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Reduction of Volatile Organic Compound Emissions from the Application of Traffic Markings

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REDUCTION OF VOLATILE ORGANIC COMPOUND EMISSIONS FROM THE APPLICATION OF TRAFFIC MARKINGS

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PREFACE

The traffic markings investigation was funded as a project of EPA's Control Technology Center (CTC).

The CTC was established by EPA's Office of Research and Development (ORD) and Office of Air Quality Planning and Standards (OAQPS) to provide technical assistance to State and Local air pollution control agencies. Three levels of assistance can be accessed through the CTC. First, a CTC HOTLINE has been established to provide telephone assistance on matters relating to air pollution control technology. Second, more in-depth engineering assistance can be provided when appropriate. Third, the CTC can provide technical guidance through publication of technical guidance documents, development of personal computer software, and presentation of workshops on control technology matters.

The technical guidance projects, such as this one, focus on topics of national or regional interest that are identified through State and Local agencies. This report discusses methods of controlling volatile organic compound (VOC) emissions from the application of highway traffic markings, a very unique source inasmuch as the State Government generally has total control of the specifications for the coatings.

The purchase and application of traffic markings is generally under the purview of the State Departments of Transportation, consequently, the control of VOC emissions, that is the development of regulations and implementation of control techniques, lies completely within the control of the Governor. Most importantly, perhaps, is that VOC emission reductions from this source can usually be obtained at a cost savings to the State since most low-VOC markings are considerably more durable than the traditional solvent-based paints.

This document provides an analysis of the cost savings that can accrue when a State converts to a low solvent coating. Further, in Section 5.3 example calculations permit the reader to analyze the cost associated with specific circumstances which may be unique to the State.

ACKNOWLEDGEMENT

This report was prepared by staff in Midwest Research Institute's Environmental Engineering Department located in Cary, North Carolina. Participating on the project team for the EPA were Karen Catlett of the Office of Air Quality Planning and Standards and Charles Darvin of the Air and Energy Engineering Research Laboratory. The data presented were generated through a literature search and surveys of paint formulators, equipment manufacturers, and State Departments of Transportation.

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1.0 INTRODUCTION

The Clean Air Act identified December 31, 1987, as the latest date for attainment of the national ambient air quality standard (NAAQS) for ozone. As of this writing, many areas of the country are not in attainment with the ozone NAAQS. The U. S. Environmental Protection Agency (EPA) has proposed to require States that have ozone nonattainment areas to submit revised State Implementation Plans (SIP's) that describe what steps will be taken to attain the standard (52 FR 45044, November 24, 1987).

Under the proposed rule (52 FR 45044), to demonstrate attainment of the NAAQS for ozone, emissions of volatile organic compounds (VOC's) must be reduced to a level that will produce ozone concentrations consistent with the NAAQS as demonstrated by atmospheric dispersion modeling. Once the State has determined the VOC emission reduction required to meet the NAAQS, it must identify and select control measures that will produce the required reductions as expeditiously as practicable.

Nonattainment areas are likely to have a high population density and, therefore, a high frequency of traffic marking applications. This report presents technical information that State and local agencies can use to develop strategies for reducing VOC emissions from the application of traffic paints and marking materials. The information in this document will allow planners to: (a) identify available alternative low- and zero-VOC traffic paints and marking materials; (b) determine the area's baseline condition; and (c) evaluate the VOC reduction, cost, and environmental impacts of implementing the alternatives.

This document provides information on traffic marking application processes, VOC emissions and emission reductions, and costs associated with the application of the alternative traffic marking materials. This information was generated through a literature search and surveys of State Departments of Transportation, traffic paint formulators, and application equipment manufacturers. Section 2.0 presents a summary of the findings of this study. Section 3.0 provides the following information on alternative marking materials: (1) factors affecting the selection of a traffic marking material, (2) descriptions of alternative traffic marking materials and associated application techniques, and (3) brief discussions of the advantages and disadvantages associated with the use of each material. Section 4.0 provides emission estimates for each alternative and estimated emission reductions from traditional solvent-borne traffic marking paints and describes the environmental impacts associated with the application of these alternative traffic marking materials. Section 5.0 presents a cost analysis that includes a methodology for computing annualized equipment and materials cost and the anticipated savings for each alternative with respect to the use of solvent-borne paints. The annualized application cost of each alternative is equal to or less than that for solvent-borne paints. In addition, Section 5.0 provides a qualitative discussion of the critical parameters required to develop annualized costs of alternative traffic marking materials. This discussion will assist the users of this document in developing the cost information necessary to develop a VOC reduction strategy specific to their area. Note that, whenever appropriate, the tables in this document are numbered and designated "a" and "b" to indicate the same table in Systeme Internationale (SI) and English units, respectively.

2.0 SUMMARY

Traffic marking materials include solvent-borne paints, waterborne paints, thermoplastics, preformed tapes, field-reacted materials, and permanent markers. Because the performance requirements for different marking situations differ and because these materials have different physical and chemical properties and a wide range of costs, different materials are advantageous for specific application situations. In some geographic areas, a combination of traffic marking materials (including solvent-borne paints and low- and zero-VOC materials) is used while in other areas solvent-borne paint is used exclusively. Therefore, the VOC emission reduction impact of implementing low- and zero-VOC alternative marking materials will vary by area depending on current practice. In choosing regulatory alternatives to reduce VOC emissions based on specific traffic marking materials, planners should coordinate with their Departments of Transportation regarding the change to an alternative material.

The traditional and most common materials used for traffic markings are solvent-borne paints.[1-16] The VOC emissions from solvent-borne paint traffic markings are estimated to be 19 kilograms per kilometer of 10-centimeter (cm)-wide solid stripe per year (kg/km-yr) (69 pounds per mile of 4-inch (in.)-wide solid stripe per year [lb/mile-yr]). The alternatives to solvent-borne paint that are discussed in this document are: (1) waterborne paints, (2) thermoplastics, (3) preformed tapes, (4) field-reacted materials, and (5) permanent markers. All of these alternative marking materials emit less VOC's than solvent-borne paint, and achievable reductions are as high as 100 percent. Although no single traffic marking material is the most desirable in all applications, a combination of low- and zero-VOC-emitting marking materials can provide the performance necessary for highway safety.

For the marking materials investigated, Tables 1a and 1b present the VOC emissions, VOC emission reductions compared to solvent-borne paint, total annualized cost, and cost savings compared to solvent-borne paint. Elimination of VOC emissions may be achieved by applying thermoplastics, field-reacted materials (epoxy and polyester), preformed tapes without

TABLE 1a. VOC EMISSIONS AND COST COMPARISON OF ALTERNATIVE TRAFFIC MARKING MATERIALS

Marking	VOC emissions, kg/km-yr[a]	VOC emission reductions from solvent-borne, kg/km-yr	Percent VOC reduction from solvent-borne	Total annualized cost, $/km-yr	Savings compared to solvent-borne, $/km-yr
Solvent-borne	19	b	NA[b]	140	b
Waterborne	3.7	16	81	120	20
Thermoplastic	c	19	100	140	0
Field reacted					
Polyester	c	19	100	87	50
Epoxy	0.07	19	100	120	20
Preformed tapes					
Without adhesive primer	0	19	100	d	d
With adhesive primer	16	3	15	d	d
Permanent markers	0	19	100	d	d

[a] Kilometer refers to one 10-centimeter-wide solid stripe that is 1 kilometer long.
[b] Not applicable.
[c] Negligible.
[d] These alternatives were not included in the cost analysis.

TABLE 1b. VOC EMISSIONS AND COST COMPARISON OF ALTERNATIVE TRAFFIC MARKING MATERIALS

Marking	VOC emissions, lb/mile-yr[a]	VOC emission reductions from solvent-borne, lb/mile-yr	Percent VOC reduction from solvent-borne	Total annualized cost, $/mile-yr	Savings compared to solvent-borne, $/mile-yr
Solvent-borne	69	b	NA[b]	230	b
Waterborne	13	56	81	200	30
Thermoplastic	c	69	100	230	0
Field reacted					
Polyester	c	69	100	140	90
Epoxy	0.25	69	100	200	30
Preformed tapes					
Without adhesive primer	0	69	100	d	d
With adhesive primer	58	11	15	d	d
Permanent markers	0	69	100	d	d

[a]Mile refers to one 4-inch-wide solid stripe that is 1 mile long.
[b]Not applicable.
[c]Negligible.
[d]These alternatives were not included in the cost analysis.

adhesive primer, and permanent markers. A significant reduction (about 81 percent) in VOC emissions can be achieved by applying waterborne paint instead of solvent-borne paint (VOC emissions would drop from 19 kg/km-yr [69 lb/mile-yr] to 3.7 kg/km-yr [13 lb/mile-yr]). Preformed tapes applied with an adhesive offer a small VOC emission reduction (about 15 percent).

Three alternative traffic marking materials were evaluated with regard to cost: waterborne paints, thermoplastics, and field-reacted materials. All of these materials have an annualized cost equal to or less than the cost of solvent-borne paint. The application of waterborne paint and field-reacted materials (epoxy and polyester) offer a savings over the annualized cost of application solvent-borne paint. The field-reacted polyester has a savings associated with it of $50/km-yr ($90/mile-yr). Waterborne paint and field-reacted epoxy both offer a savings of $20/km-yr ($30/mile-yr). Thermoplastic costs the same to apply as solvent-borne paint. Clearly, significant reductions in VOC emissions can be achieved safely and at a reduced cost.

3.0 AVAILABLE TRAFFIC MARKING MATERIALS

Traffic markings are used to provide lane delineation (centerlines, edgelines, lane lines) and other guidance and information (turn arrows, parking spaces, crosswalks, railroad markings, special lanes, etc.). These markings are usually applied by State or local highway maintenance crews or by contractors during new road construction. Emissions of VOC's from traffic marking are the result of organic solvent evaporation during and shortly after application of the marking. No traditional containment devices or add-on controls are available. Emissions of VOC's must be reduced by switching to lower VOC-emitting markings, i.e., "alternative markings."

Site-specific factors related to the performance of the marking should be considered during the selection of alternative materials to reduce VOC emissions; however, the low- and zero-VOC emitting marking materials available today provide sufficient flexibility to accommodate site-specific constraints. Section 3.1 presents and discusses factors besides VOC emissions and annual cost that are considered when selecting a marking material. Section 3.2 provides descriptions of the alternative marking materials currently available and their application procedures. Chapters 4 and 5 present discussions of VOC emissions and annualized cost, respectively.

3.1 FACTORS CONSIDERED IN SELECTING A MARKING MATERIAL

In addition to VOC emissions and cost, the factors that must be considered in selecting a traffic marking material are related to public safety or benefit, application crew safety, and performance.[5] Table 2 presents a list of factors that may affect the selection of a traffic marking material. The factors listed are greatly interrelated and have not been listed in order of importance because the relative importance of each factor is very site-specific. Factors other than VOC emissions and annualized cost are discussed briefly below.

For a marking to promote public safety effectively, it must be visible day and night under a variety of conditions. The condition that presents the greatest visibility problem for most markings is a rainy night. This nighttime visibility problem is due to the fact that most

TABLE 2. FACTORS AFFECTING THE SELECTION OF A TRAFFIC MARKING MATERIAL

VOC emissions
Visibility
Durability
Pavement type
Traffic density
Position of line or marking
Climatic restrictions
Drying or setting time
Safety of material and application procedure
Difficulty of application
Amount to be applied
Initial cost
Annual cost
Equipment availability

markings have no vertical profile that reflects light from headlights back to the driver. Glass beads typically are added to markings to improve the visibility of the markings at night. On a rainy night, the water film that forms over the marking causes specular reflection (light is reflected forward) that further decreases the nighttime visibility of the marking. Some markings, such as permanent markers and thermoplastic with drainage grooves marked across it, have a vertical profile that decreases the impact of the water film.

Durability of the markings can be influenced by pavement type, the amount of traffic to which it is exposed, and whether it is placed transversely (such as a crosswalk) or longitudinally (such as an edgeline). In some areas, traffic markings can be applied effectively only in the summer months. In these areas, a marking must be durable enough to perform adequately between seasons until it is feasible to restripe. Durability of traffic markings also impacts public safety. The installation of more durable traffic marking materials reduces the exposure of the motoring public and maintenance personnel to high-risk conditions created by frequent painting operations.[5]

Some markings, such as solvent-borne and waterborne marking materials, can be applied only in warm weather because they may not adhere properly to the pavement during cold weather or because the temperature affects the drying or setting time. Other weather or weather-related conditions which may cause similar problems are rain shortly after application, high humidity, and wet roads. These conditions limit the number of available days suitable for the application of traffic markings. Also, some types of markings, especially those that protrude above grade, rarely survive in areas with heavy snowplow activity or frequent salting and sanding operations.

After being applied, most markings must dry or set before traffic may pass over them without endangering the marking. The time required immediately after application for this drying or setting is referred to as the tracking time. If a marking has a long tracking time, a lane may have to be closed to traffic or cones may have to be placed to prevent traffic from crossing the marking. This nonuse period presents an inconvenience to the public, and the placing and removing of cones can be a safety hazard to the maintenance personnel who are exposed to traffic. Markings with a short tracking time may be protected by trailing a vehicle a reasonable distance behind the application equipment.

Other factors to consider in choosing a traffic marking material include personnel safety, purchase cost, difficulty of application, and the size and location of a specific job.

State transportation departments should be involved in developing a State's VOC emission reduction plan for traffic markings. The factors discussed in this section, as well as VOC reductions and annualized cost, should be considered in developing a plan that will reduce VOC emissions.

3.2 DESCRIPTIONS OF MATERIALS AND APPLICATION METHODS

This section describes each alternative marking material. The information presented includes VOC content, solids content, application procedure, glass bead application rate, tracking time, durability, and limitations on use. Tables 3 and 4a and 4b summarize the information presented in this section. Table 3 is a qualitative comparison of the advantages and disadvantages of the alternative marking materials. Tables 4a and 4b summarize the properties of the alternative materials.

3.2.1 Solvent-Borne Paints

Solvent-borne traffic paints typically consist of a resin, pigment, and various additives, all of which are suspended in an organic solvent. Paints containing an alkyd-based resin are the most common. Paints containing chlorinated rubber resins or alkyd resins modified with chlorinated rubber are frequently used and are similar to alkyd resin paints in most respects.[1-16,21] Epoxy paint is a two-component material. One component is a solution containing solid epoxy resin and pigments. The second component consists of a curing agent and a reaction-blocking organic solvent such as methyl ethyl ketone. The two components are mixed prior to being placed in the application equipment. The resulting mixture remains liquid for several days if kept in a closed container. After application, the reaction-blocking solvent evaporates, allowing the paint to harden.

When evaluating paint formulations, both the solids content and the VOC content are of interest. The solids content usually is expressed as a volume percent. The VOC content is expressed in one of two ways:

TABLE 3. ADVANTAGES AND DISADVANTAGES OF ALTERNATIVE TRAFFIC MARKING MATERIALS

Marking material	Advantages	Disadvantages
Solvent-borne paints	Low initial cost Good dry-night visibility Short dry times available Good equipment availability Well-established technology No pavement-type limitations	High VOC emissions Short life Poor wet-night visibility
Waterborne paints	Low VOC emissions Low initial cost Good dry-night visibility Good equipment availability Easy to adapt from solvent-borne Easy cleanup No pavement-type limitations	Poor wet-night visibility Short life Weather restrictions
Thermoplastics	Negligible VOC emissions Long life Good night (wet and dry) visibility 100 percent solids	High initial cost High application temperature Reduced durability on portland cement concrete More difficult application than for paint
Preformed tapes	No VOC emissions if adhesion primer not needed Long life Little or no application equipment needed Excellent material safety 100 percent solids	High VOC emissions if adhesive primer is used Very high initial cost Variable night visibility

(continued)

TABLE 3. (continued)

Marking material	Advantages	Disadvantages
Field-reacted materials	Negligible VOC emissions Long life Moderate initial cost Essentially 100 percent solids Good night visibility	Polyester type adheres poorly to portland cement concrete Special application equipment needed
Permanent markers	Negligible VOC emissions Long life Excellent night (wet and dry) visibility	High initial cost Poor durability in snowplow areas

TABLE 4a. PROPERTIES OF ALTERNATIVE TRAFFIC MARKING MATERIALS

Material	VOC content, g/ℓ marking	Solids content, percent by volume	Application thickness, mm-wet	Application rate, ℓ/km[a]	Glass bead application rate, g/ℓ marking	Expected life, years		
						Low	High	Typical
Solvent-borne paints	377	50	0.38	39	720	0.25	1	0.75
Waterborne paints	91	50	0.38	39	720	0.5	2	1
Thermoplastics	0	100	1.5	155	190	2	8	4
Preformed tapes	0	100	1.5	NA[b]	0	3	13	4
Field-reacted								
Epoxy	Neg.[c]	100	0.38	39	3,000	3	5	4
Polyester	Unk[d]	100	0.38	39	1,800	2	4	3
Permanent markers[e]	0	NA	NA	NA	0	5	5	5

[a]Kilometer refers to one 10-centimeter-wide solid stripe that is 1 kilometer long.
[b]NA = not applicable.
[c]Neg. = negligible.
[d]Unk. = unknown, assumed to be negligible.
[e]Based on one data point.

TABLE 4b. PROPERTIES OF ALTERNATIVE TRAFFIC MARKING MATERIALS

Material	VOC content, lb/gal marking	Solids content, percent by volume	Application thickness, mils-wet	Application rate, gal/mile[a]	Glass bead application rate, lb/gal marking	Expected life, years		
						Low	High	Typical
Solvent-borne paints	3.15	50	15	16	6.0	0.25	1	0.75
Waterborne paints	0.76	50	15	16	6.0	0.5	2	1
Thermoplastics	0	100	60	66	1.6	2	8	4
Preformed tapes	0	100	60	NA[b]	0	3	13	4
Field-reacted								
Epoxy	Neg.[c]	100	15	16	25	3	5	4
Polyester	Unk.[d]	100	15	16	15	2	4	3
Permanent markers[e]	0	NA	NA	NA	0	5	5	5

[a]Mile refers to one 4-inch-wide solid stripe that is 1 mile long.
[b]NA = not applicable.
[c]Neg. = negligible.
[d]Unk. = unknown, assumed to be negligible.
[e]Based on one data point.

1. Mass of VOC per volume of coating, e.g., gram VOC/liter (g VOC/ℓ) paint (lb VOC/gallon [lb VOC/gal]); or

2. Mass of VOC per volume of solids, e.g., g VOC/ℓ solids (lb VOC/gal).

The latter value often is the most useful because it directly relates the VOC content to the amount of solids; the amount of solids are of interest because it is the solids available in the paint that ultimately forms the marking.

Most solvent-borne traffic paints have a solids content between 45 and 55 percent by volume[1-16]. The VOC contents range from 320 to 460 g VOC/ℓ (2.7 to 3.8 lb VOC/gal) paint and 580 to 970 g VOC/ℓ (4.8 to 8.1 lb VOC/gal) solids. Typical values are 50 percent solids and 380 g VOC/ℓ (3.15 lb VOC/gal) paint (750 g VOC/gal [6.30 lb VOC/gal] solids).[1-16]

Solvent-borne paints are usually applied by spraying. The wet film thickness typically is 0.38 millimeters (mm) (15 thousandths of an inch [mils]), and dry thickness is about 0.18 or 0.20 mm (7 or 8 mils), depending on the solids content.[1-16,21] Immediately after application, glass beads are dropped or sprayed onto the wet film at a rate of about 6 lb per gallon of paint. Glass beads provide reflectivity for nighttime visibility. The time required for the paints to dry enough to receive traffic ranges from 20 seconds to several minutes, depending on the properties of the paint and on application conditions. The paint may be heated before application to decrease the drying time. Solvent-borne paints are usually applied only when the temperature of the road surface is 10°C (50°F) or higher.

Application equipment ranges in size from small hand units to large, high-speed, truck-mounted units. Solvent-borne paints may be used for all types of markings on all types of paved surfaces and last from 3 to 12 months depending on site-specific factors, with 9 months being typical.[11,13-16]

3.2.2 Waterborne Paints

Waterborne paints are latex emulsions containing pigments, additives, and usually some organic solvent. Waterborne paints typically contain about 80 g VOC/ℓ (0.70 lb VOC/gal) paint and about 50 percent solids by volume.[1-16]

Waterborne paints are applied in the same manner as solvent-borne paints and have similar appearance, lower VOC emissions, and better durability.[1-16] The range of tracking times is similar to that for solvent-borne paints (20 seconds to several minutes). The durability of waterborne paints is affected by the weather conditions at the time of application. The best conditions at which to apply waterborne paints are days with high temperatures (at least higher than 10°C [50°F]) and low humidity. One source specified that the durability of waterborne paints is affected if there is rain or heavy fog within about 7 days after application.[17] However, one vendor indicated that although durability is affected by weather conditions during curing, 7 days is is an excessive curing period.[26] If the paint is applied at the proper climatic conditions, then the durability should not be affected. Waterborne paints can generally be applied wherever solvent-borne paints are used. Waterborne paints usually last from 6 to 24 months depending on site-specific factors, with 12 months being typical.[1-16]

Some States, such as Maryland, have switched from solvent-borne paints to waterborne paints because of their cost effectiveness and low VOC content.[2]

3.2.3 Thermoplastics

The three distinct types of thermoplastics currently available are alkyd, hydrocarbon, and epoxy thermoplastics. Alkyd and hydrocarbon thermoplastics consist of alkyd and hydrocarbon resin, respectively; pigments; calcium carbonate filler; and glass beads. Alkyd thermoplastic was initially introduced as an improvement over hydrocarbon thermoplastic. The thermoplastics are solids and are usually delivered in block or granular form. The solids melt when heated and are extruded or sprayed at about 232°C (450°F). The materials are usually applied at a film thickness of 1.27 to 3.8 mm (50 to 150 mils) depending on the application method and the purpose of the line or marking. The thermoplastics contain premixed glass beads for long-term reflectivity, but additional glass beads are usually applied to the hot film to improve initial reflectivity. There is little difference in the performance of the two types of material.

Epoxy thermoplastic, sometimes called epoflex, is a thermoplastic which uses a blend of epoxy resins. It is similar to alkyd and hydrocarbon thermoplastic except that it is typically applied at a film thickness of about 0.51 mm (20 mils) and has a shorter setting time.

Data on the average expected life of thermoplastics was obtained from State survey responses. The reported average expected life of thermoplastics ranges from about 2 years (Maryland) to about 7 years (California). Other States reported averages from 4 to 5 years (New York and Colorado). The States responding to the survey supplied data only on alkyd and hydrocarbon thermoplastics and the data showed little difference in life expectancy between the two types. The life expectancy for epoxy thermoplastics should be between 2 to 4 years.[21] Alkyd and hydrocarbon thermoplastics adhere better to asphalt concrete than to portland cement concrete while epoxy thermoplastics are claimed to have good durability on both surface types.[21] Field experience with epoxy thermoplastic is still limited.[21] Thermoplastics emit a negligible amount of VOC's and are essentially 100 percent solids.

A wide range of equipment is available for applying thermoplastics.[18-20] Application temperature and thickness must be closely controlled to ensure good durability.[21] Thermoplastics have received considerable use, especially in areas where a marking more durable than paint is needed.[1-10] Because paint lasts less than a year in some locations and because traffic markings in some areas may only be applied in the summer months due to weather restrictions, a more durable traffic marking material than paint, such as thermoplastic, is desirable to provide adequate delineation from one striping period to the next.

3.2.4 Preformed Tapes

Preformed plastic tapes consist of resins, pigments, glass beads, and fillers. The tapes have an adhesive backing for direct application to the pavement. The tapes are supplied in rolls of various widths to be applied as lines and in sheets to be cut for legends and directional markings. The thickness of the tape is usually 1.52 or 2.28 mm (60 or 90 mils).

The tapes may be applied to existing or new pavement. An adhesive primer is often applied to precondition the pavement surface when tapes are used on existing pavement. No application equipment is needed to apply tapes, but equipment may be used for large jobs. Traffic tapes last from 3 to 13 years with 4 years being typical.

Tapes are 100 percent solids and emit no VOC's. Adhesive primers contain about 640 g VOC/ℓ (5.3 lb VOC/gal) and are applied at a rate of about 0.98 square meters per liter (40 square feet per gallon).[12]

Preformed tapes are applied by a large number of users but due to their high cost are used mostly for small jobs such as intersection work (crosswalks, turn arrows, etc.). Tapes also are easy to apply, emit no VOC's, and are more durable when inlaid into new asphalt. The tape is placed onto the asphalt behind the paving machine and then pressed into the asphalt with the paving roller.

3.2.5 Field-Reacted Materials

Both epoxy and polyester field-reacted materials consist of resin, pigments, and a hardening agent. The materials are stored in two separate components--one containing the resin (either epoxy or polyester) and one containing the hardener. One or both components may be heated to about 60°C (140°F) before application to improve flow. The two components are fed separately to the spray nozzle or nozzles and are mixed as they are sprayed into the pavement. As soon as the components mix, a reaction begins that forms a hard marking. The materials are normally applied at a film thickness of 0.38 mm (15 mils), and glass beads are added at a rate of 1,800 g/ℓ (15 lb/gal) of material for polyester and 3,000 g/ℓ (25 lb/gal) for epoxy.[21]

Field-reacted materials are nearly 100 percent solids and emit a very small amount of VOC's before the reaction is complete.

Polyester field-reacted markings last about 3 years, and epoxy markings last about 4 years. Polyester markings do not adhere well to portland cement concrete. Information obtained from the surveys of State Departments of Transportation conducted during this study indicates that State highway maintenance crews may require training in order to apply field-reacted materials, and that these materials are usually applied by contractors.[2,8,25]

3.2.6 Permanent Markers

Permanent markers are preformed units made of a variety of materials such as steel, ceramic, or plastic that are bonded to the pavement. The numerous designs available include nonreflective markers for daytime delineation and reflective markers for nighttime delineation. Permanent markers are bonded to the pavement with any of a number of adhesives including epoxy, magnesium phosphate cement, silicon caulk, or bituminous materials. Most permanent markers are of the raised type. They may be affixed directly to the existing pavement surface in a hole drilled for the purpose. Markers of the recessed type are installed below the road surface in grooves cut into the pavement to protect them from snowplow blades. The high profile of raised permanent markers makes them susceptible to damage from snowplows.

Permanent markers contain no VOC's, although a small amount may be emitted if an adhesive is used to bond the marker to the pavement.

Permanent markers are most often used on highways as a supplement to other marking materials. The vertical profile of permanent markers provides nighttime lane delineation during both rainy and dry periods.

4.0 EMISSIONS, EMISSION REDUCTIONS, AND ENVIRONMENTAL IMPACTS

This chapter provides VOC emission estimates and the estimated emission reductions from traditional solvent-borne paints for each of the marking materials identified in Section 3.0. The environmental impacts associated with the application of each material are also discussed. The methodology for calculating the VOC emissions from the marking materials is presented in Section 4.1. Estimated VOC emissions from each material are presented in tabular form. The baseline condition and relative reduction in VOC emissions from baseline for each alternative are discussed in Section 4.2. Other environmental impacts are discussed in Section 4.3.

4.1 EMISSIONS

This section presents the methodology for calculating the VOC emissions from each alternative. The methodology is presented using English units. The emissions are averaged over the life of the marking to account for the marking material's durability. Tables 5a and 5b present the estimated VOC emissions per application and annual emissions for each of the marking materials identified in Section 3.0. The parameters required to make these estimates include application thickness, application rate, VOC content, and expected life.

The application rate was calculated from the wet application thickness. The calculations assume a 4-inch-wide solid stripe that is 1 mile long as the basis. The equation for calculating the application rate is:

$$AR = (WAT)(4\text{ inches})\left(\frac{5{,}280\text{ ft}}{\text{mile}}\right)\left(\frac{1\text{ inch}}{1{,}000\text{ mils}}\right)\left(\frac{1\text{ ft}}{12\text{ inches}}\right)^2\left(\frac{7.48\text{ gal}}{\text{ft}^3}\right)$$

where

AR = the application rate in gal/mile, and

WAT = the wet application thickness in mils.

The thickness of the wet film must be used in the equation above. Often the wet film thickness is adjusted to give a desired dry film thickness.

TABLE 5a. VOC EMISSIONS FROM ALTERNATIVE MARKING MATERIALS

Marking	Application thickness, mm-wet	Application rate, ℓ/km	VOC content, g/ℓ	Typical expected life, years	VOC emissions per application, kg/km[a]	Typical annual VOC emissions, kg/km-year[a]
Solvent-borne paints	0.38	39	377	0.75	15	19
Waterborne paints	0.38	39	91	1	3.7	3.7
Thermoplastics	1.5	155	Neg.[b]	4	0	0
Preformed tapes						
Without primer	1.5	NA[c]	0	4	0	0
With primer	1.5	94[d]	635	4	66	16
Field-reacted						
Epoxy	0.38	39	7	4	0.3	0.07
Polyester	0.38	39	Unk[e]	3	0	0
Permanent markers[f]	NA	NA	0	5	0	0

[a]Kilometer refers to one 10-centimeter-wide solid stripe that is 1 kilometer long.
[b]Neg = negligible.
[c]NA = not applicable.
[d]Refers to the adhesive primer.
[e]Unk = unknown, assumed to be negligible.
[f]Based on one data point.

TABLE 5b. VOC EMISSIONS FROM ALTERNATIVE TRAFFIC MARKING MATERIALS

Marking	Application thickness, mils-wet	Application rate, gal/mile	VOC content, lb/gal	Typical expected life, years	VOC emissions per application, lb/mile[a]	Typical annual VOC emissions, lb/mile-year[a]
Solvent-borne paints	15	16	3.15	0.75	52	69
Waterborne paints	15	16	0.76	1	13	13
Thermoplastics	60	66	Neg[b]	4	0	0
Preformed tapes						
Without primer	60	NA[c]	0	4	0	0
With primer	60	40[d]	5.3[d]	4	233	58
Field-reacted						
Epoxy	15	16	0.06	4	1	0.25
Polyester	15	16	Unk[e]	3	0	0
Permanent markers[f]	NA	NA	0	5	0	0

[a]Mile refers to one 4-inch-wide solid stripe that is 1 mile long.
[b]Neg = negligible.
[c]NA = not applicable.
[d]Refers to the adhesive primer.
[e]Unk = unknown, assumed to be negligible.
[f]Based on one data point.

The relationship between wet film thickness and dry film thickness is:

WAT = DAT/S

where,

WAT = the wet application thickness,

DAT = the dry application thickness, and

S = the volume fraction of solids in the paint.

The VOC emissions per application (lb/mile) were calculated by multiplying the application rate (gal/mile) by the VOC content (lb/gal). The annual VOC emissions (lb/mile-yr) were calculated by dividing the VOC emissions per application (lb/mile) by the expected life (years). Therefore, emissions are averaged over the life of the marking.

As indicated in Tables 5a and 5b, solvent-borne paints have the highest annual VOC emissions of all the marking materials. Preformed tapes used with adhesive primer emit the next highest amount--about 58 pounds per mile per year (lb/mile-yr) compared to 69 lb/mile-yr for solvent-borne paint. The annual VOC emissions from waterborne paints are about 13 lb/mile-year or about 80 percent less than the emissions from solvent-borne paints. Thermoplastics, preformed tapes used without adhesive primer, field-reacted materials, and permanent markers emit negligible amounts of VOC's.

Data on low- and zero-VOC marking materials was obtained from survey responses from paint formulators and the States of Alabama, Arizona, California, Colorado, Louisiana, Maine, Maryland, New Jersey, New York, North Carolina, Ohio, and South Carolina. The values for the parameters (VOC content, expected life, etc.) used to calculate emissions are based on average or typical values obtained from available literature and survey responses. The particular marking material used by a State may have properties quite different from the average. Values for these parameters that are specific to the materials used by each State can be obtained from the State transportation department or from material suppliers. These values can then be used with the methodology described above to obtain a more accurate emission estimate for a particular marking material.

In deciding which traffic marking material to purchase, most States conduct performance tests of various marking materials supplied by various manufacturers. Also, each State has its own specifications for each type of marking material used that a manufacturer must meet. As a quality assurance procedure, States should test samples of the traffic marking material purchased to ensure that it conforms to their specifications and is of consistent quality. This type of testing should be ongoing and should be conducted independent of the manufacturer's own quality control.

4.2 BASELINE AND EMISSION REDUCTIONS

4.2.1 Explanation of Baseline

A baseline emission level was established to facilitate comparison of the impacts of various alternatives. The actual baseline emission level for a specific geographic area would comprise emissions from all the marking materials in current use. Because of the variations in usage nationwide, it was not possible to select one baseline that would be representative for all areas. However, it is possible to select a baseline level that can be used to evaluate the relative impacts of various materials.

Solvent-borne paints have been chosen as the baseline for the comparison of emission reductions and costs because solvent-borne paints are the most widely used marking material and have the greatest annual VOC emissions.

A State may calculate the true baseline emission level for a particular area by estimating the VOC emissions from each marking material used according to the methodology described in Section 4.1. A sum of the emissions from each material used will provide a true baseline. For example, if a State currently marks 8,000 miles with solvent-borne paint that emits 69 lb VOC/mile-yr and 2,000 miles with waterborne paint that emits 13 lb VOC/mile-yr, then its baseline would be:

$$(69 \text{ lb VOC/mile-yr})(8{,}000 \text{ miles}) + (13 \text{ lb VOC/mile-yr})(2{,}000 \text{ miles}) = 578{,}000 \text{ lb VOC/year}.$$

4.2.2 Emission Reductions

Tables 6a and 6b present typical annual VOC emission reductions from baseline (solvent-borne paint) for each alternative. These values were calculated by subtracting the annual VOC emissions per mile (lb/mile-yr)

TABLE 6a. VOC EMISSION REDUCTIONS FOR ALTERNATIVE TRAFFIC MARKING MATERIALS FROM BASELINE

Traffic marking material	Typical annual VOC emissions, kg/km-yr	Typical annual VOC reduction from baseline, kg/km-yr	Percent reduction from baseline
Solvent-borne paints	19	NA	NA
Waterborne paints	3.7	15	81
Thermoplastics	0	19	100
Preformed tapes			
Without adhesive primer	0	19	100
With adhesive primer	16	3	16
Field-reacted	0	19	100
Permanent markers	0	19	100

NA = not applicable.

TABLE 6b. VOC EMISSION REDUCTIONS FOR ALTERNATIVE TRAFFIC MARKING MATERIALS FROM BASELINE

Traffic marking material	Typical annual VOC emissions, lb/mile-yr	Typical annual VOC reduction from baseline, lb/mile-yr	Percent reduction from baseline
Solvent-borne paints	69	NA	NA
Waterborne paints	13	56	81
Thermoplastics	0	69	100
Preformed tapes			
Without adhesive primer	0	69	100
With adhesive primer	58	11	16
Field-reacted	0	69	100
Permanent markers	0	69	100

NA = not applicable.

for each alternative from the annual VOC emissions per mile for solvent-borne paints. Also presented is the percent reduction from baseline for each alternative. Percent reductions range from 16 percent for preformed tapes with adhesive primer to 100 percent for thermoplastics, preformed tapes without primer, field-reacted materials, and permanent markers.

4.3 ENVIRONMENTAL IMPACTS

No adverse environmental impacts from alternative traffic marking materials are apparent. Positive impacts on air quality result from the VOC reductions associated with the alternatives. Secondary impacts resulting from the cleanup of equipment and disposal of containers for the alternative marking materials are expected to be the same or smaller than those for solvent-borne paints. For example, solvent-borne paints require the use of organic solvents during the cleanup of equipment. These organic solvents further contribute to VOC emissions, although these emissions are estimated to be small in comparison to the emissions from the paint. Some alternatives (e.g., waterborne paints) do not require VOC-containing solvents during cleanup. Also, thermoplastics can be purchased in block form or in meltable plastic bags; therefore, disposal of containers is not a concern with thermoplastics.

5.0 COST ANALYSIS

A cost analysis was performed for three alternative traffic marking materials and solvent-borne paint. The alternatives that were evaluated are (1) waterborne paints, (2) thermoplastics, and (3) field-reacted materials. Waterborne paints were chosen because they reportedly are more durable than conventional solvent-borne traffic paints, they can be adopted easily with minor equipment modifications where solvent-borne paints currently are used, and their VOC emissions are about 80 percent less than those of solvent-borne paints. Thermoplastics were chosen because they are currently the most widely used zero-VOC alternative. Field-reacted materials were chosen because they are a zero-VOC alternative that has been reported as having a low cost.[21] Costs were not developed for preformed plastic tapes and permanent markers because analysis of the costs associated with these alternatives were not within the scope of this study.

The costs presented in this chapter were developed using a common basis of continuous maintenance of 32,000 kilometers of 10-centimeter-wide stripe (20,000 miles of 4-inch-wide stripe). The costs should be used for comparison purposes only because the parameters used to generate the costs will likely vary considerably from State to State. This chapter presents the methodology States can use to perform their own cost analysis based on their experience with the application of traffic marking materials. The cost methodology is presented in English units.

Section 5.1 presents the annualized costs for the alternatives, Section 5.2 presents the cost effectiveness of each alternative based on VOC reduction, and Section 5.3 discusses an approach a State can use to determine its specific costs.

5.1 ANNUALIZED COSTS

Annualized capital costs, annualized application costs, and total annualized costs are discussed in Sections 5.1.1, 5.1.2, and 5.1.3, respectively.

5.1.1 Annualized Capital Costs

Tables 7a and 7b present information on capital equipment costs used to determine annualized costs. Included in the table are total miles of

TABLE 7a. PARAMETERS USED TO CALCULATE CAPITAL EQUIPMENT COSTS ASSOCIATED WITH MAINTAINING 32,000 KILOMETERS OF TRAFFIC MARKINGS[a] [b]

Marking	Total kilometers maintained	Expected life of marking, years	Average kilometers applied per year[c]	Estimated equipment life, km	Equipment life, years[d]	Estimated equipment purchased cost, $	Annualized equipment cost, $/year[e]
Solvent-borne	32,000	0.75	42,700	160,000	3.75	200,000	63,000
Waterborne	32,000	1.00	32,000	160,000	5.00	250,000	61,000
Thermoplastic	32,000	4.00	8,000	80,000	10.00	250,000	36,000
Field-reacted polyester	32,000	3.00	10,700	80,000	7.50	300,000	53,000
Field-reacted epoxy	32,000	4.00	8,000	80,000	10.00	300,000	43,000

[a] A kilometer of traffic marking is one 10-centimeter-wide solid stripe that is 1 kilometer long.
[b] Intermediate calculated values have not been rounded to significant figures.
[c] Kilometers maintained divided by expected marking life.
[d] Estimated equipment life divided by average kilometers applied per year.
[e] Based on an interest rate of 7.26 percent.

TABLE 7b. PARAMETERS USED TO CALCULATE CAPITAL EQUIPMENT COSTS ASSOCIATED WITH MAINTAINING 20,000 MILES OF TRAFFIC MARKINGS[a] [b]

Marking	Total miles maintained	Expected life of marking, years	Average miles applied per year[c]	Estimated equipment life, miles	Equipment life, years[d]	Estimated equipment purchased cost, $	Annualized equipment cost, $/year[e]
Solvent borne	20,000	0.75	26,667	100,000	3.75	200,000	63,000
Waterborne	20,000	1.00	20,000	100,000	5.00	250,000	61,000
Thermoplastic	20,000	4.00	5,000	50,000	10.00	250,000	36,000
Field-reacted polyester	20,000	3.00	6,667	50,000	7.50	300,000	53,000
Field-reacted epoxy	20,000	4.00	5,000	50,000	10.00	300,000	43,000

[a] A mile of traffic marking is one 4-inch-wide solid stripe that is 1 mile long.
[b] Intermediate calculated values have not been rounded to significant figures.
[c] Miles maintained divided by expected marking life.
[d] Estimated equipment life divided by average miles applied per year.
[e] Based on an interest rate of 7.26 percent.

marking maintained, expected life of each marking material, average miles of marking applied per year, equipment life (miles), equipment life (years), equipment purchased cost, and annualized equipment cost.

The cost calculations are based on the continuous maintenance of 20,000 miles of 4-inch-wide stripe. The number of miles maintained divided by the life of the marking results in the average number of miles that must be applied per year to maintain the required mileage continuously. The equipment life is an estimate of the number of stripe-miles that can be applied by a piece of equipment during its useful life. The equipment life in years, or average replacement period, was calculated by dividing the equipment life in miles by the average miles applied per year. The annualized capital equipment cost was calculated using the following equation:

$$AEC = P\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$$

where

AEC = the annualized equipment cost in \$/year,

P = the installed cost of the equipment in current dollars,

n = the life of the equipment in years, and

i = the annual interest rate.

The annual interest rate used was 7.26 percent.[22] This rate is the yield on new, State-issued, long-term, tax-exempt securities and should represent the value of money to States.[23]

The annualized equipment costs presented in Tables 7a and 7b range from \$36,000/year for thermoplastics to \$63,000/year for solvent-borne paint. The estimates used to calculate the annualized equipment costs are based on a small amount of data.[18-20] However, as noted in Section 5.1.3, annualized capital equipment costs are very small in relation to the total annualized costs.

5.1.2 Annualized Application Costs

Tables 8a and 8b present the values used to calculate the annualized application costs and the results of the calculations. The calculations are based on the maintenance of 32,000 stripe-kilometers (20,000 stripe-miles) and an interest rate of 7.26 percent. The cost per mile of

TABLE 8a. PARAMETERS USED TO CALCULATE ALTERNATIVE TRAFFIC MARKING APPLICATION COSTS

Marking	Marking life, years	Application rate, ℓ/km	Marking material unit cost, $/ℓ	Marking material cost, $/km[a]	Labor, $/km	Glass beads, $/km	Other, $/km[b]	Application cost, $/km[c]	Annualized application cost, $/year[d]
Solvent-borne	0.75	38.7	1.32	51	25	16	9	101	4,600,000
Waterborne	1.0	38.7	1.59	62	25	16	9	112	3,800,000
Thermoplastic	3.0	155	2.11	327	90	16	53	486	4,700,000
Field-reacted polyester	3.0	38.7	2.64	102	50	39	31	222	2,700,000
Field-reacted epoxy	4.0	38.7	7.05	273	50	64	31	418	4,000,000

[a] Application rate multiplied by unit cost.
[b] Includes fuel, etc.
[c] Sum of marking material, labor, glass beads, and other costs.
[d] Based on an interest rate of 7.26 percent and on 32,000 stripe-kilometers maintained.

TABLE 8b. PARAMETERS USED TO CALCULATE ALTERNATIVE TRAFFIC MARKING APPLICATION COSTS[a]

Marking	Marking life, years	Application rate, gal/mile	Marking material unit cost, $/gal	Marking material cost, $/mile[b]	Labor, $/mile	Glass beads, $/mile	Other, $/mile[c]	Application cost, $/mile[d]	Annualized application cost, $/year[e]
Solvent borne	0.75	16.5	5.00	82.50	40	25	15	162.50	4,600,000
Waterborne	1.0	16.5	6.00	99.00	40	25	15	179.00	3,800,000
Thermoplastic	3.0	66.0	8.00	528.00	145	25	85	783.00	4,700,000
Field-reacted polyester	3.0	16.5	10.00	165.00	80	62	50	357.00	2,700,000
Field-reacted epoxy	4.0	16.5	26.70	440.55	80	103	50	673.55	4,000,000

[a]Intermediate calculated values have not been rounded to significant figures.
[b]Application rate multiplied by unit cost.
[c]Includes fuel, etc.
[d]Sum of marking material, labor, glass beads, and other costs.
[e]Based on an interest rate of 7.26 percent and on 20,000 stripe-miles maintained.

applying the marking is found by summing the component costs. The component costs include the costs of the marking material, labor, fuel, glass beads, etc. The application cost is calculated with the following equation:

$$AC = (APP)(m)$$

where

AC = the total application cost in \$,

APP = the application cost in \$/mile, and

m = the number of miles to be maintained.

The annualized application cost is found using the following equation:

$$AAC = AC\left[\frac{i(1+i)^k}{(1+i)^k-1}\right]$$

where

AAC = the annualized application cost in \$/year,

AC = the total application cost in \$,

k = the life of the marking in years, and

i = the annual interest rate.

The annualized application costs based on the application of 32,000 stripe-kilometers (20,000 stripe-miles) range from $2,700,000/year for field-reacted polyester to $4,700,000/year for thermoplastics.

5.1.3 Total Annualized Costs

Tables 9a and 9b present the total annualized costs for the alternatives. The total annualized cost is the sum of the annualized equipment cost and the annualized application cost:

$$TAC = AEC+AAC$$

The total annualized cost per mile of marking ($/mile-yr) to be maintained is the total annualized cost divided by the number of miles to be maintained:

$$CPM = TAC/m$$

TABLE 9a. TOTAL ANNUALIZED COSTS FOR ALTERNATIVE TRAFFIC MARKING MATERIALS [a-c]

Marking	Annualized application cost, \$/yr	Annualized equipment cost, \$/yr	Total annualized cost	
			\$/yr	\$/km-yr
Solvent-borne paint	4,600,000	63,000	4,700,000	140
Waterborne paint	3,800,000	61,000	3,900,000	120
Thermoplastic	4,700,000	36,000	4,700,000	140
Field-reacted				
Polyester	2,700,000	53,000	2,800,000	87
Epoxy	4,000,000	43,000	4,000,000	120

[a]A kilometer of traffic marking is one 10-centimeter-wide solid stripe that is 1 kilometer long.
[b]Values based on an interest rate of 7.26 percent and 32,000 kilometers maintained.
[c]Values have been rounded according to the rules of significant figures.

TABLE 9b. TOTAL ANNUALIZED COSTS FOR ALTERNATIVE TRAFFIC MARKING MATERIALS [a-c]

Marking	Annualized application cost, $/yr	Annualized equipment cost, $/yr	Total annualized cost $/yr	$/mile-yr
Solvent-borne paint	4,600,000	63,000	4,700,000	230
Waterborne paint	3,800,000	61,000	3,900,000	200
Thermoplastic	4,700,000	36,000	4,700,000	230
Field-reacted				
Polyester	2,700,000	53,000	2,800,000	140
Epoxy	4,000,000	43,000	4,000,000	200

[a]A mile of traffic marking is one 4-inch-wide solid stripe that is 1 mile long.
[b]Values based on an interest rate of 7.26 percent and 20,000 miles maintained.
[c]Values have been rounded according to the rules of significant figures.

As indicated in Tables 9a and 9b, two of the three alternatives have a total annualized cost ($/mile-yr) less than that of solvent-borne paint. The savings can be as high as $50 per kilometer per year ($90 per mile per year). The total annualized cost for thermoplastics is equal to that for conventional solvent-borne paints. None of the alternatives have a total annualized cost greater than that for solvent-borne paints.

Most of the cost of using a particular marking material is the application cost. Capital equipment costs amount to less than 2 percent of the total annualized cost. The most important factors affecting total annualized cost are the marking material cost and the life of the marking.

5.2 COST EFFECTIVENESS

Tables 10a and 10b present the total annualized cost, VOC reduction, and the savings associated with the marking processes. Traditionally, the incremental cost effectiveness of a control alternative is calculated by dividing the additional cost above baseline by the emission reduction below the baseline level. The incremental costs ($/unit of reduction) are then used to evaluate whether the cost of achieving a reduction is reasonable. However, when the cost to achieve an emission reduction results in a negative number (i.e., a savings), the calculated traditional cost-effectiveness values have no meaning because there is no additional cost associated with achieving an emission reduction. Since all the alternatives evaluated do not result in any increased cost, the incremental cost-effectiveness values are not reported. The cost advantages of the various alternatives can be evaluated by comparing the cost savings achieved.

5.3 APPROACH TO ESTIMATE STATE-SPECIFIC COSTS

The costs presented in this document are intended to be used to compare alternatives on a common basis. The information clearly indicates that VOC's can be reduced while the State saves money on its striping program. However, the savings presented here may not be representative of those for a particular State because States have differing labor rates, number of highway miles to stripe, paint costs, interest rates, etc. This section presents a summary of a methodology that can be used to calculate State-specific costs.

TABLE 10a. COST EFFECTIVENESS OF ALTERNATIVE TRAFFIC MARKING MATERIALS[a-c]

Marking	Total annualized cost $/yr	Total annualized cost $/km-yr	VOC emissions, kg/km-yr	Savings from baseline, $/km-yr	VOC reduction from baseline, kg/km-yr
Solvent-borne paint	4,700,000	140	19	NA[d]	NA
Waterborne paint	3,900,000	120	3.7	20	15
Thermoplastic	4,700,000	140	Neg.[e]	0	19
Field-reacted					
Polyester	2,800,000	87	Neg.	50	19
Epoxy	4,000,000	120	0.07	20	19

[a]A kilometer of traffic marking is one 10-centimeter-wide solid stripe that is 1 kilometer long.
[b]Values based on an interest rate of 7.26 percent and 32,000 kilometers maintained.
[c]Values have been rounded according to the rules of significant figures.
[d]NA = Not applicable.
[e]Neg. = Negligible.

TABLE 10b. COST EFFECTIVENESS OF ALTERNATIVE TRAFFIC MARKING MATERIALS[a-c]

Marking	Total annualized cost $/yr	Total annualized cost $/mile-yr	VOC emissions, lb/mile-yr	Savings from baseline, $/mile-yr	VOC reduction from baseline, lb/mile-yr
Solvent-borne paint	4,700,000	230	69	NA[d]	NA
Waterborne paint	3,900,000	200	13	30	563.5
Thermoplastic	4,700,000	230	Neg.[e]	0	693.4
Field-reacted					
Polyester	2,800,000	140	Neg.	90	692.0
Epoxy	4,000,000	200	0.25	30	692.9

[a]A mile of traffic marking is one 4-inch-wide solid stripe that is 1 mile long.
[b]Values based on an interest rate of 7.26 percent and 20,000 miles maintained.
[c]Values have been rounded according to the rules of significant figures.
[d]NA = Not applicable.
[e]Neg. = Negligible.

The following parameters are required to use the cost methodologies described in this chapter:

1. The number of miles to be maintained;
2. The initial cost of new equipment or modifications;
3. The expected life of each piece of equipment;
4. Paint cost;
5. Paint application rate;
6. Glass bead cost (if applicable);
7. Glass bead application rate (if applicable);
8. Labor cost;
9. Fuel cost;
10. Cost of miscellaneous materials and replacement parts;
11. The expected life of the marking; and
12. The annual interest rate.

A State should be able to determine the values of these parameters from experience or to develop estimates with the help of equipment and material vendors. The values used to calculate the costs presented here should be used only as default values if actual values cannot be obtained.

Some important factors to consider in estimating equipment cost are the number of stripe-miles that are to be applied each year and the number of days suitable for material application each year. These factors will determine the necessary size and number of application units required.

The major factors affecting the total annualized cost of a marking are the marking material cost and the life of the marking. If a State is choosing a new marking material, several factors should be considered that relate to material cost and marking life, especially when choosing a paint. Paints are usually purchased on a total volume basis; however, comparison only of cost per volume of various paints will not provide an accurate picture of true cost differences. It is the quantity of solids coupled with the required film thickness and useful life that are important since the solids in the paint form the marking as the carrier solvent evaporates. Therefore, a paint that contains 50 percent solids by volume will provide a marking 19 mm (7.5 mils) thick when applied at a wet film thickness of 38 mm (15 mils). A paint containing 40 percent solids and applied at the same rate will produce a marking only 15 mm (6.0 mils) thick. If the composition of the solids is the same for each paint, the thicker marking would be expected to be more durable. Because the life of the marking is an important factor affecting annualized cost, a paint with a low cost per gallon and a low solids content actually may be more expensive to use than a high-solids paint that costs more per gallon. Of course, a paint containing 40 percent solids could produce a marking 19 mm (7.5 mils) thick if applied at a wet thickness of 48 mm (18.75 mils). However, because more paint will need to be applied per mile, the real cost is again increased. For this reason, it is useful to compare paint costs on a solids basis. The paint cost can be converted to a solids basis by dividing cost per volume by the fraction of solids per volume. For example, using English units, a paint that costs $5.00 per gallon and contains 50 percent solids has a cost of $10.00 per gallon of solids:

($5.00/gal paint)/(0.50 gal solids/gal paint) = $10.00/gal solids

Similarly, a paint that costs $4.50 per gallon and contains 40 percent solids has a cost of $11.25 per gallon of solids:

($4.50/gal paint)/(0.40 gal solids/gal paint) = $11.25/gal solids

In this example, the paint with the higher cost per gallon actually costs less on a solids basis.

Also, because the life of the marking is an important factor in cost, States may want to test samples of the traffic marking purchased to ensure that it conforms to their specifications and is of consistent quality. This type of testing should be ongoing and should be conducted independent of the manufacturer's own quality control.

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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16. ABSTRACT

Traditional traffic marking materials (solvent-borne paints) are a source of volatile organic compound (VOC) emissions. This study was conducted to evaluate alternative traffic marking techniques that can be used to reduce VOC emissions from this source. This document provides information on traffic marking application processes, VOC emissions and emission reductions, and costs associated with the alternative marking techniques. This information will allow planners to (1) identify available alternative low- and zero-VOC traffic marking techniques, (2) estimate the baseline VOC emission level for the planner's geographic area, and (3) evaluate the VOC reduction and cost of implementing alternative traffic marking techniques. The primary conclusions from this study are: (1) the use of available low-and zero-VOC alternatives such as waterborne coatings, thermoplastics, field-reacted materials, preformed tapes, and permanent markers can result in VOC emission reductions ranging from 15 percent to 100 percent; (2) the annualized costs for the alternative marking techniques are less than or equivalent to those for traditional solvent-borne paints; and (3) the performance of the alternative markings is equivalent to or better than that of traditional solvent-borne paints.

17. KEY WORDS AND DOCUMENT ANALYSIS

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