan (*A-28*) reported an expected annual savings of $100,000 by the use of a new quick-dry striping paint. Prior to the adoption of this paint, their crews spent much of their time placing and removing temporary traffic barriers, because the regular paint took up to 45 min to dry. The machine used for the quick-dry operation delivers the paint to the pavement as hot as 165°F and the track-free time in average air temperature and humidity is down to 90 sec.

Florida began research several years ago to develop a paint that would be faster drying than the paint it was then using, without sacrificing durability, color, or other qualities. Their standard paint dried in 30 to 40 min and required protection for that length of time. Line smearing resulted in some cases, despite protection (*A-29*).

Drying time was reduced to 2 min by 1966 through investigations of users and producers of traffic paint; however, the paint available in Florida cost about $5 per gallon. This was considered much too high for their pavement marking budget.

By 1967, paint companies had developed traffic paints that would meet the drying time requirement of 50 sec. Florida began using this paint in urban areas in 1968. A quicker drying paint was tested at Orlando. This paint had a reported 20-sec drying time. Florida purchased 10,000 gal of this paint for regular use. The paint company helped to train the striping crews in an effort to improve quality and production. Two 12-hr training and review sessions on striping focused on the 50-sec drying time paint, equipment problems, and other related problems.

In 1970, Florida was using 18 gal of paint per mile of solid line and 7 gal per mile of skip line. They have two paint machines in each of five districts. Three of the machines have been modified to handle 180° to 190°F paint temperatures for the 20-sec drying time paint. One of the three state-constructed machines was modified to handle the 50-sec drying time paint with hot water from the compressor circulated through three heat exchangers. Nine of the machines have three-color capacity, because Florida uses black paint to accent the white skip on light-colored pavement.

In 1971, Florida purchased 215,000 gal of white, 56,000 gal of yellow, and 59,000 gal of black low-heat (120°F) paint; and 75,000 gal of white, 15,000 gal of yellow, and 41,000 gal of black high-heat (185°-195°F) paint. No premix or regular paint was purchased. Also purchased were 1,610,000 lb of water-resistant (water resistant for storage and handling purposes) regular index beads. They use 6 lb of beads per gallon of paint. Florida DOT specifications are based on performance tests rather than composition requirements.

The use of fast-dry traffic paint in Texas was reported in 1969 (*A-30*). Texas' paint chemists were confronted with an urgent need for faster drying paints and believed that (1) adhesion is affected by a paint's ability to penetrate road surface film and by a paint's ability to wet the pavement, and (2) film penetration, wetting ability, and bead penetration into a paint are proportional to the length of time that a paint remains fluid. Therefore, they formulated a paint that was a compromise between the need for fast drying and the need for the film to remain fluid. They concluded, after close observation of striping operations, that stripes could be protected for 3 min without the use of cones and without a massive traffic jam. Therefore, the paint was formulated to be pickup free in approximately 3 min. This paint combines a quick solvent-releasing vehicle, such as an alkyd-chlorinated rubber mixture, with fast-evaporating solvents retarded with just enough slow solvents to keep the film open until most of the solvent has escaped from the stripe.

This fast-dry traffic paint is applied with a wet film thickness of 15 mils, is reflectorized with 6 lb of beads per gallon, and dries in from 2 to 8 min, depending on paint temperature, pavement temperature, and wind velocity. When necessary, the paint is thinned with methylene chloride, a nonflammable, fast-evaporating solvent. Conventional drop-on equipment is used to apply the glass beads. Traffic cones are not used to protect the stripes. One or more guard trucks straddle the freshly painted line 500 to 1,500 ft in back of the striper. The number of trucks used and the distance between the striper and the last guard truck depend on traffic density, the speed of application, and drying conditions.

Texas specifications for traffic paint are based on composition requirements. In 1971, the Texas Highway Department purchased 115,000 gal of white and 85,000 gal of yellow regular traffic paint; and 450,000 gal of white plus 370,000 gal of yellow fast-dry traffic paint. Six million pounds of untreated, 1.52 refractive index glass beads were purchased. In 1972, the purchase of regular traffic paint was to be discontinued.

Texas has at least one paint striper in each of its 25 districts. Each District Engineer has the authority to modify striping procedures or equipment to meet local needs or conditions. Eighty to 90 percent of the stripers are equipped with heat exchangers that use water from the truck radiator to heat the paint to approximately 120°F.

In 1971, Wisconsin was reported (*A-31*) to be converting their paint striping machines so that the paint could be heated. The cost of converting a $20,000 truck to hot-paint application was reported to be about $5,000. The striper using heated paint travels 2 mph faster than it did when using unheated paint.

Heat exchangers utilizing hot water from the truck's cooling system heat the paint to 118° to 140°F. The heated paint dries in slightly more than 1 min. Wisconsin found it necessary to apply the beads pneumatically because of skinning of the paint film.

The painting convoy consists of three vehicles with a crew of five. The lead vehicle is the supply truck and driver; next, the paint striper with driver, crew chief, and helper; the last vehicle, about 500 ft behind the striper, is a guard pickup truck with driver. Wisconsin now has 5 of their 11 paint stripers equipped to use heated paint. The hot paint operation has eliminated the need for wet line protection by flags dropped by the trailing vehicle driver. At intervals, he had to return and recover the flags. This was a dangerous operation and occasionally his vehicle was hit by motorists.

Up to 1970 New York used conventional (unheated) traffic marking paint exclusively. In 1970, a heated rapid-drying paint was specified for all regions and all paint trucks were modified to handle 120°F paint. To heat the paint to slightly over this temperature, a double heat exchanger was connected to the radiator of the air compressor. This modification cost approximately $750 for each machine. A special roving crew assisted local mechanics in the modification.

Use of heated paint permits starting the striping program early in the spring and continuing into late fall. Paint specifications include a drying time (no tracking) of approximately 60 sec when the pavement temperature is between 40°F and 120°F, with the relative humidity not exceeding 80 percent. High humidity increases the drying time considerably.

Production rates have increased approximately 40 percent, mostly due to discontinuation of wet line protection. Between April 1 and December 1, the 20 paint crews stripe about 50,000 miles of actual line. This is roughly equivalent to 50 miles per day with no down time. Trail vehicles are used to keep traffic off the painted lines until paint is dry to no pickup. On poor drying days, as many as four trail vehicles may be required, with the last vehicle about 900 ft behind the striper. Special attention is still required for line protection at busy intersections, commercial entrances, and off- or on-ramps on expressways.

The rapid-drying paint surface skins over so fast after application that beads dropped by the usual method will not adhere. This required a modification of the glass bead delivery system. A paint gun with a reamed nozzle sprays the beads at about 5-psi air pressure. The nozzle, located about 12 in. behind the paint spray, is directed at a low angle at the paint film immediately behind the spray. This results in comparable glass bead retention.

Frequent and heavy snows, the use of tire chains or studded tires, and the maintenance practice of heavy use of salt and sand produce a severe environment for the traffic paint stripe. It is believed that a 15-mil wet thickness of paint is necessary for durability and for bead retention of the larger-size beads with the heated paint. The paint is applied generally at speeds of 8 to 10 mph. To obtain the required paint thickness, it is necessary to keep the air pressure near the 125-psi safety rating of the air compressor system. The actual pressure used varies with the temperature and viscosity of the paint. The crew foreman checks the wet film thickness as often as necessary by placing a steel plate on the line to be painted. Paint is applied at the normal speed and the beads are cut off when the bead dispenser passes over the plate. The foreman measures the paint with a thickness gauge and then makes any necessary adjustment in the paint spray pressure or truck speed. An accurate tachometer is essential for proper thickness control.

New York believes that 6 lb of beads for each gallon of paint (15-mil paint thickness) is the correct quantity for their conditions. They believe that only so many beads can be embedded and retained by the paint.

New York instructs their operators not to clean the paint system internally during the season unless the machine is not to be used for a considerable length of time. The paint system should be kept fully charged with paint at all times to reduce the chances of blockage of the lines. The paint guns are cleaned after use to prevent clogging at the tip. The paint crew is responsible for the annual winter cleaning and refurbishing of equipment with assistance, when necessary, from the equipment maintenance division. Solvent compatible with the marking paint being used is furnished with the paint for each yearly contract.

Weekly reports of time of personnel, equipment and materials used, etc., are prepared by the paint crew foreman. These are sent to the regional traffic engineer and on to the Albany headquarters. Studies of 1971 reports indicated that the paint crews in general were using less than the specified 16 gal of paint per mile and less than the specified 6 lb of beads per gallon of paint. Some headquarters personnel believe that the use of insufficient paint and beads is a major reason for the lack of durability sometimes noted.

New York has made maintenance management studies of pavement marking operations and believes that increased efficiency can be obtained by better supervision. Travel time of crews appeared to be one of the main factors in low efficiency. Their resident engineers were given a one-week management training course in Albany. The regions then held two-day meetings of all paint crew personnel.

A study (*A-21*) by New York showed that cost of center striping and edge lining for the year 1963 was

$0.017 per foot. The 1971 cost of the hot-applied paint was $0.011 per foot. The speed-up of operations by the use of the hot paint and the elimination of wet line cone protection is given credit for the reduction in cost. The 1971 cost of the paint was $1.79 per gallon for white and $1.84 per gallon for yellow in 55-gal drums.

In 1971, New York purchased 407,000 gal of white and 288,000 gal of yellow low-heat (120°F); and 30,000 gal of white and 10,000 gal of yellow high-heat (160°F) paint. No regular or premix paint was purchased. Some 4,500,000 lb of regular index glass beads were purchased. The specifications for traffic paint are based on laboratory performance requirements and a field-condition drying time test.

New York tried placing new stripes adjacent to the old stripe to determine if this improved adhesion or wear. The practice was discontinued because of the poor appearance.

New York has been evaluating the use of a 20-sec drying time paint that conforms to the Florida specification for quick-dry traffic paint. It was found that the paint dried to a track-free state in 20 to 30 sec. This paint requires use of the Wald Nite-Liner striper or comparable equipment.

In March 1969, New York reported (*A-21*) on a number of studies of traffic paints, among which was a study of paint preheating. A number of test stripes were applied, using several different paints at temperatures of about 130°F and ambient temperatures from 50°F to 90°F. A few paints (3 out of 20) had slightly better durability heated than unheated. Most paints showed little or no improvement when heated. They concluded that, based only on durability, it did not appear desirable to preheat the paint.

HRB Committee A2G02, Coating, Signing and Marking Materials, sent a questionnaire to all of the state highway departments in September 1971. In 32 returns, four states reported using a fast-dry paint with no heating; 13 reported using a low-heat (120°F) paint, and 10, including some of the previously mentioned 13, used a high-heat (160°F) paint.

"LIQUID INSTANT-SET" MARKING MATERIAL

In June 1967, California reported (*A-32*) field trials of a so-called "instant-set" marking material. The material was reported to contain approximately 80 percent total solids by weight. An experimental striping machine applied the marking material under a ram pressure of 2,400 psi at a temperature of 240°F, producing a wet film thickness of 15 mils. The durability of this material compared favorably with the State G-95 Control. California Specification G-95 for a solvent-based paint requires a "dry to no-pickup" time of 15 to 18 min at 77°F and a 15-mil wet thickness (equivalent to 7-mil dry film thickness). The "instant set" material has a dry film thickness of 8 to 10 mils with a 15-mil wet film thickness. The dry to no-pickup time was from 6 to 15 sec. The estimated price of this material was $8.00 per gallon.

In May 1968, Florida reported (*A-33*) on the use of a proprietary striping compound that had a putty-like consistency. It was necessary to build a special striping machine for the application of this material. The equipment was installed on a 1-ton flat-bed truck. A gasoline-fired boiler with 500,000-Btu capacity was converted to use a high-temperature fluid instead of water. This allowed the striping compound to be heated to 350°F, compared to 165° to 170°F for hot-water systems.

The material is handled with an air-actuated piston pump rather than under air pressure. The pump produces pressures up to 2,000 psi (although generally 1,200 to 1,300 psi are used) that atomize the material at the paint nozzle, which is in a standard airless spray gun on an outrigger carriage behind the truck.

The truck bed carries a 52-cfm air compressor that supplies air pressure to the bead dispenser and to a built-in cleaning system that flushes the liquid lines after use. Beads, from a bead tank pressurized to 40 psi, must be applied directly after the marking material application.

In use, a 55-gal drum of the marking material is placed in a holder on the truck bed. On top of the opened drum is placed a follower plate seal that has a slightly smaller diameter than the inside of the drum. The plate exerts pressure on the material in the drum and prevents cavitation when the putty-like material is pumped from the drum at high velocity.

This material, like most rapid-drying paints, skins over quickly when exposed to air and must be protected from air in storage and handling.

In a test, the striping compound achieved a 3-sec drying time. The need for barriers or traffic cones was eliminated.

FLAME-APPLIED MARKING MATERIAL

Flame-heated and -applied marking material is not a marking paint. It comes in powder form and contains approximately 50 percent by volume of glass beads. The powder is applied with a special machine that heats the powder and converts it into a liquid that is instantly "fused" to the road surface. It dries in a few seconds. Several companies supply this material, and the California Division of Highways has a specification (702-80-29) dated January 1971 that applies to this type of material.

In the fall of 1966, the District of Columbia striped three intersections and placed a number of test stripes at a location where other test stripes were under evaluation for durability and other characteristics. The Traffic Research Section of the Department of Highways and Traffic reported (*A-34*) the following:

> 1. The average speed of application of the "Instant Set" striping powder was 0.8 ft of stripe per second.
> 2. A few seconds after application the markings were dry enough for traffic to run over them.
> 3. Delays to traffic were a minimum. The critical factor causing the delay was speed of application rather than drying time.
> 4. At a signalized intersection the markings could be laid in coordination with red signal indications to produce very little delay to traffic.
> 5. For the conditions on which the experiment was performed, a coefficient of correlation of 0.80 was calculated between traffic volume and percent of marking worn out. This indicates good correlation or relationship between these two variables.
> 6. At the locations of this experiment an average of

about 1,000,000 vehicles per lane for all lanes was needed to wear out more than 50 percent of a crosswalk or stop bar marking.

DRYING TRAFFIC PAINT WITH MICROWAVE

In January 1968, California reported (*A-35*) on the development of a rapid-drying paint system using microwave energy. The report describes the results of a research contract to develop a suitable traffic paint and to design equipment that would dry the traffic paint to a state of no pickup in approximately 1 sec by the application of microwave energy. After several months of investigation, the contractor concluded that it was not technically feasible to achieve the objectives within the contract because of the difficulty in generating a sufficiently high energy intensity at the dielectric interface of the paint and the pavement surface.

SULFUR MARKING MATERIAL

One of the early experimental uses of sulfur for pavement marking material was reported by Hancock (*A-36*). He tested a number of compositions with different materials for plasticizers and also materials for bactericide with and without beads. Hansa-yellow-type pigment was used to produce a better yellow color. Several compositions with 12 to 15 percent Thiokol Type A, 3.5 percent wood rosin, 3 to 5 percent pigment, and 0.5 percent bactericide gave about 10 months of service in transverse stripes, which was about the same as solvent-based paint stripes in a comparable test. The test stripes showed good color at first, but suffered early discoloration by traffic. The color gradually returned in the stripe.

Hancock called attention to the unusual viscosity-temperature behavior of the sulfur. At the melting point of 119°C (246°F), the liquid sulfur has a viscosity of about 11 centipoises. With rising temperature, the viscosity slowly falls to about 9 centipoises at about 158°C (316°F), then rises rapidly to about 93,200 centipoises at about 187°C (369°F). This phenomenon indicates that uniform and controlled heating is required.

Louthan et al. (*A-37*) reported field tests of a sulfur-based pavement marking material in Alabama, Florida, North Carolina, Kentucky, and Colorado. They reported good durabilities (ASTM D 713-55T) and excellent bead retentions under the conditions of the tests. They reported "set-to-touch" times of less than 30 sec, better durability than conventional traffic paint, and a price competitive with it.

The California Division of Highways reported (*A-32*) experimental results with two formulations of white sulfur-based marking materials applied by the manufacturer of the material in February of 1967. The molten material was applied through an airless spray gun and post-beaded. Several test lines tracked badly at 13 sec, moderately at 18 sec, and the "dry-to-no-pickup" time was 30 to 60 sec. The white lines were yellow-white and did not comply with the California yellowness index specifications. Durability was considerably less than the standard state-specification paint, especially on concrete. Most failure of the sulfur-based paint was by loss of adhesion.

Sulfur was included with a number of traffic paints in an extensive field evaluation in North Carolina in 1967 (*A-38*). The sulfur marking material was applied in a molten condition by the manufacturer. All test stripes were transverse and rated at frequent intervals for a period of about one year. The ratings were performed by each member of a team of eight and then averaged. Appearance, durability, and reflectivity were the qualities considered in the test stripes. The experimental sulfur marking material rated considerably lower than the traffic paint that North Carolina was currently using.

PREPARATION OF THE SURFACE AND PRETREATMENTS

It has long been known that the surface to be painted should be cleaned properly where required. In *NCHRP Report 74* (*A-47*) it was stated that there was more difference in adherence and durability of the paint film as related to the surface preparation or condition of the surface than there was in the various paints evaluated. This same principle has been pointed out time and again.

It is possible to overfinish a concrete surface, which can result in laitance at the surface. This material may fail in service and cause loss of the paint film.

A substrate of portland cement concrete may have several deficiencies concerning promotion of good adhesion of paint films. Before it is opened to traffic, it may have several mils of thickness of curing compound remaining on the surface. This material is difficult to see, even though it contains a transient dye for application detection purposes. Its reaction with the concrete and with the paint film may inhibit good adhesion. Often, the material contains a wax base that may disappear in time. However, if a paint stripe is placed over a wax-base curing compound soon after opening the pavement to traffic, the adhesion may be decreased. This may not be true of a linseed oil solution or some rubber- or resin-base curing compounds.

Alkali and carbonate salts are slowly leached to the surface of many new concrete pavements. An acid etching application may have some benefit and may also improve the adhesion to the smooth, glassy appearing, aggregate particles if they exist.

Old concrete pavements should not be as prone to this condition as newer ones; however, they may have polished surfaces that can be etched slightly by an acid pretreatment.

Botts (*A-39*) was probably the first to report on the use of acid etching treatment experimentation. He used a 15 percent orthophosphoric acid solution in alcohol and water. He first applied it to a bridge deck where the surface had become highly polished and glazed. Without a pretreatment, the paint would break away from the surface a few days after application and extensive chipping and flaking followed. Then the pretreatment was applied and allowed to dry. The surface was striped by the usual spray techniques. The paint film then wore down by abrasion. The paint film gave very good service in comparison to the paint stripe on untreated concrete and also to service of stripes on the asphaltic concrete approaches to the bridge.

Over several years time, a number of traffic paint line comparisons were made between treated and untreated surfaces for traffic paint stripes. Performance of the lines on treated bases was generally superior to lines on untreated bases. Some anomalies appeared and the experiments were dropped because it was thought that no significant differences were found. Botts concluded that some of the anomalous behavior may have been due to the type of paint used in the experiments. California Manila gum-china wood oil formula, which is highly acid in character, was used prior to the experiments. It was susceptible to neutralizing action at the surface of the concrete. Adhesion loss could result. Chlorinated rubber base type, which is resistant to saponification, has good adhesion. This was the type used at the time of the experimentation. Manila gum formula paint showed marked improvement in durability when placed on phosphoric acid-treated base. Generally, the same thing was true of the chlorinated rubber type, though not as markedly so.

Each year from 1953 to 1959, Nebraska performed a series of experiments on concrete pavements using a pretreatment of phosphoric acid (85 percent) N.F. (*A-48*). Fifteen gal/mile of unbeaded conventional paint and 17 gal/mile of premix paint were applied to untreated concrete and to concrete pretreated with acid at different rates of application and by different methods of application. The pretreated pavement generally was allowed to dry for 15 min before paint application; however, some of the field tests were conducted by allowing the pretreatment to dry for 24 hr before painting the stripe. The stripes were applied transversely. Replacement of the stripes was considered necessary after 30 percent average film failure.

The 1953 tests were made with 10 percent solutions of phosphoric acid in denatured alcohol and in methanol. Evaluation showed that the stripes on untreated pavement failed more than twice as rapidly as the stripes applied to pretreated pavement. The durability of the stripes was essentially the same with either denatured alcohol or methanol pretreatment solutions.

In the 1954 evaluation it was shown that a 5 percent phosphoric acid pretreatment solution was as good as or better than a 10 percent solution. It was also shown that a solution in water was slightly better than in methanol.

As part of the 1954 test, a 10-mile stretch of new portland cement concrete pavement was pretreated with phosphoric acid solution on one line of the double center-line stripe. The other line was applied without any pretreatment. At the end of an 84-week evaluation period, the stripes applied to the untreated pavement had from three to seven times the film failure of stripes applied to pretreated pavement.

In the 1955 evaluations, a water pretreatment was compared to a phosphoric acid pretreatment. It was shown that stripes applied to untreated pavement had approximately one and one-half times as rapid a film failure as stripes applied to the pavement pretreated with water and approximately three times as rapid a film failure as stripes applied to pavement pretreated with a 5 percent solution of phosphoric acid in water. One of the paints used in these tests was the least durable of all of the paints tested on the untreated pavement. However, this same paint was the most durable of all of the paints tested when applied to the phosphoric acid pretreated pavement. This illustrates how a paint can be sensitive to the substrate. The 1956 evaluations also showed that the durability of poor paints can be remarkably improved (more than twice the durability) if the paint is applied to phosphoric acid pretreated pavements.

The 1957 evaluation showed that reflectorized binder stripes applied to untreated pavement had, on the average, three times as rapid a film failure as the stripes applied to the pavement pretreated with a 5 percent phosphoric acid solution in water. Stripes were also applied at two different rates of application of paint in the 1957 evaluation. The stripes applied at 15 gal/mile were more durable than the stripes applied at 12 gal/mile. However, the stripes applied at 12 gal/mile required 20 percent less paint but had only 10 percent less durability than the stripes applied at 15 gal/mile.

In the 1958 evaluation, no appreciable difference in film failure was evident between stripes applied to the pavement on which the pretreatment solution was poured on and scrubbed in or stripes where the pretreatment solution was sprayed on.

In 1969, New York reported studies of pavement pretreatment (*A-21*). Concrete surfaces were treated with an acid etch solution consisting of phosphoric acid and zinc chloride solution (3 and 2 percent by weight, respectively) in water. The application rate was not measured. The etching solution was sprayed on the pavement in a stripe approximately 6 in. wide, to facilitate placing the 4-in. wide paint stripe over it. Performance figures indicate that the acid etch pretreatment increased durability of paint stripes placed on both new and old concrete surfaces. The increase in durability was greater on new concrete than on old, but this was expected because the acid etching was mainly intended to reduce alkalinity, which is greater in new concrete. After about 10 months on the new concrete, about 12 percent more paint remained on the acid-etched surface than on the untreated concrete. On the pretreated old concrete, for the same period, the difference was only about 6 percent.

Increased durability of stripes on treated pavement compared to untreated pavement was noted between different paint families and within paints in the same family.

New York also experimented with a synthetic rubber primer. It was applied at a wet film thickness of about 10 mils, although thickness varied as viscosity changed with temperature. The film was allowed to dry track-free, usually for several days, before paint was applied. The synthetic rubber primer apparently decreased durability. Less paint remained on treated than on untreated concrete surfaces.

In 1970, Kansas reported a paint and glass bead study (*A-19*). They investigated several methods of paint removal in hopes of reducing their chipping problem. Two restrictions were placed on the paint removal techniques. First, they had to be rapid and fit into the regular painting operation (more than 100 miles of painting in one day in some instances). Second, the stripes removed had to be repainted the same day.

Heater units were too slow and unsuited to Kansas painting operations. Sandblasting was too slow and a hazard to traffic. Chemical removers were too slow, hazardous to workers, and harmful to the finish of cars. High-pressure water jets were too slow, hazardous to traffic, and required too much drying time before repainting. Mechanical burring and brushing methods were too slow. All of these methods were too expensive. They considered as partially successful a jet of air directed at a low angle onto the paint stripe just ahead of the striper. This method removed the loosest and therefore the most detrimental flakes of old paint.

In 1966, the Corps of Engineers reported on the use of a 50/50 solution of linseed oil and mineral spirits (*A-40*). Tests were performed on sandblasted surfaces of laboratory specimens and on concrete pavement runways. They found from laboratory weathering tests and field observations that the solution increased the adherence of oil-base traffic paint. The solution was applied at 1 gal per 100 sq ft. At this rate the solution penetrated the concrete surface rapidly on a warm day.

FAILURE OF TRAFFIC PAINT SYSTEMS

Bleeding of asphaltic material into the stripe was an early cause of deterioration and still remains one, but to a lesser degree.

Flaking or peeling on portland cement concrete pavement, wear due to traffic abrasion, and discoloration due to vehicle fume film and to natural dirt on all types of pavement were reported early as causes of deterioration (*A-41, A-42, A-43*).

The combination of the pavement substrate, the traffic paint, and the glass beads should be regarded as a system and must be engineered or designed to accomplish its intended purpose. Due regard must be given to the ability of the paint to wet and adhere to the substrate, to wet and retain the glass beads, and to allow the beads to properly position themselves in the wet paint film. This requires that the thickness of the paint film, when expanded by the glass beads that sink below the surface and beads that are partially immersed, be such that the maximum quantity of beads will be retroreflective throughout the life of the paint film.

In the Kansas study (*A-18, A-19*) it was stated: "Service life of stripes is often more dependent on the surface condition of the pavement than on the thickness of the paint film." The condition of the pavement also influences the ability of the paint to wet the surface and to be retained on the surface. Numerous early reports made reference to the influence of the condition of the surface on the durability of the paint stripe.

The Kansas reports also referred to using longitudinal rather than transverse test stripes for evaluation purposes, because the transverse stripes wore out before chipping could occur. This indicates that the intensity of traffic is one of the variables, as well as the total traffic passing over the stripe. In New York, maintenance personnel attribute more failure to abrasion than to chipping. This is based on their expressway systems where traffic counts are high. An early survey report (*A-5*) indicated abrasion as one of the main causes of failure. This survey covered an era of low traffic volumes. Kansas reported that 99 percent of their longitudinal test lines were satisfactory after one year on concrete and that some stripes were satisfactory on asphaltic concrete pavement after two years. This is another indication that the intensity of traffic influences both the durability of the paint and the mechanics of its failure. In 1949, Lyon and Robinson (*A-13*) reported that most failures of test stripes on pavements not previously painted were caused by abrasion. Stripes on hills and curves that had been cindered during the winter had become badly worn and scaled. Another part of the report stated that scaling was prevalent.

In 1944, Slate (*A-44*) observed that both laboratory and field tests showed that paints fail principally by scaling, with the loss of adhesion between the paint film and the concrete caused by the presence of water. The water, coming from the moist soil beneath the pavement, travels upward through the pavement and evaporates from the surface. The water carries soluble salts with it and these are deposited on the surface upon evaporation of the water. The paint film offers resistance to the passage of the water vapor and to the growth of the salt crystals, and the resulting forces may break the bond between the paint and concrete.

Colorado reported (*A-22*) that the paint flakes or chips off greatest where the old paint is thick. The loss of paint is responsible for most of the loss of night brilliance. They also indicated that durability evaluation in Colorado is primarily a function of the daylight appearance. Stripes are repainted before the nighttime visibility is drastically impaired.

Mechanical damage to the paint stripe has existed since the advent of the stripe. In the states where snow is a problem, tire chains and snowplows have left visible evidence of their passage. Tire chains did not ordinarily constitute a severe problem because they were removed as soon as possible to prevent wear of the chains. Since the introduction of studded snow tires numerous reports have been made of the disastrous effect that the studs have on traffic paint stripes. Dale (*A-45*) reported on the deleterious effects of studded tires on traffic stripes. Some states have prohibited the use of tire studs because of the extreme wear on the pavement and the danger developed by the rapid obliteration of the stripes. Other states are considering prohibition of studded tires.

RESTRIPING OCCASIONED BY NONFAILURE CAUSES

Many thousands of miles of pavements are restriped annually because they have been resurfaced or replaced. Poor daytime appearance is often caused by the direction of the sun on the pavement, but more often by an accumulation of traffic grime, rubber dust, and ordinary dirt on the stripe. The nighttime appearance may still be satisfactory.

A number of state highway organizations report that it is often cheaper to restripe some sections of pavement when the striper is near the location than to wait until the stripe shows distress. Also, programs of restriping at certain times cause many miles of pavement to be restriped before actually needed.

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APPENDIX B

LIST OF SPECIFICATIONS FOR TRAFFIC PAINT AND GLASS SPHERES

FEDERAL SPECIFICATIONS

1. TT-P-85D Paint, Traffic, Reflectorized for Air Field Runway Marking (Drop-on Type).
2. TT-P-110B Paint, Traffic, Black (Non-Reflectorized).
3. TT-P-115C Paint, Traffic, Highway, White and Yellow.
4. TT-B-1325A Beads (Glass Spheres), Retro-Reflective. (Covers several sizes, types and indices of refraction.)

STATE HIGHWAY DEPARTMENT SPECIFICATIONS

Conventional Paint (over 7 min)

1. Missouri
2. Nebraska
3. Pennsylvania
4. Virginia
5. Washington
6. New Jersey
7. Michigan

Fast-Dry Paint (2-7 min)

1. Florida *
2. New York *
3. Arkansas †
4. California †
5. Iowa †
6. Maryland †
7. Minnesota †
8. Mississippi †
9. Missouri †
10. New Mexico †
11. North Dakota †
12. Texas †
13. New Jersey
14. Michigan

Quick-Dry Paint (30-120 sec)

1. Florida
2. New York

Premix (Beads in Paint)

1. Alabama
2. Arkansas
3. Montana
4. South Dakota
5. Ohio

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* Performance specification.
† Composition specification.

APPENDIX C

LIST OF ASTM STANDARD TESTS FOR TRAFFIC PAINTS AND GLASS SPHERES

STANDARD TESTS FOR TRAFFIC PAINTS

Conducting Road Service Tests on Traffic Paint	D 713
Evaluating Degree of Resistance of Traffic Paint to Bleeding	D 868
Evaluating Degree of Resistance of Traffic Paint to Chipping	D 913
Evaluating Degree of Resistance of Traffic Paint to Abrasion, Erosion or Both in Road Service Tests	D 821
Evaluating Degree of Settling of Traffic Paint, Test for	D 869
Laboratory Test for Degree of Resistance of Traffic Paint to Bleeding	D 969
Night Visibility of Traffic Paint, Test for	D 1011
No Pick-Up Time of Traffic Paint, Test for	D 711
Settling Properties of Traffic Paints during Storage, Test for	D 1309
Traffic Paints. Recommended Practices for Testing	D 2205

STANDARD TESTS FOR GLASS SPHERES

Crushing Resistance of Glass Spheres, Test for	D 1213
Roundness of Glass Spheres, Test for	D 1155
Sieve Analysis of Glass Spheres, Test for	D 1214

APPENDIX D

ORGANIZATIONS INTERESTED IN TRAFFIC MARKING MATERIALS

American Association of State Highway Officials (AASHO)
National Press Building
Washington, D.C. 20004

American Society for Testing and Materials
1916 Race Street
Philadelphia, Pa. 19103

Federal Highway Administration
Office of Traffic Operations
400 7th Street, S.W.
Washington, D.C. 20590

Department of Defense
Special Assistant for Transportation Engineering
Headquarters, Military Traffic Management and Terminal Services
Department of the Army
Washington, D.C. 20315

U.S. Forest Service
Division of Engineering
Department of Agriculture
14th Street & Independence Avenue, S.W.
Washington, D.C. 20251

Service Center Operations
National Park Service
Department of the Interior
Denver Service Center
7250 West Alemeda Street
Denver, Colo. 80226

United States Coast Guard
Office of Engineers
Department of Transportation
400 7th Street, S.W.
Washington, D.C. 20590

Federal Aviation Administration
Department of Transportation
Visual Aids Branch, Standards Division, Airport Services
7th Street & Independence Avenue, S.W.
Washington, D.C. 20591

Institute of Traffic Engineers
2029 K Street, N.W.
Washington, D.C. 20036

Highway Research Board
2101 Constitution Avenue
Washington, D.C. 20418

APPENDIX E

GLOSSARY OF TERMS

ABRASION—A condition manifested in traffic paint by more or less gradual surface erosion, thinning, and disappearance of the film, due to wind, water, sand, and vehicle tire wear.

ADT—Average daily traffic.

AMBIENT AIR TEMPERATURE—Existing or surrounding air temperature.

AMBIENT PAVEMENT TEMPERATURE—Existing temperature of the pavement. (May or may not be the same as the air.)

APPLIED LINE—Marking material in place on the substrate.

BARRIER LINE—A line placed parallel to a center or lane line, or to another barrier line, to indicate that traffic must not cross the line for the purposes of overtaking and passing.

BEADS—Spheres used in conjunction with binder to produce retroreflectivity:

(a) Conventional—Glass composition with approximate refractive index of 1.52 with no surface treatment.
(b) Low refractive index—Spheres with refractive index between 1.50 and 1.64.
(c) Medium refractive index—Spheres with refractive index between 1.65 and 1.89.
(d) High refractive index—Spheres with refractive index greater than 1.89.
(e) Plastic—Spheres manufactured from organic materials.
(f) Glass—Spheres manufactured from a material that is essentially fused silica.
(g) Premix—Spheres dispersed in the binder prior to application.
(h) Drop-on—Spheres applied to the stripe after the stripe has been applied to the pavement.
(i) Moisture resistant (proof)—Spheres treated to reduce conglomeration when spheres are exposed to moisture.
(j) Floating—Spheres treated to control depth to which they will sink into the binder.
(k) Static charge—Force tending to cause erratic flow of beads caused by attraction between unlike-charged beads and repulsion between like-charged beads.
(l) Retro-directive reflectivity—Return of light by a reflector along a path parallel to the entrance path.
(m) Divergence angle—Angle formed by a line extending from the light source to a point on the reflector and a line extending from the eye to the same point on the reflector (light-sign-eye angle). Brightness is maximum when divergence angle is zero.
(n) Entrance angle—Angle formed by a line extending from the light source to a point on the reflector and a line forming a 90° angle with the reflector at the same point.

BLEEDING—Conditions in which an asphalt substrate is softened, due to heat or solvent attacks, causing the oils to rise to the surface. The line over such a surface will have multiple black spots appearing on the paint surface.

BOND—Adhesive quality of a coating to a substrate.

CENTER LINE—A line indicating the division of the roadway between traffic traveling in opposite directions.

CFM—Cubic feet per minute.

CHASSIS—The lower frame, including the wheels and engine parts, of a motor vehicle.

CHANNELIZING LINE—A line that directs traffic and indicates that traffic should not cross but may proceed on either side.

CHIPPING—The breaking away of small fragments of the painted line from the substrate. It is closely related to durability. Among the many causes are films of foreign material between the marking material and the substrate, and a glassy or slick surface of the exposed aggregate in the pavement surface.

CURING—Commonly identified as the hydraulic hardening of portland cement. It also refers to the crosslinking or hardening of paint.

CURING COMPOUND—A coating applied to freshly placed portland cement concrete to retain moisture in the concrete.

DRY FILM THICKNESS—Thickness of line when dry (less than the wet film thickness due to evaporation of solvents in paints).

DURABILITY—A measure of a traffic line's resistance to wear and deterioration. The two most common types of wear and deterioration are abrasion and chipping.

EDGE LINE—A line that indicates the edge of the roadway.

FILM INTEGRITY—Refers to the properties of a film that result in the film's ability to resist scuffing, marring, etc., and to show cohesive strength.

FREEZE-THAW CYCLE—A complete cycle of change in temperature from above freezing of water to below freezing and return to the above freezing temperature again.

GPH—Gallons per hour.

GPM—Gallons per minute.

HEAT EXCHANGER—A device used to transfer heat from the hot heat transfer fluid to the cold product prior to spraying. It generally consists of multiple lines passing product through the heat transfer fluid-filled line.

HEAT TRANSFER FLUID—Fluid capable of reaching high temperature and transferring much of its heat by means of conduction to the cold product.

HYDRAULIC—Operated by the movement and force of liquid.

LANE LINE—A line separating two lanes of traffic traveling in the same direction.

LIQUID HEATER—A device used to heat the heat transfer fluid to its required temperature before it enters the heat exchangers.

LONGITUDINAL—Running lengthwise; placed lengthwise; opposed to transverse.

MIL—Unit of measure equivalent to 0.001 in.

MPH—Miles per hour.

ORBITROL CONTROL—A brand name device, located at the base of the platform operator's steering columns and powered by a hydraulic mechanism, which acts as a power steering unit for control of the outriggers.

OUTRIGGER—A mechanism, powered by hydraulic action, that extends and supports the outrigger carriages, which, in turn, support the spray guns.

OVERSPRAY—Spray pattern exceeding the desired pattern; e.g., spraying of product in a fine mist beyond the proposed edges of the line being striped.

PAINTS—Classified by drying time:

(a) Instant dry—less than 30 sec.
(b) Quick dry—30 to 120 sec.
(c) Fast dry—2 to 7 min.
(d) Conventional—over 7 min.

PREMIX—A paint that contains reflective glass spheres held in suspension throughout the paint.

PSI—Pounds per square inch.

REFRACTIVE INDEX—The absolute index of refraction of a substance is the ratio of the velocity of light in a vacuum to the velocity of light in the substance. It is also the ratio of the sine of the angle of incidence to the sine of the angle of refraction.

REFLECTIVE—Bending or turning light.

RETROREFLECTIVE—Capable of returning light to its source.

RPM—Revolutions per minute.

SKINNING—A condition commonly occurring with paints in the container and when applied as a line or stripe where the immediate surface dries first or "skins" and the under surface remains wet (as opposed to through set of a film).

SOLVENT—Usually a liquid that, when added to paint, will reduce the viscosity of that paint and may also dissolve the resin (binder). For general purposes, the terms solvent and thinner can be used interchangeably.

SPRAYING—A procedure of applying paint to a surface:

(a) Air atomizing spray—Spraying atomization of the liquid paint through air pressure only.
(b) Airless spray—Spraying atomization of the liquid paint is accomplished through hydraulic fluid pressure only. No atomization air is used.

STRIPER—A self-contained paint spray system mounted on a truck chassis and used for over-the-road striping.

STRIPING CYCLE—The ratio of the length of painted line to the length of line left unpainted, with constant repetition of this cycle giving a "skip" effect. The standard ratio is 3:5.

SUBSTRATE—The surface to which the paint is applied.

THINNER—Usually a liquid that, when added to paint, will reduce the viscosity of that paint, but will not dissolve the resin (binder). See SOLVENT.

THROUGH SET—Property of the paint to be uniformly dry or set through its entire thickness from the line surface to the substrate surface (as opposed to skinning).

TIMER—A semi-automatic device that controls the "skip" to paint ratio. It consists of a surface-running timing wheel connected by drive mechanisms to a control box (on the platform), which is then connected to the paint spray controls.

TIP LIFE—The length of time that a spray gun tip will continue to function properly. The tip is no longer useful when the orifice elongates and the applied line deviates from its desired appearance.

TRACK FREE—The applied line will not be picked up by vehicle tires and transferred to the adjacent pavement.

TRANSVERSE—Lying, situated, placed, etc., across from side to side; crosswise. Also, perpendicular to the center line.

VISCOSITY—A measure of a fluid's tendency to resist flow. Also, the constant ratio of the shearing stress to the rate of shear in the liquid.

WET FILM THICKNESS—Thickness of line at time of application.

WETTING—A prime requisite for good adhesion, it is the flow of liquid product over the surface of the substrate to yield complete coverage. Wetting, and hence adhesion, is poor over dirty or oily surfaces.

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