Wayne State University

COLLEGE OF ENGINEERING

COST-EFFECTIVENESS PAVEMENT MARKINGS

by

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NOTICE

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16. Abstract

The objective of this study was to develop a software using DBASE III Plus for pavement marking management information system. Six data bases were developed as a part of this effort to store marking and cost-related information. A software named Pavement Marking Management Information System (PM-MIS) was also designed with the following capabilities:

- Data entry
- Editing
- Updating
- Deleting
- Long-term budgeting
- Cost-effectiveness analysis

Furthermore, a literature search was conducted and guidelines for various marking material use, as practiced by various agencies, were identified.

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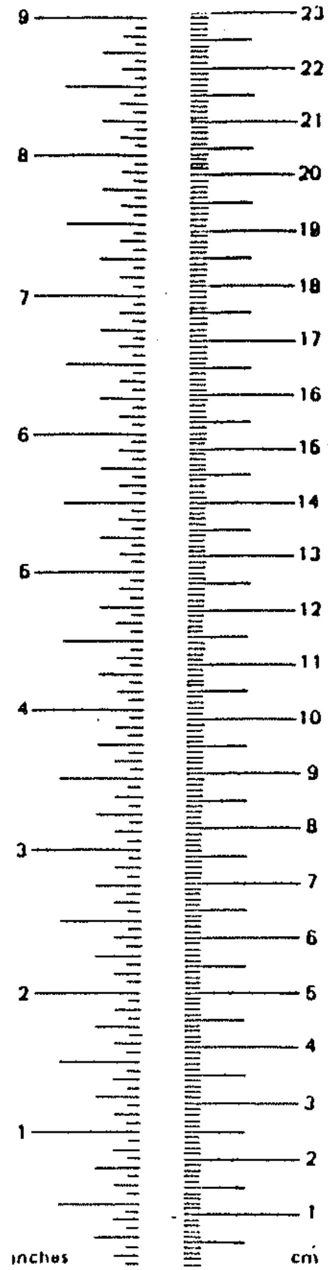
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weights and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

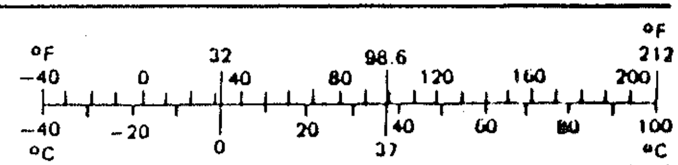


Table of Contents

List of Figures

List of Tables

Introduction

In 1986, the Michigan Department of Transportation (MDOT) retained the services of Wayne State University to develop a software for a pavement marking management information system. The primary activities of this contract consisted of: 1) establishing system requirements, 2) designing system and developing software, 3) providing system training and documentation, and 4) developing guidelines for pavement marking material use.

Establishing System Requirements: A meeting was conducted between the Contractor and Michigan Department of Transportation personnel at Wayne State University, Detroit. The Contractor demonstrated the proposed software and obtained comments from MDOT personnel on the required data elements and report format. This information was later used to design the software.

Designing System and Developing Software: A software called "Pavement Marking Management Information System (PM-MIS)" was designed as a part of this activity. PM-MIS consists of three subsystems to represent three types of marking configurations, namely:

- Lane/Edgeline Subsystem (LES)
- Special Marking Subsystem (SMS)
- Ramp Lane/Edgeline Subsystem (RES)

Each subsystem is equipped with auxiliary programs designed to add, modify and extract data items. It is designed for use on IBM-XT (or compatible) microcomputer and structured with DBASE III Plus file management system.

Each subsystem consists of two data files, totaling six data files for the three subsystems. File number one (PAVMARK.DBF, SPECMARK.DBF, RAMP.DBF) stores marking-related information, i.e., PAVMARK.DBF stores Lane/Edgeline information, SPECMARK.DBF stores Special Marking information, and RAMP.DBF stores Ramp Lane/Edgeline information. File number two stores cost information related to each marking type. Data elements of each subsystem are presented in Tables 1, 2, 3, 4, 5 and 6.

Table 1. Description of the Lane/Edgeline Subsystem Data Item

Column Heading	Data Type	Data Limitation	Description
District	Alpha-Numeric	None	The name of maintenance district.
County	Alpha	None	The name of the county.
Route	Alpha-Numeric	2 Alpha, 3 Numeric & 2 Alpha	The name of the route (such as US-23).
Alt #1 (sometimes a road segment has more than one name)	Alpha-Numeric	2 Alpha, 3 Numeric & 2 Alpha	The first alternate name of the route, if any.
Alt #2 (sometimes a road segment has more than one name)	Alpha-Numeric	2 Alpha, 3 Numeric & 2 Alpha	The second alternate name of the route, if any.
Control Section	Alpha	None	An unique number assigned to a road segment by MDOT.
Segment Description	Alpha	None	A brief description of the road segment.
Milepoint	Numeric	No Alpha	Digit 1 - begining of section. Digit 8 - end of section.
Traffic Direction	Numeric	No Alpha	Roadway configuration (such as 2-way, 1-way).
Number of Lanes	Numeric	No Alpha	Total number of lanes.
Marking Width	Numeric	No Alpha	Width of the marking in inches.
Center Lane Left Turn Option	Alpha	Y/N	Provision of left turn center lane.

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

SUBJECT Basic Properties of Pavement Components	FHWA NOTICE

September 29, 1972

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Pavement design requires that an engineer analyze pavement structures in terms of parameters which permit realistic estimates of performance. This investigation has attempted to define some of these parameters; namely, (1) those properties of saturated granular materials which contribute to deflections of asphalt pavements under moving traffic, and (2) those factors influencing the ultimate properties of asphalt concrete mixtures in tension. Because of the dissimilar nature of these two objectives of the investigation, the report is divided into two parts.

Some of the more important findings of Part I were as follows: (1) Water content, while causing a reduction in modulus as it was increased, did not cause a marked reduction in stiffness when the material was saturated. That is, liquefaction under repetitive loading was not obtained and pore water pressures were observed to be relatively small. (2) One laboratory specimen can be used to assess the resilient response of saturated granular materials over a range in both axial and radial stresses. Reasonable estimates of resilient response for a particular stress state can be determined after 50 to 100 repetitions of stress. (3) Resilient Poisson's ratio is dependent on stress, varying from 0.25 at low principal stress ratios to values greater than 0.50 at high principal stress ratios. In addition, Poisson's ratio is dependent on water content; however, this ratio exhibits less tendency to increase in value with principal stress ratio as the water content of the aggregate is increased.

From the results of Part II it may be concluded that the ultimate tensile strength and strain of asphalt mixtures can be estimated from the stiffness of the asphalt contained in the mixture. This procedure requires that the tensile strength of the asphalt concrete be measured at one specific temperature and time of loading. It would appear that this procedure is applicable to an asphalt stiffness of about 7500 psi.

Results of an analysis of the fracture and fatigue data indicate that tensile fracture data obtained for asphalt mixes tested at temperatures less than 70°F can be used to estimate the fatigue response of asphalt concrete using crack-growth models developed for other materials. Thus

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it seems possible to predict the fatigue response of asphalt mixtures from fracture tests which are short-term rather than the necessarily long-term fatigue tests. Moreover, such an approach provides a quantitative description of the fatigue process and from a practical standpoint has the potential to predict the extent of cracking in a pavement rather than only the onset, as is done with current procedures. It was emphasized, however, that quantitation of the method requires additional experimentation.

Ultimate strength analyses of bituminous surfacings were carried out for typical problems including a pavement containing cement-treated base and a runway pavement section subjected to braking tractions. A plane stress finite element analysis was used with incremental load application and nonlinear material properties. In each case the pavement section was loaded to failure and the sequence of cracking outlined. The analyses indicated the importance of the boundary conditions and materials properties including bond slip at interfaces, in the mode and sequence of failure of the loaded system.

The report constitutes the results of a 3-year contract with the University of California at Berkeley and the FHWA's Office of Research. Parts I and II are condensed versions of doctoral dissertations by Mr. R. G. Hicks and Mr. Y. M. Salam, respectively, which were conducted under the direction of Professor C. L. Monismith. Both parts represent the efforts of well-conducted and well-documented research studies.

Distributed with this Notice are sufficient copies of the report to provide a minimum of one copy to each regional office, one copy to each division office, and two copies to each State highway department. Direct distribution is being made to the division offices. Additional copies are available at the National Technical Information Service, Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22151. A small charge will be imposed for each copy ordered from NTIS.

Charles F. Scheffey
Charles F. Scheffey
Director of Research

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(under separate cover)**

Table 1. Description of the Lane/Edgeline Subsystem Data Item (Continued)

Column Heading	Data Type	Data Limitation	Description
Estimate Quantity in Feet	Numeric	No Alpha	This represents the quantity in LFT of marking by type, such as: Solid white - Broken white - Solid yellow - Broken yellow -
Road Surface	Alpha	(B,C,L,R)	The roadway material (such as bituminous, concrete, etc.).
Material	Alpha	No Numeric	The marking material (such as fast dry, polyester, etc.).
Product Brand	Alpha-numeric	None	Brand of the marking material is divided into two broad categories based on color: White - Yellow - A typical brand could be 3M, etc.
Contract Number	Numeric and Alpha	5 Numeric 1 Alpha	The contract number assigned to a particular painting job.
Date	Date	-	Date variable consists of only two segments; month and year of marking.
Cycle	Numeric	No Alpha	When information on a road segment marking is entered into the system, the system sets cycle to 1. However, when the same section of the roadway is repainted, the system sets cycle to (current year - previous year of painting).

Table 2. Description of the Lane/Edgeline Subsystem Contractor Information File

Column Heading	Data Type	Data Limitation	Description
Contractor Name	Alpha-Numeric	None	The name of the contractor.
Federal Project Number	Alpha-Numeric	5 Numeric & 1 Alpha	The federal project number relate to a specific contract.
Unit Cost	Numeric	No Alpha	This variable provides the cost/LFT information regarding the yellow paint and white paint.
Mobilization Cost	Numeric	No Alpha	This represents the cost of mobilization.
Minor Traffic Cost	Numeric	No Alpha	This represents the cost related to temporary traffic barricading, etc. while marking the roadway.

Table 3. Description of the Special Marking Subsystem Data Item

Column Heading	Data Type	Data Limitation	Description
District	Alpha-Numeric	None	The name of maintenance district.
County	Alpha	None	The name of the county.
Route	Alpha-Numeric	2 Alpha, 3 Numeric & 2 Alpha	The name of the route (such as US-23).
Alt #1 (sometimes a road segment has more than one name)	Alpha-Numeric	2 Alpha, 3 Numeric & 2 Alpha	The first alternate name of the route, if any.
Alt #2 (sometimes a road segment has more than one name)	Alpha-Numeric	2 Alpha, 3 Numeric & 2 Alpha	The second alternate name of the route, if any.
Federal AID System	Alpha	No Numeric	A special code for the federally funded projects.
Control Section	Alpha	None	An unique number assigned to a road segment by MDOT.
City of Township	Alpha	No Numeric	The name of the city or township.
Cross Street or Railroad Crossing	Alpha-Numeric	None	The name of the nearest cross street or rail-road crossing.
Surface	Alpha	None	The name of the roadway surface material (such as bituminous, concrete, etc.).
Geometry	Numeric	No Alpha	This represents the roadway configuration (such as 2-way, 1-way).

Table 3. Description of the Special Marking Subsystem Data Item (Continued)

Column Heading	Data Type	Data Limitation	Description
Number of Lanes	Numeric	No Alpha	This represents the number of lanes.
Intersection Leg	Alpha	No Numeric	This represents the compass direction of the intersection leg (such as N for North, S for South, etc.).
Affected Lane	Alpha-Numeric	1 Numeric & 1 Alpha	This represents the number and the type of lane affected by the special marking.
Distance from Cross Street	Numeric	No Alpha	Distance of the special marking from the nearest cross street.
Marking Type	Alpha	No Numeric	This represents the type of special marking (such as S for School, LTO for left turn only, etc.).
Contract Number	Alpha-Numeric	5 Numeric & 1 Alpha	The contract number assigned to a particular job.
Quantity (Each)	Numeric	No Alpha	The number of special markings.
Quantity (Linear Ft)	Numeric	No Alpha	The amount of marking in LFT.
Milepoint	Numeric	No Alpha	This represents the reference point of a marking.
Cycle	Numeric	No Alpha	When information on a road segment marking is entered into the system, the system sets cycle to 1. However, when the same section of the roadway is repainted, the system sets cycle to (current year - previous year of painting).

Table 4. Description of the Special Marking Contractor Information File

Column Heading	Data Type	Data Limitation	Description
Contractor Name	Alpha-Numeric	None	The name of the contractor.
Job Number	Alpha-Numeric	5 Numeric & 1 Alpha	The job number related to a specific contract.
Material	Alpha	No Numeric	The marking material (such as fast dry, polyester, etc.).
Product Brand	Alpha-Numeric	None	Brand of the marking material is divided into two brand categories based on color: White - Yellow -
Unit Cost (Each)	Numeric	No Alpha	Cost of marking by number.
Unit Cost (Linear Ft)	Numeric	No Alpha	Cost of marking by LFT.

Table 5. Description of the Ramp Lane/Edgeline Subsystem Data Item

Column Heading	Data Type	Data Limitation	Description
District	Alpha-Numeric	None	The name of maintenance district.
Date	Date	No Alpha	The date of installation (month/year).
Federal AID System	Alpha	No Numeric	A special code for the federally funded projects.
County	Alpha	None	The name of the county.
Route	Alpha-Numeric	2 Alpha, 3 Numeric & 2 Alpha	The name of the route (such as US-23).
Alt #1 (sometimes a road segment has more than one name)	Alpha-Numeric	2 Alpha, 3 Numeric & 2 Alpha	The first alternate name of the route, if any.
Alt #2 (sometimes a road segment has more than one name)	Alpha-Numeric	2 Alpha, 3 Numeric & 2 Alpha	The second alternate name of the route, if any.
Control Section	Alpha	None	An unique number assigned to a road segment by MDOT.
Location Description	Alpha	None	A brief description of the road segment.
Name of Exit	Alpha-Numeric	None	The name of the exit (such as 123A, 14A, etc.)
Number of Ramps	Numeric	No Alpha	The number of ramps (entrance and exit) at a particular location.
Interchange Number	Numeric	No Alpha	The number of the nearest interchange.

Table 5. Description of the Ramp Lane/Edgeline Subsystem Data Item (Continued)

Column Heading	Data Type	Data Limitation	Description
Material	Alpha	No Numeric	The marking material (such as fast dry, polyester, etc.).
Estimated Quantity (Ft)	Numeric	No Alpha	This represents the quantity in LFT of marking by type, such as: 4 in white 6 in white 6 in yellow 12 in white 4 in white thermoplastic
Product Brand	Alpha-Numeric	None	Brand of marking material is divided into two brand categories based on color: White Yellow A typical brand could be 3M.
Contract Number	Alpha-Numeric	5 Numeric & 1 Alpha	The contract number assigned to a particular job.
Cycle	Numeric	No Alpha	When information on a road segment marking is entered into the system, the system sets cycle to 1. However, when the same section of the roadway is repainted, the system sets cycle to (current year - previous year of painting).

Table 6. Description of the Ramp Lane/Edgeline Subsystem Contractor Information File

Column Heading	Data Type	Data Limitation	Description
Contractor Name	Alpha-Numeric	None	The name of the contractor.
Job Number	Alpha-Numeric	5 Numeric & 1 Alpha	The job number relate to a specific contract.
Unit Cost	Numeric	No Alpha	Unit cost of four marking types are stored in this regard, namely: 4 in white 6 in white 6 in yellow 12 in white 4 in white thermoplastic
Mobilization Cost	Numeric	No Alpha	This represents the cost of mobilization.
Minor Traffic Cost	Numeric	No Alpha	This represents the cost related to temporary traffic barricading, etc. while marking the roadway.

Providing System Training and Documentation: PM-MIS software, along with source code, were delivered to Michigan Department of Transportation and training was conducted in Lansing. The training consisted of providing MDOT personnel with hands-on experience in generating various system output and overall system familiarization. A user's guide was also developed as a part of this project to provide continued guidance to MDOT personnel.

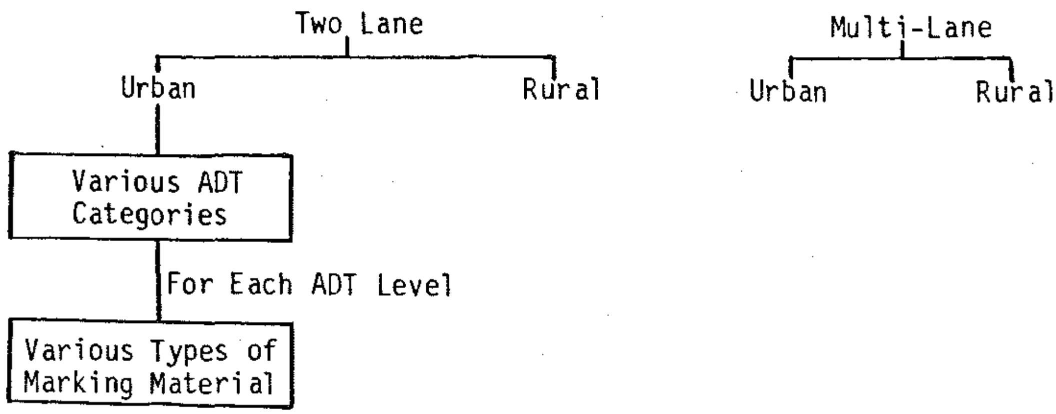
Developing Guidelines for Pavement Marking Material Use:

General Guidelines

Selection of various pavement marking materials should be based on their performance under various traffic and environmental conditions in addition to their relative cost. Determination of the service life of various marking materials should be done either by testing markings under real-life situations or MDOT should attempt to use other research results as a criteria for replacement of pavement markings. The following factors should be used for developing criteria for marking replacement:

- Traffic volume
- Snowfall
- Salting rate
- Type of roadway
- Others

The dependent variable will be the average marking life. So, MDOT needs to develop a set of service life curves for determining the productive life of various types of pavement markings. A typical stratification to be used is presented below.



Figures 1 and 2 represent some examples of service life curves for various materials. Please note that curves presented in figures 1 and 2 should be developed either by extensive research or adopted from the other available sources.

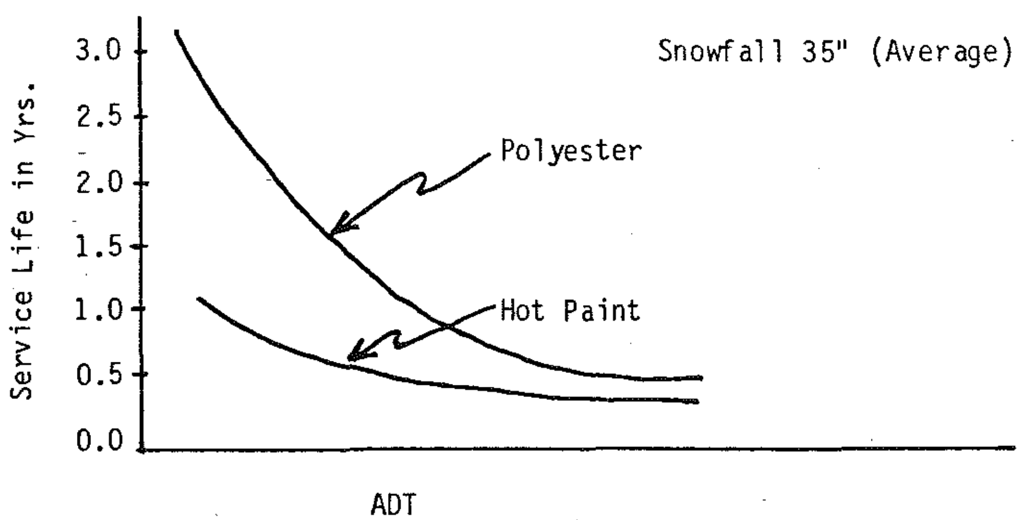


Figure 1. Service life curves for 35" snowfall.

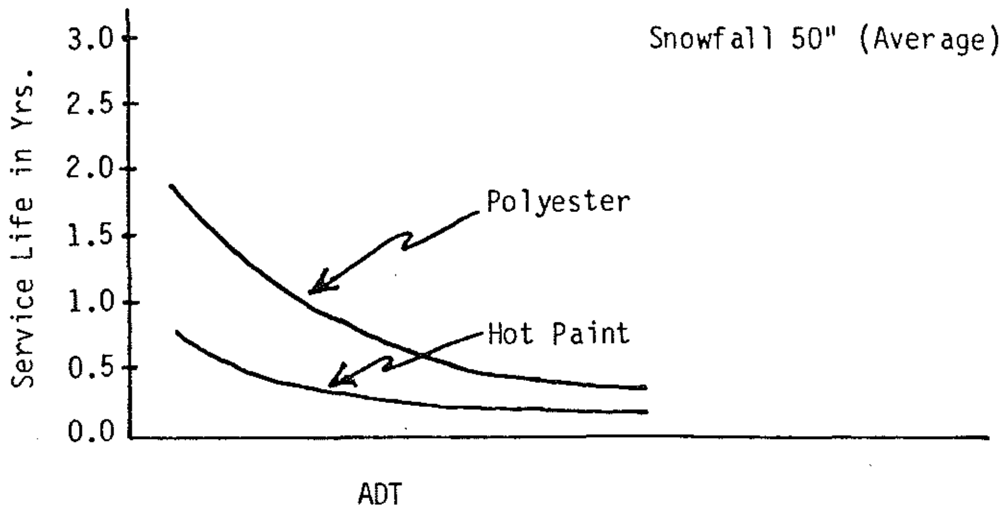


Figure 2. Service life curves for 50" snowfall.

Life cycle cost comparisons between the various pavement marking materials may be performed by a cost-analysis model, which assumes equal benefits of the pavement markings, but considers cost differences due to varying service lives, material costs, installation costs, etc. The mathematical expression of this model, as reported in the FHWA Roadway Delineation Practices Handbook (Sept. 1981) is as follows:[1]

- Cost-Analysis Model
  Present Worth of Cost = PWC

$$PWC = \sum_{n=0}^{N} \left[\frac{(TIC)_n}{(1+i)^n} + \frac{(MC)_n}{(1+i)^n} \right] + \frac{TC}{(1+i)^N}$$

Where:

- v = annual percent increase in traffic volume
- i = discount rate (set to zero because MDOT does not use a discount rate)
- N = analysis period
- $(TIC)_n$ = total installed cost in year n
- TC = terminal cost at the end of analysis period
- $(MC)_n$ = maintenance cost in year n

A schematic flow diagram of this economic model is given in figure 3. This involves first identifying the highway situation (i.e., tangent, curve, or intersection with given ADT range) within an area where snowfall and maintenance is distinctly different than other areas. The Present-Worth of Cost Model (Cost-Analysis Model) can be used to compare pavement marking materials, since benefits (accident benefits) are extremely difficult to quantify correctly. Those material types with the smallest Present-Worth of Cost (PWC) are the most economical for the appropriate roadway and traffic volume groups.

Specific Guidelines

As a part of this effort a literature search was conducted, and guidelines for various marking use as practiced by various agencies were identified. Cost information on marking material by years was not available to the Contractor, therefore, no cost-effectiveness analysis was conducted with Michigan data. However, information available from other agencies should be useful to MDOT in determining various material use under different traffic conditions.

Schematic of Cost Analysis Model

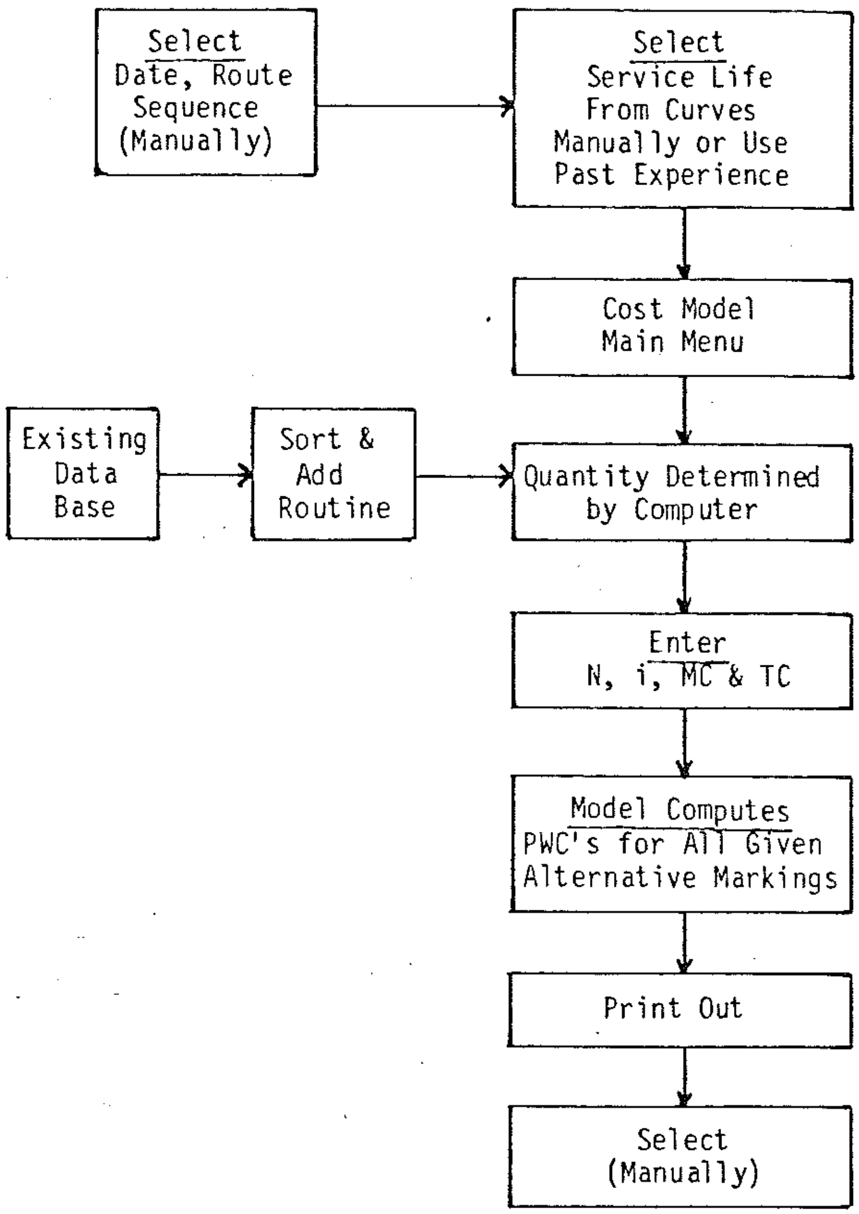


Figure 3. Illustration of economic model.

Thermoplastic stripping

- Thermoplastic striping performed better on bituminous pavement than concrete pavement.
- Thermoplastic striping is less desirable on older pavement.
- Volumes required for thermoplastic to be economical are presented in Table 7.

Epoxy

- Epoxy adheres to both bituminous and portland concrete pavements.
- Epoxy withstands high traffic volumes, sanding, salting and plowing more effectively.
- Epoxy has more reflectivity than paint.
- Epoxy is prone to chipping, however, it is not noticeable to drivers until approximately 50 percent of the striping is removed.

Polyester

- Polyester adheres well to bituminous pavement but not portland cement.
- Application costs for polyester are higher than those of epoxy or paint.
- The reflectivity properties of polyester were better after one year than those of paint.

A typical cost and service life of different types of marking material is presented in Table 8. It is evident from Table 8, that epoxy appears to be the most cost-effective material for higher volume roadways. Cost breakdowns of each material type are also included in Table 9. Readers interested in more information should refer to references [2, 3, 4 and 5].

Table 7. Comparison of costs of thermoplastic and conventional paint striping.

PAVEMENT TYPE	LINE COLOR	VOLUME (ADT) REQUIRED FOR THERMOPLASTIC STRIPING TO BE MORE ECONOMICAL		
		TWO-LANE HIGHWAY	FOUR-LANE HIGHWAY	SIX-LANE HIGHWAY
Bituminous	White and Yellow	15,000	28,000	38,000
Portland Cement Concrete	White	26,000	46,000	65,000
	Yellow	52,000	93,000	120,000

Source: Pigman, J.G. and Agent K.R., "Evaluation of Thermoplastic Pavement - Striping Materials (Louisville and Jefferson County)," Division of Research, Kentucky Bureau of Highways, May 1976.

Table 8. Comparison of service life and costs of pavement-marking materials by ADT level.

			Two Years		Four Years	
ADT	Material	Service Life (days)	Number of Applications	Cost (¢/ft)	Number of Applications	Cost (¢/ft)
<5000	Paint	365	2	9	4	16
	Epoxy	>730				
	10 mils		1	13		
	15 mils		1	18		
	Thermoplastic	<180	4	38	8	76
5000-15 000	Paint	180	4	18	8	36
	Epoxy	>730				
	10 mils		1	13		
	15 mils		1	18		
	Thermoplastic	<180	4	38	8	76
	Polyester	365	2	25	4	50
70 000	Paint	90	12	54	16	72
	Epoxy	365				
	10 mils		4	52		
	15 mils		4	72		
	Thermoplastic	<180	8	76		

Source: Gillis, H.J., "Durable Pavement - Marking Materials," TRB Record 762, 1980.

Table 9. Cost comparison of striping materials.

	PAINT	THERMO-PLASTIC	EPOXY (Fast Set)**
Material cost	$.012	$.0714	$.14
Labor and overhead	.017	.0446	.027
Traffic delay	.005	.005	—
Lane marking life	3 mos.	12 mos.	24 mos.
2 year cost	.272	.242	.1670
Cost lineal foot per year	$.136	$.121	$.0885

*cost based on averages of 40 mil applications, 4" wide striping in the states of Minnesota, Wisconsin, and Indiana.

**cost per lineal foot per application based on a 4" wide, 15 mil stripe on PCC in Minnesota, excluding cost of glass beads.

Source: Fullerton, I.J., "Roadway Delineation Practices Handbook," JHK & Associates, September 1981.

References

1. Fullerton, I.J., "Roadway Delineation Practices Handbook," JHK & Associates, September 1981.

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