MINNESOTA DEPARTMENT OF TRANSPORTATION
Engineering Services Division
Technical Memorandum No. 04-19-MAT-02
September 7, 2004

To: Distribution 57, 612, 618, 650

From: Douglas H. Differt
Deputy Commissioner/Chief Engineer

Subject: Pavement Selection Process

Expiration
This Technical Memorandum supersedes Technical Memorandum No. 04-06-MAT-01 and will expire on September 7, 2009 unless superseded prior to that date.

Implementation
The provisions of this Technical Memorandum should be used for all projects involving new and/or reconstructed pavements on the trunk highway system. Any projects already submitted and in process will continue to use the provisions of 01-22-MRR-07 until completed.

Introduction
Pavement Selection is the process used by Mn/DOT to determine if a new or reconstructed pavement project will have a bituminous or concrete surface. In August 2002, at the direction of then Deputy Commissioner Doug Weiszhaar, the Pavement Selection Task Force was formed to fully evaluate the pavement selection process. The Task Force made both short and long-term recommendations. The short-term recommendations are implemented through this Technical Memorandum. The long-term recommendations will require further study. Refer to Mn/DOT report MnDOT/OM-PM--2003-01 for more details.

Guidelines
Pavement selection refers to the process used by Mn/DOT to determine if new and reconstruction projects will have an asphalt or concrete surface. Mn/DOT has had a process, in one form or another, since 1959. The current process, as of the date of this Technical Memorandum, is described below.

Part I. The Pavement Selection Process

Exemptions
All new pavement construction and reconstruction projects must go through the pavement selection process. Pavement construction is defined as any activity that involves working the subgrade. It does not include rehabilitation activities such as bituminous or unbonded concrete overlays, cold in-place recycling, full-depth reclaiming or rubbilizing. Any questions as to whether a certain project is required to go through the pavement selection process should be directed to the Mn/DOT Pavement Engineer.

Pavement Selection Categories
The pavement selection process has three categories that a project may fall into: District, Informal and Formal. To determine which type of process is required, refer to the descriptions below or Table 1.

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District Process:
Short projects meeting the following criteria:

Two-Lane Roadways: Projects less than 3.22 km **(2 miles)** long
Multi-Lane Roadways: Projects less than 25,083 m^2 **(30,000 square yards)**

The project length/size listed above are determined using only the driving lanes, no turn lanes, parking lanes or ancillary lanes.

Informal Process
The Informal process involves determining the pavement type based on the amount of traffic, as measured by the length-weighted Bituminous Equivalent Standard Axle Loads (BESALs), and the subgrade soil strength.

Informal Flexible: Projects where the 20-year design lane BESALs are 7 million or less and the design subgrade R-value is greater then 40. Projects in this category will be constructed with bituminous.

Informal Rigid: Projects where the 20-year design lane BESALs exceed 10 million. Projects in this category will be constructed with concrete.

Formal Process:
All projects not meeting the Informal criteria listed above. The pavement type will be determined by a detailed cost estimate.

Table 1. Pavement Selection Process & Design Options

20-Year Design Lane BESALs	Subgrade Soil R-Value	Process Type Design(s)	Description of Design(s)
1,000,000 or less	> 40	Informal – Flexible Design #6	Flexible – Aggregate Base (BAB) Flexible – Deep Strength (BDS)
	<= 40	Formal Design #3 & 6	Rigid – Aggregate Base Flexible – Aggregate Base (BAB) Flexible – Deep Strength (BDS)
1,000,001 to 7,000,000	> 40	Informal – Flexible Design #4 & 5	Flexible – Aggregate Base (BAB) Flexible – Deep Strength (BDS)
	<= 40	Formal Design #1, 2, 4, & 5	Rigid – Open Graded Base Rigid – Select Granular Flexible – Aggregate Base (BAB) Flexible – Deep Strength (BDS)
7,000,001 to 10,000,000	All Values	Formal Design #1, 2, 4, & 5	Rigid – Open Graded Base Rigid – Select Granular Flexible – Aggregate Base (BAB) Flexible – Deep Strength (BDS)
Over 10,000,000	All Values	Informal – Rigid Design #1 & 2	Rigid – Aggregate Base Rigid – Open Graded Base

Notes: Design numbers refer to standard designs shown in Figure 1.

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The District Process
The District process involves a Life Cycle Cost Analysis (LCCA) by district personnel comparing different pavement types and designs. The District is not required to use the low-cost option but needs to document reasons for choosing another option. The LCCA documentation must accompany the pavement design recommendation letter for the project.

The Informal Process
The Informal process mainly involves a review of the proposed pavement design followed by the appropriate signatures.

Informal – Flexible *(20-Year Design Lane BESALs <=7 Million & Subgrade R-value > 40)*
These are reconstruction or construction projects, over the minimum size requirement, with 20-year design lane BESALs equal to 7 million or less and design subgrade R-value greater than 40.

For this type of project, the District must include the following information in their pavement selection packet, which is sent to the Pavement Analysis and Integration Engineer.

- Cover letter signed by the District Engineer requesting a pavement selection via the informal process. This letter should include, at a minimum, the following:
    - State Project Number
    - Roadway Number and Termini
    - County the project is located in
    - Project Length, including reference post limits where possible
    - Signature/Date blocks for the Pavement Design & Pavement Engineers
    - Proposed Letting Date
- A preliminary soils letter with laboratory test results substantiating the R-value.
- A detailed traffic forecast indicating the 20-year BESALs. The forecast must be signed by the State Traffic Forecast Engineer and be dated no earlier than one year of the submittal date of the pavement selection packet.
- A description of the proposed pavement design. Designs shall be developed in accordance with Figure 1.
- A life cycle cost analysis worksheet justifying the selection of the proposed design.

Informal – Rigid *(20-year Design Lane BESALs > 10 million)*
These projects must include all of the same documentation as the Informal – Flexible process with the exception that the traffic forecast must also include a forecast of the 35-year CESALs.

The Formal Process
All projects meeting the minimum size requirements and not qualifying for the Informal process must use the Formal process to determine the pavement surface type.

The Formal process has five basic steps, as follows:

(1) The District sends in a request for pavement selection to the Pavement Analysis and Integration Engineer. The submittal packet should include, at a minimum, the following information:

- Cover letter signed by the District Engineer.

- A general description of the project and its location.

- A map showing the existing and/or proposed roadway.

- Typical sections of the existing and proposed roadway showing lane, shoulder, and granular subgrade treatment widths.

- A preliminary soils letter describing past history and providing information to be used in the pavement design, including laboratory test results substantiating the subgrade R-value. R-value sampling rates shall be as shown in Table 5-3.1 of the Geotechnical and Pavement Manual.

- A list of known aggregate sources that could be used as a source of material for the project. The District Materials Engineer will work with the Aggregate Engineer and to refine the list of possible aggregate sources to be used in the estimate.

- A signed traffic forecast showing 20-year BESAL and 35-year CESAL estimates. The forecast must be signed by the State Traffic Forecast Engineer and dated no earlier than one year prior to the submittal date of the pavement selection packet.

- A list of any extenuating circumstances, such as the presence of boulevard trees, narrow working conditions, etc. should be identified so that special design considerations may be considered prior to the estimate being done.

(2) The project is logged in and the packet is sent to the Pavement Design Engineer who develops the standard pavement sections for comparison. The designs are done in accordance with Table 1 and Figure 1 and include two or more of the following:

- Rigid – Open Graded Base
- Rigid – Select Granular Base
- Flexible – Deep Strength
- Flexible – Aggregate Base

(3) Once the designs are complete, the packet is sent to the Estimating Engineer who prepares a detailed cost estimate for each design. Information is gathered from the Concrete Paving Association of Minnesota (CPAM) and the Minnesota Asphalt Pavement Association (MAPA) on any additional aggregate sources they may know about that were not included in the initial submittal. For each pavement design, a Present Worth Cost is calculated on a per mile basis and the low lost option is determined. The analysis is described in Section II of this document.

(4) Once the estimate is finished, the Pavement Analysis and Integration Engineer sends a memo to the District identifying the low cost option and the pavement type to be used.

(5) If the District concurs with the low-cost option, the process is complete and MAPA and CPAM are notified. If the District does not agree the low-cost option should be used, it can appeal to the Deputy Commissioner/Chief Engineer for a variance. The variance process begins by the District Engineer informing the Director of the Office of Materials, in writing, that the District is seeking a variance.

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Premium Enhanced Designs
Once the pavement selection process is complete and a pavement type determined, premium enhanced designs may be considered. Enhanced designs include such items as Stone Matrix Asphalt (SMA) mixtures, premium dowel bars, improved aggregate quality, and increased aggregate base and/or select granular material over the minimum thickness specified in Figure 1 of this document.

Adding bituminous or concrete thickness is *not* considered a design enhancement and will not be allowed once the low-cost option is determined. Any concerns over the design thickness should be brought to the attention of the Pavement Design Engineer at the time the pavement selection packet is submitted.

Pavement Structure Materials/Subgrade Costs
The cost of all materials above the subgrade soil, as depicted in Figure 1 of this document, shall be included in the pavement selection economic analysis.

Recycled Materials & Salvage Value
The benefit of reusing any in-place bituminous or concrete material, which can be recycled back into the new pavement structure, will be incorporated into the initial cost estimate. This results in separate cost estimates for designs using virgin material and designs using the recycle material. However, no salvage value will be assigned any recyclable materials at the end of the analysis period.

Concrete Yield Losses
Yield losses from any concrete options will not be included in the pavement selection economic analysis.

Combining Adjacent Projects
When the Formal Process is used, adjacent projects can be combined for the pavement selection process provided the following two conditions are true:

- The combined length of the projects is 40.23 km **(25 miles)** or less, and
- The time between the earliest and latest letting date is five years or less

Combining adjacent projects for pavement selection purposes accommodates longer projects that may be done in stages. This will result in a single pavement type for the combined length of the projects.

Part II. Economic Analysis

The low-cost option will be the design that results in the lowest annual cost per km **(mile)**, using present worth analysis as outlined in the Attachment. The number of designs considered is determined from Table 1. Each design will result in a different initial construction cost and depending on the pavement type and traffic level, various scenarios for future preventive maintenance and rehabilitation strategies according to Tables 2, 3 and 4.

For pavement selection, a 50-year analysis period will be used. In addition, the present worth will be calculated using a discount rate equal to the real interest rate on 30-year treasury bonds as published each year by the federal Office of Management and Budget (OMB). For 2003, this value was 3.5%. The value to be used each year will be determined by the Mn/DOT Office of Investment Management and kept on file in the Mn/DOT Estimating Unit.

The costs to be used in the pavement selection process for future rehabilitation and maintenance activities will be determined annually. The value will be based on the cost of similar projects done over the most recent 10-year period. The costs will be on file in the Mn/DOT Estimating Unit.

Since the activity costs are based on historical projects, many of which were built to standards not used today, a Cost Adjustment (CA) will be used. The CA reduces the cost of the future maintenance and rehabilitation activities by 10 percent to reflect the fact that we are using better materials and designs today.

An Inflation Adjustment (IA) will be used to account for the difference between the general inflation rate (measured by the chained price index for the gross domestic product, GDP) and the inflation rate in the highway construction sector (measured by the chained price index for state and local construction spending, SLC). For 2003, the SLC rate was 0.21% higher than the GDP rate. As a result, the cost of future maintenance and rehabilitation activities will be multiplied by $(IA)^n$, where n equals the number of years until the treatment will be applied.

Table 2. Bituminous Pavement with Low ESALs (7 Million or less)

Pavement Age	Treatment
0	Initial Construction
6	Route & Seal Cracks
10	Surface Treatment
20	Mill & Overlay
23	Route & Seal Cracks
27	Surface Treatment
35	Mill & Overlay
38	Route & Seal Cracks
43	Surface Treatment
50	End of Analysis Period (no residual value)

Table 3. Bituminous Pavement with High ESALs (> 7 Million)

Pavement Age	Treatment
0	Initial Construction
7	Crack Fill
15	Mill & Overlay
20	Crack Fill
27	Mill & Overlay
32	Crack Fill
40	Mill & Overlay
45	Crack Fill
50	End of Analysis Period (no residual value)

Table 4. All Concrete Pavements

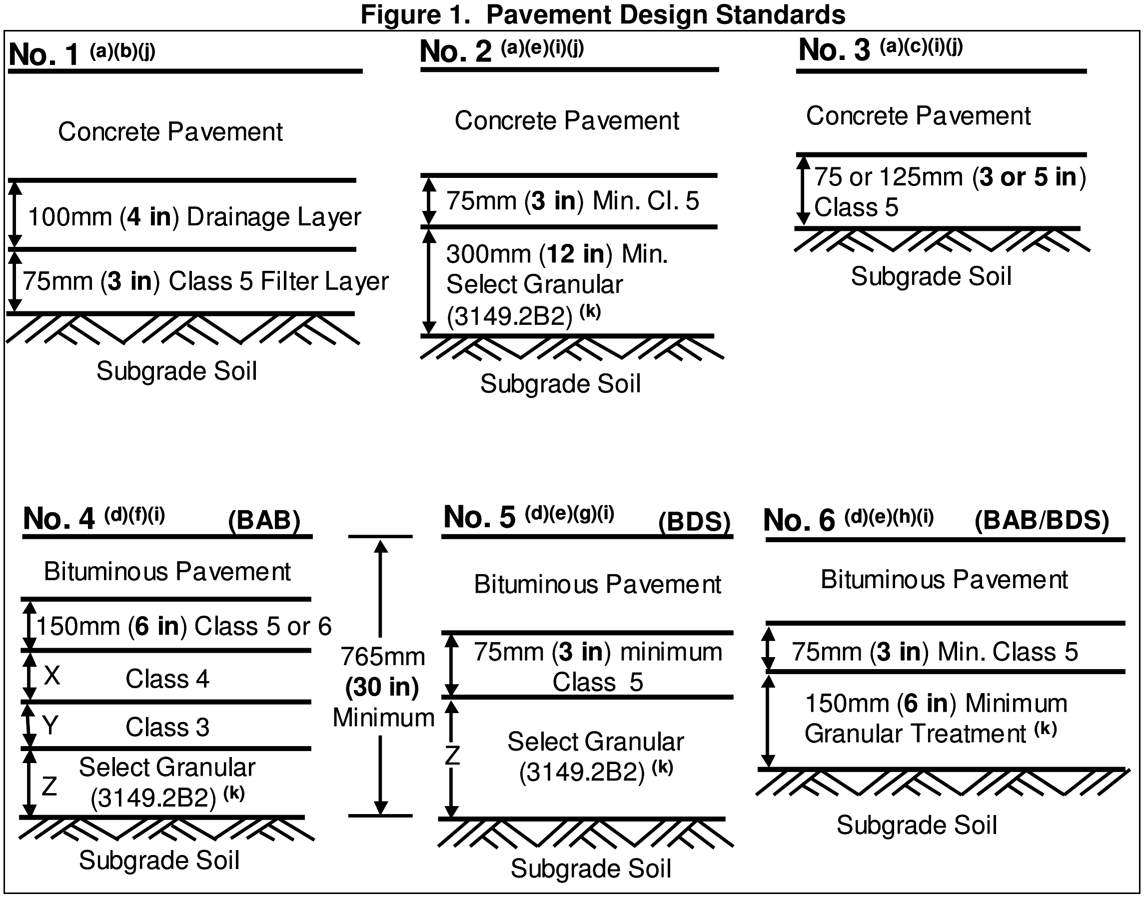
Pavement Age	Treatment
0	Initial Construction
17	Joint Reseal and Minor CPR (partial depth repairs)
27	Minor CPR (partial depth repairs) and some full depth repairs
40	Major CPR (Full Depth Repair & Diamond Grinding)
50	End of Analysis Period (last rehab has 33% residual life)

Part III. Pavement Design Standards Policy

The pavement structural designs used in the pavement selection process shall be in accordance with Figure 1 of this document. Modifications to the standard design features, but not the pavement type, will be permitted after the pavement selection process for the purpose of providing the most appropriate design that meets specific needs and/or maximizes the use of locally available materials.

These pavement designs are subject to change and will be evaluated periodically in terms of the Mn/ROAD and SHRP research findings and Mn/DOT's objectives in designing and constructing pavements that will provide smooth ride and long-term performance and service life.

Figure 1. Pavement Design Standards



(a), (b),(c)…(k) Refer to Design Option Notes

Design Option Notes

(a) Design #'s 1, 2 and 3

- Concrete pavement structural designs shall be based on 35-year design lane CESALs for Design #1, 2, and 3.
- Use current standard design procedures and practices.

(b) Design #1

- Table 1, which is shown in "Permeable Aggregate Base Drainage Systems Design Guidelines," dated July 1994, should be used in determining when and where a drainage layer should be given consideration for incorporation into the pavement design.

- Design of the permeable aggregate base drainage system, if recommended, should be in accordance with the above design guidelines.

(c) Design #3

- Use 75mm (**3 in**) and 130mm (**5 in**) Class 5, Aggregate Base, when constructing over granular [less than 20 percent passing 0.075mm (**#200**) Sieve] and non-granular (plastic/semi-plastic) subgrade soils, respectively.

(d) Design #'s 4, 5 and 6

- Bituminous pavement structural designs shall be based on 20-year design lane BESALs.

(e) Design #'s 2, 5 and 6

- Subgrade design R-Value should be adjusted to reflect the increase in support value provided by the use of Select Granular Material (3149.B2). The adjustment should be based on the design chart for Bituminous Aggregate Base (Inv. #183), Figure 5-36, Geotechnical and Pavement Manual, using the design R-Value and the thickness of the Select Granular Material in terms of the granular equivalent factor (G.E. = 0.50).

(f) Design #4, Bituminous Aggregate Base Pavement (BAB)

- Determine structural design thickness in accordance with the Bituminous Aggregate Base design chart (Inv. #183), Figure 5-3.6, Geotechnical and Pavement Manual.

- Provide a minimum pavement structural thickness of 765mm (**30 in**); however, if the 20-year design lane BESALs exceeds 7 million, then the minimum thickness shall be increased to 900mm (**36 in**).

- If the design chart provides a total thickness that is:

  1. Greater than the minimum pavement structural thickness, then the structural thickness design shall be in accordance with the chart.

  2. Less than the minimum pavement structural thickness, then the structural thickness shall be increased to the minimum thickness using Class 3 or Select Granular or a combination of these materials. However, the type(s) of material selected should be based on economic considerations and ease of construction.

- If the project 20-year design lane BESALs are 7 million or less with the inplace/native subgrade soils meeting the requirements for Granular Material [3149.2B1, less than 20 percent passing the 0.075mm (**#200**) Sieve] and the required "Z" thickness is greater than 300mm (**12 in**), the "Z" thickness may be reduced to 300mm (**12 in**). (R-Value adjustment shall be based only on the thickness of the select granular material.)

(g) Design #5 - Bituminous Deep Strength Pavement (BDS)

- Determine structural design thickness in accordance with the Bituminous Full-Depth design chart (Inv. #195), Figure 5-3.7, Geotechnical and Pavement Manual.

- Provide a minimum structural thickness of 765mm (**30 in**) [consisting of bituminous pavement, 75mm (**3 in**) of Class 5, and Select Granular Material]. If the 20-year design lane BESALs exceeds 7 million, the minimum structural thickness shall be increased to 900mm (**36 in**).

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- Refer to Design Option Note (f) for a possible reduction in the "Z" thickness.

(h) Design #6

- Determine structural design thickness (bituminous and/or aggregate base thickness) in accordance with the Bituminous Aggregate Base and Bituminous Full-Depth Design Charts, Figures 5-3.6 and 5-3.7, respectively, Geotechnical and Pavement Manual.

- Provide a 150mm (**6 in**) minimum granular treatment under the 75mm (**3 in**) of Class 5, Aggregate Base. The treatment may be constructed with Class 5, Aggregate Base, and/or Select Granular Material (3149.2B2). The depth and type(s) of granular treatment material will be determined by the District Material Engineer and the Pavement Design Engineer and will be evaluated relative to economic considerations and ease of construction.

(i) Design #'s 2, 3, 4, 5 and 6

- If the subgrade soils consist of non-granular material [greater than 20 percent passing 0.075mm (**#200**) Sieve], then consideration should be given to providing subcut drains for design #'s 3, 5 and 6 and pavement edge drains for design #'s 4 and 7. These drains should be in accordance with the guidelines provided in Chapter 5, Geotechnical and Pavement Manual.

(j) Design #'s 1, 2 and 3

All transverse contraction joints which are constructed in pavements less than 270mm (**10.5 in**) thick shall utilize 32mm (**1.25 in**) minimum diameter dowel bars for load transfer. (In accordance with Figure 5-297-221M, Standard Plans.)

(k) Design #'s 2, 4, 5 and 6

Typical Select Granular subgrade treatments for rural and urban sections are as shown in Figures 2 and 3. Due to project specific constraints such as excess grading soils on the project, lack of locally available select granular material, long hauls, etc., the actual design may need to be different. At the time of project submittal, the District Materials/Soils Engineer should provide the treatment(s) that represent what will actually be designed and constructed. It may be that several treatment types are applicable. The location and length of the various treatments are required for a representative pavement selection preliminary estimate.

Provide drains when select granular material overlies non-granular soils (greater than 20% passing 0.075mm (**#200**) sieve) in accordance with guidelines provided in Chapter 5, "Geotechnical & Pavement Manual." In rural sections, the ditch bottom must be an adequate distance below drain exits and the bottom of the select granular material. However, if adequate ditch depth cannot be provided for the drain outlets, then the select granular material should be placed the full width of the embankment. In urban sections, drains must exit to the storm sewer.

Figure 2. Typical Full-Width Select Granular Subgrade Treatment, Rural Section

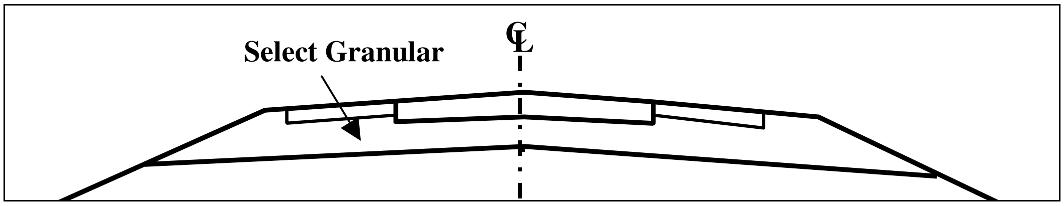
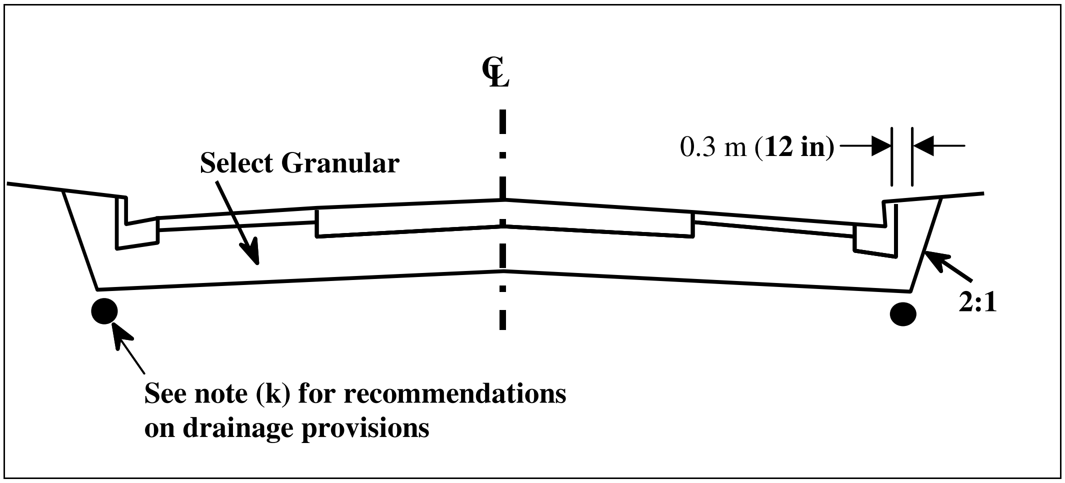


Figure 3. Typical Select Granular Subgrade Treatment, Urban Section



Questions
Questions regarding this Technical Memorandum should be addressed to Curt Turgeon, Pavement Engineer at (651) 779-5535, curtis.turgeon@dot.state.mn.us

Any questions regarding the publication or distribution of this Technical Memorandum should be referred to Benjamin Christensen, Design Standards Unit 651-284-3447, or Mohammad Dehdashti, Design Standards Engineer 651-296-4859. All active Memoranda and a list of historical Technical Memoranda can be viewed at http://www.dot.state.mn.us/tecsup/tmemo/index.html

Attachments
FORMULA 1: Bituminous Pavement with Low ESALs (7 Million or less)
FORMULA 2: Bituminous Pavement with High ESALs (> 7 Million)
FORMULA 3: Concrete Pavement (All traffic levels)

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FORMULA 1: Bituminous Pavement with Low ESALs (7 Million or less)

If the 20-year projected AADT is 10,000 or less, the surface treatment should be a chip seal. If the AADT exceeds 10,000 vehicles, the surface treatment should be micro-surfacing and the costs adjusted accordingly.

$$\mathbf{C = A + C_A[(Ers)(PWFnrs_1)(I_A)^{nrs_1} + (Est)(PWFnst_1)(I_A)^{nst_1} + (Emo_1)(PWFnmo_1)(I_A)^{nmo_1}}$$
$$\mathbf{+ (Ers)(PWFnrs_2)(I_A)^{nrs_2} + (Est)(PWFnst_2)(I_A)^{nst_2} + (Emo_2)(PWFnmo_2)(I_A)^{nmo_2}}$$
$$\mathbf{+ (Ers)(PWFnrs_3)(I_A)^{nrs_3} + (Est)(PWFnst_3)(I_A)^{nst_3}\,]}$$

Where C = Comparative Cost Per km **(Mile)**

C_A = Cost Adjustment = 0.90. Since the activity costs are based on historical projects, this factor is used to reduce the cost of the rehabilitation activities by 10 percent to reflect the fact that we are using better materials and designs today.

I_A = Activity costs will be adjusted by the difference between the general inflation rate (measured by the chained price index for the gross domestic product, GDP) and the inflation rate in the highway construction sector (measured by the chained price index for state and local construction spending, SLC). For 2003, the SLC rate was 0.21% higher than the GDP rate. As a result, the Inflation Adjustment (I_A) is 1.0021.

r = Discount Rate
n = Analysis Period, in years (50-years)
A = Initial Construction Cost per km **(Mile)**

Ers = Cost per mile for Route & Seal (same for all)
Est = Cost per mile for Surface Treatment (same for all)
Emo_1 = Cost per mile for 1st Mill & Overlay
Emo_2 = Cost per mile for 2nd Mill & Overlay

nrs_1 = Years to 1st Route & Seal = 6 years
nst_1 = Years to 1st Surface Treatment = 10 years
nmo_1 = Years to 1st Mill & Overlay = 20 years
nrs_2 = Years to 2nd Route & Seal = 23 years
nst_2 = Years to 2nd Surface Treatment = 27 years
nmo_2 = Years to 2nd Mill & Overlay = 35 years
nrs_3 = Years to 3rd Route & Seal = 38 years
nst_3 = Years to 3rd Surface Treatment = 43 years

PWF = Present Worth Factor = $\frac{1}{(1+r)^n}$, where n = nrs_1, ncs_1, nmo_1, etc.

FORMULA 2: Bituminous Pavement with High ESALs (> 7 Million)

$$C = A + C_A[(Ecf)(PWFncf_1)(I_A)^{ncf_1} + (Emo_1)(PWFnmo_1)(I_A)^{nmo_1} + (Ecf)(PWFncf_2)(I_A)^{ncf_2}$$
$$+ (Emo_2)(PWFnmo_2)(I_A)^{nmo_2} + (Ecf)(PWFncf_3)(I_A)^{ncf_3} + (Emo_3)(PWFnmo_3)(I_A)^{nmo_3}]$$

Where C = Comparative Cost Per km **(Mile)**

C_A = Cost Adjustment = 0.90. Since the activity costs are based on historical projects, this factor is used to reduce the cost of the rehabilitation activities by 10 percent to reflect the fact that we are using better materials and designs today.

I_A = Activity costs will be adjusted by the difference between the general inflation rate (measured by the chained price index for the gross domestic product, GDP) and the inflation rate in the highway construction sector (measured by the chained price index for state and local construction spending, SLC). For 2003, the SLC rate was 0.21% higher than the GDP rate. As a result, the Inflation Adjustment (I_A) is 1.0021.

r = Discount Rate
n = Analysis Period, in years (50-years)
A = Initial Construction Cost per km **(Mile)**

Ecf = Cost per km **(mile)** for Crack Fill (same for all)
Emo_1 = Cost per km **(mile)** for 1st Mill & Overlay
Emo_2 = Cost per km **(mile)** for 2nd Mill & Overlay
Emo_3 = Cost per km **(mile)** for 3rd Mill & Overlay

ncf_1 = Years to 1st Route & Seal = 6 years
nmo_1 = Years to 1st Mill & Overlay = 20 years
ncf_2 = Years to 2nd Crack Fill = 23 years
nmo_2 = Years to 2nd Mill & Overlay = 35 years
ncf_3 = Years to 3rd Crack Fill = 38 years
nmo_3 = Years to 3rd Mill & Overlay = 43 years

PWF = Present Worth Factor = $\frac{1}{(1+r)^n}$, Where n = ncf_1, nmo_1….nmo_3

FORMULA 3: Concrete Pavement (All traffic levels)

$$C = A + C_A[(Ecpr_1)(PWFncpr_1)(I_A)^{ncpr1} + (Ecpr_2)(PWFncpr_2)(I_A)^{ncpr2}$$
$$+ (0.67)(Ecpr_3)(PWFncpr_3)(I_A)^{ncpr3}]$$

Where C = Comparative Cost Per km **(Mile)**

C_A = Cost Adjustment = 0.90. Since the activity costs are based on historical projects, this factor is used to reduce the cost of the rehabilitation activities by 10 percent to reflect the fact that we are using better materials and designs today.

I_A = Activity costs will be adjusted by the difference between the general inflation rate (measured by the chained price index for the gross domestic product, GDP) and the inflation rate in the highway construction sector (measured by the chained price index for state and local construction spending, SLC). For 2003, the SLC rate was 0.21% higher than the GDP rate. As a result, the Inflation Adjustment (I_A) is 1.0021.

r = Discount Rate
n = Analysis Period, in years (50-years)
A = Initial Construction Cost per km **(Mile)**

$Ecpr_1$ = Cost per mile for 1st Concrete Rehab
$Ecpr_2$ = Cost per mile for 2nd Concrete Rehab
$Ecpr_3$ = Cost per mile for 3rd Concrete Rehab (cost is reduced by 33% to account for residual value of last rehab, 5 years left on the expected 15 year fix)

$ncpr_1$ = Years to 1st Concrete Rehab = 17 years
$ncpr_2$ = Years to 2nd Concrete Rehab = 27 years
$ncpr_3$ = Years to 3rd Concrete Rehab = 40 years

PWF = Present Worth Factor = $\frac{1}{(1+r)^n}$, where n = $ncpr_1$, $ncpr_2$, etc.