GUIDELINES FOR REHABILITATING FLEXIBLE PAVEMENTS

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SUMMARY

The guidelines presented in this report are intended as an aid to the engineer in selecting the most appropriate type of pavement rehabilitation from those that are available.

The basic types of distress in pavement surfaces and their causes are described. Techniques such as milling, preventive maintenance, and structural strengthening are discussed, and two methods of designing overlays are described. A present-worth method of economic analysis that can be used to determine the most cost-effective rehabilitative measure for a given type of distress is illustrated.

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CHAPTER I

BACKGROUND AND APPROACH

Introduction

Virginia's pavement management system (PMS) will, it is hoped, provide "information and procedures necessary to optimize the design and rehabilitation of pavements. The PMS can be used by decision makers to determine the what, where, and when of pavement design and rehabilitation; what type of design and rehabilitation to select; and where and when rehabilitation should be performed."(1) The PMS should be useful to administrators in decisions concerning funding projections, allocations, and requests for pavement rehabilitation. Also, it should be helpful to district and resident engineers in deciding when rehabilitation needs to be done and what type is most cost-effective.

The guidelines in this booklet can be considered a supplement to the PMS, as they are intended as an aid to the district and resident engineers in selecting the best rehabilitative technique available; however, it is emphasized that they are not intended as a substitute for engineering judgment. They deal with the types of distress, rehabilitative techniques, and economic comparisons of alternative techniques.

Purpose

The purpose of this project was to develop guidelines for the selection of appropriate rehabilitative strategies for flexible pavements. District engineers and resident engineers should find the information helpful in making decisions concerning the upkeep and rehabilitation of pavements.

Methodology

A great deal of literature on pavement rehabilitation was reviewed. Several cookbook type of tabular listings matching various rehabilitation techniques with types of distress were found; however, it was concluded that while these listings would be useful to a novice in the highway field, they were too general to be of help to engineers responsible for the maintenance of hundreds of miles of roads.

The major types of pavement distress and their causes are presented in a form intended to help an engineer select the proper rehabilitative alternative for a given type of distress. The alternatives that have been used in Virginia are discussed with emphasis on the degree to which they have proven successful.

The inclusion of a method of cost analysis was not contemplated in the original plan for the project, but later it was concluded to be a very important factor in the selection of rehabilitation alternatives, and the project was expanded to include a method.

CHAPTER II

DISTRESS

Types of Pavement Distress

The many types of flexible pavement distress can be categorized under several general headings. For simplification, in developing the guidelines presented in this document, the five types of distress used in the pavement maintenance rating system were adopted. These are cracking (longitudinal and alligator), rutting, pushing, raveling, and patching, and all are described in the Virginia Department of Highways and Transportation's MT-5-70 Training Guide (2) and Pavement Condition Rating Manual.(3) In the discussion of these major types of distress it has been necessary to include some subgroups that do not fit readily under the types to which they are assigned but which cannot be ignored.

Cracking

Longitudinal cracks can result from construction practices such as the use of cold joints; however, this type of distress will not be considered for rehabilitation. Such cracks are primarily a temporary maintenance problem and require only good engineering judgment in deciding whether or not they should be sealed (refer to the MT-5-70 Training Guide).

Transverse cracks usually are caused by shrinkage of one of the pavement layers and, again, a judgment decision is made as to whether or not they should be sealed. If water can enter the cracks and cause pavement failure, sealing is necessary. Otherwise, no repair is recommended.

The longitudinal and alligator cracks evaluated in the pavement maintenance rating procedure are associated with the loads carried by the pavement. They can be created by traffic loadings causing excessive movements that result in fatigue failure of the bituminous base, the surface layer, or both. In this instance, the basic cause may be traced to excessive moisture in the pavement system, resilient subgrades, or weak or poorly constructed bases. Also, it is possible for the surface to be too stiff to endure the normal load deflections.

Sometimes, cracking is the first evidence of stripping in the intermediate or base layers. If the stripping continues, potholes can develop before severe alligator cracking becomes apparent. Usually, some type of structure rehabilitation is necessary for crack distress caused by excessive loads and/or a weak pavement structure. Except in extreme cases, structural strengthening to reduce the pavement deflection is usually accomplished by the application of thick overlays. Occasionally, it may be advisable to remove the cracked layer to prevent reflection cracking in the overlay or to strengthen the foundation.

Rutting and Pushing or Shoving

Rutting is visibly different from pushing or shoving; however, the two are discussed jointly because the underlying causes are similar.

Rutting appears as longitudinal, parallel depressions in the wheel paths. It is caused by shear failure or consolidation of one or more of the pavement layers. Deep shear failure in the subgrade or base materials usually is manifested by upheaval of the pavement at some distance from the rut, while deep consolidation usually causes no upheaval. Shear failure of the surface layer results in upheaval of the pavement close to the wheel path, while surface consolidation may or may not.

Rutting occurs to a limited degree on many flexible pavements carrying moderate to heavy traffic loads; however, it usually is not considered to be a problem if it is not readily visible and is less than 1/4-in deep.

Rutting can occur under slow or fast traffic, but pushing or shoving usually occurs where braking or stop-and-go traffic is common. Suspect locations are intersections with traffic signals, bus stops, and steep hills that require braking. These forms of distress result from longitudinal or transverse movement of the bituminous concrete layers and are usually characterized by a washboard appearance.

Both rutting and pushing or shoving are caused by the inability of the bituminous mix to resist wheel-load forces. Mixes can be designed with stabilities adequate to prevent these failures; however, if they are used as overlays, the distressed surface should be milled to provide a smooth base, and it might be necessary to remove the entire weak layer.

Raveling

Raveling is the progressive disintegration of the pavement from the surface downward and is evidenced by a loss of aggregate particles. It is caused by a lack of adhesion between the asphalt and aggregate or by extraordinary embrittlement of the asphalt-fines matrix. Raveling can rarely be attributed to stripping.

Patching

Patching is not a type of distress but is evidence of the prior need for temporary pavement repairs. Patches may indicate the repair of potholes, alligator cracking, localized pushing, or severe raveling. Usually, the type of distress that has been repaired will be visible in an adjacent unpatched area. The type of distress that has been temporarily corrected by patching should be considered when more permanent methods of rehabilitation are appraised.

Severity of Distress

The type of rehabilitation to be used depends upon the severity of the pavement distress. The three levels of severity used here are identical to those used in the pavement condition rating procedure; namely, not severe, severe, and very severe.(3) A "not severe" level of distress usually does not require major rehabilitation; preventive maintenance may be justified. When the distress level is "severe," rehabilitation may or may not be necessary, but when it is "very severe," rehabilitation is definitely necessary.

Special Investigations

There are situations where the distressed pavement should be closely examined to determine the most suitable type of rehabilitation. The two conditions discussed below describe when more than a visual inspection is justified.

1. When the rate of pavement deterioration suddenly accelerates. Sudden acceleration of pavement deterioration (Figure 1) signifies that the cause should be determined. The accelerated deterioration can be detected by using the pavement rating age curve, or, if the engineer is familiar with the pavement, an unusually rapid deterioration will be obvious. It may be necessary to take pavement cores or samples, trench the pavement, or perform laboratory tests on the asphalt concrete to determine the source of the problem. The layer causing the deterioration should be identified and corrected. Unless the defects are corrected, normal rehabilitation will be futile and no satisfactory service life can be obtained.

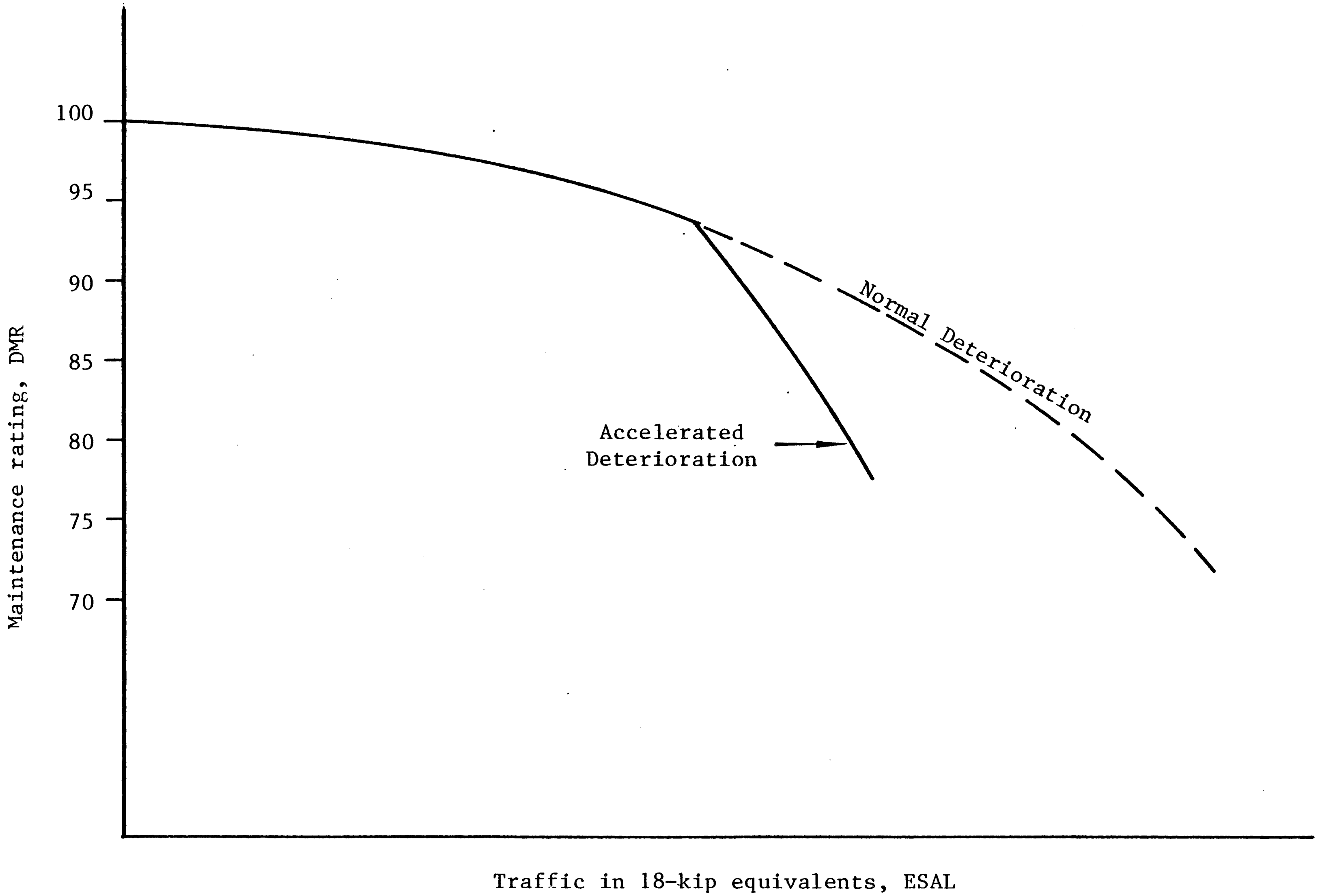

Figure 1. Performance curve — DMR vs. accumulated traffic.

2. When milling is a possibility. Cold milling is a worthwhile procedure in many cases where flexible pavements must be rehabilitated. If the surface deterioration is severe enough to require milling, determinations should be made of the depth of the deterioration and the amount of pavement that should be removed.

Stripped bituminous concrete should be removed if it will adversely affect the performance of an overlay significantly. It should be examined during late winter and early spring, when it is in its weakest condition. Because stripped material will tend to heal itself as it dries, an investigation that is conducted during summer or during extremely dry periods may yield misleading conclusions. There are no quantitative tests to determine when stripping damage is severe enough to require the removal of material. The decision to remove is an engineering judgment usually based on a visual inspection of the stripped material and a review of the performance of the pavement.

CHAPTER III

REHABILITATION TECHNIQUES

Generally, rehabilitation techniques can be grouped under one of two classifications: preventive maintenance or structural strengthening. Preventive maintenance involves sealing the pavement to prevent the entrance of surface water or applying a thin surface layer to prevent further deterioration of the existing surface. Structural strengthening stiffens the pavement structure to reduce deflection under traffic and to prevent cracking.

Milling

Milling prior to overlaying a deteriorated bituminous pavement is cost-effective in many instances. Where an overlay is placed over certain defects, its service life is reduced. In some cases a portion of the pavement surface should be removed to provide proper clearance under bridges, restore the curb line, or improve pavement drainage. Where milling is a consideration, the following recommendations offer guidance.

1. When overlaying a cracked pavement and the cracks do not extend into the lower layers, remove the surface layer to prevent reflection cracks from developing in the overlay.

2. When pavement ruts are at least 0.75-in deep, mill at least deep enough to obtain a planar surface. An irregular surface can result in low density in the overlay because of the depth differential.

3. If the surface appears to be very unstable (pushing), it may be necessary to remove the entire layer.

4. Stripped pavement should be strongly considered for removal. Experience has indicated that failure to remove even a thin stripped layer can cause deterioration of a thick overlay.

5. Milling may be necessary to remove previous overlays adjacent to curbs and drop inlets so that drainage will be maintained, and may also be needed under bridges to maintain proper clearance.

Preventive Maintenance

Surface Treatment

A surface treatment is an application of emulsified asphalt covered immediately with a layer of aggregate. The treatment prevents surface water from penetrating underlying layers; however, it adds only negligible structural strength to the pavement. A surface treatment performs well on secondary roads and may be adequate on primary routes carrying low traffic volumes (less than 2,000 vehicles per day). An estimate of the average service life of a treatment on low-trafficked primary routes is 4.9 years.

Slurry Seal

A slurry seal is a mixture of slow-setting emulsified asphalt, fine aggregate, mineral filler, and water. It is used to seal the surface against the entry of water and to renew the surface. A fine slurry seal, "B", or a coarse slurry seal, "C", is used, depending upon the function that is desired. The "C" slurry provides a longer wearing surface, but the "B" slurry should be a better crack-sealer.

Some engineers prefer the use of slurry seals rather than surface treatments on subdivision streets because the loose covering stone in the latter creates unfavorable public reactions. Slurries also have been used successfully on stabilized shoulders and to seal access roads to rest areas.

The engineer should be cautious of placing a slurry seal on plant mix that may be susceptible to stripping. If moisture is originating in the subsurface layers, the seal could trap the moisture and cause acceleration of the stripping. In cases where moisture is entering the stripped layers from the surface, a slurry seal may deter stripping. When a subsequent overlay is planned, a slurry seal should not be placed on a deformed surface. The ponding of water in ruts or depressions may cause stripping of the overlay.

It is recommended that slurry seals be used in the following instances.

1. Slurry seals should be used only on primary, secondary, and subdivision roads carrying low traffic volumes. They might cause stripping in a pavement carrying a high volume of traffic.

2. Slurry seals should not be used as a maintenance treatment on pavements that have structural distress, except as a temporary measure.

3. Slurry seals can be used to seal access roads to rest areas and on stabilized shoulders.

S-3 Overlay

The S-3 is a fine mix (100% passing the 3/8-in sieve) placed in a thin layer (90 lb/yd^2) to renew the surface. The mix gradations are listed in Table 1. Because of the light application, no benefit to the pavement structure should be assumed. It can also be used to top a hot surface recycling-in-place.

Table 1

Design of Mix Gradations

Percent Passing by Weight

Sieve \ Mix	S-3	S-4	S-5	S-6	S-7	S-8	S-9, S-10, I-2
1					100		100
3/4					86-100		
1/2		100	100	100	70-80	100	
3/8	100				60-70	85-100	63-77
No. 4	88-100	76-90	53-67	52	42-50	15-32	43-57
No. 8	79-87				28-36	0-7	
No. 30	36-44	31-39	19-27	15	12-18		
No. 50	21-29	16-24			6-12		6-14
No. 200	5-9	4-8	4-8	4.5	2-5	0-0.5	2-6

S-8 Overlay

The S-8 mix is an open-graded friction course that reduces the accumulation of water on the surface during heavy rainfall, and it also seals the underlying layers. It can be used beneficially at locations experiencing a large number of accidents during wet pavement conditions. It is usually placed in a thin layer (70 lb/yd^2), so no structural benefit should be assumed. As is the case with slurry seals, the engineer should be cautious of using the S-8 mix over plant mix that is prone to strip.

Structural Strengthening

Approximately 94% of the plant mix used in Virginia in 1984 was equally divided between the S-5 and S-10 surface paving mixes. The estimated average service life of the overlays on primary routes is 6.9 years.

Types of Overlays

S-5 -- An S-5 mix provides a smooth riding surface with an adequate service life. It should not be applied at a rate of less than 125 lb/yd^2 so that the design density can be attained and some structural strengthening will be realized.

S-10 (surface paving) and I-2 -- The S-10 mix is identical to the I-2, except that 95% of the plus #4 aggregate must be polish resistant. A fine S-10 mix can closely resemble a coarse S-5; however, a coarser surface texture is usually achieved with the S-10. The S-10 may be preferable to the S-5 under heavy traffic, because it usually is more stable. Mix segregation is sometimes a problem with S-10 mixes, and this can result in a permeable pavement and an unsightly surface.

S-6 -- Similar to the S-5 mix, the S-6 contains 1/2-in top size aggregate but is slightly coarser than the S-5 mix. The S-6, which has been used primarily in the Lynchburg District on urban pavements, appears to resist shoving, or pushing. It can be applied in thinner lifts than the urban I-2 mix, and although it has more surface texture than an S-5, there usually is no problem with segregation.

S-9 (urban mix) -- The S-9 mix should be used where stop-and-go traffic is likely to cause pushing or shoving of the surface course. The use of AC-40 asphalt cement or a stiffening additive is required, and the asphalt content is less than that of a standard I-2 mix. The urban mix has proven to be very stable and satisfactory.

S-4 -- The S-4 mix, which utilizes local pit materials, is used in the Fredericksburg District. Because it has a lower stability requirement than other dense-graded mixes, it could deform under heavy traffic.

S-7 -- The S-7 mix was developed in 1985 to provide a surface that would resist rutting under a large volume of high-speed truck traffic. Hydrated lime (1%) and AC-30 asphalt cement are specified to help provide stability.

Design of Overlay

Numerous methods for designing the thickness of an overlay are available to the engineer. Most are based on the strength of the present pavement structure and the anticipated volume of truck traffic the pavement will carry during the life of the overlay. Two methods for computing the needed thickness of an overlay, which were recommended by McGhee,(4) are illustrated below. Method No. 1, which uses pavement deflection data obtained with the dynaflect machine, traffic data, and the pavement cross section, is preferred over Method No. 2,(5) which requires only traffic data from the initial construction through the life of the overlay. Method No. 1 uses the present strength of the pavement, whereas Method No. 2 assumes that the pavement will continue to undergo the same average rate of deterioration as that experienced since construction and is based upon the average performance of overlays in Virginia. Method No. 2 does not recognize rapid strength losses that may occur during the latter stages of the service life.

A menu type computer program, "OVERLAY," is available to engineers of the Virginia Department of Highways and Transportation for use in computing the overlay thickness by either method.

Occasionally, the results of the computations may be unreasonable, particularly those from Method No. 1. Negative overlay thicknesses are possible for highways with low traffic volumes.

Method No. 1 -- Use of this design procedure requires current traffic information and a pavement thickness index (T. I.) obtained from dynaflect deflection data. The steps of the procedure may be summarized as follows:

1. Determine the daily 18-kip equivalent single-axle loads (ESAL's) from traffic counts and Figure 2. The total daily EWL-18 = ESAL of trailer trucks + ESAL of 3-axle trucks + ESAL of 2-axle trucks + ESAL of buses.

2. Determine the T. I. of the pavement from the dynaflect deflection data or the known thickness of individual layers. The Virginia Highway and Transportation Research Council will provide a dynaflect evaluation upon request.

3. Determine the required thickness of the overlay from equation 1 given subsequently.

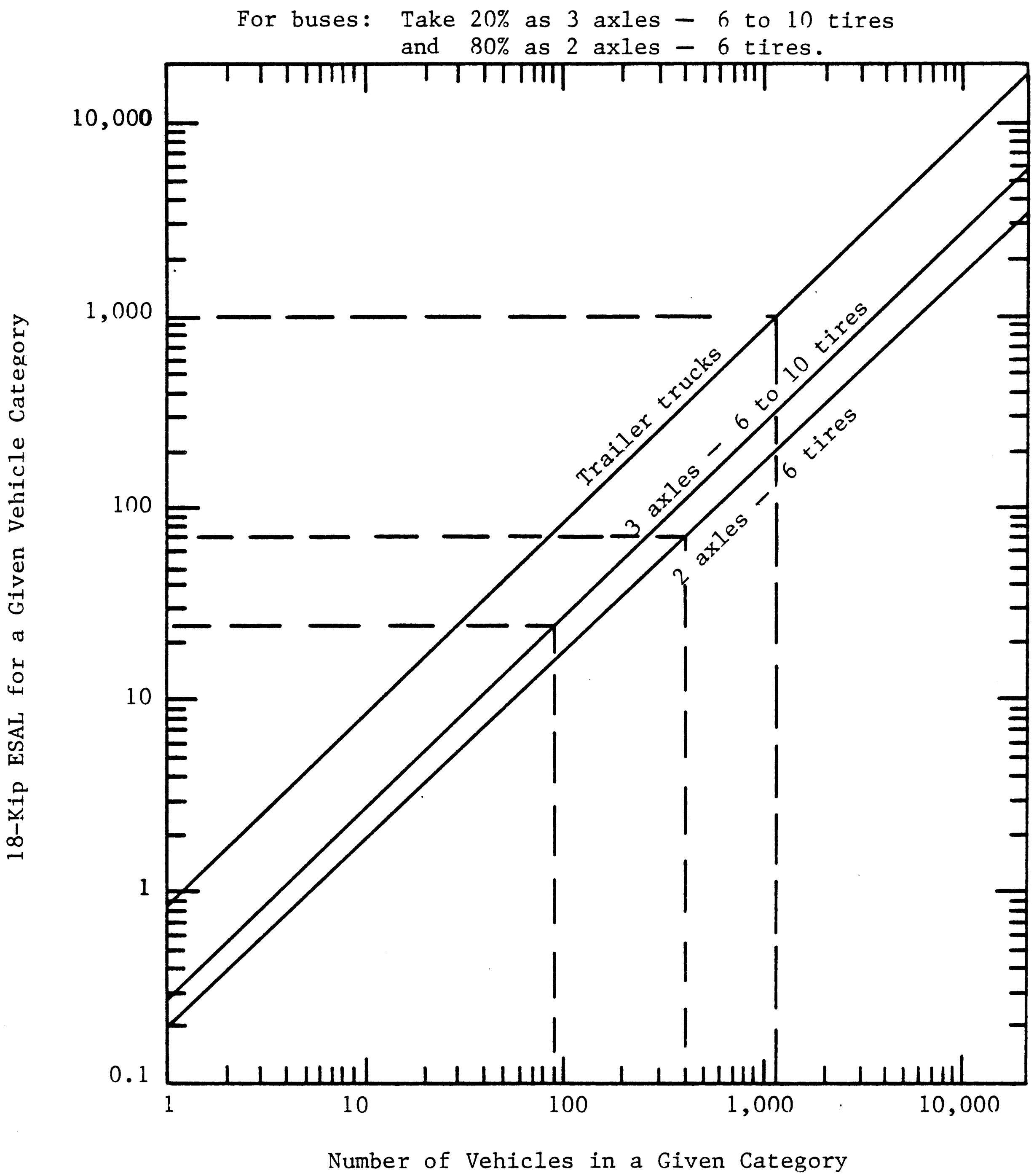

Figure 2. Determination of daily 18-kip equivalent from traffic count. (From reference 4) Metric Conversion: 18-kip = 8,160 kg.

Example: Rehabilitation is needed on a primary 2-lane highway with flexible pavement in the Salem District. It is decided that the pavement will be upgraded by applying an overlay with a design service life of 10 years. Determine the required thickness of the overlay using the following information.

Average daily traffic

2-axle, 6-tire	1,050
3-axle, 10-tire	260
Trailer trucks	700
Buses	20

The pavement cross section consists of 8-in of bituminous concrete and 6-in of crushed stone. An analysis of dynaflect measurements has yielded an effective T. I. of 9-in.

1. Determine the daily ESAL's. From the known ADT and Figure 2,

2-axle, 6-tire	210
3-axle, 10-tire	70
Trailer trucks	600
Buses (1 + 3)	4

Total 18-kip EWL = 884 ESAL

Each lane will carry 0.5 x 884 = 442 ESAL

NOTE: The traffic on a 4-lane highway is assumed to be divided with 0.5 in each direction and 80% of the truck and bus traffic in the outside (design) lane.

From Table 2, use the mid-life (5th year) growth rate to adjust the ESAL, assuming a 5% growth rate per year.

1.22 x 442 = 539 ESAL

2. Determine the T. I. of the present pavement that should be used in the design of the overlay.

Dynaflect measurements have indicated that the pavement had a T. I. of 9-in, which should be used in the overlay computation.

If dynaflect data are not available, the T. I. can be estimated by summing the product of the individual layers times their respective thickness equivalency values (Table 3). Therefore, for this example:

$$T.\ I. = \Sigma \text{ (thickness equivalency x layer thickness)}$$

$$T.\ I. = 0.35 \times 6 + 1.0 \times 8 = 10$$

3. Compute the overlay thickness by the equation

$$T = 4 \log (ESAL) + 4 \log (n) + 5.41 - 2\ T.\ I., \qquad (1)$$

where

T = required thickness of overlay, in,

ESAL = daily 18-kip equivalent single-axle loads,

n = estimated life of overlay, and

T. I. = thickness index of existing pavement.

For the example,

$$T = 4 \log 539 + 4 \log (10) + 5.41 - 2\ (9)$$

$$T = 2.3\text{-in}$$

Method No. 2 -- Use of this overlay design method requires only traffic information. The computation of the overlay thickness according to equation 2 below is based upon the ratio of the expected accumulated traffic during the life of the overlay to the accumulated traffic before the overlay.

$$T = 4 \log\left(1 + \frac{AT_2}{AT_1}\right), \qquad (2)$$

where

T = required overlay thickness, in,

AT_1 = 18-kip equivalent single-axle loads accumulated from time of construction to time of proposed overlay, and

AT_2 = 18-kip equivalent single-axle loads expected during the life of the overlay.

Table 2

Growth Rate and Accumulated Traffic
Assuming 5 Percent Annual Growth

Period of Traffic in Years	Growth Factor	Accumulated Traffic Factor
1	1	365
2	1.05	748
3	1.10	1,149
4	1.16	1,572
5	1.22	2,017
6	1.27	2,480
7	1.34	2,969
8	1.40	3,480
9	1.47	4,016
10	1.54	4,578
11	1.62	5,169
12	1.70	5,789
13	1.78	6,438
14	1.87	7,120
15	1.97	7,839
16	2.07	8,595
17	2.17	9,387
18	2.28	10,219
19	2.39	11,091
20	2.51	12,007

Table 3

Thickness Equivalencies of Materials in Virginia For Interstate, Arterial, and Primary Roads

Location	Material	Notation	Thickness Equiv.
Surface	Asphalt concrete.	AC	1.0
Base	(a) Asphalt concrete.	AC	1.0
	(b) Cement treated aggregate base material over untreated aggregate base or soil cement or soil lime and under AC mat.	CTA	1.0
	(c) Untreated aggregate base material crushed or uncrushed. Spec. No. 20, 21, and 22.	Agg.	0.35
	(d) Select material I directly under AC mat and over a subbase of good quality (a < 0.2).	Agg.	0.35
Subbase	(a) Select material types I, II, & III.	Sel. Mat.	
	1. In Piedmont area.		0.0
	2. In Valley and Ridge area and Coastal Plain.		0.2
	(b) Soil cement or soil lime.	SC	0.4
	(c) Cement treated aggregate base directly over subgrade.	CTA	0.6

The basic procedure involves the following steps.

1. Determine the total 18-kip equivalent single-axle loads that the pavement has carried from time of construction to the time of the proposed overlay, irrespective of any previous overlays.

2. Determine the total 18-kip equivalent single-axle loads that the pavement is expected to carry during the life of the overlay.

3. Compute the thickness of the overlay by equation 2.

Example: An interstate highway pavement built in 1970 and resurfaced in 1976 with 1.9-in of bituminous concrete has a maintenance rating which indicates that rehabilitation is needed in 1985. The type of distress indicated that structural strengthening, i.e., an overlay, was necessary. Determine the thickness of the overlay that is required for a 10 year service life.

The 1982 traffic information is as follows:

Type of Vehicle	Daily Traffic Volume	*Design ESAL's
2-axle, 6-tire	400	70
3-axle, 10-tire	90	25
Trailer trucks	1,200	1,000
Buses**	30	4 + 2 = 6
		1,101

* From Figure 2
**Assume 20% 3-axle and 80% 2-axle vehicles

Virginia Department of Highways and Transportation traffic counts, which are published annually, include both directions of travel.(6) It is assumed that one-half of the traffic travels in each direction and 80% of the traffic uses the outside design lane. Therefore, the daily traffic volume for design is

$$ADT_o = 1,101 \times 0.5 \times 0.8 = 440 \text{ ESAL.}$$

1. Determine the ESAL's accumulated from the time of construction until the time of the proposed overlay. If the traffic record is not available, the accumulated traffic can be estimated by assuming a 5% annual growth rate.

Accumulated traffic before overlay

= Design daily ESAL in 1970 x accumulated traffic factor

$$= \frac{\text{Design daily 18-kip ESAL in 1982}}{\text{Growth rate from 1970 to 1982}} \times \text{accumulated traffic factor.}$$

The growth factor for 12 years (1970 to 1982) from Table 1 is 1.70 and the accumulated traffic factor for 15 years (1970 to 1985) is 7,839. Therefore, by substitution

Accumulated traffic before overlay

$$= \frac{440}{1.70} \times 7{,}839 = 2.03 \text{ million ESAL.}$$

2. Determine the ESAL's that the overlay is expected to carry during its 10-year life.

Accumulated traffic during service life

= Design daily ESAL's in 1985 x accumulated traffic factor

= Design daily ESAL's in 1982 x growth factor from 1982 to 1985 x accumulated traffic factor.

The growth rate factor for 3 years (1982-1985) from Table 2 is 1.10 and the accumulated traffic factor for 10 years (service life) is 4,578. Therefore, by substitution

Accumulated traffic during service life

= 440 x 1.10 x 4,578 = 2.22 million ESAL.

3. The required overlay thickness is computed as

$$T = 4 \log\left(1 + \frac{2.22}{2.03}\right) = 1.3 \text{ in.}$$

CHAPTER IV

ECONOMIC COMPARISON OF ALTERNATIVES

Method of Analysis

An economic analysis of the various alternatives is essential before an alternative is selected. The two methods of economic analysis commonly used are annual cost and present worth. Both methods have pros and cons; however, from an engineering economy perspective where pavement lives are long, the present-worth method is the only suitable technique.

The present worth of a rehabilitation alternative "can be defined as the amount of money that would have to be set aside at the time of initial construction, plus interest, to yield the amount of money required for the future activity."(7) Data essential for a present-worth analysis are realistic estimates of the initial cost, the service life, and the annual cost of maintenance. It is also necessary to assume a discount rate -- that is the value placed on money that could be used elsewhere. A discount rate need or need not include the inflation rate. The option of including inflation is discussed in a subsequent section. The magnitude of the discount rate can have a major influence on the results of the economic comparison; therefore, it may be advisable to compare high, medium, and low rates. Some analysts also consider factors, such as user costs, that are affected by traffic delays and pavement condition. Because the estimation of user costs is open to debate, it is usually assumed that they are equal for all alternatives; therefore, they do not appear in the analysis. The present worth of a rehabilitation alternative is computed by the formula (8)

$$\text{Total present worth} = \sum_{i=1}^{n} C_i (f_i) - SVF_n \quad (2),$$

where

n = number of years in the analysis period,

C_i = construction costs for i^{th} year based on current costs,

f_i = present worth factor for i^{th} year (Table 4),

f_n = present-worth factor for year corresponding to the end of the analysis period, and

RV = residual value.

Analysis Period

Select the analysis period which coincides with the longest life of one of the alternatives. The analysis period may also depend on future plans such as relocation, reconstruction, and possible change in the function of the section of highway. The pavement rating should be maintained above the minimum acceptable value during the analysis period for all alternatives.

Service Life Estimate

It is important that the best possible estimate of service life for a rehabilitation alternative be used in the economic analysis. As the pavement data system is developed, reliable service life data will become available; however, they are currently very limited.

Cost Estimates

Construction and maintenance estimates are based on current prices, no matter when the work is performed. Any effects of interest and inflation on future costs usually are automatically included in the analysis. Local costs should be used; however, it may be necessary to obtain estimates from other localities if no similar work has been performed locally recently.

Residual Value

If the service life of an alternative is longer than the analysis period, the residual value of the pavement rehabilitation should be subtracted from the cost. For instance, if only 3 years of a 5-year slurry seal were used, the value of the two remaining years at the end of the analysis period could be estimated as 2/5 of the original cost of the slurry seal.

Discount Rate

The discount rate reflects the time preference for money and is used to account for the fact that funds expended in later time periods are of less value than funds expended in the present period. The discount rate is dependent upon market interest rates and the inflation rate among other less tangible factors. An appropriate discount rate for analyzing government projects is in the range of 6% to 8%, excluding inflation.

Table 4

Present-worth Factors for Different Discount Rates

Year	DISCOUNT RATE									
	1	2	3	4	5	6	7	8	9	10
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	.990	.980	.971	.962	.952	.943	.935	.926	.917	.909
3	.980	.961	.943	.925	.907	.890	.873	.857	.842	.826
4	.971	.942	.915	.889	.864	.840	.816	.794	.772	.751
5	.961	.924	.888	.855	.823	.792	.763	.735	.708	.683
6	.951	.906	.863	.822	.784	.747	.713	.681	.650	.621
7	.942	.888	.837	.790	.746	.705	.666	.630	.596	.564
8	.933	.871	.813	.760	.711	.665	.623	.583	.547	.513
9	.923	.853	.789	.731	.677	.627	.582	.540	.502	.467
10	.914	.837	.766	.703	.645	.592	.544	.500	.460	.424
11	.905	.820	.744	.676	.614	.558	.508	.463	.422	.386
12	.896	.804	.722	.650	.585	.527	.475	.429	.383	.350
13	.887	.788	.701	.625	.557	.497	.444	.397	.356	.319
14	.879	.773	.681	.601	.530	.469	.415	.368	.326	.290
15	.870	.758	.661	.577	.505	.442	.388	.340	.299	.263
16	.861	.743	.642	.555	.481	.417	.362	.315	.275	.239
17	.853	.728	.623	.534	.458	.394	.339	.292	.252	.218
18	.844	.714	.605	.513	.436	.371	.317	.270	.231	.198
19	.836	.700	.587	.494	.416	.350	.296	.250	.212	.180
20	.828	.686	.570	.475	.396	.331	.277	.232	.194	.164
21	.820	.673	.554	.456	.377	.312	.258	.215	.173	.149
22	.811	.660	.538	.439	.359	.294	.242	.199	.164	.185
23	.803	.647	.522	.422	.342	.278	.226	.184	.150	.123
24	.795	.634	.507	.406	.326	.262	.211	.170	.138	.112
25	.788	.622	.492	.390	.310	.247	.197	.158	.126	.102
26	.780	.610	.478	.375	.295	.233	.184	.146	.116	.092
27	.772	.598	.464	.361	.281	.220	.172	.135	.106	.084
28	.764	.586	.450	.347	.268	.207	.161	.125	.098	.076
29	.757	.574	.437	.333	.255	.196	.150	.116	.090	.069
30	.749	.563	.424	.321	.243	.185	.141	.107	.082	.063

Inflation

The discount rate can be selected to take care of inflation; however, most analysts elect to exclude inflation. It is important that consistency in inclusion or exclusion of inflation be maintained throughout the analysis.

It is important to include inflation if the cost of two alternatives will inflate at different rates. For instance, several years ago the price of asphalt inflated faster than that of concrete because of the oil embargo.

Maintenance Costs

Ordinary maintenance costs should be included for each alternative. For example, it is likely that the type and amount of maintenance may not be the same for a distressed pavement that is slurried as for the same pavement that is overlaid.

Example: Economic Comparison of Alternative Rehabilitation Methods

A 5-mile section of 24 ft bituminous pavement has reached a distress maintenance rating that necessitates repairs or rehabilitation. The following three alternatives were considered.

Alternative A

Repair pavement to maintain present condition for 3 years and then apply a 3.0-in overlay of bituminous concrete during the 4th year. Repairs are estimated to cost $5,000/year and the plant mix cost is $30/ton in place. The estimated service life of the overlay is 10 years. No ordinary maintenance is anticipated.

Alternative B

Apply a 2.0-in overlay immediately and apply a type B slurry seal during the 7th year. Plant mix cost $30/ton in place and type B slurry seal is $0.60/yd^2. The estimated life of the slurry seal is 4 years. No ordinary maintenance is anticipated.

Alternative C

Apply a 2.5-in overlay immediately. Plant mix costs $30/ton. The estimated service life of the overlay is 10 years. Annual ordinary maintenance is estimated to be $3,000 beginning in 1990.

Results

The present-worth costs of Alternatives A, B, and C, as shown computed on Figures 3, 4, and 5, respectively, are:

A = $276,250 B = $262,300 C = $217,000

While cost is a major factor that should be considered when the type of rehabilitation is finally selected, other factors must also be considered. Other factors that might influence the choice are public satisfaction, traffic control, and availability of funds. There are undoubtedly other factors unique to specific locations. Factors such as traffic control need to be included in the economic analysis if their costs are significant.

ALTERNATIVE A Repair pavement for 3 years and apply 3-in overlay the 4th year

ANALYSIS PERIOD 10 **YEARS**

DISCOUNT RATE 5%

YEAR	M & R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1984	Repair	5,000	1.000	5,000
85	Repair	5,000	0.952	4,760
86	Repair	5,000	0.907	4,535
87	3" Overlay @ $5.06/yd^2	356,400	0.864	307,929
88				
89				
90				
91				
92				
93				
94				
			TOTAL	$ 322,225

2 years' service life remaining

SALVAGE VALUE = $ 2/10 (356,400) (0.645) = 45,975

PRESENT WORTH = $ 322,225 - 45,975 = 276,250

Figure 3. Present-worth analysis of Alternative A.

ALTERNATIVE B 1 1/2-in overlay and apply type B slurry seal the 7th year

ANALYSIS PERIOD 10 **YEARS**

DISCOUNT RATE 5%

YEAR	M & R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1984	2" Overlay @ $3.38/yd^2	237,600	1.0	237,600
85				
86				
87				
88				
89				
90	Type B slurry @ $0.60/yd^2	42,240	0.746	31,511
91				
92				
93				
			TOTAL	$269,111

1 year service life remaining

SALVAGE VALUE = $ 1/4 (42,240) (0.645) = 6,811

PRESENT WORTH = $ 269,111 - 6,811 = 262,300

Figure 4. Present-worth analysis of Alternative B.

ALTERNATIVE C 2 1/2-in overlay

ANALYSIS PERIOD 10 YEARS

DISCOUNT RATE 5%

YEAR	M & R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1984	1-1/2" Overlay @ $2.53/yd^2	196,000	1.0	196,000
85				
86				
87				
88				
89	Ordinary Maintenance	4,000	0.784	3,140
90	Ordinary Maintenance	5,000	0.746	3,730
91	Ordinary Maintenance	6,000	0.711	4,270
92	Ordinary Maintenance	7,000	0.677	4,740
93	Ordinary Maintenance	8,000	0.645	5,160
			TOTAL	$217,040

SALVAGE VALUE = $ 0

PRESENT WORTH = $ 297,000

Figure 5. Present-worth analysis of Alternative C.

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SI CONVERSION FACTORS

To Convert From	To	Multiply By
Length:		
in	cm	2.54
in	m	0.025 4
ft	m	0.304 8
yd	m	0.914 4
mi	km	1 . 609 344
Area:		
in^2	cm^2	6.451 600 E+00
ft^2	m^2	9.290 304 E-02
yd^2	m^2	8.361 274 E-01
mi^2	Hectares	2.589 988 E+02
acre (a)	Hectares	4.046 856 E-01
Volume:		
oz	m^3	2.957 353 E-05
pt	m^3	4.731 765 E-04
qt	m^3	9.463 529 E-04
gal	m^3	3.785 412 E-03
in^3	m^3	1.638 706 E-05
ft^3	m^3	2.831 685 E-02
yd^3	m^3	7.645 549 E-01
Volume per Unit Time:	NOTE: $1m^3$ = 1,000 L	
ft^3/min	m^3/sec	4.719 474 E-04
ft^3/s	m^3/sec	2.831 685 E-02
in^3/min	m^3/sec	2.731 177 E-07
yd^3/min	m^3/sec	1.274 258 E-02
gal/min	m^3/sec	6.309 020 E-05
Mass:		
oz	kg	2.834 952 E-02
dwt	kg	1.555 174 E-03
lb	kg	4.535 924 E-01
ton (2000 lb)	kg	9.071 847 E+02
Mass per Unit Volume:		
lb/yd^2	kg/m^2	4.394 185 E+01
lb/in^3	kg/m^3	2.767 990 E+04
lb/ft^3	kg/m^3	1.601 846 E+01
lb/yd^3	kg/m^3	5.932 764 E-01
Velocity: (Includes Speed)		
ft/s	m/s	3.048 000 E-01
mi/h	m/s	4.470 400 E-01
knot	m/s	5.144 444 E-01
mi/h	km/h	1.609 344 E+00
Force Per Unit Area:		
lbf/in^2 or psi	Pa	6.894 757 E+03
lbf/ft^2	Pa	4.788 026 E+01
Viscosity:		
cS_t	m^2/s	1.000 000 E-06
P	Pa·s	1.000 000 E-01

Temperature: °F-32)5/9 = °C

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