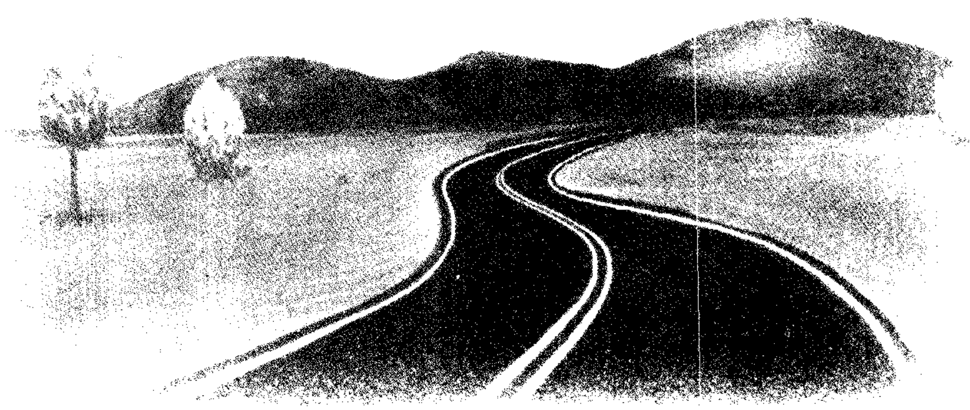
COST-EFFECTIVENESS AND SAFETY OF ALTERNATIVE ROADWAY DELINEATION TREATMENTS FOR RURAL TWO-LANE HIGHWAYS

VOL. VI. APPENDIX D, COST OF ROADWAY ACCIDENTS
APPENDIX E, COST AND SERVICE LIFE OF ROADWAY DELINEATION TREATMENTS



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FINAL REPORT

REPORT NO. FHWA-RD-78-55

FOREWORD

This six-volume report presents the findings of a research study to assess the effect of various delineation treatments on accident rates. Cost-benefit and cost models for evaluating specific delineation treatments were developed. Delineation guidelines were formulated by executing the cost-benefit models for selected delineation treatments.

The six volumes are:

Vol. I	Executive Summary
Vol. II	Final Report
Vol. III	Appendix A, Site Selection and Data Collection
Vol. IV	Appendix B, Development and Description of Computerized Data Base
Vol. V	Appendix C, Statistical Model Development
Vol. VI	Appendix D, Cost of Roadway Accidents and Appendix E, Cost and Service Life of Roadway Delineation Treatments.

Sufficient copies of the Executive Summary are being distributed to provide a minimum of two copies to each FHWA Regional Office, one copy to each Division Office, and five copies to each State highway agency. One copy of the Final Report is being provided to each FHWA Regional and Division Office and one to each State highway agency. Volumes III through VI are available only on request.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

Technical Report Documentation Page

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16. Abstract

Under this research study, the effect of various delineation treatments on accident rates was assessed by analyzing accident data from more than 500 roadway sites in 10 States for tangent, winding and isolated horizontal curve sections on two-lane rural highways. Cost-benefit and cost models for evaluating specific delineation treatments were developed and guidelines formulated by executing the cost-benefit models for selected delineation treatments.

This Volume contains two appendixes. Appendix D discusses various alternative accident cost information and presents the rationale for using specific accident cost data. Appendix E discusses the cost and service life information of delineation treatments used in the study. Over 20 references are cited and the information presented provides the background for the inputs to the cost-benefit model. Other volumes produced under this research study are:

Vol.	FHWA No.	Report Title
I	78-50	Executive Summary
II	78-51	Final Report
III	78-52	Appendix A, Site Selection and Data Collection
IV	78-53	Appendix B, Dev. & Descrip. of Computerized Data Base
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PREFACE

This document and its appendices constitute the final report for the study "Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments." The study was conducted by Science Applications, Inc., with the assistance of Alan M. Voorhees and Associates, Inc., Dr. James Taylor, University of Notre Dame, and Mr. John Glennon, for the Federal Highway Administration under Contract DOT-FH-11-8587.

Science Applications, Inc., and FHWA wish to acknowledge the assistance of the many people who participated in this study, particularly Robert Felsburg of AMV, Sandra Morrow, SAI, and the key individuals in the ten states, listed below, where data collection took place. Without their cooperation this study would not have been possible.

States	Key Personnel
Arizona, Department of Transportation	Mr. Ross E. Kelley, Traffic Engineer, Safety Projects Services
California, Department of Transportation	Mr. Perry Lowden, Chief, Sign and Delineation Section
	Mr. James B. Dobbins, County Traffic Engineer for the County of Riverside
Connecticut, Department of Transportation	Dr. Charles E. Dougan, Chief of Research and Development
Georgia, Department of Transportation	Mr. Archie C. Burnham, Jr., State Traffic and Safety Engineer
	Mr. Arthur Durshimer, Jr., Traffic and Safety Engineer
Idaho, Department of Transportation	Mr. James L. Pline, Traffic Engineer

Louisiana, Department of Highways	Mr. Grady Carlisle, State Traffic and Planning Engineer
	Mr. John E. Evanco, Highway Planning and Needs Engineer
Maryland, Department of Transportation	Mr. Pierce E. Cody,III, Chief, Bureau of Highway Maintenance
	Mr. Paul S. Jaworski, Chief, Bureau of Accident Studies
Ohio, Department of Transportation	Mr. John LeGrand, Chief, Bureau of Transportation Safety
	Mr. John H. White, Assistant, System Facilities
Virginia, Department of Highways and Transportation	Mr. A. L. Thomas, Assistant, State Traffic and Safety Engineer
	Mr. P. J. Stenger, Associate Traffic Engineer
Washington, State Highway Commission	Mr. J. A. Gallagher, Traffic Engineer
	Mr. W. R. Curry, Traffic Operations Engineer

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METRIC CONVERSION FACTORS

Several customary units appear in the text of this report. Generally, it is the policy of FHWA to express measurements in both customary and SI units. The purpose of this policy is to provide an orderly transition to the use of SI exclusively. It was decided that dualization of tables was not warranted because of the additional cost and delay in making this research available. Instead, the following conversion table is included.

To Convert	To	
in	mm	Multiply by 25.4*
ft	m	Multiply by 0.3048*
mi	km	Multiply by 1.609
mi/h	km/h	Multiply by 1.609
ft^2	m^2	Multiply by 0.0929
gal	L	Multiply by 3.785
°F	°C	Subtract 32 and multiply by 5/9
accidents/MVM	accidents/MVkm	Divide by 1.609
lb	kg	Multiply by 0.4536

The pound is a measure of force (weight) and the kilogram is a measure of mass. Mass and weight are not equivalent. For an object weighed under normal gravitational conditions, however, the above relationship may be used.

The Federal Highway Administration recognizes the "Standard for Metric Pracitce," E380 of the American Society for Testing and Materials, as the authority for SI usage.

*Denotes exact conversion factor.

APPENDIX D

COST OF ROADWAY ACCIDENTS

The major difficulties that arise in estimating the cost of roadway accidents are: (a) the identification of specific cost elements that should be included in cost calculations, and (b) attaching dollar values to these elements. There are several studies that have tried to identify the cost elements of accidents and attach dollar values. However, because of the subjective nature of this procedure, this is invariably accompanied by controversy. The controversy relates primarily to those costs that should be included as accident costs.

The controversies associated with accident costs have often been discussed and will not be pursued here in detail. However, a comprehensive bibliography of accident cost studies has been included.

Another controversy that arises when dollar values are assigned to accidents relates to the basic assumption that dollar values can be assigned to traffic fatalities. It is generally agreed that in "property damage only" accidents, such values can be assigned because existing market value for the property can be estimated. Kuhn has stated[(1)] "... there is no market for human life, health and grief, and there will never be one, it is hoped. For professionals in the transportation field to translate human life into dollars and cents is not only highly misleading, it may even be regarded as immoral by some." The National Highway Traffic and Safety Administration (NHTSA) report entitled "Societal Costs of Motor Vehicle Accidents"[(2)] emphatically states that "there has been no attempt to value a human life." It further avers that "no attempts were made to quantify the joy of living, love and affection, child guidance and companionship, or grief and sorrow, which are in themselves sufficient justification for expenditures in safety programs." The point is again stressed that "this value (that a person places on his or her life) in a majority of instances is probably infinite and constrained only by the amount of money a person could beg, borrow, steal, or earn."

In spite of the controversies that exist in associating dollar values with accidents, attempts have been made to quantify accident costs. The reason for this is that it provides a common unit for measurement of multiple benefits which have different units. For example, different safety programs may have different effects on accidents with different effects on severity rates--i.e., one may reduce the number of fatal accidents, the other may reduce level of injuries, while maintaining the same level of fatality. Bringing all accidents into the same unit of measurement allows for an "optimal" allocation of resources which maximize benefits where all the benefits are measured in the same unit. However, as noted in the NHTSA report, "A very serious drawback of measuring accident losses with a common scale is that such indexes are easily misinterpreted or misused. The real safety problem is the reduction of fatalities and not maximization of dollar benefits."

The quantification of accidents in dollar values can be traced back to as early as 1949 when the manual of a procedure for a study of the cost of motor-vehicle accidents was published by the Bureau of Public Roads(3). Since then, several studies have been published which have tried to quantify the cost of accidents. These studies generally follow the guidelines provided by the manual in identifying the cost elements of the accidents. There are also studies which have discussed the controversies associated with various elements of their costs. As noted in the beginning of this section, these controversies pertain to the cost elements, the actual cost assigned to each element, and such things as discount factor. It is not the objective of this report to go into the controversies, and therefore, only a comprehensive bibliography listing important studies has been included. An overview of the controversies can be obtained from Appendix E of NCHRP Report 130(4).

The Manual of 1949 categorizes the cost into two parts — direct and indirect costs. The direct costs, as the name implies, are costs which can be unambiguously assigned to specific accidents (such as damage to vehicle, hospital costs, etc.). Indirect costs are those which cannot be assigned to any specific accident (e.g., insurance overhead expenses, etc.). Direct and indirect costs are often related to "variable" and fixed costs. Most of the studies evaluating accident costs have followed the guidelines provided by the 1949 manual with respect to direct and indirect costs.

An evaluation(5) of accident cost data collected in six states (Massachusetts(6), New Mexico(7), Utah(8), Illinois(9), Ohio(10), and the Washington Metropolitan Area(11), was conducted to compare these data with National Safety Council cost figures. This evaluation encompassed consideration of the study area characteristics, methodology and data sources, definition and scope of study. It was recommended that the Illinois, Ohio, and Washington Metropolitan Area cost data be used in cost-benefit analysis.

The direct cost per involvement classified by accident severity and location as reported in each of the above mentioned six studies and the cost data from the National Safety Council is presented in Table 1. The exceptionally large values for costs of fatal accidents reported in the Washington study results from the fact that the loss of future earning power has been included as a direct cost. The data from the National Safety Council is also substantially different because it includes some indirect costs such as insurance administration costs. The costs in this table are presented in terms of dollars per involvement.

One involvement is counted for each motor vehicle involved in an accident. Thus, if a vehicle collides with another vehicle, there are two involvements in that single accident. Similarly, if a single vehicle runs off the road and hits a culvert, there is one involvement and one accident. A method for converting involvement into accidents and conversely has been developed in Reference 12. Their table of conversion by vehicle type and highway location is reproduced here as

Table 1. Direct cost per involvement classified by accident severity and location.

Massachusetts

Severity of Accident	Passenger Cars			Trucks		
	Rural	Urban	All Areas	Rural	Urban	All Areas
Fatal	$4,005	$5,092	$4,773	$8,292	$6,007	$6,815
Nonfatal Injury	541	529	530	828	485	530
Property Damage Only	129	112	114	125	52	61
All Classes	257	224	228	309	134	156

New Mexico

Severity of Accident	Passenger Cars			Trucks		
	Rural	Urban	All Areas	Rural	Urban	All Areas
Fatal	$2,821	$2,987	$2,870	$2,328	$1,213	$2,155
Nonfatal Injury	1,287	1,197	1,225	1,572	472	1,066
Property Damage Only	164	114	132	219	92	152
All Classes	277	231	247	441	133	282

Utah

Severity of Accident	Passenger Cars			Trucks		
	Rural	Urban	All Areas	Rural	Urban	All Areas
Fatal	$3,549	$3,556	$3,552	$1,468	$1,622	$1,510
Nonfatal Injury	1,273	717	868	2,453	761	1,623
Property Damage Only	161	136	143	369	104	220
All Classes	356	251	282	520	142	310

Illinois

Severity of Accident	Passenger Cars			Trucks		
	Rural	Urban	All Areas	Rural	Urban	All Areas
Fatal	$5,572	$4,268	$5,061	$5,790	$3,805	$5,128
Nonfatal Injury	1,199	749	821	1,363	402	695
Property Damage Only	147	93	101	176	63	86
All Classes	319	176	196	340	89	141

Ohio

Severity of Accident	Passenger Cars			Trucks		
	Rural	Urban	All Areas	Rural	Urban	All Areas
Fatal	$4,771	$3,350	$4,236	$5,931	$2,283	$5,006
Nonfatal Injury	1,160	686	833	1,391	674	991
Property Damage Only	160	107	118	191	78	111
All Classes	375	179	221	410	127	213

Washington Metropolitan Area

Severity of Accident	Passenger Cars	Trucks	All Vehicles		
	All Areas	All Areas	Rural	Urban	All Areas
Fatal	$49,137	$28,817	$61,875	$45,373	$47,481
Nonfatal Injury	874	699	1,495	831	863
Property Damage Only	199	126	292	190	193
All Classes	542	349	1,439	491	527

National Safety Council

Severity of Accident	All Vehicles
	All Areas
Fatal	$27,826
Nonfatal Injury	1,590
Property Damage Only	174
All Classes	377

Table 2. Hence, according to this table, for every accident involving cars on rural highways, 1.41 cars are involved per accident.

Table 2. Conversion from accidents to involvement and conversely.

Type of Vehicle	Rural	Urban	All Areas
Car	1.41 : 1	1.83 : 1	1.75 : 1
Truck	1.39 : 1	1.83 : 1	1.71 : 1
Car and Truck Combined	1.41 : 1	1.83 : 1	1.75 : 1

In a recent study, the "indirect costs," of traffic accidents were estimated by the Center for Environment and Man, Inc.(13). In defining the objective of the study, the authors note: "In this study, the emphasis is on accident-related costs which are not a consequence of the physical destruction caused by the accident itself, but on those costs which occur due to the social mechanism in force for the purpose of preventing accidents or managing activities subsequent to the accident event." To assess these costs, CEM conducted a nationwide survey complemented by actual field visits to establish the order of magnitude of the various indirect cost components. All the states except Alaska and Hawaii were contacted in this study.

Based upon the evaluation of surveys and direct information gathered through various agencies, the cost categories considered appropriate as indirect costs were identified. The important conclusions derived by CEM are given below.

- For the cost categories considered, the total indirect costs related to traffic accidents were estimated to be between $5.5 and $6.4 billion in 1969.

- Accident prevention costs of $0.8 to $1.4 billion represent from 13 to 24 percent of annual indirect traffic accident costs.

- Of the total indirect costs, allocated "fixed" costs of insurance varies between 35 to 40 percent, a sizable cost component.

- Police, courts, and motor vehicle agencies together account for another 20 to 35 percent of annual indirect costs.

- Public and overhead costs including welfare and social security administration expenses represent a small fraction (less than one percent) of total accident consequence expenditures.

In a relatively recent study, the National Highway Traffic and Safety Administration has developed cost data on motor vehicle accidents which include both the direct and indirect costs. This report is different from the other reports because it computes the overall cost to society as a result of an automobile accident rather than just a part of the cost (e.g., direct cost). As the authors of the report point out, "One objection to this procedure (whereby only out-of-pocket costs are estimated) is that such costs account for only a small portion of total societal losses resulting from motor vehicle accidents." Although the report recognizes the controversies associated with some of the cost components, it also asserts that "... even when empirical information on a component is lacking, a reasonable approximation of costs should be made. Omitting the component altogether essentially assumes a zero cost for that item (by default)."

Hence, the cost components considered in this report comprise an extensive list. The specific cost items considered in the report are: property damage costs, medical costs, productivity losses (loss of future earning), insurance administration, losses to other individuals, employer losses, funeral costs, community service, pain and suffering,and miscellaneous accident costs.

The study utilizes various sources to estimate the costs associated with each of the above noted cost items. For example, costs associated with property damage are estimated based on the Illinois, Ohio and Washington studies and the National Safety Council data, whereas the monetary value of pain and suffering is estimated on the basis of court settlements. Discussing the cost of pain and suffering, the authors note: "a subjective evaluation by a jury is the most reasonable expression we have of societal preference." Similarly, in estimating the cost of a funeral, it is assumed that the only cost associated with the accident is the difference in cost which results due to an early death of the person.

Final cost estimates derived through these various techniques are categorized according to the level of severity. Table 3, which is reproduced here from Reference 2, presents the cost estimates factored according to level of severity. It should be noted that NHTSA cost figures are substantially higher than those reported by other studies. This was expected because of the greater number of cost items considered here as compared to other studies.

A critical evaluation of various cost studies which were reviewed under this project indicates that the NHTSA cost figures are most appropriate for the cost-benefit analysis to be conducted under this study. There are several reasons for this. Some of the important reasons are listed below:

- NHTSA represents the latest study on the subject. It has, therefore, reviewed and evaluated the cost items presented in other studies before giving its own estimates.

- It does not consider just the direct or indirect cost of accidents. Its figures represent overall monetary value of roadway accidents. It appears that it is indeed more appropriate than using only the direct costs of accidents.

- NHTSA report makes all its assumptions explicit and where subjective judgement is used, the rationale is clearly stated. Furthermore, the report is prepared in modular configuration to facilitate refining the estimates as new and better information becomes available. This is unlike the National Safety Council estimates where very little information is available on the specific elements included in costs of accidents.

Table 3. Average cost per person, per accident, and per involvement.

Severity Type	Persons		Accidents		Involvements	
	Number*	Average Cost	Number*	Average Cost	Number*	Average Cost
Fatality	55,000	$200,700	47,000	$234,960	69,000	$160,000
Nonfatal injury	3,800,000	7,300	2,469,600	11,200	4,510,000	6,100
Property damage only			14,000,000	500	24,000,000	300
Total	3,855,000		16,517,000		28,579,000	
Average		10,000		2,800		1,610

*Totals do not add due to rounding.

- Some of the cost estimtes appear to have better rationale than other studies. (For example, the cost of housewife services is estimated as the earnings a woman would obtain if she chose to enter the labor force. This appears to be preferable over some other assumption such as that by NSC, where daily wages of domestic workers is taken as a proxy for the loss due to incapacitiation of a housewife.)

After consideration of the various types and levels of cost information available, it was decided to use the average accident cost of $2,800 in the cost-benefit analysis.

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APPENDIX E

COST AND SERVICE LIFE OF ROADWAY DELINEATION TREATMENTS

Most of the roadway delineation treatments can be classified into three categories:

1. Pavement Stripes
2. Raised Pavement Marker (RPM) Lines
3. Post Delineators

Pavement stripes and RPM lines are a class of treatments applied to the pavement to delineate the path in the near vicinity of the vehicle. To an extent, these treatments also satisfy driver need with respect to far delineation, particularly under clear weather conditions.

On the other hand, post delineators (or guideposts) are mounted off the pavement and fulfill the driver's need for far delineation. A post delineator is comprised of a retro-reflective unit mounted on a post or other roadway feature. These devices aid in defining the general alignment of the road and in identifying geometric inconsistencies and hazardous locations.

This discussion of roadway delineation treatments has been organized according to the above noted subdivisions. For each type of treatment, the cost and service life is discussed separately.

E.1 PAVEMENT STRIPES

Pavement stripes can be classified into two categories: (a) paint stripes, and (b) plastic stripes according to the prinicpal material of the marking. This categorization is also convenient for discussing the cost and service life of the treatments since they are homogeneous within each group and differ significantly between the.

two groups. The discussion of pavement stripes is, therefore, further organized according to paint stripes and thermoplastic stripes.

E.1.1 Cost of Pavement Stripes

Before discussing the cost of paint and thermoplastic stripes, a brief discussion of the principal components of the cost is presented.

There are three principal costs for a pavement stripe. These are:

a. material cost

b. equipment cost

c. labor cost

The total striping cost, however, depends upon several other factors such as the agency's overhead rate and accounting procedure. These factors can significantly alter the total striping cost even when the material, equipment, and labor cost remains unaltered. It is for this reason that a separate discussion of the principal cost items is presented.

E.1.1.1 Pavement Striping Material Cost

There are two major cost components within the material cost: the cost of paint (or thermoplastic), and the cost of glass beads. Other cost items within the material costs relate to the cost of material utilized for cleaning the pavement such as phosphoric acid.

All pavement stripes used today are reflectorized. This is accomplished by adding glass beads to the marking material to make the stripes retro-reflective for nighttime driving. The amount and methods of application of glass beads vary. In the literature, the cost of paint often includes the cost of beads, but in other instances, the cost of striping material and glass beads is reported separately. This depends, to an extent, upon the method of glass bead application.

Glass beads can be classified into three groups according to their method of application. These are:

a. premixed beads

b. drop-on beads

c. combination beads

The premixed beads are mixed in the paint during production and are often referred to as reflectorized paints. The cost of such paint generally includes the bead cost. As the name implies, drop-on type beads are dropped or sprayed on the stripe at the time of application. For such stripes, the cost of paint and glass beads are reported separately. In the combination type beads, there is a combination of premix and drop-on type beads.

The rate of application of glass beads varies between 4 to 6 pounds (1.814 to 2.721 kg) (3.785 L) for each gallon of paint. Four pounds (1.814 kg) per gallon is more common for premixed type beads and 6 pounds (2.721 kg) per gallon (3.785 L) for drop-on type beads. (At this rate, between 66 and 99 pounds/mile (18.60 - 27.90 kg/km) of beads are used in a continuous 4-inch (101.6 mm) wide stripe).

In the discussion of pavement marking material cost follows, an effort is made to identify whether or not a reported paint cost also includes the cost of glass beads. However, this has not always been possible.

Cost of Paint Material

Paints utilized for striping today come in a variety of bases including alkyd, rubber, vinyl, epoxy, water base and high polymers. Pros and cons of different types of paint materials can be found in various studies listed in the references.[1-6]

Irrespective of the paint material, a paint has to meet certain standards for approval for use as a striping material. ASTM tests for these standards are contained in a set of procedures for performance specification for the purchase of pavement marking paints.[3]

Although research and development over the years has resulted in improvements in the general characteristics of the paint material, the greatest improvement has come in the drying time of paints. Today, hot-applied paints which dry within twenty seconds of application are available. Technical Council Committee 4N-S of Institute of Transportation Engineers classifies paints according to the drying time as follows:

Paint Type	Drying Time
a. Conventional paint	greater than 3 minutes
b. Rapid dry paint	1 to 3 minutes
c. Quick dry paint	less than 1 minute

Paint drying time is an important consideration as it has a direct impact on the cost of the treatment. First, the cost of application of paint stripes can be significantly affected by the drying time of the paint. Fast-drying paint stripes can be applied at a much faster rate, thereby requiring smaller crew size and improving the utility of the application equipment. In the case of quick-dry paints, no special traffic control measures, such as the placement and removal of traffic cones, are required because traffic can pass over the stripe within a few seconds of its application. Secondly, the costs associated with traffic delay and interruption can be significantly reduced through the application of a fast-drying paint. Drying time of paint also has an impact on maintenance crew safety as crew exposure to traffic is substantially reduced.

In reviewing the cost of paint material, therefore, an effort has been made to identify the drying time of the material, but this has not always been possible. The variation in the reported cost is due to a variety of factors including the minor variations in material type and the buying policy of individual agencies.

1. Chaiken[7] estimated the average cost of conventional white paint in 1965 to be $1.65 per gallon (3.785 L). The corresponding cost of yellow paint was estimated to be $1.95 per gallon (3.785 L).

2. Chaiken[7] also reports on the cost of fast-dry paints:

- Nite-line paint produced by Prismo Universal, Inc., is claimed to dry in 3 minutes or less; paint is heated and applied at 165°F (73.8°C) and costs (including glass beads) about $6 per gallon (3.785 L).
- A similar fast-drying product is called green light striping compound. Applied at 250°F (122.7°C), this compound dries in 2-20 seconds and costs nearly $8 per gallon (3.785 L).

3. In a 1971 Alabama study[8], it is reported that the paint was purchased at the low bid price of $2.21 per gallon (3.785 L). The required glass beads were purchased at the low bid price of 9.981¢ per pound (.4536 kg). Based upon these low bid prices, the material cost of painted dashed line (15 ft. (4.57 m) mark; 25 ft. (7.62 m) gap) was also estimated for varying amounts of glass bead applications. These estimates are given in the following table.

Table 1. Paint striping materials cost per mile (Alabama 1971).

Paint Type	Cost Per Mile
Reflectorized Paint	$15.80*
Reflectorized Paint + 2 lbs./gal. "drop-on" beads	$17.03
Paint + 4 lbs/gal. "drop-on" beads	$16.10
Paint + 5 lbs/gal. "drop-on" beads	$16.72
Paint + 6 lbs/gal. "drop-on" beads	$17.34

*Based on a low bid price of $2.56 per gallon for the reflectorized paint.

Note: 1 mile = 1.609 km; 1 lb = .4536 kg; 1 gal = 3.785 L

4. A District of Columbia study[9] reports on the bid prices of various paint samples that were tested. The cost of various samples and their expected service life in days, for both asphaltic and portland cement concrete pavements, is given in Table 2. The drying time for each sample is not reported; but the maximum allowable time was specified as 30 minutes. It should be noted that the least expensive sample has one of the highest service lives.

Table 2. Bid price and life expectancy of white pavement marking paints (District of Columbia 1974).

Sample	Bid Price $ per Gallon	Life Expectance in Days on AC	on PCC
1	1.70	470	378
1A	1.96	277	375
2	1.78	360	380
2A	1.75	338	391
3	3.19	305	500
3A	1.60	383	358
5	2.06	256	335
9	2.19	301	158
9A	2.48	246	225
10	2.21	246	158
10A	2.46	183	225

1 Gallon = 3.785 L

Cost of Glass Beads

The cost of glass beads depends on the general characteristics of the beads. ITE Technical Council Committee 4N-S[3] recommends testing for the following properties:

1. Crushing Resistance

2. Roundness

3. Index of Refraction

4. Gradation

5. Chemical Resistance

6. Flotation

7. Flow Properties

8. Color

The committee also identifies ASTM and Federal Test Method tests for the above properties. The cost of glass beads, as reported below, is for beads meeting these specifications.

1. In a 1969 report, Chaiken(7) estimated the average cost for the nation for glass beads in 1965 to be 11.2¢ per pound (.4536 kg).

2. In an Alabama(8) study, the glass beads for testing were obtained at a low bid price of 9.981¢ per pound (.4536 kg).

3. In a Mississippi(10) report, the cost of beads of different refractive index is reported. These costs are reported in the form of cost per mile of striping. The rate of bead application is reported to be 39 pounds (17.69 kg) per mile (1.609 km) for dashed lines (15 ft. (4.57 m) mark; 25 ft. (7.62 m) gap) and 103.5 pounds (46.95 kg) per mile (1.609 km) for solid lines. This includes a 5% spillage.

Table 3. Cost of beads per mile (Mississippi 1971).

Type of Line	Index of Refraction		
	1.51	1.65	1.91
Skip Line (15 ft. Mark; 25 ft. Gap)	$3.51	$ 4.88	$10.73
Solid Line	$9.32	$12.94	$28.46
Cost per Pound	$0.09	$ 0.125	$ 0.275

1 Ft = .3048 m

1 Pound = .4536 kg

E.1.1.2 Equipment Cost

Equipment utilized for striping can generally be divided into two groups. The first is comprised of small, self-propelled but manually-controlled, low-capacity machines which are generally used to stripe sidewalks and other transverse lines. The second is comprised of heavy-duty, truck-mounted units which have higher capacity and are invariably used for longitudinal stripes. The hand-operated stripers can lay down up to 5000 linear feet (1524 m) of longitudinal stripe in one day. A brief lucid description of various striping equipment can be found in Reference 2. Additional information gathered on the subject is presented below.

1. In a 1972 Mississippi report(11), the following is noted:

   - A small one-line machine costs about $1,000 and can be used to place stripes in any location but is quite slow.

   - A hand-operated extrusion applicator and small preheater (primarily for thermoplastic striping) costs less than $10,000 and can be used for crosswalks, gores, restriping, and repair work.

   - Thermoplastic striping equipment consists of a preheater to raise the temperature of the material to about 400°F (204.4°C) and an applicator to place the hot material on the roadway. The cost varies from $8,000 to $100,000, depending on the capacity and capability of the equipment.

2. California reports on the capabilities of a larger striper in a 1973 report(12).

   - The machine is capable of treating material up to 400°F (204.4°C).

   - It can stripe up to the rate of 15 mi/h (24.13 km/h).

   - Material is applied in three layers, with beads sandwiched between the second and third layers.

   - It has a capability of placing three 4-inch (101.6 mm) lines simultaneously.

- The start-up time is a maximum of 5 minutes from cold paint to application temperature. Clean-up time at the close of the day involves only the closing of a few valves.

3. Flanakin[13] reports on the equipment cost of laying thermoplastic material in the District of Columbia. These data are given in Table 4.

Table 4. Cost of striping equipment (District of Columbia 1975).

Type of Machine	Cost Estimate Purchase	Daily Rent
Truck Mounted Linear Plant	$200,000	$160
Hand Operated Liner	$ 8,000	$ 8

4. A personal communication with the Arizona Highway Department provided guidelines for equipment requirements for striping edgelines. These are presented in Table 5.

Table 5. Equipment requirements for edgeline striping (Arizona).

Machine	Number	Hourly Rate ($/hr)
Striper	1	18.00
Supply Truck	2	2.30
Crew Cab	1	1.85

5. The California Department of Transportation has also established guidelines for equipment requirements for various types of pavement stripes. Table 6, developed from these guidelines, presents the equipment requirements associated with various markings. California, like the State of Arizona, has established hourly rates for the required equipment for stripe installation cost computations.

Table 6. Equipment requirements for various types of stripes (California).

Type of Stripe	Recommended Equipment
1. Dash or Double Yellow Center Line (Cold)	One Striper One Traffic Control Truck
2. Dash or Double Yellow Center Line (Hot)	One Striper One Truck or Pickup
3. Shoulder Edgeline or 8 inch Solid Line (Both Cold and Hot)	One Striper One Truck or Pickup
4. Localized Markings such as Gore Markings and Stop Approaches (Both Cold and Hot)	One Pavement Marking Unit One Truck

1 inch = 25.4 mm

E.1.1.3 Labor Cost

Labor costs are directly related to the equipment that is utilized for striping. The California Department of Transportation (CALTRANS) has reported that the new striper it has developed to apply quick-dry paint will reduce striping labor requirements from 3.7 man-hours per mile (1.609 km) to 0.6 man-hour per mile (1.609 km). Additional data gathered on labor requirements are presented below.

1. NCHRP Synthesis of Highway Practice 17[2], reports that:

> "The size of the striper crew varies with the striping operation. If edgelines are applied at the same time at the centerline 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 such operations. If cones are needed, another 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 smallest striping operation requires about five men and two trucks plus the striper truck."

2. Direct contact with the Arizona Highway Department revealed that the state recommends the use of a 5-man crew to stripe edgelines when the state's hot line striper is used. With this crew and equipment, the application rate is estimated to be 250 miles (402.32 km) of stripe per 40-hour week (single coat).

3. California Department of Transportation Maintenance Manual specifies crew size requirements associated with various types of stripes. In addition, it also provides guidelines for labor requirements in man-hours per mile. These requirements and guidelines are presented in Table 7.

E.1.1.4 Cost of Painted Stripes

This section reviews data on the installed cost of painted lines. Installed cost includes such cost items as material cost, equipment and labor cost, and an agency's overhead rate. The material cost depends upon line pattern (dashed line vs. double solid line, wet paint thickness, glass bead application rate, etc.). Labor and equipment cost depends upon the type of equipment used (sophisticated equipment has higher application rates and reduces labor requirements). Hence, an effort was made to specify the line pattern, type of equipment used, etc., when reporting the cost of installed stripes. This, however, has not always been possible.

1. According to a 1969 survey conducted by Chaiken(6), the cost of paint is only one-third of the total cost of the installed stripe.

2. As a result of a survey conducted in Britain in 1969, James, *et al.*(14) report that "...The material cost is nearly always less than half and in some cases as little as ten percent of the total initial cost of the applied markings." Other interesting observations include:

   - There is no significant difference between the price of continuous and dotted lines.

Table 7. Estimated labor requirements for various pavement stripes--State of California.

S.N.	Type of Stripe	Recommended Crew Size	Labor Requirement
1	Dash Yellow Centerline (Cold Paint)	3 to 5	2.00 man-hr/mile
2	Dash Yellow Centerline (Hot Paint)	3 to 4	1.40 man-hr/mile
3	Double Yellow Centerline (Cold Paint)	3 to 5	3.50 man-hr/mile
4	Double Yellow Centerline (Hot Paint)	3 to 4	2.60 man-hr/mile
5	Edgeline (Cold Paint)	2 to 3	2.80 man-hr/mile
6	Edgeline (Hot Paint)	2 to 3	1.50 man-hr/mile
7	8-Inch Line (Cold Paint)	3	25.00 man-hr/mile
8	8-Inch Line (Hot Paint)	3	15.00 man-hr/mile
9	Localized Markings* (Cold Paint)	3	0.015 man-hr/sq. ft.
10	Localized Markings* (Hot Applied)	3	0.013 man-hr/sq. ft.
11	Localized Markings* (Plastic) with or without stencil but no preheater	3	0.042 man-hr/sq. ft.
12	Localized Markings* (Plastic) with preheater but no stencil	3	0.013 man-hr/sq. ft.
13	Localized Markings* (Plastic) with preheater and stencil	3	0.036 man-hr/sq. ft.

*Such as gore areas and stop approaches.
1 mile = 1.609 km
1 ft^2 = 0.0929 m^2

- The ratio of material cost to the total cost of striping is a function of paint drying time (due to its effect on the traffic control measures).

- The total cost primarily depends upon the equipment used and the crew required for striping.

3. In a 1970 Kentucky report[15], it is noted that the cost of paint stripes ranged from 85¢ to $1.95 per linear foot (3.038 m) ($44.88 to $102.96 per mile (1.609 km)). These cost figures include the cost of paint, beads, labor, and equipment.

4. In a 1970 Minnesota Department of Highways report[16] on the evaluation of thermoplastic pavement markings, it is observed that in 1967 the average cost of a 4-inch (101.6 mm) skip line, when done by state forces, was $43 per lane mile (1.609 km).

5. A 1972 Mississippi report[11] also addresses the cost of installed stripes. Pertinent observations made are:

   - Contract cost of all traffic paint averages about $120 per mile (1.609 km), with yellow costing more than white and continuous lines costing more than skip lines.

   - Short sections cost more per unit length of striping than long sections.

   - Stripes by state forces cost about one-half of contract painting costs. (It is not evident here what cost items were considered in computing the costs associated with the striping by the state forces.)

6. In a California report[17], the initial cost of dashed stripes (9 ft. (2.74 m) mark; 15 ft. (4.57 m) gap) which includes costs associated with initial alignment and two coats of paint, is estimated to be $120 per mile (1.609 km). Cost for a twenty-year period is estimated to be $1070 per mile (1.609 km) which reduces to an average yearly cost of $53 per mile (1.609 km).

7. In response to an inquiry, a district office of the Pennsylvania Department of Transportation (Penn DOT) provided cost data for the period 1-1-75 to 12-31-75. These costs (of paint stripes per mile of highway broken down according to material, labor, and equipment cost) are presented in Table 8. These average costs are computed by dividing the total cost (material, labor, and equipment costs) by the number of miles of stripes installed. Total miles of roadway striped, and the total amount of paint and glass beads used are given in Table 9.

8. The Arizona Highway Department cost estimates for 1974 for edgeline installation when striped by the state's hotline striper are $200.42 per mile (1.609 km) for initial installation (two applications). The restriping cost (single application) is estimated to be $107.41 per mile (1.609 km). These estimates are based upon an application rate of 250 miles (402.32 km) of striping for a 40-hour week period (125 miles (201.16 km) of striping per 40-hour week when two applications are required). The detailed cost breakdown as provided by the state is included in Figures 1 and 2.

9. The State of Georgia provided the following 1975 cost data for pavement stripes.

Type of Stripe	Cost
4-inch Solid Paint Stripe	$360.00/mile
4-inch Skip Paint Stripe	$280.00/mile
8-inch Traffic Stripe	$381.50/mile
18-inch Solid Traffic Stripe	$0.70/lin. ft.
24-inch Solid Traffic Stripe	$1.20/lin. ft.

1 Mile = 1.609 km
1 Ft = .3048 m
1 Inch = 25.4 mm

Table . 8. Striping cost for a Pennsylvania DOT District for 1975.

Road Type	Paint Type	Cost in Dollars Per Mile of Stripe					Average Stripe Cost per Mile		Remarks
		Yellow Line	White Line	Beads	Wages	Equipment	Yellow Line	White Line	
2 Lane	Conventional Paint	25.91	18.08	11.72	5.95	3.25	46.83	38.99	First Striping
2 Lane	Low Heat Rapid Dry	53.28	39.64	10.92	7.25	3.03	74.48	60.84	" "
3 Lane	" "	55.01	32.34	10.72	10.79	4.13	80.65	51.98	" "
4 Lane	" "	58.77	42.23	11.40	10.86	4.69	85.72	69.18	" "
5 Lane	" "	60.41	40.63	11.05	17.31	6.51	95.28	75.50	" "
2 Lane	" "	55.27	42.81	11.33	8.32	3.29	78.21	65.75	Restriping
3 Lane	" "	57.06	47.57	11.60	13.60	5.05	87.32	77.83	"
4 Lane	" "	73.05	54.64	14.63	12.70	4.26	104.64	86.23	"

1 mile = 1.609 km

Table 9. Total miles of line striped and material used for a Pennsylvania DOT District (1/1/75 to 12/31/75).

	Miles of Yellow Line	Miles of White Line	Gallons of Paint Used Yellow	Gallons of Paint Used White	Lb. of Beads Used	Average per Mile of Line Paint (gallon) Yellow	Average per Mile of Line Paint (gallon) White	Average per Mile of Line (lbs) Beads	
2 Lane C	37.85	21.74	604.99	300.00	5,500.00	15.98	13.80	92.50	First Painting
2 Lane L	3,224.51	1,882.10	47,071.48	22,957.35	439,045.31	14.60	12.20	85.98	First Painting
3 Lane L	98.59	96.30	1,385.95	958.25	16,446.11	15.07	9.95	84.39	First Painting
4 Lane L	165.15	438.12	2,659.29	5,692.71	54,156.05	16.10	12.99	89.77	First Painting
5 Lane L	2.53	1.00	41.87	12.50	307.06	16.55	12.50	86.99	First Painting
2 Lane L	131.52	45.56	1,991.46	600.07	15,804.47	15.14	13.17	89.25	Restriping
3 Lane L	23.14	17.41	361.77	254.83	3,704.72	15.63	14.64	91.36	Restriping
4 Lane L	111.90	63.91	2,239.44	1,074.42	20,257.07	20.01	16.81	115.22	Restriping

1 mile = 1.609 km
1 gallon = 3.785 L
1 pound = .4536 kg

Labor:

5 men x 40 hrs. x 6.65/hr = $1,330.00

Subsistence

Mon.	20.00
Tues., Wed., Thurs.	25.00
Fri.	6.00

$101.00 per week x 5 = $505.00 per week

Equipment:

05	Striper	= 18.00/hr x 40 hrs.	= 720.00
02	Supply truck	= 2.30/hr x 40 hrs.	= 92.00
02	Supply truck	= 2.30/hr x 40 hrs.	= 92.00
01	Crew cab P/U	= 1.85/hr x 40 hrs.	= 74.00
			$978.00

Materials:

250 pass miles x 16 gallons/pass mile x 4.8686 =	19,474.40
4,000 gallons x 6 lbs. glass/gal. x $0.15 per lb. =	3,600.00
Thinner and incidentals = 0.10 per gal. x 4,000 gallons =	400.00
	$23,474.40

Summary:

Overhead = $2.26 per pass mile x 250 = $565.00

Labor	1,330.00
Subsistence	505.00
Equipment	978.00
Materials	23,474.40
Overhead	565.00
	$26,852.40

$$\frac{\$26,852.40}{250} = \$107.41 \text{ per pass mile}$$

$$\frac{\$107.41}{5,280} = \$0.0203 \text{ per foot}$$

Note: 1 mile = 1.609 km
1 ft. = .3048 m
1 gallon = 3.785 L
1 pound = .4536 kg

Figure 1. Cost to restripe edgeline in the State of Arizona.

Labor:

5 men x 40 hrs. x 6.65/hr. = $1,330.00

Subsistence

Mon.	20.00
Tues., Wed., Thurs.	25.00
Fri.	6.00
	$101.00

$101.00 per week x 5 = $505.00 per week

Equipment:

05	Striper =	18.00/hr x 40 hrs. =	720.00
02	Supply truck =	2.30/hr x 40 hrs. =	92.00
02	Supply truck =	2.30/hr x 40 hrs. =	92.00
01	Crew cab P/U =	1.85/hr x 40 hrs. =	40.00
			$978.00

Materials:

125 pass miles x 32 gallons per p.m. (2 applications) x $4.8686 =	19,414.40
2,000 gallons x 6 lbs. glass x .15 lb. =	1,800.00
Thinner and incidentals = .10 per gallon x 4,000 gallons =	400.00
	$21,674.40

(250 = $565.00)

Summary:

Overhead = $2.26 per pass mile

Labor	1,330.00
Subsistence	505.00
Equipment	978.00
Materials	21,674.40
Overhead	565.00
	$25,052.40

$\frac{25{,}052.40}{125}$ = $200/pass mile (2 applications)

$\frac{200.42}{5{,}280}$ = $0.0379/foot for 2 applications

Note: 1 mile = 1.609 km, 1 ft. = .3048 m, 1 gallon = 3.785 L, 1 pound = .4536 kg

Figure 2. Cost to install edgeline in the State of Arizona (initial installation).

10. The State of California maintains a data bank on the installation cost of pavement lines and other roadway delineation treatments. Annual summaries are also prepared. Tables 10 through 19, extracted from the state-supplied data for the fiscal year 1975-76, provide striping cost data with the following breakdown:

a. By Type of Stripe

- all painted stripes
- dashed and dashed solid lines
- double yellow centerline
- single 4-inch (10.16 cm) white or yellow line

b. By District

c. By Type of Paint

- cold-applied
- hot-applied

E.1.1.5 Cost of Thermoplastic Stripes

Before reviewing the cost of thermoplastics, it should be pointed out that there are also cold-applied plastic stripes which come in prepared shapes with an adhesive backing. The adhesive backing is protected by a sheeting which is removed prior to striping. Cold-applied stripes are mainly applied on bituminous pavements in high-density areas and are generally used for delineating localized situations such as crosswalks and channelization. Because of the specialized use of these plastic stripes, they are not included in this discussion.

Since the advent of thermoplastic material during World War II, this material has increasingly been used for pavement striping. Although its use is still somewhat limited in the United States, it is reported that 80 to 90 percent of roadways in Britain are now striped with hot-applied thermoplastic material. This increase in popularity

Table 10. Striping cost in California for FY 1975-76 -- all lines (cold paint).

District	May 1976 Inventory Miles	Restriped Miles	Man-Years in Restriping	Man-Hours Per Mile	Cost in thousands			Total Cost Per Mile
					Equipment	Materials	Total	
01	3,401.90	943	1.94	3.70	7.0	49.9	89.8	95.23
02	5,429.77	2,257	2.42	1.93	25.0	30.9	94.9	42.05
03	4,830.86	4,455	3.07	1.24	28.9	128.0	223.0	50.06
04	1,858.42	1,831	3.70	3.64	25.2	110.1	196.9	107.54
05	2,957.76	22	.13	10.64	.5	2.4	5.0	22.72
06	4,841.80	442	.79	3.22	4.3	28.2	46.8	105.88
07	5,522.18	773	.88	2.05	4.6	55.6	76.5	98.96
08	4,849.74	1,328	2.81	3.81	46.4	77.2	147.5	110.07
09	2,718.08	2	.02	18.00	.3	--	.7	350.00
10	5,031.32	848	1.39	2.95	12.4	48.1	86.2	101.65
11	2,782.92	583	.81	2.50	6.3	35.1	55.2	94.68
TOTAL	44,224.75	10,304	17.36	3.03	123.7	565.7	1023.4	99.32

1 mile = 1.609 km

Table 11. Striping cost in California for FY 1975-76 -- all lines (rapid dry paint).

District	May 1976 Inventory Miles	Restriped Miles	Man-Years in Restriping	Man-Hours Per Mile	Cost in Thousands			Total Cost Per Mile
					Equipment	Materials	Total	
01	3,401.90	751	1.17	2.80	12.8	44.8	78.3	104.26
02	5,429.77	1,831	2.64	2.59	24.3	45.4	124.2	67.83
03	4,830.86	1,358	1.97	2.61	30.3	74.0	147.0	108.25
04	1,858.42	2,289	1.02	0.80	11.1	65.9	94.3	41.20
05	2,957.76	1,033	1.22	2.12	13.1	76.5	113.5	109.87
06	4,841.80	2,229	1.96	1.58	25.7	120.3	182.4	81.83
07	5,522.18	547	0.61	2.01	6.8	31.5	49.4	90.31
08	4,849.74	1,454	1.96	2.43	19.4	75.4	130.4	89.68
09	2,718.08	2,361	2.22	1.69	27.5	88.9	164.2	69.55
10	5,031.32	1,079	0.99	1.65	12.9	77.7	110.0	101.95
11	2,782.92	451	0.59	2.35	6.7	27.3	44.1	97.78
TOTAL	44,224.75	14,108	16.35	--	191.9	727.7	1,237.4	87.71

1 mile = 1.609 km

Table 12. Striping cost in California for FY 1975-76 -- dashed and dashed solid lines (cold paint).

District	May 1976 Inventory Miles	Restriped Miles	Man-Years in Restriping	Man-Hours Per Mile	Cost in Thousands			Total Cost Per Mile
					Equipment	Materials	Total	
01	1,101.20	466	.86	3.32	3.6	16.6	35.1	75.32
02	1,875.78	1,131	1.92	3.06	10.9	24.8	75.6	66.84
03	1,317.61	1,068	1.41	2.38	13.6	44.9	89.3	83.61
04	371.07	287	.51	3.20	3.3	10.9	22.7	79.09
05	837.81	--	--	--	--	--	--	--
06	1,308.70	23	.12	9.39	0.6	3.5	6.2	269.56
07	1,827.20	73	.05	1.23	0.3	4.8	6.1	83.56
08	2,902.80	694	1.23	3.19	8.4	75.9	57.4	82.71
09	882.32	--	--	--	--	--	--	--
10	1,165.75	422	.62	2.64	6.2	20.5	39.1	92.65
11	1,301.37	280	.37	2.38	2.4	14.6	24.3	86.78
TOTAL	14,991.61	4,449	7.09	2.87	49.4	166.5	355.8	79.97

1 mile = 1.609 km

Table 13. Striping cost in California for FY 1975-76 -- dashed and dashed solid lines (rapid dry paint).

District	May 1976 Inventory Miles	Restriped Miles	Man-Years in Restriping	Man-Hours Per Mile	Cost in Thousands			Total Cost Per Mile
					Equipment	Materials	Total	
01	1,101.20	339	.64	3.40	6.6	17.6	35.5	104.72
02	1,875.78	994	1.47	2.66	13.7	22.6	67.5	67.91
03	1,417.61	865	.97	2.02	14.9	29.7	66.3	76.65
04	371.07	176	.21	2.15	1.9	5.6	11.4	64.77
05	837.81	342	.47	2.47	5.2	15.9	30.5	89.18
06	1,308.70	1,239	1.10	1.60	15.1	59.4	95.2	76.84
07	1,827.20	327	.26	1.43	3.2	9.4	17.4	53.21
08	2,902.80	777	.86	1.99	8.1	25.3	48.7	62.67
09	882.32	791	.91	2.07	10.6	27.4	58.4	73.83
10	1,165.75	476	.48	1.82	5.8	28.7	44.1	92.65
11	1,301.37	235	.31	2.37	3.5	11.2	20.3	86.38
TOTAL	14,991.61	6,565	7.68	2.11	88.6	252.9	495.2	75.43

1 mile = 1.609 km

Table 14. Striping cost in California for FY 1975-76 double yellow line (cold paint).

District	May 1976 Inventory Miles	Restriped Miles	Man-Years in Restriping	Man-Hours Per Mile	Cost in Thousands			Total Cost Per Mile
					Equipment	Materials	Total	
01	281.40	59	.17	5.19	.7	7.7	11.3	191.53
02	216.56	106	.15	2.55	1.5	3.7	8.1	96.42
03	288.39	175	.38	3.91	3.8	30.2	41.3	236.00
04	170.73	163	.48	5.30	3.0	25.3	36.1	221.47
05	284.37	4	.02	9.00	.1	--	.3	75.00
06	128.60	--	--	--	--	--	--	--
07	1,175.53	99	.14	2.55	.8	13.8	17.1	172.73
08	369.67	320	.77	4.33	32.8	34.2	52.8	165.00
09	175.63	--	--	--	--	--	--	--
10	836.29	66	.13	3.55	.9	7.8	11.0	166.67
11	532.45	39	.08	3.69	1.7	3.4	5.5	141.03
TOTAL	4,459.62	1,026	2.35	4.12	16.8	126.3	184.1	179.43

1 mile = 1.609 km

Table 15. Striping cost in California for FY 1975-76 -- double yellow line (rapid dry paint).

District	May 1976 Inventory Miles	Restriped Miles	Man-Years in Restriping	Man-Hours Per Mile	Cost in Thousands			Total Cost Per Mile
					Equipment	Materials	Total	
01	281.40	112	.17	2.73	1.9	9.7	14.5	129.46
02	216.56	107	.21	3.53	1.6	10.3	17.2	160.75
03	288.39	84	.11	2.36	2.0	8.6	13.4	159.52
04	170.73	99	.17	3.09	1.7	16.2	20.6	208.08
05	284.37	103	.18	3.14	1.4	17.8	22.9	222.33
06	128.60	40	.04	1.80	.3	7.4	8.7	217.50
07	1,175.53	68	.13	3.44	1.4	10.4	14.3	210.29
08	369.67	285	.49	3.09	5.0	29.6	43.9	154.04
09	175.63	223	.36	2.91	4.5	24.9	37.2	166.82
10	836.29	11	.02	3.27	.3	3.8	4.5	409.09
11	532.45	96	.08	1.50	.9	9.5	11.8	122.92
TOTAL	4,459.62	224	1.97	2.90	22.1	148.2	209.0	170.75

1 mile = 1.609 km

Table 16. Striping cost in California for FY 1975-76 -- white and yellow shoulder edgeline (cold paint).

District	May 1976 Inventory Miles	Restriped Miles	Man-Years in Restriping	Man-Hours Per Mile	Cost in Thousands			Total Cost Per Mile
					Equipment	Materials	Total	
01	1,985.20	392	.72	3.31	3.2	22.4	37.9	96.68
02	3,283.64	57	.14	4.42	1.1	2.0	5.5	96.49
03	3,028.71	906	1.07	2.13	9.5	45.4	76.5	84.44
04	1,302.79	924	1.49	2.90	9.4	48.5	82.9	89.22
05	1,764.57	--	--	--	--	--	--	--
06	3,296.60	414	.63	2.74	3.5	24.5	39.3	94.93
07	2,381.97	589	.61	1.86	3.0	35.0	49.4	83.87
08	1,390.30	263	.59	4.04	3.8	11.0	75.6	97.34
09	1,638.52	--	--	--	--	--	--	--
10	2,921.79	329	.42	2.30	4.2	16.7	28.3	86.02
11	783.31	264	.36	2.45	2.2	17.1	75.4	96.21
TOTAL	23,777.40	4,141	6.02	2.62	40.0	222.5	370.9	89.57

1 mile = 1.609 km

Table 17. Striping cost in California for FY 1975-76 white and yellow shoulder edgeline (rapid dry paint).

District	May 1976 Inventory Miles	Restriped Miles	Man-Years in Restriping	Man-Hours Per Mile	Cost in Thousands			Total Cost Per Mile
					Equipment	Materials	Total	
01	1,985.20	300	.36	2.16	4.3	17.5	28.3	94.33
02	3,283.64	709	.85	2.16	7.6	11.4	35.1	49.51
03	3,028.71	449	.64	2.57	9.7	25.6	48.2	107.35
04	1,302.79	655	.63	1.73	7.4	43.9	61.9	94.50
05	1,764.57	579	.53	1.65	5.9	41.3	57.2	98.79
06	3,296.60	922	.68	1.33	8.7	49.1	70.3	76.25
07	2,381.97	139	.16	2.07	1.4	9.7	13.9	100.00
08	1,390.30	355	.31	1.57	3.3	14.9	24.2	68.17
09	1,638.52	1,337	.90	1.21	11.8	36.6	67.1	50.19
10	2,921.79	591	.48	1.46	6.6	44.1	60.0	101.52
11	783.31	114	.17	2.68	2.1	5.9	10.7	93.86
TOTAL	23,771.40	6,154	5.71	1.61	69.0	300.0	476.7	77.46

1 mile - 1.609 km

Table 18. Striping cost in California for FY 1975-76 -- 8-inch (203.2 mm) solid line (cold paint).

District	May 1976 Inventory Miles	Restriped Miles	Man-Years in Restriping	Man-Hours Per Mile	Cost in Thousands			Total Cost Per Mile
					Equipment	Materials	Total	
01	34.10	26	.19	13.15	.5	3.2	5.5	211.54
02	53.79	20	.21	18.90	1.5	.4	5.7	285.00
03	96.15	49	.21	7.71	2.0	7.5	15.9	324.49
04	13.83	457	1.22	4.81	9.5	25.4	55.2	120.79
05	71.01	18	.11	11.00	.4	2.3	4.7	261.11
06	107.90	5	.04	14.40	.2	.2	1.3	260.00
07	137.48	12	.08	12.00	.5	2.0	3.9	325.00
08	186.97	51	22.00	7.76	1.4	6.1	11.7	229.11
09	21.61	2	.02	18.00	.3	0.0	.7	350.00
10	107.49	31	.22	12.77	1.1	3.1	7.8	251.61
11	165.79	--	--	--	--	--	--	--
TOTAL	996.12	688	1.90	4.97	17.5	50.4	112.6	163.66

1 mile = 1.609 km

Table 19. Striping cost in California for FY 1975-76 -- 8-inch (203.2 mm) solid line (rapid dry paint).

District	May 1976 Inventory Miles	Restriped Miles	Man-Years in Restriping	Man-Hours Per Mile	Cost in Thousands			Total Cost Per Mile
					Equipment	Materials	Total	
01	34.10							
02	53.79	21	.11	9.43	1.4	1.1	4.4	209.52
03	96.15	36	.25	12.50	3.7	10.1	19.1	530.55
04	13.83	1	.01	18.00	.1	.2	.4	400.00
05	71.01	9	.04	8.00	.6	1.5	2.9	322.22
06	107.90	28	.14	9.00	1.6	4.4	8.2	292.86
07	137.48	13	.06	8.31	.8	2.0	3.8	292.31
08	186.97	37	.30	14.59	3.0	5.6	13.6	367.57
09	21.61	10	.05	9.00	.6	0.0	1.5	150.00
10	107.49	1	.01	18.00	.2	1.1	1.4	1,400.00
11	165.79	6	.03	9.00	.2	.7	1.3	216.67
TOTAL	996.12	162	1.00	11.58	12.2	26.7	56.6	418.17

1 mile = 1.609 km

* Data not available

is due to its longer life, reduction in cost with large-scale production, and better performance under inclement weather and wet pavement conditions.

Thermoplastic stripes in the United States are still primarily applied in urban areas to mark gore areas and crosswalks. They can be applied in 4-inch (101.6 mm) stripes and reflectorized with glass beads. However, in contrast to paint lines, thermoplastic stripes are necessarily thicker. The thickness of extruded thermoplastic stripes is generally 0.125 inches (3.175 mm) with 0.090 inches (2.286 mm) as the minimum. Hot-sprayed thermoplastic stripes can be as thin as 0.060 inches (1.524 mm).

A review of recent literature on the cost of thermoplastic stripes follows:

1. Chaiken(6) reports the results of a survey which included all the states, Puerto Rico and the District of Columbia. The results of this survey show that the installed cost of thermoplastic stripes range from a low of 17¢ to a high of 63¢ per linear foot (.3048 m) of longitudinal 4-inch (101.6 mm) stripe ($897 to $3,326 per mile (1.609 km)). Reporting on these costs, Chaiken noted that the few agencies reporting extremely low costs had either performed the work themselves or stated that the contract price was the same or less than the contractors' cost because the contractors had taken a loss to demonstrate the merits of the material. Extremely high costs were reported only for very small installations or for city installations in which the cost reflected expensive traffic control and slow application rates. The average cost of all 4-inch (101.6 mm) longitudinal thermoplastic stripes was calculated to be 32.7¢ per linear foot (.3048 m) ($1,726 per mile (1.609 km)) and generally represented the average contract price for large installations on open highways.

2. The cost of installed thermoplastic stripes in Minnesota for 1967 was estimated to be 39¢ per linear foot (.3048 m) ($2,059 per mile (1.609 km)) for a 4-inch (101.6 mm) wide stripe. This cost was based upon the installations made on a contract basis [16].

3. In a 1972 Mississippi report [11], the cost of dashed thermoplastic lines is estimated to be between $300-$500 when laid down by state forces, and $400-$600 when performed under contract. The continuous lines are estimated to cost about twice as much as skip lines because 2 - 2.5 times as much material is required.

4. Flanakin [13] reports the results of a study conducted by the District of Columbia Department of Highways and Traffic to assess its marking needs. In this report, the cost of thermoplastic lane and centerline markings was estimated to be 19¢ per linear foot (.3048 m) ($1,003 per mile (1.609 km)) when laid down by D.C. forces and 26¢ per linear foot (.3048 m) ($1,373 per mile (1.609 km)) when performed under contract. The corresponding costs of crosswalks and stop lines were 32¢ per linear foot (.3048 m) and 43¢ per linear foot (.3048 m) ($1,690 - $2,270 per mile (1.609 km)), respectively.

5. Georgia provided the following data on the installed cost of thermoplastic stripes for the year 1975.

- 4" (101.6 mm) Solid Stripe (Yellow or White) — $1,160/mile (1.609 km)
- 4" (101.6 mm) Skip Stripe (Yellow or White) — $ 425/mile (1.609 km)
- 8" (203.2 mm) Solid Stripe (Yellow or White) — $2,100/mile (1.609 km)
- 18" (457.2 mm) Solid Traffic Stripe (White) — $2.10/lin. ft. (.3048 m)
- 24" (609.6 mm) Solid Traffic Stripe (White) — $2.35/lin. ft. (.3048 m)

6. The State of California utilizes thermoplastics primarily to stripe localized situations such as gore areas and stop approaches. For such situations, the striping cost is measured in dollars per square foot (0.0929 m^2) of pavement. This cost for various methods of application is provided below.

	Method of Application			
	No Stencil; No Preheater	Stencil; No Preheater	No Stencil; Preheater	Stencil; Preheater
Cost in dollars per square foot (0.0929 m^2)	0.90	1.90	0.70	1.15

E.1.2 Service Life of Pavement Stripes

The determination of the life of pavement stripes requires a definition of the "service life of a stripe" and an understanding of the important parameters which affect this service life.

The pavement stripe deteriorates gradually with time and exposure to traffic. The life of the stripe is a subjective estimate of the period over which the deterioration is such that the agency decides to restripe. Hence, the life of the stripe is somewhat dependent upon the deterioriation that can be tolerated before restriping is necessary.

Although there are no definite procedures to determine the service life of stripes on highways, the ITE Technical Council Committee 4N-S has developed procedures for determining the useful life of test samples(3). The procedure outlined by this committee provides insight into the factors that should be considered when estimating service life. Therefore, a brief description of the procedure is appropriate here.

The Committee recommends that the evaluation of service life be based on three characteristics: appearance, durability,and night visibility. For each characteristic, the test should be rated numerically from very poor to perfect, using numbers from 0 to 10, with number 10 indicating a perfect condition and 0 complete failure.

1. Appearance: The complete impression conveyed when the marking is viewed at a distance of at least 10 feet (3.048 m).

2. Durability: The factor used in rating paint failure is equal to 1/10 of the percentage of material remaining on the pavement when examined closely by the unaided eye. This determination is to be made in each wheel track in an area extending 9 inches (228.6 mm) each side of the point of greatest wear. Percentage of material remaining on the pavement will be considered as the percentage of the prescribed area of test stripe in which the substrate is not exposed.

3. Night Visibility: Night visibility designates the apparent brightness when examined at night under tungsten illumination from the side of the road, with eye and light source separated by distance which correspond to a divergency of viewing angle of approximately one-third degree. Night visibility determination will be made on the same areas as those made for rating durability.

The service life is then estimated by determining the service factor R and the weight rating, W. The service factor R is determined for each of the three criteria that is, R_a for appearance, R_d for durability, and R_n for night visibility by the formula

$$R = \frac{r_1 t_1 + r_2 t_2 \dots r_x t_x}{t_1 + t_2 + \dots t_x}$$

where

t_1, i = 1, 2, ... x is the time in days between the (i - 1)th and ith evaluation.

t_x is the time interval at which the rating goes below four (4).

r_1, i = 1, 2, ... x is the average rating (average over all observers and all test sites) at the ith evaluation.

A weighted factor W is needed as the three characteristics, appearance, durability and night visibility are not considered of equal importance in rating a pavement marking. Recommended weights are:

- Appearance - 30 percent
- Durability - 30 percent
- Night Visibility - 40 percent

The weighted rating W then is determined from the formula:

$$W = 0.30\ R_a + 0.30\ R_d + 0.40\ R_n$$

in which R_a, R_d, and R_n are the service factors for appearance, durability and night visibility.

The duration of the test is recommended to be one year or whenever a stripe is rated below four (4) in one or more of the service factors. (One year is recommended so that the lines are subject to both summer and winter wear and deterioration.)

Having computed the weighted factor W, the service life is computed from

$$L = D \times \frac{(10 - E)}{(10 - W)}$$

where

L = the service life of the stripe

D = days of the period of test

E = weight rating of a time at the end of its useful life (4 recommended here)

W = weighted rating at the end of the test period

Service life, whether determined through the above procedure or any other way, depends upon several roadway traffic, geometric and climatic factors. Important factors which appear to govern the life of a pavement stripe are:

1. Type of Stripe: Edge stripes wear less than centerlines due to the reduced number of wheel passes over the marking. Similarly, transverse markings wear faster than longitudinal lines.

2. Pavement Type: Service life of stripes on bituminous concrete pavements is believed to be higher than on portland cement concrete pavements.

3. Traffic Volume and Maneuvers: Stripe wear depends on traffic volume. Traffic maneuvers such as turning, lane changing, etc., also affect service life.

4. Stripe Dimensions: Thickness of the paint film and the width of the stripe also affect service life.

5. Climatic Conditions: The amount of snowfall which dictates the snowplowing activity and the use of studded tires can significantly affect the service life.

6. Method of Application: Surface preparation prior to the application of stripes may also have an effect on the life of the stripe.

A brief review of literature pertaining to the service life of paint and thermoplastic stripes follows:

E.1.2.1 Service Life of Paint Stripes

1. In a 1969 review paper, Chaiken[7] summarizes various studies which were conducted to determine the life of painted stripes.

   - In a 1959 study, it is reported that sandblasting (compared to simple brooming or use of compressed air alone) substantially increased the stripe life on portland cement concrete pavements.

   - A research report published by the Department of Transportation in 1969 notes that neither acid etching nor synthetic rubber primer increased the durability of traffic paint on either concrete or bituminous surfaces.

- According to a 1966 study by the Corps of Engineers, adherence of paint to portland cement concrete can be improved by pretreating the pavement with a 50-50 mixture of boiled linseed oil and mineral spirits.

- Chipping or loss of adhesion, rather than abrasion loss, is a major cause of traffic paint failure, as per a study by the Kansas State Highway Commission. A similar observation was also made in an earlier study by the Texas Highway Department.

- According to a Michigan study, thicker paint films were more durable but the additional life of a stripe thicker than 16 mils was not in direct proportion (but less) to the additional thickness used.

- In a 1965 study, conducted by Georgia Institute of Technology, it is reported that the durability of the stripes improved when the stripe thickness was in the range of 10-20 mils. However, wet film thickness of 10 mils was incapable of binding drop-on beads.

- Kentucky Department of Highways, experimenting with multiple film application of 15 mils each, reported that multiple coats provided improved durability over a 15 mil coat.

2. Efforts to develop functional relationships between the service life of pavement stripes and various traffic and environmental parameters are reported in another study by Chaiken[6]. Through a national survey, Chaiken developed data on the service life of paint stripes for various traffic volumes, pavement types, and snow conditions. The analysis of data revealed that service life depends only on traffic volume and pavement type. No relationship was found between service life and snowfall in the region. The developed relationships are presented in Figures 3, 4, and 5.

3. In a British study[14], the results of a survey on life and cost of various markings are reported. Questionnaires were sent to fifteen counties and six cities. A summary of replies to the questionnaire is presented in Table 20.

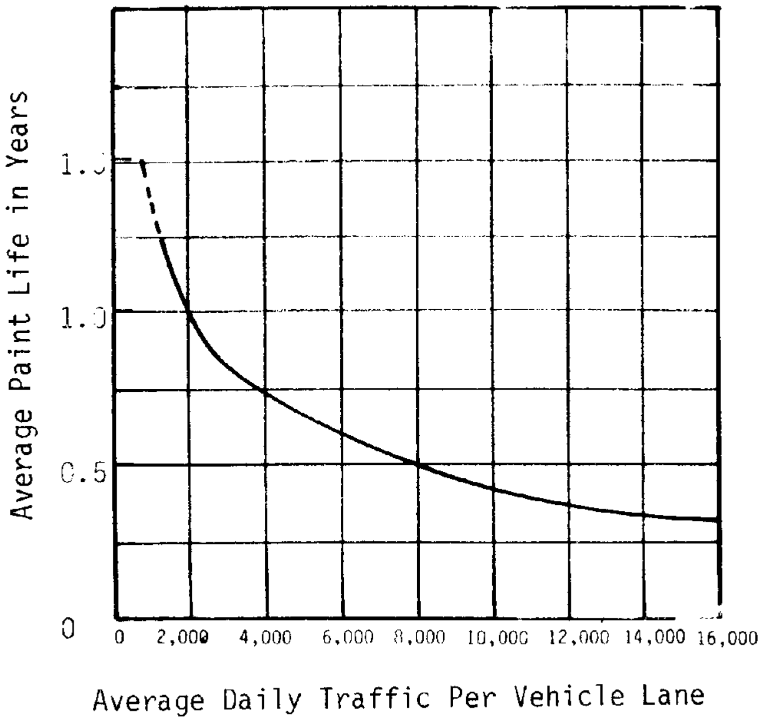


Figure 3. Useful life of paint as affected by traffic density--bituminous pavement (Chaiken, 1969).

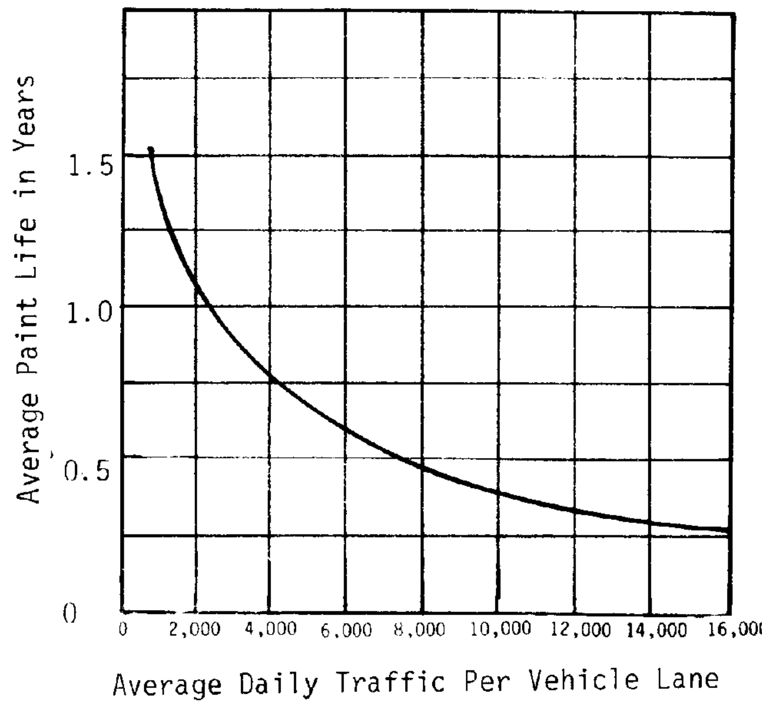


Figure 4. Useful life of paint stripes as affected by traffic density--concrete pavement (Chaiken, 1969).

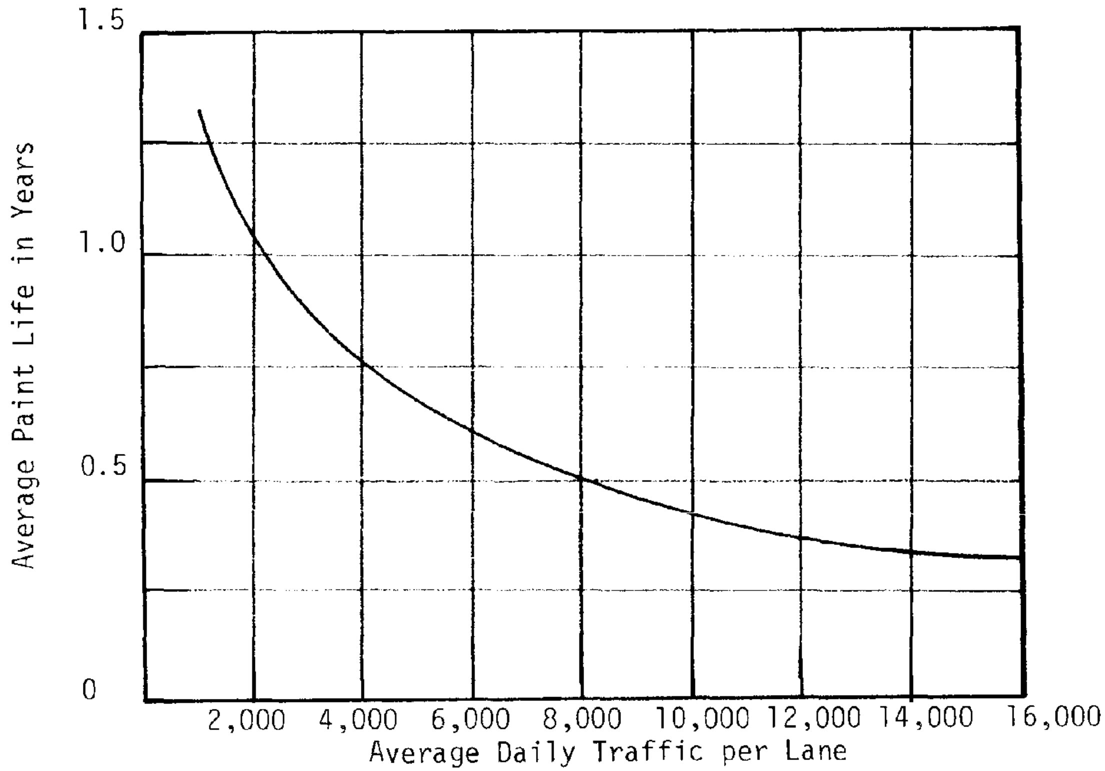


Figure 5. Average useful life of paint striping as affected by traffic density - both bituminous and concrete pavement (Chaiken, 1969).

Table 20. Summary of questionnaire responses on service life of roadway markings (James and Reid, 1969).

Type of Road Marking	No. of Replies	Mean (months)	Range (months)
Lane-line on a heavily trafficked bituminous road	8	5.8	1.12
Lane-line on a heavily trafficked concrete road	5	6.6	1.5-12
Lane-line on a lightly trafficked bituminous road	8	11.3	3-24
Lane-line on a lightly trafficked concrete road	4	11.1	2.5-24
Edgeline on a bituminous road	7	12	2-24
Edgeline on a concrete road	3	16	12-24

4. Rahal and Hughes(16) in a study conducted by the Kentucky Department of Highways in 1970 reported the following:

- Conventional paint stripes performed consistently better on bituminous concrete pavements than on portland cement concrete with the performance on new PCC pavement particularly poor. Repainting over the old stripes, however, enhanced the durability of the stripe.

- On an average, centerline stripes placed on PCC pavements required repainting each year whereas stripes placed on bituminous concrete required painting only once every two years.

- Edgelines required repainting every two years on PCC pavements and every three years on bituminous pavements.

- Fading was more prominent on bituminous concrete pavements and may have resulted from asphaltic bleeding. The bond between the paint and the bituminous surface was normally quite good and could be attributed to solvents within the paint fusing the two materials. Flaking normally occurred on PCC pavements, and was probably due to a low degree of bond. Surface laitance was also suspected to have contributed to loss of stripes, particularly for relatively new PCC surfaces.

5. The effect of glass beads on the performance of paint stripes was the subject of an Alabama study[8]. Pertinent results are:

- Precleaning a pavement with detergent and water prior to stripe application had no significant effect on the performance of the stripes.

- Stripes with very high "drop-on" bead application rates (9.9 to 17.4 pounds per gallon (1.18 to 2.08 kg per litre)) were rated low in daytime appearance and durability but had good nighttime visibility.

- Reflectorized paint with about 2 pounds per gallon (0.24 kg per litre) of "drop-on" beads performed best on concrete pavement and was one of the two best performers on the bituminous pavement.

6. In a 1971 report on the evaluation of pavement markings under different pavement conditions, the following observations were made[10]:

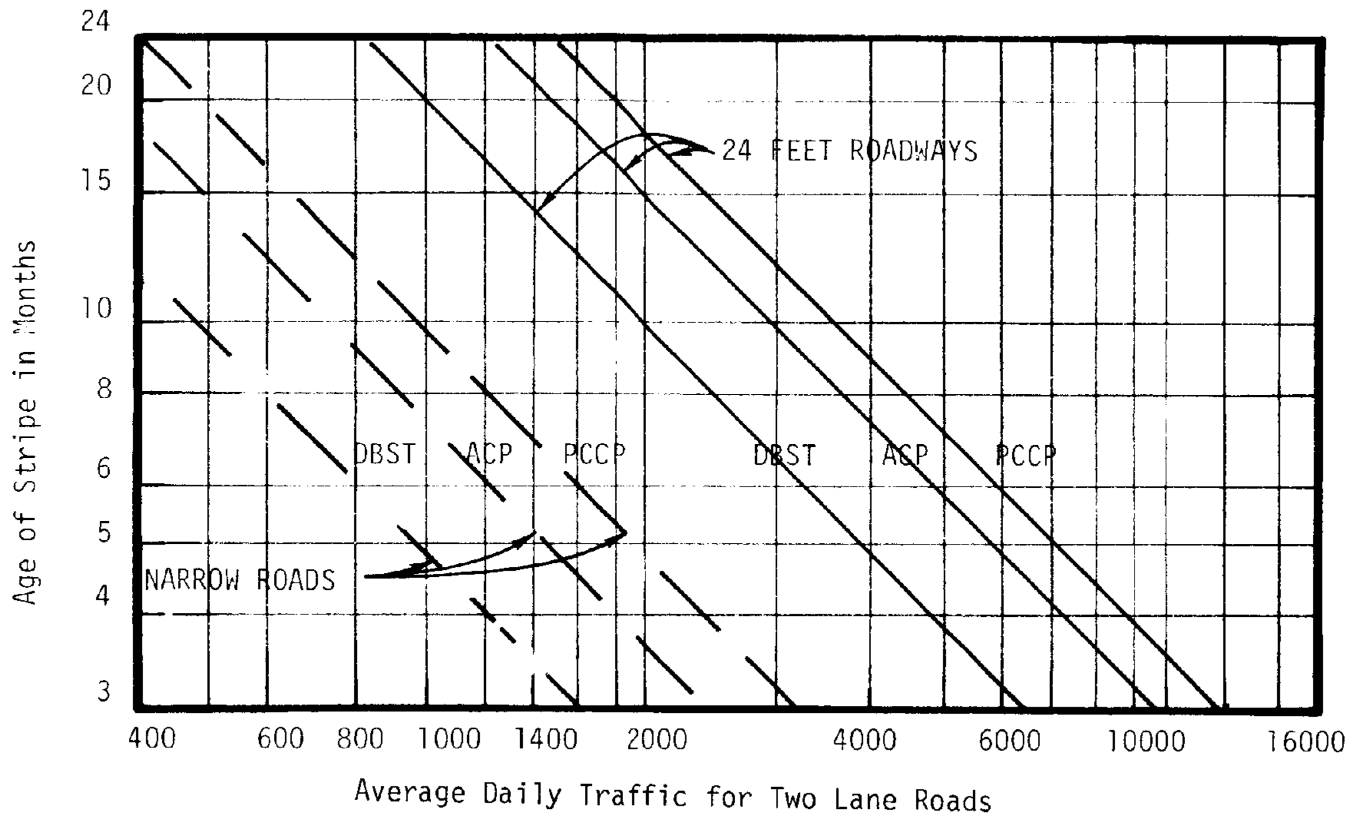
- Portland cement concrete pavement, striped for the first time, produced a better bond between the paint and the surface when pretreated with a weak phosphoric acid solution.

- The smoothest pavement types, e.g., portland cement concrete pavements, displayed a much longer service life than did rougher asphaltic pavements. Stripes placed on a pretreated surface had the poorest service life and indicated a need for restriping after a short period of time. A reason for rapid wear on rougher surfaces is that the paint flows into the depressions in the road surface causing a decrease in film thickness at crests where the wear is the greatest.

- The service life of traffic paint is reduced when roads are less than 24 feet (7.31 m) wide.

- Traffic stripes placed on existing traffic stripes perform better than traffic stripes placed on the road surface, especially on asphaltic concrete pavements.

- There is a definite relationship between the noticeable wear in the stripes and traffic volume in ADT. The life of a stripe can be assumed to be twice the period it takes to develop noticeable wear. Reported relationships are given in Figure 6. It should be noted that this is for



Legend:

PCCP = Portland Cement Concrete Pavement
ACP = Asphaltic Concrete Pavement
DBST = Double Bituminous Surface Treatment

Note: 1 foot = .3048 m; 1 pound = .4536 kg

Figure 6. Conditions for noticeable traffic stripe wear (white traffic paint placed at 15 mils, wet with 6 lb. of beads/gal.) (Mississippi, 1971).

Mississippi data, where there is little snowfall and a law prohibits the use of studded tires.

7. Van Vechten reports on a District of Columbia study[9] wherein the average service life of paint lines based upon 16 samples was determined. Service lives of each paint were determined by a method similar to that specified by the ITE Technical Council Committee on 4N-S. The qualities examined were: (a) appearance, (b) durability, and (c) nighttime visibility. Each of the above qualities were rated on a scale of 10 with overall rating given by

$$R = 0.30A + 0.30D + 0.40N$$

where

R = weighted overall rating
A = appearance
D = durability
N = night visibility

Estimated average service life, as estimated through the above procedure, is given below.

	White Paint		Yellow Paint	
	AC	PCC	AC	PCC
Average Service in Days	292	311	313	309

E.1.2.2 Service Life of Thermoplastic Stripes

1. A lucid discussion on the service life of thermoplastic stripes is presented by Chaiken[6].

- Cleaning and surface preparation practices before the application of thermoplastic stripes differed from agency to agency.

- Sandblasting, brooming, airblasting, buffing and acid etching were the primary methods of cleaning. However, the most prevelant practice, especially on bituminous pavements, was no precleaning at all.

- Different types of primer pretreatments were used by the various agencies for both bituminous and concrete surfaces. Some agencies did not use primer at all.

  On bituminous surfaces, the most common practice was to apply a thermoplastic stripe to the unprimed pavement. On concrete surfaces, the most prevalent primer was epoxy resin solution. Early failure was reported when no primer was used on concrete surfaces.

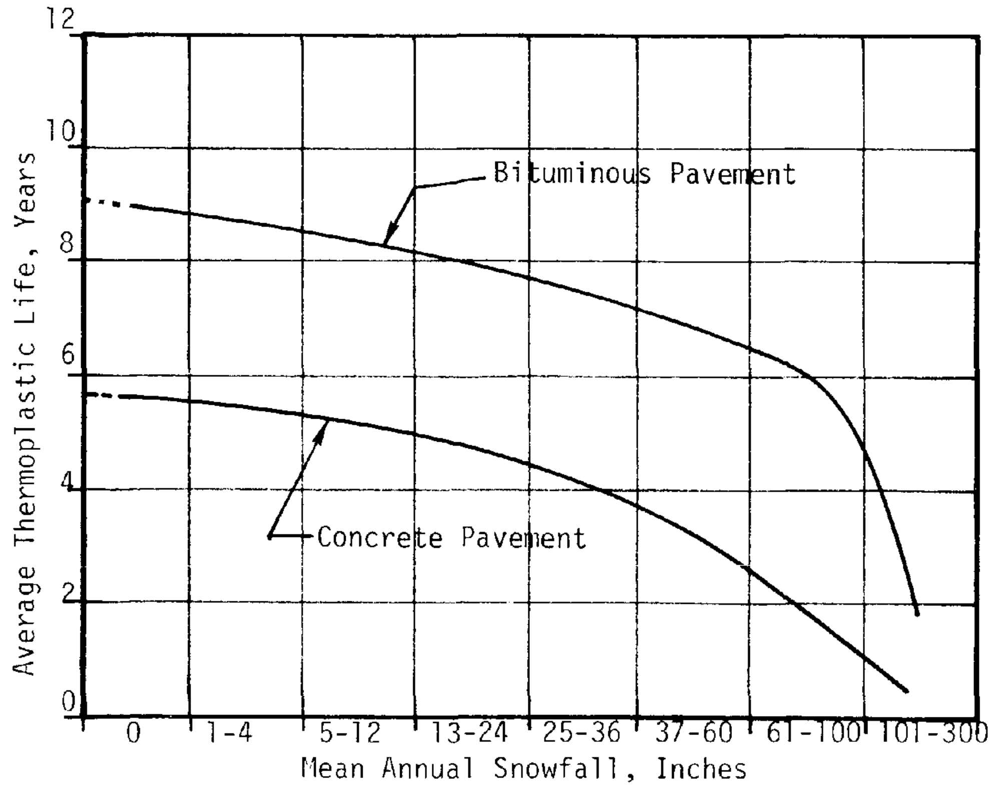
- With respect to primer application rate, the most prevalent rate for rubber-based primer was 50 sq. ft. per gallon (1.23 m^2 per litre). For epoxy primers, the approximate application rate was about 320-420 sq. ft. per gallon (7.92-10.39 m^2 per litre). Commenting on the optimum application rate, Chaiken observed that it probably depended upon several factors such as age, porosity and texture of the pavement, and the active solid content of the epoxy solution used.

- Thermoplastics are much more durable on bituminous pavements than on portland cement concrete pavements. Also, thermoplastic stripes performed better on older concrete than on new concrete.

- The other variables affecting service life of thermoplastic stripes are snowplow operation, pavement pretreatment, primer application rate, traffic volume and pavement age.

- Chaiken failed to develop any relationship between the traffic volume and the service life of thermoplastic stripes from the data he collected for the study through the nationwide survey. However, he was able to develop regression models relating service life to the snowfall. These models, which were developed for centerlines and lane lines, are presented in Figure 7. For other lines, Chaiken observed that edgelines last about one and one-half times as long as the center and lane lines, and transverse lines about one-half as long.

2. James and Reid report on a British study where a questionnaire was sent to fifteen counties and six cities[14] The results of this questionnaire are given in Table 21.



Note: 1 inch - 25.4 mm

Figure -7. Relationship between average thermoplastic life and annual snowfall (Chaiken, 1969).

Table 21. Life of thermoplastic material (James and Reid, 1969).

Type of Road Markings	No of Replies	Mean (months)	Range (months)
Lane-line on a heavily trafficked bituminous road	16	18.0	9-36
Lane-line on a heavily trafficked concrete road	7	9.0	3-18
Lane-line on a lightly trafficked bituminous road	16	30.4	12-60
Lane-line on a lightly trafficked concrete road	4	13.9	6-18
Edgeline on a bituminous road	11	23.1	12-48
Edgeline on a concrete road	3	13.0	9-21

3. Rahal and Hughes(15) report the results of a study on thermoplastic markings conducted by the Kentucky Department of Highways. The study concerned itself with two popular brands known as "Perma-Line" and "Cata Therm." Significant results reported are:

- The test thermoplastic stripes developed transverse cracks at expansion joints.
- The plastic stripes were much more durable on bituminous concrete pavements than on PCC pavements. (The reason for this was thought to be the heat from the freshly placed thermoplastic which softened the bituminous surface and thereby contributed to the bond.)
- Due to the poor bond of thermoplastics on PCC pavements, the use of primer is essential. The presence of surface laitance required that the primer be capable of penetrating the laitance for bonding to the pavement.

4. Hughes(16) reports on a study conducted by the Minnesota Department of Highways to determine comparative costs and service

lives of conventional traffic paint and thermoplastic pavement marking materials.

- An analysis of the data gathered from projects using different surface preparation methods (such as sand-blasting, air cleaning, acid etching and the use of epoxy primer) failed to develop any relationship between the life of the thermoplastic stripes and surface preparation.

- The loss of thermoplastic stripes from bituminous pavements was generally due to wear rather than removal by snow-plowing.

- The effective life of thermoplastic stripes on bituminous pavements appeared to depend upon the traffic volume. Based upon the data gathered at five different projects, a relationship between the life of thermoplastic stripes and ADT was developed and is given as Figure 8.

- Based upon its performance in Minnesota, the effective life of thermoplastics was estimated to be 1-1/2 years on PCC pavement. This was mainly due to the force exerted by plows during snowplowing operations which exceeds the adhesion force between the thermoplastic and the concrete.

5. In a study on road marking materials conducted by the Mississippi State Highway Department(11), it was found that the average service life of thermoplastic stripes was more than ten years for the State of Mississippi. The minimum life was estimated to be somewhere between five and seven years.

6. Appendix C of a report by Van Vechten(9) contains the results of a study which was designed to assess the dependence of service life of thermoplastics on traffic flow characteristics. Important findings of the study are:

- Marking wear is a function of various traffic volume parameters such as total volume, volume turning left, volume per lane, etc. Correlation factors between thermoplastic marking wear and various traffic parameters are given in Table 22.

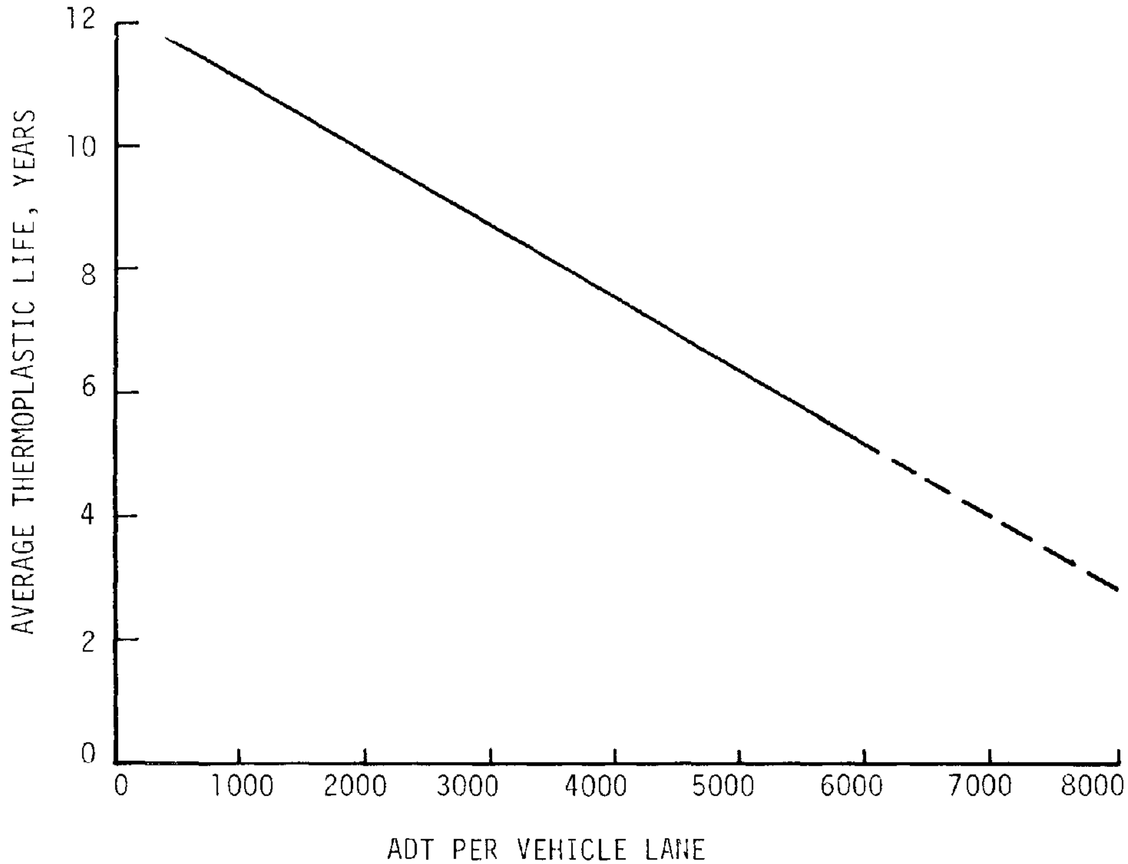


Figure 8. Life of thermoplastic stripes as a function of volume (Hughes, 1970).

Table 22. Correlation factors between the amount of wear in thermoplastic markings and various traffic volume parameters (Van Vechten, 1975).

Traffic Volume	Correlation Factor
Total volume	.476
Left Turning	.241
Through traffic volume	.440
Right turning	.267
Volume per lane	.598

- The percentage of material worn away in the wheel path depended upon the traffic volume. A functional relationship between the two is given in Figure 9. This relationship was developed from the data collected at 96 intersections which were striped with thermoplastic markings.

7. Azar, *et al.*[18], report on a Louisiana study undertaken to develop specifications for thermoplastic marking materials. Important observations made in this 1975 report are:

- The thermoplastic material should be installed with the use of proper primer, and the material should be preheated to proper temperature for good bonding between the thermoplastic and pavement.

- The thermoplastic material becomes dirty after installation resulting in a drop in the reflectance reading. Dirt buildup causing this drop, however, reaches a maximum at about 18 months causing the reflectivity reading to become stable at that point. A typical reflectance-exposure time curve, reproduced from the report is given in Figure 10.

- The estimated life expectancy of the thermoplastic marking compound is a minimum of 5 years. (Life expectancy of standard paint, under similar situations, was found to be from 6 to 12 months).

E.2 RAISED PAVEMENT MARKER LINES

Raised pavement markers (RPMs) have become increasingly popular over the last few years due to their excellent visibility under nighttime

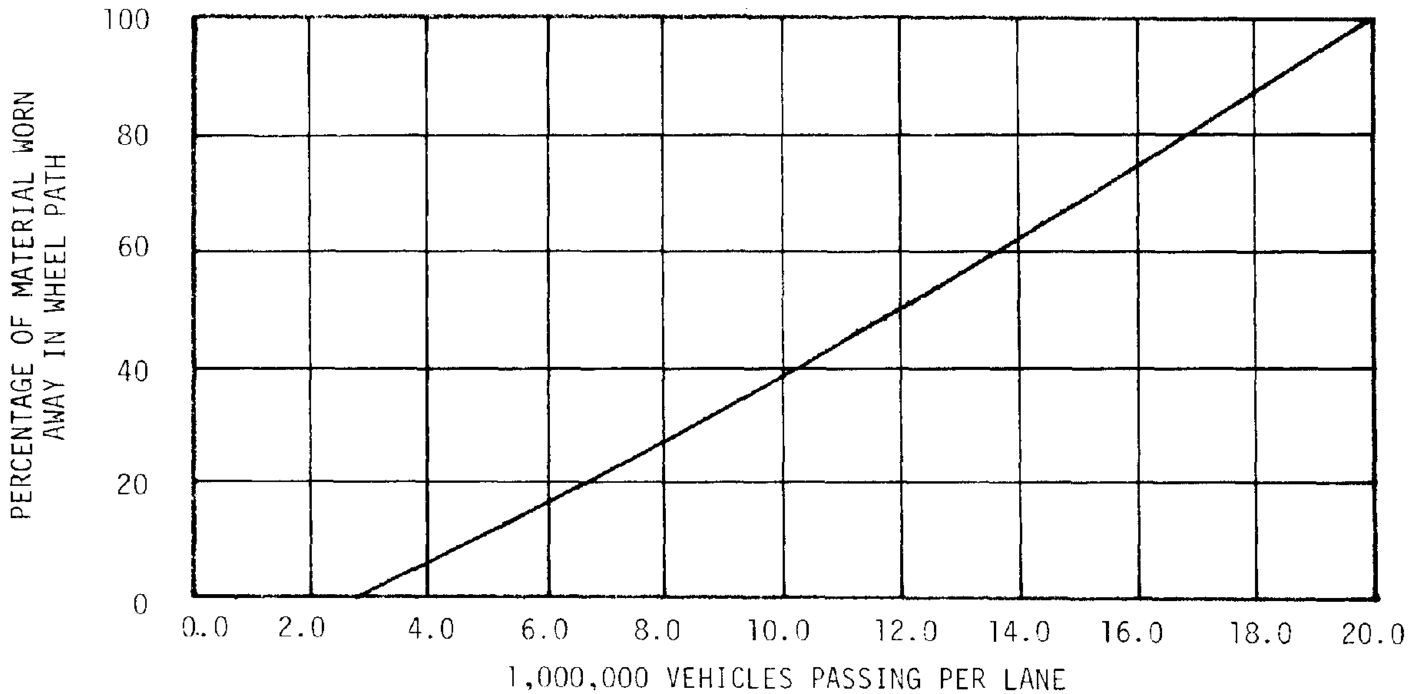


Figure 9. Performance of thermoplastic pavement marking material under traffic flow, District of Columbia, 1965-1975.

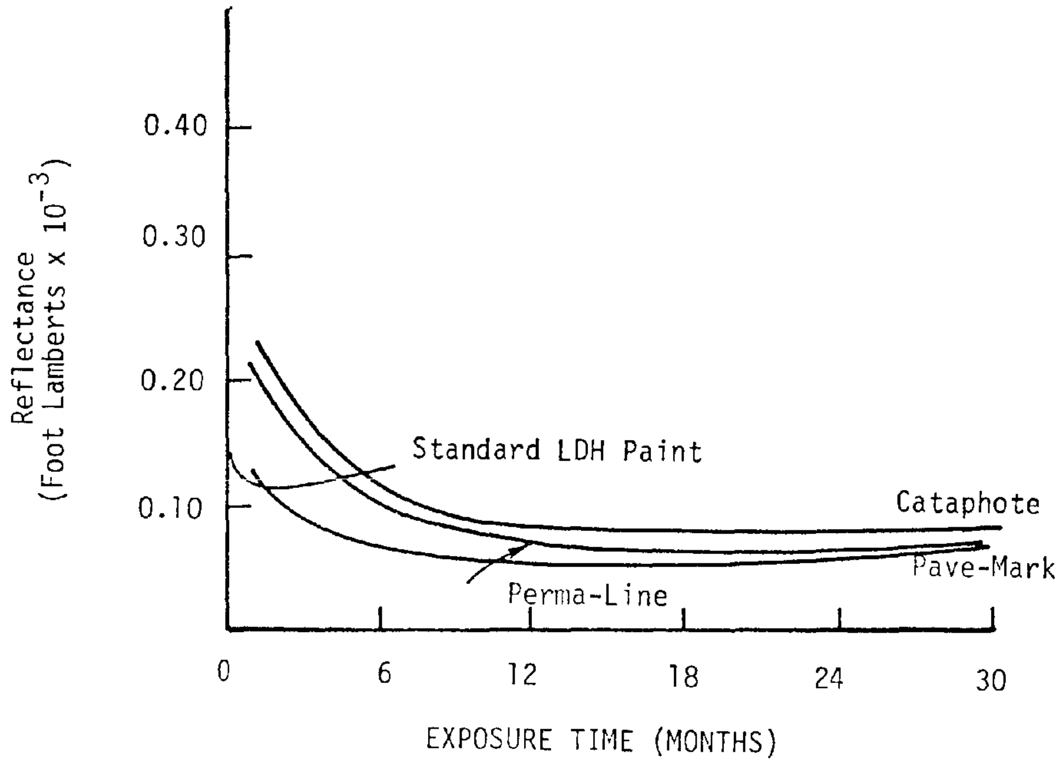


Figure 10. Reflectance as a function of exposure time (Azar, *et al.*, 1975).

and wet pavement conditions. A combination of retro-reflective and ceramic markers have been found to provide excellent visibility at all times and under all weather conditions. Tactile stimulation created by driving over the markers is also believed to aid the driver. The only drawback which appears to be negating its nationwide use is its inability to withstand heavy snowplowing.

Currently various types of markers are used, some for nighttime visibility, others for daytime use and still others are used for regions with substantial snowfall. Raised pavement markers are used both alone and in conjunction with painted lines. A sequence of RPMs can be placed to simulate both a solid and dashed line; and by using colored markers, they can generate yellow as well as white lines. Nighttime visibility is achieved by using retro-reflective markers while for daytime visibility, ceramic markers are more common. For good day and night visibility, a combination of both are used. The State of California, in delineating lanes on its freeways, uses a sequence of four ceramic markers placed 3 feet (.914 m) apart and repeated at every 15 feet (4.57 m) to create a module of 24 feet (7.31 m). Nighttime visibility is provided by placing a retro-reflective marker at every other gap.

Current research in raised pavement markers is directed toward the development of markers which can undergo substantial snowplowing. "Stimsonite 99" and "formed in place" are some of the markers that have been developed primarily for regions with significant snowfall; none, however, have performed to full satisfaction. The use of raised pavement markers in snow belt regions has been very limited.

The discussion contained herein pertains to "cost" and "service life" of raised pavement markers. Wherever possible, an effort is made to specify the marker type and its location.

E.2.1 Cost of Raised Pavement Markers

1. Chaiken[6] reports on the cost of snowplowable markers in a 1969 state-of-the-art review report. The installed cost of these

snowplowable markers (steel casting with two keels which contain a retro-reflector) was estimated to be $4 per marker. Replacement cost of reflective elements was reported to be 25¢ per marker.

Reporting on the economics of formed-in-place markers, Dale observed that the material cost of such markers is $0.11 per marker(19). The cost breakdown is provided in Table 23.

The total cost of these markers, including labor and equipment, is estimated to be $0.31 per marker. This is based on the estimate that a 4-man crew could apply 1,000 markers in an 8-hour day for a maximum labor cost of $0.10 per marker. The additional cost for depreciation, fuel, and other miscellaneous items was estimated to be $0.10 per marker.

To compare the economics of formed-in-place markers with other markers, Dale also reported on the average cost of more commonly used retro-reflective and non-reflective markers. The reported costs broken down by material, labor, etc., are given in Table 24 below:

Table 24. Cost of commercial markers (Dale, 1970).

Cost Item	Cost of Commercial Markers ($)	
	Non-Reflectorized	Reflectorized
Marker Unit	0.25	0.85
Epoxy	0.15	0.15
Labor	0.15	0.15
Depreciation, fuel, etc.	0.10	0.10
Total	0.65	1.25

In a 1972 California Department of Transportation report(17), the installed cost of RPMs was estimated to be $950 per mile (1.609 km). This was based on a pattern of 4 ceramic markers placed 3 feet (.914 m) apart with a gap of 15 feet (4.57 m) giving a module length of 24 feet (7.31 m). At every other gap, a retro-reflective marker is placed.

Table 23. Composition and raw material cost of formed-in-place markers (Dale, 1970).

Wt./ Marker (Gram)	Material	Supplier	Raw Material Cost ($/lb)	Approximate Cost ($/Marker) With	
				Uncoated Beads	Coated Beads
28.0	Epon 828 Resin	Shell Chemical	0.49	0.0302	0.0302
28.0	RCHT Pigment	Titanium Pigment Corp.	0.09	0.0055	0.0055
7.0	Curing Agent U	Shell Chemical	0.80	0.0123	0.0123
7.0	19 0.25 in. beads	Corning Glass	1.25	0.0193	---
	19 0.25 in coated beads	The 3M Co.	3.75*	---	0.0580
70.0				0.0673	0.1060

*Experimental product by The 3M Co. Commercial cost not available from the 3M Co.; estimated by the research agency.

1 lb = .4536 kg.

4. In a 1973 Mississippi State Highway Department report, the cost of RPM lines is provided. This cost is based upon three contracts for the installation of RPMs on various high volume divided highways. The contract cost of RPM lines was estimated to be $240 per mile (1.609 km) when placed at 40 foot (12.19 m) intervals. The cost of ceramic markers was estimated to be $640 per mile (1.609 km) when placed in a pattern of 6 markers placed at 3 foot (.914 m) intervals with a gap of 25 feet (1.62 m). For a pattern of 4 markers, 3 feet (.914 m) apart, with a gap of 15 feet (4.57 m), the same cost was estimated to be $710 per mile (1.609 km).

5. Pigman and Agent[20] report the cost of raised pavement markers installed at five lane drop locations. The total cost of installed markers for all five locations was estimated to be $734 (this gives an average cost per installation of $147). The cost breakdown according to individual cost items is given in Table 25.

Table 25. Cost of installation of RPM at lane drops (Pigman and Agent, 1974).

	Number Used	Unit Price	Total Cost
Ray-O-Lite (regular)	61	1.28	78.08
Ray-O-Lite (replaceable lens)	57	1.00	57.00
Stimsonite	79	1.045	82.56
Permark	63	0.45	28.35
Safety Guide	41	0.60	24.60
Installation Epoxy - 3 gallons - $42.00 Labor - $420.00 Total Cost = $734.00			

1 gallon = 3.785 litres

6. Kentucky reports another study[21] where different types of markers were evaluated with respect to their brightness and durability. Although no estimates are made on labor cost, etc., the unit cost of various markers that were tested was reported and is given in Table 26.

7. Georgia provided the following data on the 1975 average bid price for the installed cost of RPMs:

   - Raised pavement markers (bi-directional) - $3.50/each
   - Raised pavement markers (uni-directional) - $3.50/each.

8. The State of Washington also provided data on average unit bid prices for various RPMs for the first six months of 1975. These average prices are provided separately for the eastern and the western part of the state. Overall average costs are also provided. Yearly averages for 1972-1974 are provided for comparison. These data are reported in Table 27.

9. In California, the initial installation of RPMs is always contracted for by the state. The state only maintains and installs RPMs lost during operation. 1975 contract prices for various types of markers are provided in Table 28. These should be compared against the figure of $1.89 which is the average cost to the state when the markers are installed by the state forces.

Table 26. Cost of raised pavement markers (Kentucky, 1975).

BRAND NAME	COST PER MARKER[a]		
Permark P-15		Nonreflective - $0.22 Monodirectional - $0.50 Bidirectional - $0.705	
Stimsonite and Ray-O-Lite	Quantity	Bidirectional	Monodirectional
	1-99	$1.20	$1.10
	100-499	1.14	1.045
	500-999	1.08	0.99
	1000-4000	1.02	0.935
	5000 or more	0.96	0.88
Little Jewel[b]		Monodirectional - $0.60 Bidirectional - $0.68	
Safety Guide[b]		Monodirectional - $0.75 Bidirectional - $0.90	
PD-50 (3M)	List - $0.673	Quantity	Discount
		200-1600	List
		1800-3200	5%
		3400-4800	10%
		5000 and over	15%

[a]All costs are for markers with silver-white reflective lens systems and white marker base (the 3M marker is an exception) and does not include installation costs.

[b]No definite price list was published.

Table 27. Contract price for raised pavement markers (Washington).

S.No.	Type of RPM	Six Month Average Price for 1975 (dollars)	Average 1974 Price (dollars)	Average 1973 Price (dollars)	Average 1972 Price (dollars)
1	Plastic Traffic Button (white ceramic and plastic marker)				
	East	---	---	7.00	---
	West	5.1000	4.4700	4.5400	4.4500
	All	5.1000	4.4700	4.6100	4.4500
2	Lane Markers (Type #1) (white ceramic and plastic marker)				
	East	---	---	---	---
	West	0.5975	0.8270	0.6059	0.6526
	All	0.5975	0.8270	0.6059	0.6526
3	Lane Markers (Type #2) (retro-reflective marker)				
	East	---	---	---	---
	West	1.9626	2.2303	2.0863	1.9188
	All	1.9626	2.2303	2.0863	1.9188

Table 28. Contract bid prices for raised pavement markers (California).

Marker Type	Quantity	Unit Price (/marker)
White Non-Reflective	61,960	0.9841
Yellow Non-Reflective	29,268	1.1241
Red Clear Reflective	39,234	2.9032
Two-Way Yellow Reflective	67,778	2.7303
One-Way Clear Reflective	22,613	2.7790
One-Way Yellow Reflective	68,287	2.4570

E.2.2 Service Life of Raised Pavement Markers

1. James and Reid[14] report on the service life of "Catseye" markers from the data collected through a survey involving England's 15 counties and 6 cities. The reported results are presented in Table 29.

Table 29. Mean life of catseye reflector pads (James and Reid, 1969).

Type of Road Marking	No of Replies	Mean (months)	Range (months)
Lane-line on a heavily trafficked bituminous road	14	32.5	12-84
Lane-line on a heavily trafficked concrete road	14	32.5	12-84
Lane-line on a lightly trafficked bituminous road	13	44.4	24-84
Lane-line on a lightly trafficked concrete road	13	44.4	24-84
Edgeline on a bituminous road	5	44.4	24-72
Edgeline on a concrete road	5	44.4	24-72

2. Calhoun reports the results of a study where the performance of four brands of raised pavement markers was evaluated[22]. Pertinent observations made are:

- The attachment of the markers to the roadway with a contact adhesive rubber was a failure due to the pumping action of the water between the marker and the roadway.

- The epoxy adhesive performed very well with the plastic markers on asphaltic roadways. All those lost with use were due to failure of the asphaltic roadway. Epoxy did not perform as well on ceramic markers. The failure was due to the loss of the bond between the ceramic and the adhesive.

The study also reports on the percentage loss of different brands with time for different locations of the markers within the roadway. Reported results for Stimsonite markers are given in Figure 11.

3. The State of Mississippi reports on the performance of raised pavement markers when placed on high volume, divided roadways. On portland cement concrete pavements, nearly 95 percent of reflective markers and 80 percent of ceramic markers remained in place after two years of service. Nearly 5 percent of the remaining reflective markers had some damage but were still effective.

On asphaltic pavements, raised pavement markers did not perform as well. Markers were found to fail. The failure was attributed to the impact of traffic and the shearing force which dislodged a portion of the asphalt. The epoxy asphalt bond generally remainted intact.

4. Performance of different brands of markers is reported in a Kentucky study[20]. Different brands of raised pavement markers were installed as a supplement to existing lane lines and edgelines. Periodic inspections were made to assess lines with time. The reported results are given in Figures 12 and 13. Other pertinent remarks are:

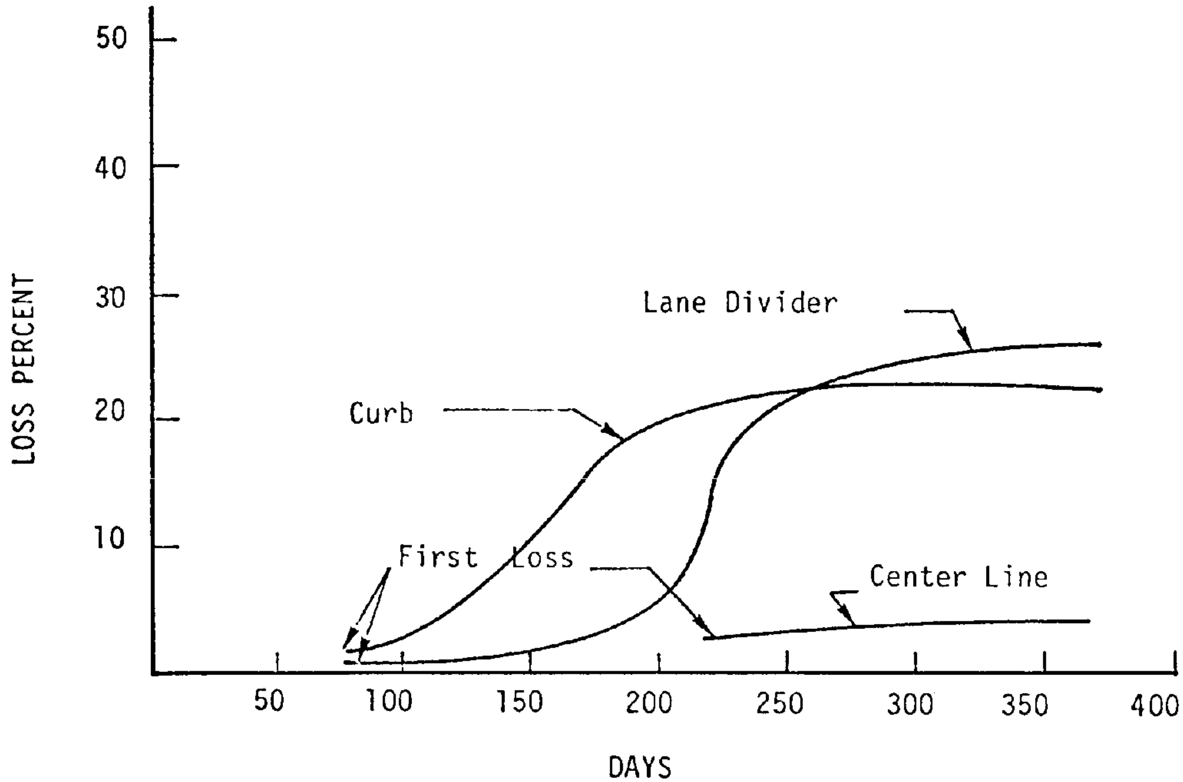


Figure 11. Loss of Stimsonite markers (Calhoun, 1970).

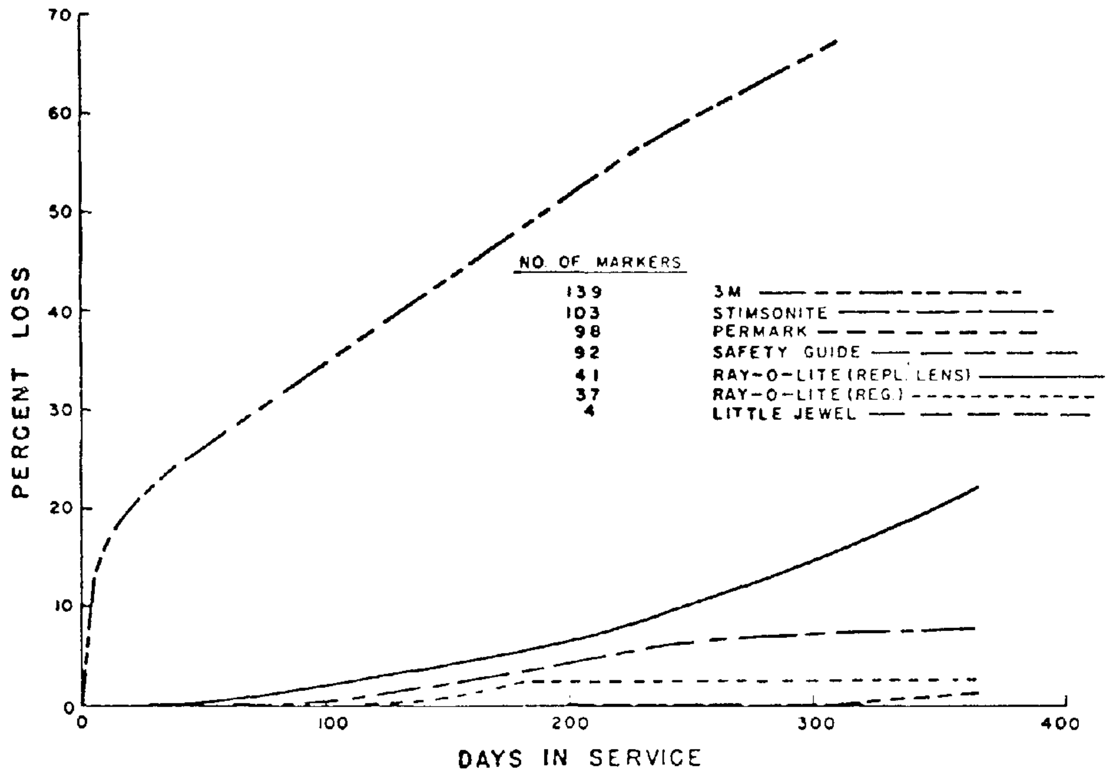


Figure 12. Durability of various markers as supplements to lane lines (Pigman, *et al.*, 1975).

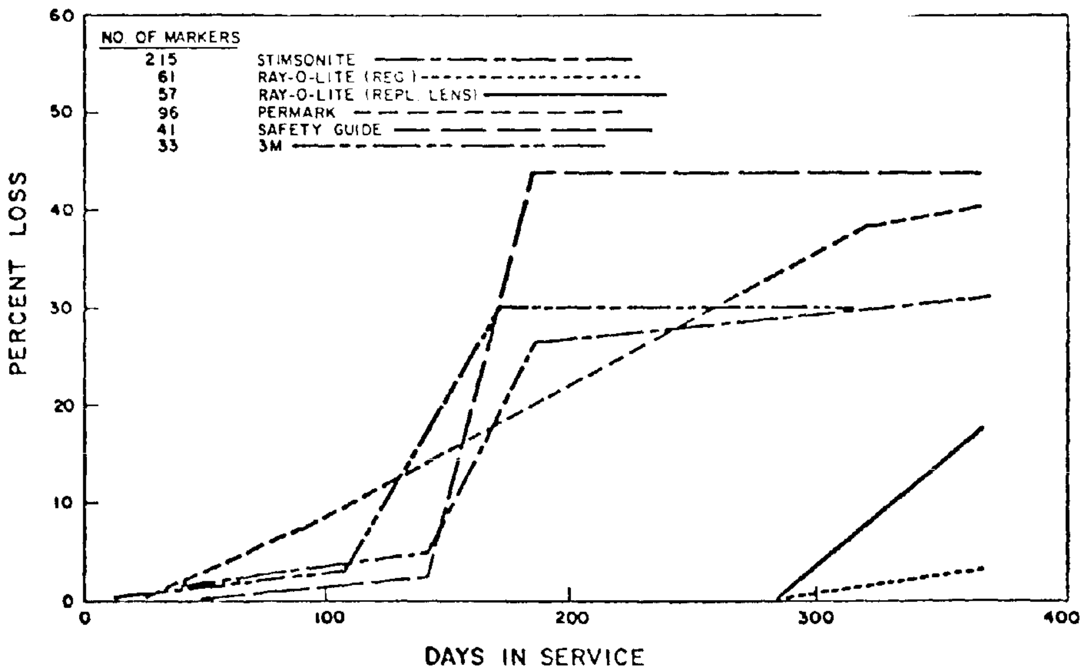


Figure 13. Durability of various markings as edgelines (including snowplow damage) (Pigman, *et al.*, 1975).

- Many of the Stimsonite markers were found to have dislodged from the pavement through asphalt failure.
- There was a substantial loss in markers due to snowplowing operation. Other factors responsible were the high truck volume (high speed trucks were believed to have generated sufficient impact to break some markers) and failure of the adhesive.
- Apart from dislodging from the pavement, the markers were also damaged. This damage was due to chipping the lens and the body and the shearing off of the top of the marker due to snowplowing.

E.3 SUMMARY

It is evident from the treatment cost and service life data reviewed within this appendix that there is a wide variation in the reported data. There are some obvious factors contributing to this variation. For example, the important factors contributing to the variation in the reported treatment installation costs appear to be the differences in the purchase price of the treatments and the different accounting procedures utilized in cost computations. Similarly, the variation in the treatment service life data, in most part, appears to be due to the difference in roadway surface properties, traffic volume and the snowfall conditions of the region.

Despite the fact that a few selected parameters cause variation in the reported data, the reported data are not comprehensive enough to develop valid models for the estimation of treatment installation cost and service life of various delineation treatments. For the purpose of developing general delineation guidelines within this study, ranges of treatment installation cost and service life are estimated. These are reported in Table 30.

Table -30. Ranges of cost and service life data.

Treatments	Costs Range in Dollars/Mile	Service Life Range in Years
Conventional Paint Line	50-100	1-3
Rapid Dry Paint Line	50-100	1-3
Quick Dry Paint Line	50-150	1-3
Thermoplastic Line	1000-3000	1-10
Raised Pavement Marker Line	500-3000	1-10
Post Delineators	50-300	1-10

Note: 1 mile = 1.609 km

E.4 COST ASSOCIATED WITH TRAFFIC INTERRUPTION

Three specific cost items associated with traffic interruption resulting from the installation of roadway delineation treatments are identified as:

(1) Cost of Delay to the Motorist (DC)

(2) Additional Running Cost of Motor Vehicles (ARC)

(3) Cost Associated with Increased Accident Potential (IAC)

A detailed discussion and a procedure to estimate each of the above cost items is given below. Due to the controversy over the inclusion of these costs in cost-benefit calculations, it is recommended that the operating agency make an independent decision whether or not a particular cost item should be included in the analysis.

E.4.1 Cost of Delay to Motorists (DC)

The cost of delay is a significant cost item, particularly when high volume roads are involved. This cost can also substantially vary from treatment to treatment. The cost of delay associated with conventional paint can be shown to be substantially higher than the cost of delay for thermoplastic striping.

The recommended procedure for computing this cost involves computing the cost of delay to both the passenger cars and the commercial vehicles. The total delay cost is then obtained by taking a weighted sum of the two. The weights correspond to the proportion of each vehicle type which comprises the traffic stream. Since the procedure for computing delay cost for passenger cars and commercial vehicles is the same (only the input data are different), only the general procedure is presented.

1. Compute delay to an individual motorist from:

   (a) For longitudinal sections

$$DIM = \left(\frac{1}{V_I} - \frac{1}{V_D}\right) \quad \frac{hr}{mile}$$

(b) For isolated situations

$$DIM = \left(\frac{v_D - v_I}{v_D}\right) \times t \quad \text{(hr)}$$

where

DIM = delay to an individual motorist in hours

v_D = desired speed of the motorist (mph)

v_I = interrupted speed of the motorist (mph)

t = time for which traffic is interrupted in hours

2. Compute total number of vehicles affected

$$TVA = t \times f \times ADT$$

where

TVA = total number of vehicles affected per mile

t = time in hours for which traffic is interrupted per mile of treatment installation or per localized installation

ADT = average daily traffic

f = factor denoting a ratio between the estimated hourly traffic during the treatment installation and the ADT

3. Determine the value of time for individual vehicles, VOT. (Guidelines on value of time are presented later in the section.)

4. The cost of delay of a vehicle type is then given by

$$COD = DIM \times TVA \times VOT$$

where

COD = total cost of delay of a vehicle type

5. The total delay at the site associated with a treatment installation is then computed from

$$DC = f_p \, COD_p + (1-f_p) \, COD_c$$

where

DC = cost of delay

f_p = fraction of the passenger cars

COD_p = total cost of delay associated with passenger cars

COD_c = total cost of delay associated with commercial vehicles

The delay occurs because vehicles have to slow down while traversing the site where delineation is being installed. The total cost depends upon the traffic volume and the value of time associated with the different vehicles. A brief discussion pertaining to some of the important model parameters follows.

E.4.2 Delay to Individual Motorists

Delay to individual motorists depends on the speed reduction caused by the installation operation. Different speed reductions should be assigned to different treatments. For example, a greater speed reduction would be expected for conventional paint striping operations as compared to thermoplastic striping operations due to the slower rate of application of traffic paint and the need for traffic control devices during paint striping.

E.4.3 Total Number of Vehicles Affected

The total number of vehicles affected depends upon the traffic volume during the treatment installation operation and the time required to install the treatment. Since most of the delineation treatment installation is done during off-peak daylight or nighttime hours, the traffic volume during off-peak hours should be considered while estimating the number of vehicles exposed to traffic interruption.

The Highway Capacity Manual contains a description of the manner in which traffic volume varies over a 24-hour period. On the average, nearly 70 to 75 percent of the daily travel occurs in the 12-hour period from 7:00 am to 7:00 pm. Hence, 25 to 30 percent of the ADT is estimated to be uniformly distributed over the 12-hour non-peak period during which the treatments are generally installed. The hourly traffic volume during these non-peak hours is, therefore, 2 to 2.5 percent of the total ADT. These are the recommended values for parameter f.

The time to install treatments, t, also varies from treatment-to-treatment. For example, Chaiken assumed that it takes an hour to stripe one mile of highway with conventional paint. This time included drying time and time to place and remove traffic control devices to protect fresh paint from the traffic. For thermoplastic and quick-dry paints, this time can be assumed to be as little as 4 minutes, based upon the fact that some machines can stripe at a rate of 15 mph and the striping does not require any special traffic control devices.

E.4.4 Value of Travel Time (VOT)

The value of travel time is a complex issue, although its definition is straightforward. It is generally accepted that what the traveler will pay to reduce travel time can be taken as the value of the travel time. The complexity pertains to the method by which the price of the traveler's willingness to pay is determined.

The value of travel time is different for passenger cars and commercial vehicles and, therefore, separate guidelines are provided for each.

1. The Value of Passenger Car Travel Time.

   Winfrey[(23)] identifies the following factors as affecting the value of passenger car travel time.

- Persons in automobile - Ages, number, occupations, wage earnings, whether paid during time to travel.
- The trip - Distance, number of stops, purpose (business, pleasure, etc.), regularity and frequency, total travel time, who pays the cost of the trip.
- Environmental - Day of the week, hour of day, season of year, local land use, legal speed limit, rural or urban area, speed of travel, traffic volume and composition, type and design of highway.
- Factors of value - Activity just before starting trip, activity at end of the trip, amount of time available consecutively, amount of total time (hours, minutes), hour of the day that the trip begins and ends, place that time may be utilized, productive time (work output), reliability of the required travel time each trip, utilization of the travel time decrease, value of "do-it-yourself" work, value of "time delayed" when delayed, value of leisure time, wages and earnings.

The simplest procedure to compute the value of passenger time would be to start with the federal minimum wage of $2.65 per hour and multiply it by 0.75; this is based upon the fact that some passengers are unemployed. A more complex and accurate method would be to estimate the passenger's willingness to pay to reduce his travel time. Several studies based upon this method have been reported. The value of travel times estimated in these studies varies. Winfrey[23], in summarizing some of these studies, notes that a reasonable value appears to lie within a range of $1.00 to $4.00 per car-hour depending upon the prevailing local factors. These figures were recommended in 1967-69. For this study, any value between $1.00 to $6.00 would be appropriate if relevant factors were properly evaluated before arriving at a figure.

2. Value of Commercial Vehicle Travel Time.

The value of travel time of commercial transport vehicles, in general, can be assumed to be equivalent to the wage rate of the vehicle driver. However, this assumption ignores the value of commercial vehicles and the investment in these vehicles whose return depends upon the travel time. Winfrey[(23)] reports on a study where the value of vehicles was included in the computations. The dollar value per hour of travel time for a composite commercial vehicle, stratified by geographic regions, as reported in this 1965 study, is presented below and if necessary, can be used.

Table 31. Value of travel time ($/hr) of a composite commercial vehicle.

New England	Middle Atlantic	Southern	Central	North-western	Mid-western	South-western	Rocky Mountain	Pacific
4.86	5.16	5.45	5.39	6.11	5.62	6.56	5.16	5.75

E.4.5 Additional Running Cost of Motor Vehicles (ARC)

In addition to the delay that results from traffic interruption, it has been found that the traffic interruption can also substantially increase the running cost of the affected vehicles. The studies have shown that the running cost of motor vehicles, which includes such items as fuel cost and tire wear cost, can substantially increase with the cyclic changes in vehicle speed. The installation of some of the delineation treatments can cause enough disruption in traffic, and, therefore, enough cyclic changes in vehicle speeds to increase the running cost of vehicles by a substantial amount.

The additional running cost of motor vehicles is computed from the data reported by Winfrey. Based upon the analysis of these data, Winfrey reports on the increase in motor vehicle running cost as a function of 1000 speed change cycles for various initial speeds and various vehicle types. These data are presented in Table 32. This increase in vehicle cost is for the following five vehicle types:

(1) 4,000 lb passenger car

(2) 5,000 lb commercial vehicle

(3) 12,000 lb single unit truck

(4) 40,000 lb gasoline powered tractor-semitrailer combination four axle

(5) 50,000 lb diesel powered tractor-semitrailer combination five axle.

Utilizing the data presented in Table 32, the additional running cost of a motor vehicle can be computed as follows:

- For each of the vehicle types listed above, assume the desired speed v_D, interrupted speed v_I and the number of speed change cycles W (v_D, v_I) before the vehicle clears the installation site.

- For the chosen v_D, v_I and W (v_D, v_I), compute the additional running cost from Table 32. Hence, for 4,000 lb passenger cars, and for v_D = 55, v_I = 35. For W=20, the additional running cost would be $0.3636 ($18.18 x 20/1000). Let this cost be denoted by ARCIU.

- Update the ARCIU for the current fuel and oil prices. Table 31 was generated for the fuel, oil and tire prices given in the following table.

Table 33. Unit prices used in calculating the running-cost table.

	4-kip Passenger Car	5-kip Commercial Delivery	12-kip Single Unit Truck	2-S2 Gasoline	50-kip 3-S2 Diesel
Fuel, cents per gallon	23	22	20	18	16
Engine oil, cents per quart	60	55	40	20	20
Tires, cents per 0.001 in. of tread wear per tire	8.712	9.846	13.235	15.658	15.658

Table 32. Dollars excess cost* of speed-change cycles**--
excess cost above continuing at initial speed.

Vehicle 4-kip passenger car
Unit: Dollars per 1,000 cycles

Roadway surface: High type pavement in good condition

	Initial Speed	Speed Reduced to and Returned from, mph															
	mph	Stop	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
4,000 Lb. Passenger Car	5	0.86															
	10	1.34	0.94														
	16	3.26	2.15	1.17													
	20	4.35	3.81	2.66	1.44												
	25	6.96	5.80	4.62	3.28	1.79											
	30	9.36	8.19	6.98	5.61	4.02	2.19										
	35	12.24	11.05	9.83	8.43	5.84	4.94	2.70									
	40	15.76	14.55	13.31	11.87	10.26	8.35	6.12	3.33								
	45	19.99	18.78	17.50	16.05	14.40	12.46	10.25	7.39	4.05							
	50	25.15	23.89	22.60	21.09	19.40	17.40	15.19	12.31	8.94	4.89						
	55	31.43	30.11	28.76	27.23	25.45	23.36	21.06	18.18	14.78	10.69	5.83					
	60	39.09	37.66	36.18	34.54	32.69	30.55	28.06	25.13	21.68	17.59	12.70	6.94				
	65	48.48	46.87	45.27	43.47	41.16	39.19	36.56	33.55	29.99	25.80	20.88	15.09	8.26			
	70	59.91	58.06	56.17	54.13	51.90	49.40	46.60	43.41	39.70	35.39	30.36	24.53	17.72	9.73		
	75	73.81	71.65	69.21	66.46	63.38	60.08	56.51	52.64	48.50	44.11	39.23	33.31	27.61	20.37	11.63	
	80	90.30	87.28	84.21	80.69	77.12	73.18	69.30	65.02	60.53	55.72	50.56	44.92	38.74	31.81	23.72	13.72
5,000 Lb. Commercial Vehicle	5	1.00															
	10	2.17	1.11														
	15	3.70	2.58	1.39													
	20	5.64	4.42	3.17	1.71												
	25	8.00	6.71	5.38	3.86	2.09											
	30	10.86	9.49	8.10	6.51	4.63	2.52										
	35	14.33	12.89	11.43	9.77	7.87	5.68	3.07									
	40	18.55	17.02	15.51	13.78	11.80	9.52	6.85	3.74								
	45	23.62	22.01	20.40	18.60	16.55	14.20	11.48	8.29	4.50							
	50	29.67	27.98	26.29	24.39	22.27	19.83	17.04	13.76	9.90	5.37						
	55	36.80	35.01	33.23	31.23	29.02	26.50	23.58	20.25	16.32	11.69	6.30					
	60	45.19	43.29	41.41	39.32	36.99	34.34	31.33	27.89	23.86	19.18	13.69	7.38				
	65	55.00	53.02	51.05	48.82	46.30	43.64	40.50	36.94	32.78	27.98	22.41	15.94	8.58			
	70	66.40	64.30	62.19	59.83	57.27	54.39	51.08	47.41	43.11	35.23	32.50	25.26	18.41	11.22		
12,000 Lb. Single Unit Vehicle	5	1.92															
	10	4.73	2.32														
	15	8.30	5.54	2.95													
	20	12.57	9.70	6.90	3.67												
	25	17.65	14.71	11.78	8.46	4.55											
	30	23.76	20.76	17.71	14.29	10.30	5.57										
	35	31.07	27.98	24.88	21.36	17.32	12.51	6.83									
	40	39.92	36.75	33.58	29.96	25.82	26.26	15.17	8.32								
	45	50.49	47.25	43.96	40.28	36.06	31.12	25.29	18.37	10.04							
	50	63.11	59.82	56.44	52.65	48.30	43.27	37.34	30.33	21.97	11.98						
	55	78.00	74.66	71.14	67.27	62.82	57.67	51.61	44.52	36.07	26.00	14.04					
	60	95.45	92.01	88.46	84.47	79.92	74.66	68.51	61.28	52.71	42.56	30.54	16.49				
	65	115.79	112.23	108.71	104.52	99.96	94.58	88.31	80.98	72.27	61.99	49.87	35.71				
40,000 Lb. Gasoline Tractor Trailer	5	7.36															
	10	15.80	8.48														
	15	26.88	19.42	11.08													
	20	41.06	33.22	28.43	14.07												
	25	58.85	50.70	42.19	31.47	17.57											
	30	80.92	72.59	63.69	52.77	38.94	21.63										
	35	107.94	99.54	90.50	79.27	65.22	47.84	26.42									
	40	141.08	132.56	123.41	111.84	97.60	80.05	58.57	32.20								
	45	181.23	172.52	63.14	151.47	137.04	119.29	97.58	71.14	38.62							
	50	229.62	220.76	211.17	199.27	184.58	166.65	144.75	118.16	85.71	46.52						
	55	287.13	278.09	268.26	256.12	241.24	223.04	200.87	173.93	141.18	101.78	54.80					
	60	355.49	346.16	336.07	323.65	308.37	289.76	267.05	239.57	206.35	166.56	119.50	64.45				
50,000 Lb. Diesel Tractor Semi-Trailer	5	9.08															
	10	21.00	10.03														
	15	34.50	23.91	13.14													
	20	52.51	41.64	35.27	16.83												
	25	74.75	63.71	52.30	38.35	21.26											
	30	102.21	90.96	79.37	65.07	47.92	26.61										
	35	136.05	124.55	112.67	98.29	80.85	59.46	33.03									
	40	178.00	166.14	154.19	139.28	121.56	100.04	73.60	40.99								
	45	229.46	217.31	204.75	189.71	171.64	149.80	123.16	90.57	50.25							
	50	292.31	279.81	266.88	251.45	232.33	210.64	183.58	150.68	110.26	60.91						
	55	368.52	355.53	342.04	326.05	306.91	283.92	256.20	222.67	191.69	132.28	72.45					
	60	462.48	448.35	433.25	416.54	396.26	372.26	343.57	309.11	267.42	217.78	165.57	85.65				

*Cost includes fuel, tires, engine oil and depreciation
**A speed-change cycle is reducing speed from and returning to an initial speed.

The cost of fuel in this table does not include the state and federal fuel tax which was about 11¢ per gallon total. To compute the running cost of an individual vehicle RCI from the ARCIU, the following formula is recommended:

$$ARCI = \frac{(P_f \times .82 + P_0 \times .07 + P_t \times .11)}{(P_{f0} \times .82 + P_{00} \times .07 + P_{t0} \times .11)} \times ARCIU$$

where

P_f = current fuel price excluding state and federal motor fuel tax, cents per gallon

P_0 = current oil price including local sales tax, cents per quart

P_t = current tire price in cents per .001 inch of tread wear

The P_{f0}, P_{00}, P_{t0} are the corresponding prices in Table 33.

The above procedure for updating the running cost is based upon the assumption that the relative cost of fuel, oil and tires in the vehicle running cost is in the ratio of .82: .07: .11. This ratio is computed from Table 13.5 in Reference 23.

The total running cost of motor vehicles, ARC, is then computed from

$$ARC = \left(\sum_i f_i \cdot ARCI_i \;.\; TVA\right)$$

where

TVA = Total number of vehicles affected per mile

f_i = fraction of vehicles of type i, i = 1,2,...5

$ARCI_i$ = running cost of a vehicle of type i, i = 1,2...5

and $f_1 + f_2 + f_3 + f_4 + f_5 = 1$

E.4.6 Cost of Increased Accident Potential (IAC)

This is perhaps the single most important item of the traffic interruption cost. In response to an inquiry, a CALTRANS engineer noted that the safety of the maintenance crew responsible for treatment installation is an important, and sometimes overriding, consideration in the delineation application decision-making process. It was noted that an important consideration in the state's decision to discontinue the use of paint stripes on its freeway system in favor of raised pavement marker lines was crew safety. RPMs, due to their longer life, require less overall crew exposure to traffic and were therefore considered better from the safety standpoint.

The approach suggested is based upon the hypothesis that the true measure of maintenance-related accidents is the number of vehicles exposed to maintenance-caused disruption. This hypothesis would be justified if it is assumed that the accident occurrence is a purely random phenomenon -- not an altogether unrealistic assumption. A discussion with CALTRANS engineers has indicated that in California, most of the accidents involving maintenance crews have been freak accidents, in that a vehicle, for no apparent reason, ran over the crew.

The model proposed to compute cost of increased accident potential is

$$IAC = C \cdot TVA$$

where

IAC = cost of increased accident potential

TVA = total number of vehicles affected per mile

C = a constant in dollars per vehicle.

An added advantage of this methodology is that by assigning different values to C, the contribution of this cost item in overall cost calculations can be adjusted.

Utilizing the calculation procedures discussed above, the total traffic interruption cost (TIC) is then given by

Traffic Interruption Cost = Cost of Delay (DC) +
Additional Running Cost (ARC) +
Increased Accident Potential Cost (IAC)

or

$$TIC = DC + ARC + IAC$$

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