10. What analysis period used for each pavement type?

50 years for high volume freeways
30 years for secondary highways and rehabilitation

11. Are there different foundation/base requirements for AC and PCC?

No.

12. For those agencies that use smoothness as criteria do they use the same initial serviceability in design?

Yes.

13. Typical costs and method of contract measurement

Difficult to determine. It is regional and contract specific.

ACP in place $/______________/ton sy cy other
JPCP (slab only) $/______________sy cy other
JRCP (slab only) $/______________sy cy other
CRCP (slab only) $/______________sy cy other

14. How important is first cost versus future costs?

They are weighted the same and used in the LCCA. The LCC dominates the decision process.

15. Is life cycle cost analysis used?

Yes

16. Analysis period

50 years new and reconstruction
30 years rehabilitation

17. Discount Rate (how established)

Ministry of Finance (similar to OMB) social discount rate for infrastructure. The current rate is 5.3 percent and they suggest a 2 percent sensitivity level.

Engineering and Construction Considerations

Factors used, scoring system, primary factors secondary factors, weights, importance, etc

Factor	Considered	Primary or Secondary	Importance (0 to 5)	Comments
1. Roadway/lane geometrics (lane widths, cross slopes, ability to provide drainage)	Y	P	5	Is a given with all designs.
2. Highway functional class	Y	P	3	
3. Traffic	Y	P	5	
4. Roadway peripheral features (overhead clearance, weigh-in-motion, guardrails, etc)	Y	S	3	
5. Construction considerations				
a. Staging	Y	S	3	Is considered but minimal impact.
b. Clearance for equipment	N			
c. Construction operations	Y	S	2	
d. Traffic operations during construction	Y	S	3	
e. Construction seasons	Y	S	2	Scheduled to prevent late season paving.

Factor	Considered	Primary or Secondary	Importance (0 to 5)	Comments
6. Consideration of future maintenance operations (maintenance of traffic, ease of maintenance)	Y	S	3	
7. Performance of similar pavements in the area	Y	P	4	Tend to keep similar pavement types together.
8. Availability of local materials, contractor's capabilities, and experienced agency personnel.	Y	P	5	If materials or expertise is not available, it will drive up costs.
9. Pavement Continuity				
a. Adjacent sections	Y	P	4	
b. Adjacent lanes	Y	P	5	Would not put significantly differing materials in adjacent lanes.
10. Noise issues	Y	P	3	MTO has a policy on noise and pavement type.
11. Subgrade soils	Y	P	5	
12. Climate	Y	S	4	
13. District or local preference	Y	S	2	Regions can exercise local preference on a project by project basis
14. Ease of maintenance	Y	S	2	
15. Recycling	Y	P	3	
16. Conservation of materials and energy	Y	P	3	
17. Stimulation of Competition	Y	P	3	
18. Safety considerations (rutting, friction, lighting, etc)	Y	P	5	
19. Smoothness	Y	P	3	

18. Initial Costs – Estimating procedure

HiCo (Highway Cost) database is used. Contains an average of 3 lowest bids on recent projects in each regional area. Designer has the ability to review the prices to see what are reasonable for the project area.

19. How does agency determine unit cost to include in the cost analysis (standardized or project by project)? Is the size of the project used in the database considered (economy of scale)? Age of the price data. How often updated.

HiCo (Highway Cost) database is used. Contains an average of 3 lowest bids on recent projects in each regional area. Designer has the ability to review the prices to see what are reasonable for the project area. The costs are updated electronically continuously and are kept for the past 10 + years.

20. Are price adjustment factors used for any materials, and if so are they used in the life cycle cost analysis.

Yes. Most materials and placement have price adjustment. They are not included in the LCCA.

21. Actual cost versus estimated cost (are completed projects evaluated for overruns etc.)

Only bid costs are used.

22. Routine maintenance (how estimated, operations included)

Includes items such as ditching, grass cutting, etc. These are considered similar for all options and are not included in the LCCA.

23. Rehabilitation (how is timing estimated, techniques used, etc.)

Based on LCCA models developed by a consultant (ERES) in conjunction with MTO and industry representatives. Based on serviceability levels, trigger values and performance measures.

Salvage Value (remaining life): Included.
Residual value (recycling): Not included. Considered equal for all pavements.
Construction traffic control (crossovers, added lanes, barriers, detours, etc.): Not included. Part of normal design, not LCCA.
Engineering and administration: Not included in LCCA. Assume that everything outside of the pavement section is the same. Not include in initial or future costs.

24. How are users costs weighted in relation to agency costs?

Not used currently. Will likely be in 2004.

25. Vehicle operating costs

Not used currently. Will likely be in 2004.

26. User Delay

Not used currently. Will likely be in 2004.

27. Description of the analysis process

28. Routine maintenance

Shoulder grading, ditch cleanout, pothole filling, spall repairs, etc.

29. Preventive maintenance

Crack sealing, surface seals, selective resurfacing (area patching), thin lift resurfacing, hot in-place recycling, micro-surfacing, NovaChip, Dynapatch, slurry seals, etc.

30. What are the state's standard routine and preventive maintenance operation and schedule by pavement type?

See ERES Benefits of New Technology Report

31. Allocation of resources between maintenance, rehab, new and reconstruction

Current focus is on rehabilitation and preventive maintenance. Not much new construction.

32. Do you have a formal system to track pavement condition, cost, and survivability?

Yes. Detailed pavement management system.

33. Do you allow old concrete to be recycled? If so into what products? Percentage limits?

Yes. 100 percent can be recycled into base/subbase.

34. Do you allow HMA materials to be recycled? If so into what products? Percentage limits?

Yes. 30 percent can be recycled into base/subbase. Percentage in HMA varies from about 10 to 30 percent depending on the type of mix.

Purpose

The purpose of this interview is to gain insight into the following Pennsylvania Department of Transportation practices:

- Pavement type selection
- Engineer's estimate and life cycle cost analysis
- Other items that affect cost

Agency Interviewed

Pennsylvania Department of Transportation
400 North Street
Sixth Floor
Harrisburg, PA 17101-1900

Person(s) Interviewed

Name	Title	Phone	Email
Mr. Dan Dawood	Chief, Pavement Analysis & Design Section	(717) 787-4246	ddawood@state.pa.us

Overview of Procedure and General Notes:

The life cycle cost procedure is documented in a manual from the Pavement Design Analysis Section. The life cycle cost analysis procedure is in the form of an excel spreadsheet and is performed on all interstate project exceeding $1M and all other projects exceeding $10M, regardless of the funding source. A deterministic approach is used, and the inputs represent the median values, rather than the average values. The software can be obtained from PennDOT from their website.

The procedure has been recently updated and can be downloaded from the Pennsylvania DOT website. FHWA is currently reviewing the updated procedure. The current update was prepared to answer questions and issues that had been raised by industry related to pavement type selection. The Department is considering adding a probabilistic approach to the procedure, but that has yet to be completed.

The district determines the options to be considered. However, a field view or oversight committee that consists of district and central personnel and FHWA personnel is established that overviews the type of alternates that are considered for each project. Industry is not represented on this field view committee. The only external agency involved in the procedure is FHWA. A minimum of two alternates are considered for each project --- one PCC surfacing and one HMA surfacing option. The types of options that are considered consist of a decision between pavement preservation and reconstruction unless it is a new alignment project. The options for reconstruction are listed below.

- Jointed plain concrete pavements with a 4-inch open-graded drainage layer stabilized with asphalt or cement. If 10 percent patching is required, this is considered total reconstruction.
- Full-depth hot-mix asphalt concrete pavements – a drainage layer is not required for the HMA pavement. If there are severe distresses (rutting and cracking), this is considered total reconstruction.

Rubblization is not used that much in Pennsylvania. However, crack and seat is used quite extensively. The crack and seat includes sawing the PCC slabs and cutting the steel.

In some cases, the LCCA can be waived depending on the structure of adjacent lanes or adjoining sections with the same type of surface. Chapter 11-1 in the Pavement Design Analysis Manual gives a summary of when the rules can be bent or waived. Composite pavements are not considered and there is no bin with the LCCA for considering this type of pavement structure.

The LCCA procedure is used to calculate the present worth costs for each alternate. Equivalent annual costs have been used on very few projects. If the cost between the two alternatives has a difference of greater than 10 percent, the alternative with the lowest costs is selected, unless the district has some reason for selecting the other alternative, which does not happen very often. If the cost between the two alternatives is less than 10 percent, the district selects the option based on other factors. The district executive reviews the recommendation and approves or rejects the recommendation. In most cases the district executive approves the recommendation. The final recommendation then goes to the central office for review and concurrence.

User costs for initial construction are not considered as part of the LCCA because it is assumed that they will be equal for all alternatives. This assumption is dependent on the type and number of structures that occur along the project length.

1. Do you have a documented pavement type selection procedure for:

New Construction – Yes and it is documented in Chapter 11 of the Life Cycle Cost Analysis Procedure of the Pavement Design Analysis Manual.
Reconstruction – Yes and it is documented in Chapter 11 of the Life Cycle Cost Analysis Procedure of the Pavement Design Analysis Manual.
Rehabilitation – Yes and it is documented in Chapter 11 of the Life Cycle Cost Analysis Procedure of the Pavement Design Analysis Manual.

The following types of design strategies, new construction and rehabilitation by surface type are considered as part of the LCCA:

Bituminous Pavements:	HMA or bituminous overlay
	HMA overlay – crack-n-seat
	HMA Reconstruction – Rubblization
	HMA Reconstruction – Remove & replace

PCC Pavements:
- Concrete pavement rehabilitation
- Bonded & Unbounded PCC overlays
- PCC overlays – Unbounded; crack-n-seat
- PCC Reconstruction – Rubblization
- PCC Reconstruction – Remove & replace

2. How long have you used the current type selection procedure?

The procedure was developed around 1985. It is about 18 years old. The current procedure has been automated and the software is available for use from the PennDOT website. However, there is no periodic review of the procedure.

3. Changes made over the last 5 years:

The maintenance schedules and initial service lives are routinely updated from data that has been collected through or for their pavement management system. In addition, the difference in costs between two alternatives of 5 percent was increased to 10 percent during the last update.

> **What prompted the change?** New data had been collected for their pavement management system and to answer questions or concerns that the asphalt industry had on the procedure regarding the comparison of different alternatives

4. Have you used alternative bidding as a means of making a pavement type selection during the past 5 years? If yes describe the process. Was alternate bidding used on a Federal-aid project? If so, what was the basis of FHWA's approval?

The Pennsylvania DOT does not plan to use the alternative bidding process in the future. The Department has used the alternative bidding process once, which is on-going. This is a federal aid project, but has yet to be reviewed and approved by FHWA. This project has two alternatives which have a 3 percent cost difference between the two alternatives, based on the engineers estimate. This first project is considered to be a pilot project. However, the Department has no intentions to continue or implement this process in the future.

5. Importance and extent of industry involvement in the development of type selection process?

Industry was not involved in the development of the life cycle cost analysis procedure. Industry is only involved when they ask to be involved. FHWA is the only external agency involved in the process. The Department wants two strong industries in Pennsylvania from a competitive standpoint.

6. How was the selection process implemented within the agency?

The Department developed the process or procedure in-house without involving industry. The LCCA is completed at the district level. The district engineer recommends the pavement type to be considered from the LCCA. The recommendation is forwarded to the district executive. The district executive recommends the selection to the central office for review. The central office evaluates the recommendation and forwards the recommendation to the FHWA for concurrence.

7. How is the type selection process related to the overall project selection, budgeting, planning process used by the agency?

There is no interrelationship between project selection, budgeting and planning within the pavement type selection process. The budget is predetermined for each project. The Department assumes that both or all alternatives considered within the LCCA procedure provide the same benefit to the DOT. The winning bid for the construction project must be within 10 percent of the engineers estimate. If the bid is greater than 10 percent of the engineers estimate, then the project is pulled, evaluated and re-advertised. However, the pavement type selection will not change once established for a particular project.

8. Pavement types used for new construction or reconstruction over the last 5 years

Pavement Type	Approximate lane miles		Performance (Good Fair Poor)
	Interstate	Other 4 lane	
Full depth ACP			This group really falls under ACP with 6-inch or less aggregate base.
Deep Strgth ACP			Does not use asphalt treated base layers.
ACP(less than 6") agg base	75 – 125	225 – 250	Within the last 2 to 3 years. Rated between good to fair. The Department has had some problems with Superpave mixes in the past.
Jointed Plain (JPCP)	450 – 500	225 – 275	Rated between good to fair. The Department has had some problems on a few projects with mid-slab cracking.
Jointed Reinforced (JRCP)			Does not use this type of pavement.
Continuously Reinf. (CRCP)			Does not consider this type of pavement.

9. Thickness design procedure used and design life (if AASHTO which version)

A 20-year design period is used for both ACP and PCCP.

ACP: The 1993 AASHTO Design Guide is used. In addition, the Department uses a frost factor for designing ACP. This frost factor is separate from the DARWin program. The increase in pavement structural thickness is applied to the HMA base thickness. The Department does not like to use more than 12 inches of an unbound aggregate base material for any design or roadway. The standard deviation used in design is 0.45. Moisture coefficients are also used in the design and are dependent on the type of material. The following table summarizes the layer coefficients that are used in the procedure.

Layer	Material Type	Structural Layer Coefficient
Wearing & Binder Layers	Superpave	0.44
	ID-2, ID-3	0.44
	FB-1, FB-2	0.20
	FJ-1, FJ-1C, FJ-4	0.35
Base Layer	Superpave	0.40
	Bituminous Concrete Base	0.40
	Crushed Aggregate	0.14
	Crushed Aggregate, Type DG	0.18
	Bituminous Base	0.30
	Aggregate Cement Base	0.40
	Aggregate Lime Base	0.40
Subbase Layer	Open-Graded	0.11
	No. 2 Subbase	0.11
	Asphalt Treated Permeable Base	0.20
	Cement Treated Permeable Base	0.20
	Rubblized PCC	0.20

PCCP: The 1993 AASHTO Design Guide is used. The frost factor used or considered in the design of ACP is not used or considered in PCCP designs. The average 28-day flexural strength used in design is 631 psi, and the modulus of elasticity is 4,000,000 psi. However, the District can use other values based on their experience and data. A loss of support is used in design --- values of 0.5 and 1.0 are used and depend on the material. The standard deviation used is 0.35.

10. What analysis period used for each pavement type?

A 40-year analysis period is used for both ACP and PCCP.

11. Are there different foundation/base requirements for AC and PCC?

Yes, as noted below.

- Subgrade preparation is the same for all alternatives. Lime or lime-fly ash stabilization is considered for both ACP and PCCP. This subgrade stabilization process is being used more routinely in Pennsylvania. The stabilization process has provided good performance in areas with frost susceptible or very weak soils. The Department has over-excavated frost susceptible soils for both pavement types. This is the other process that is being used to improve the subgrade foundation for both pavement types. The subgrade improvement process used is the same for both or all alternatives of a project or LCCA procedure.
- The ACP alternative, however, always includes a 6 to 8-inch dense- graded aggregate base for thick HMA bases (greater than 7 inches), but not for PCCP.
- The PCCP alternative always includes a 4 to 6-inch asphalt or portland cement open-graded drainage layer under PCCP, but not under ACP.

12. For those agencies that use smoothness as criteria do they use the same initial serviceability in design?

No. The following summarizes the values used in design for ACP and PCCP.

PSI-Value for LCCA and Design	Roadway Type	PCCP	ACP
Initial Value	Interstate or Limited Access Roadways	4.5	4.2
	All Other Roadways	4.5	4.2
Terminal Value	Interstate or Limited Access Roadways	3.0	3.0
	All other 4-lane Roadways	2.5	2.5
	Local Roadwdays	2.0	2.0
NOTE: However, the department uses a lower IRI-value for ACP in accepting pavement construction as part of their acceptance program. The IRI-value for PCCP is higher because of the tinning requirements.			

The above values are given in Chapter 6-12 of the Pavement Design Analysis Manual.

13. Typical costs and method of contract measurement

ACP in place \$/____See below___________/~~ton~~ sy ~~cy other~~

HMA Thickness, inches	Layer Type	In-Place Costs, \$/sy
1.5	Wearing Surface	4.5 to 5.5
2	Binder Layer	6.25 to 6.8
5 to 7	Base Layer	About 7.0
NOTE: The Department pays for the binder separately. The binder costs is not included in the in place cost tabulated above. The cost for the liquid asphalt includes a price adjustment factor for HMA. The costs noted above have been reasonably stable over the past years.		

JPCP (slab only) \$/___65 to 75__________sy ~~cy other~~
Price adjustment factors for PCCP are not used.
JRCP (slab only) \$/____NA_________sy cy other
CRCP (slab only) \$/____NA_________sy cy other

14. How important is first cost versus future costs?

The Pennsylvania DOT does not use any kind of scoring system in selecting the pavement surface type. It is based on the total life cycle costs for each alternate or option. Present Worth cost is what matters and used in selecting the type of pavement. First costs and future costs is an issue, but not considered --- not open for discussion.

15. Is life cycle cost analysis used?

Yes. As noted above, the total life cycle costs for each alternate or option to select the type of design strategy or type of pavement surface.

16. Analysis period

The analysis period is 40 years for both types of pavements or for each design strategy considered in the LCCA.

17. Discount Rate (how established)

A discount rate of 6 percent is used. Industry has complained with the value, but has not been changed since the procedure was developed. This value is considered fixed but could be up for future consideration.

18. Initial Costs – Estimating procedure

The Department does not have an estimating procedure. The unit costs for each cost item are collected from the bid items. The median value for each cost item is used in the LCCA.

19. How does agency determine unit cost to include in the cost analysis (standardized or project by project)? Is the size of the project used in the database considered (economy of scale)? Age of the price data. How often updated.

The unit costs are complied for every bid item on a state wide basis and stored in the Contract Management System (CMS) database. These costs can be broken down by district, quantities, high and low bids, averages of all winning bids.

The age of the price data is updated after every letting.

20. Are price adjustment factors used for any materials, and if so are they used in the life cycle cost analysis.

For ACP, price adjustment factors are used. For PCCP, price adjustment factors are only considered for the HMA permeable base layers. The price adjustment factors are not used directly in the LCCA, but are indirectly included in the cost computations.

Engineering and Construction Considerations

Factors used, scoring system, primary factors secondary factors, weights, importance, etc

Factor	Considered	Primary or Secondary	Importance (0 to 5)	Comments
1. Roadway/lane geometrics (lane widths, cross slopes, ability to provide drainage)	*Yes*	*S*	*2*	*Steep grades can be a factor if the difference in cost between the two alternatives in less than 10 percent.*
2. Highway functional class	*No*			*Generally defines that a LCCA should be done; i.e.; interstate and limited access roadways.*
3. Traffic; Truck Overall Traffic	*Yes* *Yes*	*P* *S*	*3* *3*	*These items or factors are considered when there is less than a 10 percent difference between the costs.*
4. Roadway peripheral features (overhead clearance, weigh-in-motion, guardrails, etc)	*Yes*	*S*	*3*	
5. Construction considerations				
a. Staging	*Yes*	*P*	*3*	
b. Clearance for equipment	*No*			
c. Construction operations	*No*			*This factor maybe considered in the future based on comments or complaints from industry.*
d. Traffic operations during construction	*Yes*	*S*	*3*	*A factor that is considered, but most traffic control and delay costs are assumed to be equal between each alternate or option for initial construction.*
e. Construction seasons	*No*			
6. Consideration of future maintenance operations (maintenance of traffic, ease of maintenance)	*Yes*	*P*	*5*	*Definitely has an effect on the user or delay costs for the maintenance cycling and cost of the maintenance.*
7. Performance of similar pavements in the area	*Yes*	*P*	*4*	*Considered on a project by project bases. This factor is implemented on a system wide analysis and will change the maintenance cycles, and can have a significant effect on the LCCA. These are updated on a 4 to 5 year basis.*

Engineering and Construction Considerations

Factors used, scoring system, primary factors secondary factors, weights, importance, etc

Factor	Considered	Primary or Secondary	Importance (0 to 5)	Comments
8. Availability of local materials, contractor's capabilities, and experienced agency personnel.	*No*			
9. Pavement Continuity				*Pavement continuity factors do have an effect but only when the cost difference between the two options are less than 10 percent.*
a. Adjacent sections	*Yes*	*S*	*2*	
b. Adjacent lanes	*Yes*	*S*	*2*	
10. Noise issues	*Yes*	*S*	*2*	
11. Subgrade soils	*Yes*	*S*	*2*	*The foundation for all pavement designs or options must have a good foundation, which is considered in design.*
12. Climate	*No*			
13. District or local preference	*Yes*	*S*	*4*	*When the costs difference is less than 10 percent.*
14. Ease of maintenance	*Yes*	*S*	*4*	*When the costs difference is less than 10 percent.*
15. Recycling	*No*			*However, this factor could have an effect on the rehabilitation strategy selection.*
16. Conservation of materials and energy	*No*			
17. Stimulation of Competition	*Yes*	*S*	5	*[More than just those projects where the difference in costs is less than 10 percent.]*
18. Safety considerations (rutting, friction, lighting, etc)	*Yes*	*S*	*4*	*When the costs difference is less than 10 percent.*
19. Smoothness	*Yes*	*S*	*4*	*When the cost difference is less than 10 percent.*

21. Actual cost versus estimated cost (are completed projects evaluated for overruns etc.)

Not during the LCCA process or within the LCCA procedure. Overruns are evaluated from a CMS construction management systems approach.

22. Routine maintenance (how estimated, operations included)

Routine maintenance if included from a pavement surface type. The type and timing of the routine maintenance applications if obtained from the maintenance department. This information and data are included in the Maintenance Operations Reporting Information System (MORIS). The following lists the annual maintenance costs for each surface type. The maintenance and rehabilitation activity time lines are included as figure 1.

Pavement Surface Type	Annual Maintenance Cost, $/Lane Mile
PCCP	825
ACP	1,825

23. Rehabilitation (how is timing estimated, techniques used, etc.)

The type and timing of the rehabilitation activities for a pavement surface type is determined though the data included in the pavement management system database. The median values are included in the LCCA. This information is input initially from the county managers. The resurfacing schedule can be shortened but not extended on high-volume heavy truck routes based on the district's experience. Currently the type of approach is solely based on the PMS data. The following lists the time to first resurfacing and the interval between resurfacings.

Pavement Surface Type	Time to First Resurfacing, yrs.	Interval of Resurfacing, yrs.
PCCP	30	10
ACP	10	10

Salvage Value (remaining life): No, none is used or considered in the LCCA.
Residual value (recycling): No, none is used or considered in the LCCA.
Construction traffic control (crossovers, added lanes, barriers, detours, etc.): The traffic control costs during construction are considered to be equal between the different options or alternatives.
Engineering and administration: No, none is used or considered in the LCCA.

24. How are users costs weighted in relation to agency costs?

No; Agency costs are not considered.

25. Vehicle operating costs

Yes the vehicle operating costs are a part of the user delay costs. Idling costs, stopping costs, and time value costs are determined by vehicle type. An inflation factor is determined by vehicle class and multiplied by the time value costs. This is described and discussed in the appendix and Chapter 11.6 of the Pavement Design Analysis Manual.

26. User Delay

User delay costs are not considered for initial construction, but are included for the maintenance cycling and rehabilitation times.

27. Description of the analysis process

A detailed analysis of the maintenance cycles are done and related to traffic control, user patterns, etc.

28. Routine maintenance

Refer to figure 1 as summarized in the Pavement Design Analysis Manual.

29. Preventive maintenance

Refer to figure 1. Basically mill and fill; more rehabilitation type activities are noted in the manual and in figure 1.

30. What are the states standard routine and preventive maintenance operation and schedule by pavement type?

See figure 1 (next page). These are defined by the central office from the database.

31. Allocation of resources between maintenance, rehab, new and reconstruction

No; built into the maintenance cycles.

32. Do you have a formal system to track pavement condition, cost, and survivability?

The PMS database is used for performance. The RMOIS is used for the maintenance cycles and costs.

33. Do you allow old concrete to be recycled? If so into what products? Percentage limits?

Yes, as an aggregate base, but only used as backfill for structures. Recycled PCC is not used or allowed in the PCC mixtures.

34. Do you allow HMA materials to be recycled? If so into what products? Percentage limits?

Yes, 15 percent is allowed in HMA mixtures. This material is used heavily is shoulders and widening projects and as unbound aggregate base materials.

Pavement Type	Activity and Time in years of Activity					
New Bituminous, Bit. Reconstruction & Bit. Overlay	5	10	15	20		30	35
	Seal coat Shoulders or do nothing as defined by mix type.	1.5 – 2.0 in. mill & fill; full-depth patches over 2% of area; saw & seal joints; seal coat shoulders; maintenance. & protection of traffic; user delay.	Seal coat shoulders depending on mix type.	Full-depth patches over 2% of area; HMA leveling course; saw & seal joints; adjust rails & drainage features; Type 7 paved shoulders; maintenance & protection of traffic; user delay.		Same as for 10 years.	Seal coat shoulders.
New PCCP, reconstruction, & Unbounded concrete overlays	5	10	15	20		30	35
		Clean & seal 25% of longitudinal joints & 5% of transverse joints; seal coat type 1 paved shoulders.		Concrete patch 2% of area; diamond grind 50% of area; clean & seal all longitudinal & transverse joints; maintenance & protection of traffic; user delay.		Concrete patch 5% of area; clean & seal all joints; HMA leveling course; 3.5-4 inch HMA overlay; saw & seal joints in overlay; type 7 paved shoulders; adjust rails & drainage features; maintenance & protection of traffic; user delay.	Seal coat shoulders.
PCCP Bonded Concrete Overlay	5	10	15	20	25	30	35
	Clean & seal 25% of longitudinal joints & 5% of transverse joints.	Concrete patch over 5% of area; spall repair over 5% of transverse joints; diamond grind 10% of area; clean & seal 25% of longitudinal joints & 10% of transverse joints; seal coat shoulders (Type 6 or 7); maintenance & protection of traffic; user delay.	Clean & seal 25% of longitudin al joints & 10% of transverse joints; seal coat shoulders.	Concrete patch over 10% of area; spall repair 10% of transverse joints; slab stabilization of 25% of transverse joints; diamond grind 100% of area; clean & seal all joints; type 6 shoulders; maintenance & protection of traffic; user delay.	Clean & seal 25% of longitudinal joints & 10% of transverse joints; seal coat type 6 shoulders.	Concrete patch 2% of area; clean & seal all joints; HMA leveling course; 3.5-4 inch HMA overlay; saw & seal joints in overlay; type 7 paved shoulders; adjust rail & drainage features; maintenance & protection of traffic; user delay.	Seal coat shoulders.
PCCP - Restoration	5	10		18	26	32	
	Seal coat shoulders; clean & seal 25% of all joints.	Concrete patch over 25% of initial quantity; slab stabilization of 25% of initial quantity; clean & seal all joints; HMA leveling course;3.5-4 inch HMA overlay; saw & seal joints in overlay; type 6 or 7 paved shoulders; adjust rail & drainage features; maintenance & protection of traffic; user delay.		Full-depth path over 1% of area; HMA leveling course; 1.5-2 inch HMA overlay; saw & seal joints in overlay; type 7 paved shoulders; adjust rail & drainage features; maintenance & protection of traffic & user delay.	1.5-2 inch mill & fill with HMA; full-depth patch over 3% of area; saw & seal joints; seal coat shoulders; maintenance & protection of traffic; user delay.	Same as year 18.	

Figure 1. Standard routine and preventive maintenance and rehabilitation schedules used in the LCCA.

Purpose

The purpose of this interview is to gain insight into the following Washington State Department of Transportation practices:

- Pavement type selection
- Engineer's estimate and life cycle cost analysis
- Other items that affect cost

Agency Interviewed

Washington State Department of Transportation
2655 South 2nd Avenue
Tumwater, WA 98512

Person(s) Interviewed

Name	Title	Phone	Email
Linda Pierce, PE	State Pavement Engineer	360 709-5470	piercel@wsdot.wa.gov

1. Do you have a documented pavement type selection procedure for:

New Construction - yes
Reconstruction - yes
Rehabilitation - no

2. How long have you used the current type selection procedure?

Approximately 15 years (current procedure is under revision)

3. Changes made over the last 5 years:

Probability analysis, focus on other factors (engineering, environmental, operational, and societal) and not only LCCA.

What prompted the change? Need to update 15 year old document.

4. Have you used alternative bidding as a means of making a pavement type selection during the past 5 years? If yes describe the process. Was alternate bidding used on a Federal-aid project? If so, what was the basis of FHWA's approval?

No

5. Importance and extent of industry involvement in the development of type selection process?

Both industries are currently reviewing and commenting on WSDOT Pavement Type Selection Protocol revision

6. How was the selection process implemented within the agency?

WSDOT Directive issued by DOT Secretary requires use of a pavement type selection process on new and reconstructed pavements.

7. How is the type selection process related to the overall project selection, budgeting, planning process used by the agency?

A new or reconstruction project is deemed necessary, during the design stage, the pavement type selection process is activated and incorporated into the final design recommendations.

8. Pavement types used for new construction or reconstruction over the last 5 years

Pavement Type	Approximate lane miles		Performance (Good Fair Poor)
	Interstate	Other 4 lane	
Full depth ACP			
Deep Strgth ACP			
ACP(less than 6") agg base			
Jointed Plain (JPCP)	243	36	Good performance, approximately 210 lane miles are pending construction due to funding limitations
Jointed Reinforced (JRCP)	N/A	N/A	
Continuously Reinf. (CRCP)	N/A	N/A	

9. Thickness design procedure used and design life (if AASHTO which version)

ACP – AASHTO 1993
PCCP – AASHTO 1993

10. What design life used for each pavement type?

40 years for high volume designs

11. Are there different foundation/base requirements for AC and PCC?

Require use of 2 to 4 inches of HMA beneath PCCP to minimize mitigation of fines beneath PCCP.

12. For those agencies that use smoothness as criteria do they use the same initial serviceability in design?

Smoothness for PCC based on profilograph. Working on a specification covering both pavement types based on IRI. Same initial serviceability used for both pavement types.

13. Typical costs and method of contract measurement

ACP in place $/____35______/ton sy cy other
JPCP (slab only) $/____74______sy cy* other
JRCP (slab only) $/______________sy cy other
CRCP (slab only) $/______________sy cy other
*Quantity is based on core thickness up to 0.5 inches over plan thickness

14. How important is first cost versus future costs?

Equated as the same importance.

15. Is life cycle cost analysis used?

Yes. Probabilistic

16. Analysis period

20 years on low volume and 60 years on high volume routes.

17. Discount Rate (how established)

4 percent, based on FHWA recommendation and OMB Circular A-94

18. Initial Costs – Estimating procedure

Conducted by Project Office based on past project bid items and costs. Performed in the district office on a project-by-project basis. Reviewed by headquarters pavement design office

19. How does agency determine unit cost to include in the cost analysis (standardized or project by project)? Is the size of the project used in the database considered (economy of scale)? Age of the price data. How often updated.

Analysis is conducted project by project using up-to-date cost information from the bid item summary. Since many projects have varying lane configurations, ramp tapers, acceleration-deceleration lanes, etc., Project Offices are requested to conduct analysis based on a typical one-mile section.

Engineering and Construction Considerations

Factors used, scoring system, primary factors secondary factors, weights, importance, etc

Factor	Considered	Primary or Secondary	Importance (0 to 5)	Comments
1. Roadway/lane geometrics (lane widths, cross slopes, ability to provide drainage)	X	S		
2. Highway functional class	X	S		
3. Traffic	X	S		
4. Roadway peripheral features (overhead clearance, weigh-in-motion, guardrails, etc)	X	S		
5. Construction considerations		S		
a. Staging	X	S		
b. Clearance for equipment	X	S		
c. Construction operations	X	S		
d. Traffic operations during construction	X	S		
e. Construction seasons	X	S		

Factor	Considered	Primary or Secondary	Importance (0 to 5)	Comments
6. Consideration of future maintenance operations (maintenance of traffic, ease of maintenance)	X	S		
7. Performance of similar pavements in the area	X	S		
8. Availability of local materials, contractor's capabilities, and experienced agency personnel.	X	S		
9. Pavement Continuity		S		
a. Adjacent sections	X	S		
b. Adjacent lanes	X	S		
10. Noise issues	X	S		
11. Subgrade soils	X	S		
12. Climate	X	S		
13. District or local preference		S		*Reasoning for preference must be quantified*
14. Ease of maintenance	X	S		
15. Recycling	X	S		
16. Conservation of materials and energy	X	S		
17. Stimulation of Competition		S		
18. Safety considerations (rutting, friction, lighting, etc)	X	S		
19. Smoothness				

20. Are price adjustment factors used for any materials, and if so are they used in the life cycle cost analysis.

No

21. Actual cost versus estimated cost (are completed projects evaluated for overruns etc.)

Currently investigating this issue on past projects.

22. Routine maintenance (how estimated, operations included)

Since routine maintenance is such a small item, it is typically excluded in the LCCA. WSDOT intends to collect this data in the future to confirm this assumption.

23. Rehabilitation (how is timing estimated, techniques used, etc.)

The Washington State Pavement Management System is utilized to determine typical pavement service life.

Adjustments have made based on improved performance as a result of the use of dowel (all existing pavements were undoweled). In addition, stainless steel clad dowels being used on premium pavements.

Performance of HMA is based on performance of adjacent projects. Currently the State does not require contractor QA/QC. Some Superpave. No much use of stone matrix mixes.

> **Salvage Value (remaining life):** Used as a ratio of cost and anticipated remaining life.
> **Residual value (recycling):** Not specifically included.
> **Construction traffic control (crossovers, added lanes, barriers, detours, etc.):** Included in estimate.
> **Engineering and administration:** Included in estimate. Flat rate for all projects. Same for HMA and PCC.

24. How are users costs weighted in relation to agency costs?

Currently weighted equally. However, the analysis is summarized to show results with and without user costs.

25. Vehicle operating costs

Not included.

26. User Delay

Included as a function of delay due to construction.

27. Description of the analysis process

As utilized by FHWA in LCCA software.

28. Routine maintenance

Crack sealing, patching

29. Preventive maintenance

Chip sealing

30. What are the states standard routine and preventive maintenance operation and schedule by pavement type?

There are no standards or routine schedules.

31. Allocation of resources between maintenance, rehab, new and reconstruction

None

32. Do you have a formal system to track pavement condition, cost, and survivability?

The Washington State Pavement Management System is used to track pavement condition and survivability.

33. Do you allow old concrete to be recycled? If so into what products? Percentage limits?

Yes, everything (as long as it meets the material specifications for the product it is replacing) except new concrete pavement, hot mix asphalt pavement, and gravel backfill for dry walls.

Becomes property of the contractor. Biggest difficulty is meeting LA wear specs.

34. Do you allow HMA materials to be recycled? If so into what products? Percentage limits?

Yes, may be used in ballast, shoulder ballast, crushed surface, aggregate for gravel base, gravel backfill for foundations, and borrow (with some limitations) as long as the total bitumen content does not exceed 1.2 percent (or 8.0 percent in some borrow applications) and the combined material must meet the material specifications.

Allowed in HMA up to 20% no new mix design required. Over 20% new mix design required.

Purpose

The purpose of this interview is to gain insight into the following Wisconsin Department of Transportation practices:

- Pavement type selection
- Engineer's estimate and life cycle cost analysis
- Other items that affect cost

Agency Interviewed

Wisconsin DOT
Hill Farms State Transportation Building
4802 Sheboygan Avenue
P.O. Box 7910
Madison, WI 53707-7910

Person(s) Interviewed

Name	Title	Phone	Email
Mr. Steve Krebs	Chief Pavements Engineer	(608) 246-5399	steven.krebs@dot.state.wi.us
Ms. Laura Fenley	Structural ???	(608) 246-5455	laura.fenley@dot.state.wi.us

General Notes:

Scot Schwandt had 95% developed a probabilistic LCCA but it never got adopted. WisDOT will go to probabilistic, but they're waiting for FHWA guidance.

WisDOT primary pavement types are conventional AC (AC over flexible base with 2 to 3:1 ratio of base/AC) and doweled JPC. Service life (i.e., time to first rehab) of AC is 18 yrs, while service life of PCC is 25 yrs.

Designer can develop multiple AC and multiple PCC designs and then run them through the LCCA (up to 8 can be analyzed at a time)

1. **Do you have a documented pavement type selection procedure for:**

   New Construction (defined as starting from a new grade): Yes. WisPave software with documented procedure (Facilities Development Manual [FDM]l, Chapter 14)
   Reconstruction: (defined as creation of new structure, with range being pulverization or removal of top bound layers to removal down into subgrade [incl. subgrade modification]) Yes. WisPave software and FDM
   Rehabilitation: Yes. WisPave software and FDM

2. How long have you used the current type selection procedure?

Current procedure has been in place for about 20 years. It has been fully automated using Visual Basic for about 3 years, and with Excel spreadsheets for about 8 years.

3. Changes made over the last 5 years? What prompted the change(s)?

Some changes have been made, including automation using Visual Basic and the determination and use of hard-coded service lives. These changes were prompted by the desire for better execution and more standardization.

4. Have you used alternative bidding as a means of making a pavement type selection during the past 5 years? If yes describe the process. Was alternate bidding used on a Federal-aid project? If so, what was the basis of FHWA's approval?

No

5. Importance and extent of industry involvement in the development of type selection process?

Involvement has been pretty high through the Pavement Design User Group, which consists of WisDOT engineers, consultants, and industry reps. A Pavement Policy Committee, consisting of WisDOT engineers/managers only, help guide policy changes by answering the question, "Are we making the right decision?"

6. How was the selection process implemented within the agency?

Through the Facilities Development Manual (FDM). See chapter 14 of FDM.

Mid 1980's is when WisDOT began instituting LCCA, more on their own than as a result of FHWA or others.

7. How is the type selection process related to the overall project selection, budgeting, planning process used by the agency?

It's an independent process.

8. Pavement types used for new construction or reconstruction over the last 5 years

Pavement Type	Approximate lane miles		Performance (within last 5 yrs, any early failures?) (Good Fair Poor)
	Interstate	Other 4 lane	
Full depth ACP	None	None	Not applicable
Deep Strength ACP	190 (I-39)	30	Good
ACP(less than 6") agg base	1,700 total		Good
Jointed Plain (JPCP)	214 total		Good
Jointed Reinforced (JRCP)	None	None	Not applicable
Continuously Reinf. (CRCP)	None	None	Not applicable

9. Thickness design procedure used and design life (if AASHTO which version)

ACP: AASHTO '72 (design life=20 yrs, estimated ESALs)
PCCP: AASHTO '72 (design life = 20 yrs, estimated ESALs)

10. What analysis period used for each pavement type?

50 years

11. Are there different foundation/base requirements for AC and PCC?

WisDOT uses 2 to 3:1 ratio (base/surface) for AC pavements. Designers have flexibility to select ratio. Also, designers have a range for structural coefficients for some materials, but not others (e.g., crushed stone=0.14).

Standard base requirement for PCC is 6 in. If permeable base is to be used, a 4-in drainage layer on top of a 6-in aggregate base must be specified.

Subgrade improvement required based on geographical location (66% of State required to use subgrade improvement, usually a sand material). Designers are required to spec for it, unless local data show otherwise. When used, credit can be given to structure (increased k for PCC design, increased soil support value for HMAC design). Reason for the requirement is purely construction platform-related.

12. Does WisDOT use smoothness as design criteria and, if so, do they use the same initial serviceability in design?

Yes, within the design equation (PSI). Initial = 4.2 for AC, 4.5 for PCC (Steve: this is absolutely backward, we only use it because that's what '72 Guide says to use). Same terminal values (2.5) are used for AC and PCC.

For construction acceptance testing, California profilograph is used to measure smoothness. Typical IRI for new AC is 0.85 m/km. Typical IRI for new PCC is 1.1 m/km. Incentive is paid for smoothness (designer's option)

For in-service testing of the network, South Dakota type profiler is used to measure smoothness.

13. Typical costs and method of contract measurement

ACP in place $18 to 30/ton (depending on mix type). Cost of asphalt cement ranges from $175 to 275/ton.
JPCP (slab only) $15 to 32/yd^2 (this includes cost of dowels). For a 10-in JPC, typical cost is $21/yd^2)
JRCP (slab only) Not Applicable
CRCP (slab only) Not Applicable

14. How important is first cost versus future costs?

These are considered the same; one is not weighted any higher than the other. The LCCA procedure is what it is, discount rate determines relation.

15. Is life cycle cost analysis used?

Yes.

16. What analysis period is used?

50 years

17. Discount Rate (how established)

5%, as dictated by Department. 5% value was developed by an economist in the old planning unit. The economist researched the discount rate to a great extent and came up with this value, which is somewhat of a social discount rate, based on resource allocation versus capital financing. No documentation of the research is available, however.

18. Initial Agency Costs – Estimating procedure

WisPrice data are used. Construction costs only are used. No accounting of engineering, design, traffic control costs, etc. is made. Although traffic control costs will vary, they are too difficult to determine.

19. How does WisDOT determine unit cost to include in the cost analysis (standardized or project by project)? Is the size of the project used in the database considered (economy of scale)? Age of the price data? How often updated?

Done at the designer level, on a project-by-project basis. The size of project is considered. Price data are up to the most recent letting and are updated every month.

20. Are price adjustment factors used for any materials and, if so, are they used in the life cycle cost analysis.

Yes. Fuel cost adjustment factor. There is a bid item for this. Not used in LCCA though.

21. Actual cost versus estimated cost (are completed projects evaluated for overruns etc.)

All projects are evaluated for cost overruns, but overruns are not considered in pavement type selection process.

22. Routine maintenance (how estimated, operations included)

Rough costs, in terms of $/lane-mi, are provided by Maintenance. Costs are a statewide number, there is no breakdown by county (note: maintenance of State highways is performed by the counties). Costs are only for mainline maintenance and they include routine activities such as crack filling and seal coating for AC, and joint resealing for PCC.

23. Rehabilitation (how is timing estimated, techniques used, etc.)

Based on service life analysis (actual data). Rehab treatments are outline in FDM, but most common include conventional overlay, mill-and-overlay, and diamond grinding. Designer has the option of changing the timing of rehabs and not assigning them.

> **Salvage Value (prorated life or other procedure):** Yes. Prorated life method.
> **Residual value (recycling):** No. WisDOT doesn't know what they're going to do at the end of the analysis period.
> **Construction traffic control (crossovers, added lanes, barriers, detours, etc.):** Not considered.
> **Engineering and administration:** Not considered.

Description of the analysis process: See figure 1.

24. How are user costs weighted in relation to agency costs?

User costs are not considered.

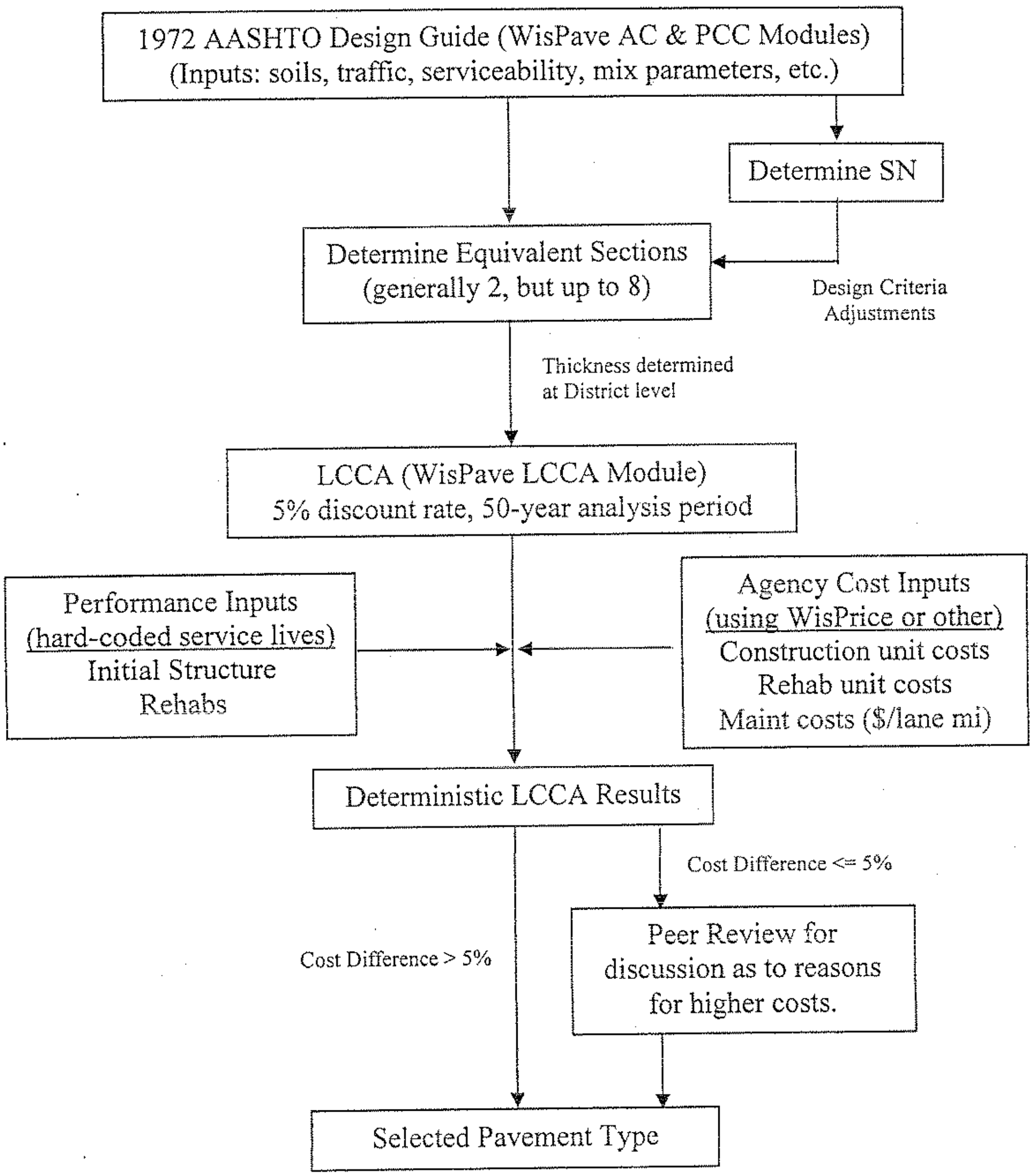
Engineering and Construction Considerations

Factors used, scoring system, primary factors secondary factors, weights, importance, etc

Factor	Considered	Primary or Secondary	Importance (0 to 5)	Comments
1. Roadway/lane geometrics (lane widths, cross slopes, ability to provide drainage)	*No*			
2. Highway functional class	*No*			
3. Traffic	*Yes*	*P*	*5*	*ESALs*
4. Roadway peripheral features (overhead clearance, weigh-in-motion, guardrails, etc)	*Yes*	*S*	*2*	*Only considered in rehab in selecting a typical strategy, such as rubblization.*
5. Construction considerations				
a. Staging	*No*			
b. Clearance for equipment	*No*			
c. Construction operations	*No?*			*Only In weird situations.*
d. Traffic operations during construction	*No*			
e. Construction seasons	*No*			

Factor	Considered	Primary or Secondary	Importance (0 to 5)	Comments
6. Consideration of future maintenance operations (maintenance of traffic, ease of maintenance)	*Yes*	*S*	*3*	*Sometimes considered, based on who is the maintaining authority of the roadway.*
7. Performance of similar pavements in the area	*Yes*	*S*		*Statewide it is considered in the service life. It is not considered locally.*
8. Availability of local materials, contractor's capabilities, and experienced agency personnel.	*No?*			*Not a direct consideration. Availability of materials would only affect the unit prices of the material.*
9. Pavement Continuity				
a. Adjacent sections	*Yes*	*P*	*4*	*More commonly adjacent sections than adjacent lanes.*
b. Adjacent lanes	*Yes*	*P*	*4*	
10. Noise issues	*Yes*	*S*	*2*	*Sometimes considered, but it is not a selection factor---WisDOT builds quiet pavements.*
11. Subgrade soils	*Yes*	*P*	*5*	
12. Climate	*No*			
13. District or local preference	*Yes*	*S*	*3*	*Only as related to maintenance, never district preference (has to fall within the 5% cost difference category)*
14. Ease of maintenance	*Yes*	*S*	*3*	*Only as related to maintenance, never a district preference (has to fall within the 5% cost difference category)*
15. Recycling	*No*			
16. Conservation of materials and energy	*No*			
17. Stimulation of Competition	*No*			
18. Safety considerations (rutting, friction, lighting, etc)	*Yes?*	*S*	*1*	*Potentially for rehabs, but not for new construction.*
19. Smoothness	*No*			*Considered in design, but doesn't determine which pavement type.*

Figure 1. Diagram of WisDOT pavement type selection process.



25. Vehicle operating costs

User costs are not considered.

26. User Delay

User costs are not considered.

27. Description of the analysis process

User costs are not considered.

28. Routine maintenance

Routine and preventive maintenance **of the mainline only** are combined into one statewide cost. Maintenance includes crack sealing, patching, seal coating, joint resealing.

29. Preventive maintenance

See response above.

30. What is WisDOT's standard routine and preventive maintenance operation and schedule by pavement type?

Maintenance for new AC and AC overlays): Crack seal at 3 years, seal coat at 8 years
Maintenance for PCC: Joint reseal at 10 and 15 years.

31. Allocation of resources between maintenance, rehab, new and reconstruction

Not determined by Pavement Mgt group. Not sure how this plays into the selection process. Department can investigate this a little further.

32. Does WisDOT have a formal system to track pavement condition, cost, and survivability?

Pavement Conditions: Tracked through pavement monitoring and the Pavement Management System database. South Dakota profiler is used. Each section is surveyed every other year.

Pavement Costs: Proposal Management group (outside of WisDOT) provides Department with cost data for use in WisPrice. WisPave includes ability to filter projects according to size, location, etc. It is based on 3 lowest prices for each bid item for each project.

Survival is evaluated.

33. Does WisDOT allow old concrete to be recycled? If so into what products? Percentage limits?

Some of this is done, goes into unbound layers and into new PCC. Vast majority is for unbound.

34. Does WisDOT allow HMA materials to be recycled? If so into what products? Percentage limits?

This is done, goes into unbound layers and into new AC. Vast majority is going back into unbound.

Appendix D

Comparison of State Pavement Practices

Feature	Ohio	Illinois	Indiana	Maryland	Michigan	Minnesota	New York	Ontario	Pennsylvania	Washington	Wisconsin
Documented Type Selection											
New Construction	X	X	X	X [7]	X	X	X	X	X	X	X
Reconstruction	X	X	X	X [7]	X	X	X	X	X	X	X
Rehabilitation	X	X			X		X	X	X		X
Time Used	6 months	> 10 years [23]	>10 years	6 months	3 years	6 years	4 years	5 years	18 years	15 yr	20 yr
Modified last 5 years?	Yes	Minor	No	Yes	Yes	Yes	Minor	Yes	Yes	Prob. Analysis	Yes
Modifications underway	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No
Extent Industry Involvement	Input & review	Input and Review during development	Review	Review	Yes, ad hoc committee	Non-voting	Minor	Partici-pant	Review	Review	Significant (via PD User Group)
How implemented	Issued by Depart-ment	Design Manual	Design Manual	Design Manual	Design Manual	Commissioner Issues	Design Manual	Design Manual	Design Manual	Directive	Facilities Development Manual
Alternate bidding used	Consider-ing	No	No	1 proj. [8]	2 proj.	No	No	1 proj.	1 Pilot Project Proposed	No	No
Pavement Types used											
HMA-Full depth	No	Yes	Yes	No	No	No	No	<1%	Yes	No	No
HMA-Deep Strength	Yes	No	Yes	Yes	Yes	Yes	90%	95%	No	Yes	Yes
PCC-JPCP	Yes	Yes	Yes	Yes	Yes [12]	Yes	10%	<5%	Yes	Yes	Yes
PCC-CRCP	No	Yes	No	No	No	No	No	No	No	No	No
Design Procedure											
HMA thickness design	AASHTO 93	M-E [24]	AASHTO 93	AASHTO 93	AASHTO 93	Modified AASHTO	Modified AASHTO 93	Modified AASHTO 93	AASHTO 93	AASHTO 93	AASHTO '72
Traffic Design Life	20	20	20	15	20	20	50	20	20	40	20
"a" bituminous surface	0.35	n/a	0.34	0.44	0.42	n/a	0.42	0.42	0.44	0.44	0.44
"a" bituminous intermediate layer	0.35	n/a	0.36	0.40	0.36	n/a	0.42	0.42	0.44	0.44	0.44
"a" bituminous base	0.35	n/a	0.34	0.25	0.36	n/a	0.42	0.42	0.40	0.30	0.34
PCC thickness design	AASHTO 93	M-E [24]	AASHTO 93	AASHTO 93	AASHTO 93	AASHTO 86	Modified AASHTO 93	Modified AASHTO 93	AASHTO 93	AASHTO 93	AASHTO '72
Traffic Design Life	20	20	30	25	20	35	50	30	20	40	20

Feature	Ohio	Illinois	Indiana	Maryland	Michigan	Minnesota	New York	Ontario	Pennsylvania	Washington	Wisconsin
PCC Mr (S'c)	700	650 [25]	652	700	670	675	650	725 [20]	631 [20]	650	650
PCC Ec	5,000,000	n/a	3,408,390	5,000,000	4,200,000		4,000,000	4,350,000	4,000,000	4,000,000	4,200,000
Are foundation requirements for HMA and PCC the same	Yes	Yes	Yes	Yes	No [13]	No	Yes	Yes	No	same subgrade	Yes
Is initial serviceability same for PCC and HMA	4.2 PCC 4.5 HMA	N/A	Yes	4.5 PCC 4.2 HMA	Yes	n/a	n/a	Yes	4.5 PCC 4.2 HMA	Yes	No
Method of Payment											
HMA											
Ton (produced)			X	X	X	X	metric	metric	X [32]	X	X
Sq. yd. (measured thickness)		X							X [32]		
Cu. Yd. (measured)	X										
PCC											
Sq. yd. (design thickness)	X	X	X	X	X	X [5]		X	X		X
Cu. Yd. (design thickness)						X [5]	cu. meter				
Cu. Yd. (measured thickness)										X [6]	
Liquid AC Price Adjustment	Yes	No	No	Yes	No	No	Yes	Yes	Yes	No	Yes
Economic Analysis											
Use LCCA	Modified [21]	Yes [26]	Yes	Yes	Yes EUAC	Yes	Yes	Yes	Yes	Yes	Yes
Analysis period	35	40	40	40	Varies [14]	35	50 new 30 rehab	50 new 30 rehab	40	60	50
Discount rate	OMB A94	3	4	4	OMB A94	4.5 [9]	OMB A94	5.3 [11]	6	4	5 [19]
Sensitivity Analysis	No	No	0 to 10	3 to 5	No	No	No	2%	No	2-5 Prob	No
Initial Cost											
Centrally developed cost data for LCCA	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No
Project Specific (discretionary adjustment)	No	No	Yes	No	geographic area	Yes [10]	Yes	Yes	Yes	Yes	Yes
Adjust LCCA for as built quantities	No	No	No	No	No	No	No	No	No	No	No

Feature	Ohio	Illinois	Indiana	Maryland	Michigan	Minnesota	New York	Ontario	Pennsylvania	Washington	Wisconsin
Routine Annual Maintenance Costs ($/lane-mile)	No	Yes [27]	No	No	No	No	No	No	Yes	No	No
Scheduled Maintenance Costs	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes
How estimated	n/a	Committee	MM system	n/a	Past History	Committee	Best Est.	Best Est.	MM system	n/a	MM system
Rehabilitation (overlay, CPR, etc.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
How estimated	Best Est.	Best Est.	PM sys	PM sys	PM & MM	Best Est.	Best Est.	Best Est.	PM sys	PM sys	PM sys
HMA											
Year at 1st Rehabilitation for LCCA	12	Function of traffic - 4 categories (see detailed schedule)	project specific	project specific	10 [22]	15	15	19	10	15	18
Year at 2nd Rehabilitation for LCCA	22	Function of traffic - 4 categories (see detailed schedule)	project specific	project specific	13 [22]	27	27	31	20	30	project specific
PCC											
Year at 1st Rehabilitation for LCCA	22	20 (CPR) [28]	project specific	project specific	9 [22]	17	15	18	20	20	25
Year at 2nd Rehabilitation for LCCA	32	None to reconstruction	project specific	project specific	15 [22]	27	30	28	30	40	project specific
Residual Value	No	No	No	No	No	No	No	No	No	No	No
Salvage Value	No	No	Rem life	Rem life	No [15]	No	Rem Life	Rem Life	No	Rem Life	Rem Life
Construction Traffic Control											
Initial construction	No	No	No	Yes	No	Yes	No	No	No	Yes	No
Rehabilitation	Yes	No	No	No	Yes	No	No	No	Yes	Yes	No
Engineering and Administration											
Initial construction	No	No	No	No	No	No	No	No	No	Yes	No
Rehabilitation	Yes	No	No	No	Yes	No	27%	No	No	Yes	No

Feature	Ohio	Illinois	Indiana	Maryland	Michigan	Minnesota	New York	Ontario	Pennsylvania	Washington	Wisconsin
User Costs											
Delay	Indirectly	No	No	Yes FHWA	Yes U of Mich	Future	Future	Future	Yes	Yes	No
VOC (roughness, tire wear, rolling resistance, etc.)	No	No	No	No	No	No	Future	Future	No	No	No
Are user costs include in LCCA	No	No	No	Yes	Yes	No	Future	Future	Yes	Yes	No
Spread of LCCA considered equal	0 to 3 Init 0 to 10 fut.	10%	10%	10%	0%	0%	0%	0%	10%	15%	5%
Recycling											
PCC	No	Yes	Yes	no recent projects	Yes [16]	Yes	Yes	Yes	Yes	Yes	Yes, some
Uses	n/a	Capping, Subbase, Concrete, Shoulder, Fill	Subbase		granular materials	base, subbase	base, subbase	base, subbase	typically used as backfill for structures	granular materials	unbound base (most) PCC (very little)
HMA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Uses	HMA	Capping, Binder, Shoulder, Fill	HMA	HMA	HMA [17]	HMA	HMA	HMA	HMA	HMA	unbound base, HMA
Max % in Wearing Course	20 [1]	30 [29]	25 [2]	15	14 [18]	30 [3]	20	10 to 30	5 - 15 [30]	20 [4]	20 [31]
Max % in Intermediate Course	35 [1]	30 [29]	25 [2]		28 [18]	50 [3]	20	10 to 30	5 - 15 [30]	20 [4]	35 [31]
Max % in Bituminous Base	35 [1]	30 [29]	25 [2]	25	28 [18]	50 [3]	30	30	5 - 15 [30]	20 [4]	35 [31]

Table Notes

1. Whenever more than 10% of reclaimed asphalt concrete pavement is used it must be included in the mix design to establish the job mix formula and conform to the requirements of the specified asphalt binder for the asphalt binder proposed for use in the mixture, by the combination of reclaimed asphalt, virgin asphalt, and rejuvenating agents. A maximum of 10% RAP is allowed in polymer modified surface mixtures.
2. Up to 15% use grade of asphalt binder specified for the project. 15% to 25% asphalt softer required
3. Subject to meeting mix design requirements
4. Up to 20% no new mix design, over 20% required a new mix design
5. Two pay items for PCC sq. yd and cu. yd. the cu. yd. quantity is base on planned thickness
6. Quantity is based on cored thickness up to 0.5 in over planned thickness
7. Maryland is currently operating under an interim procedure that has not been formally issued and has not been published.
8. Maryland did one alternate bid project under FHWA SEP-14
9. Currently 4.5% but going to OMB -A94
10. Not unit cost based. Develop costs based on materials and construction costs at the specific site. Features for premium enhanced designs are included after pavement type has been selected and are not included in the LCCA analysis
11. Ministry of Finance social discount rate. They suggest a s percent sensitivity level
12. Also still build some JRCP
13. Greater sand subgrade depth required for HMA, for frost protection
14. 26 years for new high-volume PCC and HMA, 21 years for unbonded PCC, 20 years for HMA on rubbilized
15. Analysis period selected to coincide with the end of the pavements service life
16. Must meet specification requirements for material being used as. Material becomes property of contractor and is generally used in non-state funded commercial work
17. Material becomes property of contractor and is generally used in non-state funded commercial work
18. Percentage is by weight of total binder in the mix. Above 17% binder grade adjustments required
19. WisDOT policy set by economist in Planning a long time ago. Rate is somewhat of a social discount rate.
20. Flexural strength based on actual field data.
21. First and future costs have separate weightings.
22. Strategies reflect the overall maintenance approach that has been used network wide for a specific fix based on historical maintenance and pavement management records

23: Some sort of type selection process has been in place in Illinois since the mid-70s; the latest revision is more than 10 years old.

24 For new and reconstructed JPCP and Full-depth pavements which enter the LCCA stream, M-E design is used. However for JRCP and CRCP, modified AASHTO procedures are used. Same is true of composite pavements and certain cross-sections widened and resurfaced with HMA.

25: Center-point loading at 14 days.

26: Only for Full-depth HMA and JPCP

27: Fixed cost and includes striping, lane delineators, reflectors, etc.

28: There are 7 rehabilitation activities in the life cycle including patching and sealing. Quantities are specified in detailed schedule. Shown here is the time to major activity.

29: The maximum percentage of rap is a function of mix design and ranges from 0 percent for an Ndesign of 105 to 30 percent for an Ndesign of 30 and is not allowed in polymer modified mixes.

30. For mixtures with more than 15 percent RAP, the department evaluates the asphalt cement content of the RAP source material and determines the grade of the asphalt cement and recycling agent the contractor will be required to use in the final mixture. When RAP is used, a plan to control RAP and procedures to handle the RAP of different compositions must be developed and provided to the department.
31. Combined RAP and virgin aggregate shall meet percent crushed and natural sand quality requirements. The blend of new asphaltic material with extracted RAP asphaltic material shall meet the penetration or viscosity requirements for the specified asphaltic material.
32. Payment is based on square yards for most projects. Tonnage is only used on very small projects and for leveling courses.

Appendix E
Concepts for Development of Survival Curves and Procedures for Adjustment of Survival Curves to Account for New Technology

Concepts for Development of Survival Curves and Procedures for Adjustment of Survival Curves to Account for New Technology

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Introduction

Survival curves have been developed and used by various agencies to determine the expected service life of previously built designs and materials for use in LCCA and for other management purposes. Survival curves are uniquely useful to LCCA because every point on the curve represents the probability that a given pavement section will be rehabilitated (or reach a given critical condition level). Thus, the time in years when the probability equals 0.50 (or 50 percent) is the age used in LCCA pavement life projections.

The Illinois DOT (1, 2) and the Ontario Ministry of Transportation (3, 4, 7) recently sponsored studies that utilized survival curves. The procedures utilized in these studies are generally recommended for use. These curves can be developed for various original pavements (e.g., deep strength flexible, full depth flexible, jointed plain and jointed reinforced concrete pavement) and for all types of rehabilitations (e.g., thin HMA overlays, thick HMA overlays, unbonded PCC overlay, diamond grinding restoration). The paving industries have sponsored the developed survival curves for various highway networks, including corridors (such as a 100-mile corridor), and even for specific counties.

This document briefly describes the development of survival curves that can be used in developing the expected service life of pavement design and rehabilitation strategies appropriate for use in LCCA. It also provides very preliminary concepts to modify these survival curves based on new design procedures or new materials/design features that are not available in the existing historical databases.

Development of Survival Curves

Survival analyses—also called probability of failure analyses—have been used for decades in actuarial sciences. They have also been used in the pavement industry for many years. Survival analysis is a statistical method for determining the distribution of lives, as well as the "life expectancy," of a subset of pavements. Since not all of the pavements included in the analysis have reached the end of their service life, the mean of all sections ages cannot be used. The life expectancy and probability of failure are computed considering all sections in the subset using statistical techniques such as the PC SAS LIFETEST procedure. Survival curves have been used to compare the mean and standard deviation of the expected service life for different design features and site factors in evaluating the adequacy of the design procedure.

Survival curves are typically based on age but can also be based on traffic loadings (ESALs). The age or ESALs at "failure" must be based on a clearly defined condition, such as the age or ESALs at major rehabilitation (overlay, reconstruction) or at a specific pavement condition (such as PCI =65). The Illinois and Ontario survival curves are based on both age and ESALs, which consider different survival aspects of these pavements. Together, these survival curves tell a more complete story about how the pavements performed.

The Illinois curves are based on a definition of failure as when rehabilitation is actually placed. Ontario curves are based on a definition of failure as when a certain Pavement Condition Index (PCI) is achieved. Illinois survival curves for one family of pavement are shown in figure E-1 for both age and traffic. Care must be taken when inferring results from survival curves because they directly represent the population of pavements they are based on. For example, if the 50th percentile life is 15 years, and these pavements were designed for 20 years, it does not necessarily follow that they did not perform as designed because traffic may have been much higher than planned for most of the sections included in the survival analysis. Thus, the traffic survival curves are important to determine the traffic that these sections have been subjected to during their lifetime, which may be two to four times greater than design traffic. So both survival curves are needed to tell the complete story.

Mathematical models are best fitted to the points in the survival curves to predict the probability of survival or failure as a function of age or cumulative ESALs. The general form of these models is as follows:

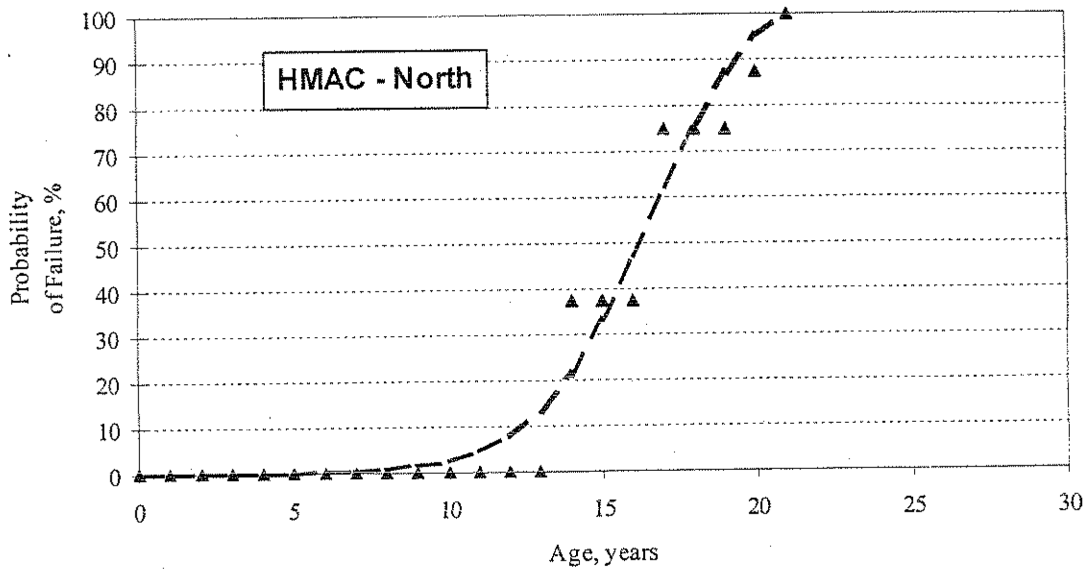
$$\text{Probability of Failure} = \frac{a}{1+e^{b*(Age-c)}} + d \qquad \text{Eq. E-1}$$

$$\text{Probability of Failure} = \frac{a}{1+e^{b*(ESAL-c)}} + d \qquad \text{Eq. E-2}$$

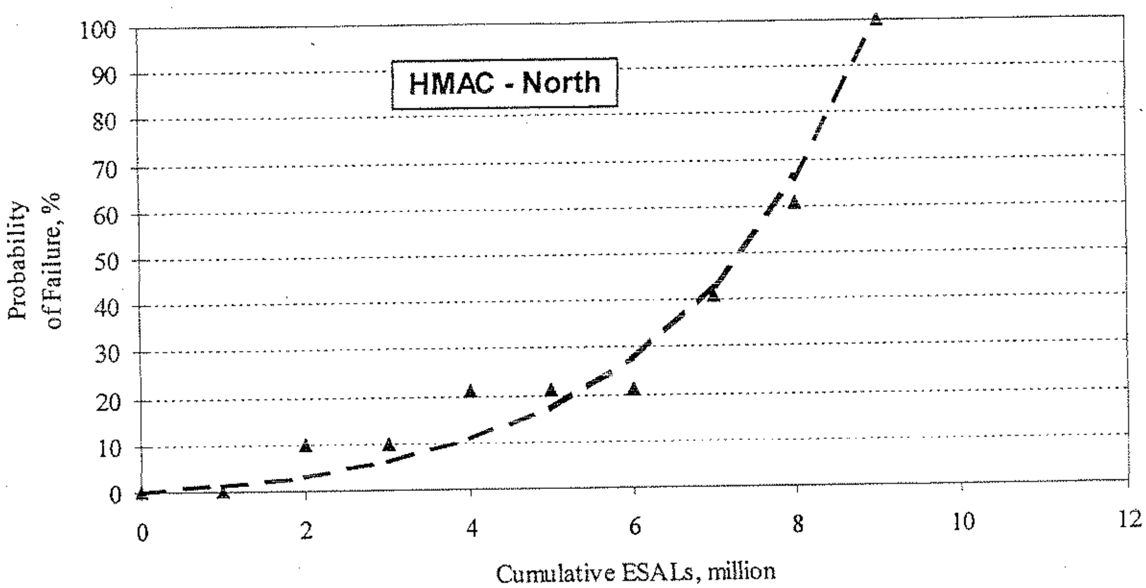
Where:

Failure	=	existing pavement is overlaid or reconstructed
Age	=	number of years since construction (new pavement or overlay)
ESAL	=	cumulative equivalent single axle loads since construction (new pavement or overlay), millions
a, b, c, d	=	regression coefficients determined from analysis

Of course, the probability of survival is 1 minus the probability of failure. Optimization was used to determine the regression coefficients that best fit the survival points to the above models for each type of pavement and overlay of interest.



A. Age survival curves



B. ESAL survival curves

Figure E-1. Age and ESAL survival curves for HMAC in the northern Illinois.

It is important to note that survival curves for pavements are necessarily based on previously built designs, materials, construction, and maintenance. The data used to develop the survival rates or probability of failure curves are those included in pavement management databases and represents typical construction, material specifications, mixture designs, and structural cross sections that have been designed and built by the agency within the past time period represented by the data. These can be called "benchmark" survival curves. It is often the case that many if not most of the pavements included in an agency's pavement management system database are no longer constructed by the agency due to poor performance.

The next section of this document presents some preliminary concepts on how to adjust benchmark survival curves. Two methods are described to adjust benchmark survival curves to reflect new technology in improved pavement designs and rehabilitations. The performance of these improved pavements is of course not available in the historical databases.

Modification of Survival Curves for New Conditions and Materials

Within the past decade, there have been major changes in the methods used by agencies to design, build, and maintain pavements. Many agencies have just implemented some of these new technologies, such as the Performance Graded (PG) binder specification, SMA, jointed plain concrete pavements with dowels (JPCP), subdrainage layers, and others. Technical progress thus creates problems in that the survival curves based on "old" pavement technology may not be the same as survival curves based on "new" technology. But there are no or little physical data from "new" pavement projects to develop "new" curves. This will always be the case as technology continues to develop over time. The existing survival curves must be adjusted to fit the new technology more closely before they can be used in LCCA.

Most agencies agree that the survival curve and mean expected service life need to be adjusted due to improvements in design and materials and construction. However, there is no accepted or standard procedure that has been published for adjusting historically based survival curves. The only known significant work of this kind was performed for the Ontario Ministry of Transportation (4, 7). This work utilized a panel of agency and industry experts to provide subjective input on the impact of the technological improvements and resulted in a small "shift" of a couple of years in the 50 percentile life. The reason for the small shifts were the clear recognition that many factors cause the deterioration of pavements and no single improvement in technology will shift the 50 percentile life by a large amount.

Practical Adjustment of Survival or Probability of Failure Curves

It is critical to define the reasons for the spread in survival shown in figure E-1. Why do some pavements fail early and some later on? The answer is that there are many causes of mechanisms that lead to failure, and any population of pavements exhibits deterioration from many causes and mechanisms. Major causes include the following:

- Construction quality (e.g., compaction of unbound materials, thickness of layers, placement of dowels in JPCP, HMA air content).
- Design quality (e.g., HMA thickness, JPCP joint spacing, traffic loadings, subgrade support).
- Materials quality (e.g., durability to climatic factors like freeze-thaw, chemical attack).
- Maintenance quality (e.g., cleaning/clogging of subdrainage outlets).

Variations of each of these factors can result in shortening or lengthening of the time when different distress types and smoothness becomes significant, causing a need for rehabilitation and thus contributing to the spread of the survival curve. In addition, there is always "random variation" in fatigue life (of replicate sections) due to unknown causes that will cause some spread of the survival curve for all pavement types.

Therefore, if a given design deficiency was addressed, this would have an impact on the survival curve but not as great as might be expected because there are so many other factors that affect performance that would not be affected. The use of data from limited test sections must be carefully considered. For example, assume an experimental site that contained two test sections. Test section B (new design) performed 50% longer than section A (conventional or old design). This would not shift the overall population survival curve representing these designs by a factor of 50%. The true shift in survival curve would be far less than 50% because many other factors affect the life of pavement sections.

This can be illustrated by the example that follows for conventional HMA pavements. For the example, let us assume that the pavement management database was used to determine the number of projects within each age category and the types of distress that exceeded the critical levels of the distress, requiring some type of rehabilitation. Table E-1 shows the major types of distress over the design analysis period. Within each cell is the estimated percentage of total failure that each contributes to HMA rehabilitation for that age group. The type of rehabilitation will vary by distress, however, for this example the type of rehabilitation is not considered.

For this example, it is assumed that the agency is considering adopting the Performance Grade (PG) binder specification to minimize the number of projects with early or premature rutting and thermal cracking. The PG binder specification has been found to eliminate early rutting caused by inferior binder properties on the high temperature side and eliminate early thermal cracking caused by inferior binder properties on the low temperature side. For the data, we will make the following assumptions.

- Half of the projects with premature rutting are caused by inferior materials and the other half are caused by inadequate construction procedures. Use of the PG binder specification will have no effect or impact on the inferior construction practices.
- Two-thirds of the projects with premature transverse cracking are caused by inferior materials or binder properties on the cold side, while one-third of the projects are caused by inadequate construction. The number of projects that are expected to exhibit transverse cracking for service lives greater than 20 years are not affected by the PG binder specification.

Table E-1. Number of projects by distress type that exceed the critical levels of distress causing rehabilitation (note, the numbers are fictitious, shown for illustration only).

Distress Type & Causes of Failure		Age of Pavement, years				
		0 to 5	5 to 10	10 to 15	15 to 20	20 to 30
Total Number of Projects in Each Age Category		90	75	60	45	30
Rutting	Inferior Materials & Construction	4	2	1	1	0
Bleeding	Inadequate Mix & Construction	1	1	0	0	0
Transverse Cracking	Inferior Materials	3	2	2	3	3
Raveling	Inadequate Construction	1	1	2	2	2
Bottom-Up Cracking	Inadequate Thickness	0	1	3	4	4
Top-Down Cracking	Inadequate Mix Properties	0	1	2	2	2
Edge Cracking, LCNWP	Expansive Soils	0	1	2	1	1
Block Cracking	Climate & Inadequate Mix	0	0	2	3	3
Smoothness	Distress & Inferior Construction	1	1	3	2	4
Total Number of Failed Projects		10	10	17	18	19
Probability of Failure, %		11.1	23.5	46.5	67.1	87.1

Given the above assumptions, new design strategy A in table E-2 summarizes the number of projects that are expected to exhibit high levels of distress given the use of the PG binder specification to improve the performance of HMA mixtures and pavements. New design strategy B in table E-2 summarizes the number of projects that are expected to exhibit high levels of distress with the assumption that the agency adopts the PG binder specification and perpetual pavement concept. For the projects shown in column B, it was assumed that the perpetual pavement concept will eliminate the bottom-up fatigue cracks but not the surface-initiated cracks. Thus, the number of these projects was reduced to zero.

Table E-2. Projects that exceed the critical levels of distress, causing rehabilitation (numbers are fictitious, shown for illustration only).

Distress	Age Category, years									
	0 to 5		5 to 10		10 to 15		15 to 20		20 to 30	
Number of Projects	90		75		60		45		30	
New Design Strategy	A	B	A	B	A	B	A	B	A	B
Rutting	2	2	1	1	0	0	0	0	0	0
Bleeding	1	1	1	1	0	0	0	0	0	0
Transverse Cracking	1	1	0	0	0	0	1	1	3	3
Raveling	1	1	1	1	2	2	2	2	2	2
Bottom-Up Cracking	0	0	1	0	3	0	4	0	4	0
Top-Down Cracking	0	0	1	1	2	2	2	2	2	2
Edge Cracking	0	0	1	1	2	2	1	1	1	1
Block Cracking	0	0	0	0	2	2	3	3	3	3
Smoothness	1	1	1	1	3	3	2	2	4	4
Total Number of Failed Projects	6	6	7	6	14	11	15	11	19	15
Probability of Failure, %	6.7	6.7	16.0	14.8	37.0	31.9	58.3	50.0	84.7	76.6

Figure E-2 graphically illustrates the increase in expected service life for the example assuming that the agency adopts the PG binder specification and perpetual pavement concept given the other types of distress are found that occur on the highway network from the pavement management database. The mid-range of each age group was used in the example for simplicity.

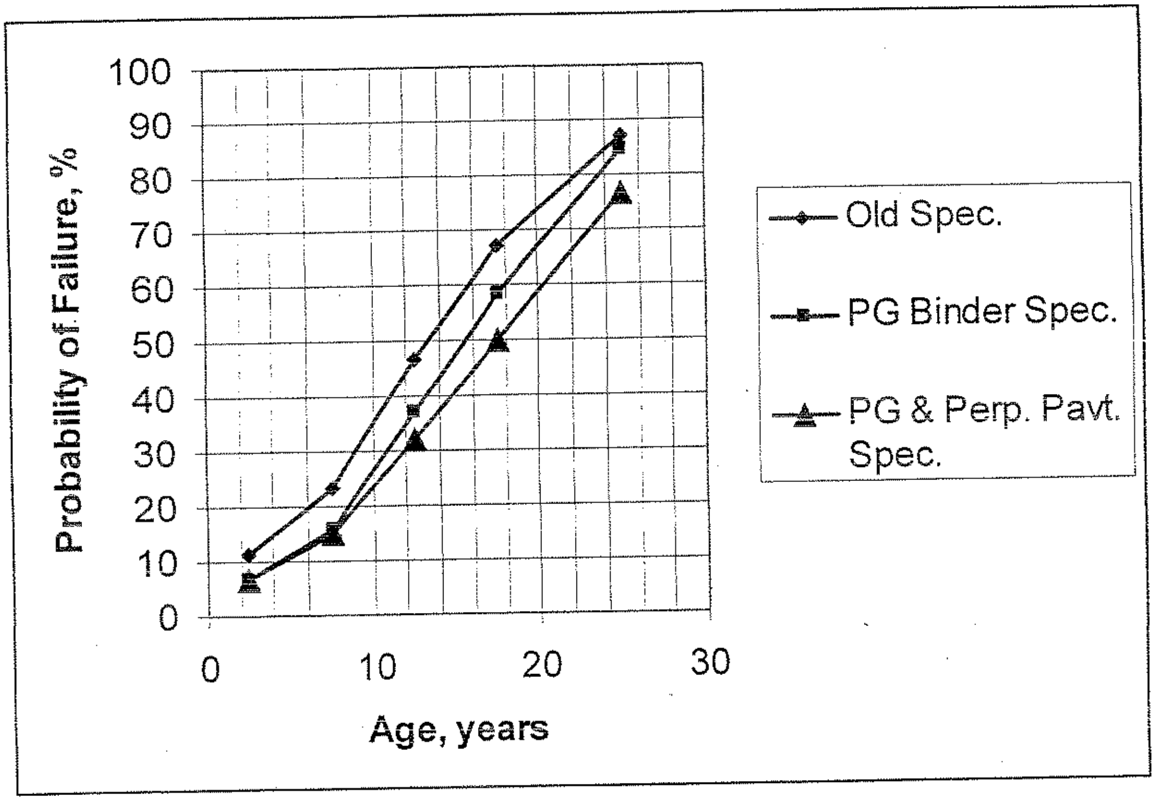


Figure E-2. Increase in expected service life for using new technology based on the types of distress that typically occur on the highway network (numbers are fictitious, shown for illustration only).

As shown in figure E-2, the 50 percentile expected service life prior to rehabilitation for the three conditions is about 13 years for the old specifications and design method, 15.5 years after adopting the PG binder specification, and 17.5 years after adopting the PG binder specification and perpetual pavement design method. Please note that these values are fictitious and shown only for illustration. Note that a similar example could be created for rigid pavements.

The point of this illustration is that the improvement of some aspect of design, construction, materials, and rehabilitation will certainly shift the survival curve for the pavement type under consideration, but the shift will not be that much because other factors affect performance and life.

Theoretical Adjustment of Survival or Probability of Failure Curves

The reliability of a pavement depends on the length of time it has been in service and design features and site factors that are not properly accounted for in a thickness design procedure. Thus, the distribution of the time to failure of a pavement type is of fundamental importance in reliability studies. A method used to characterize this distribution is the failure rate. The failure rate can be defined as follows.

If $f(t)$ is the probability density of the time to failure of a given pavement type and design strategy, that is, the probability that the pavement will fail between times t and $t+\Delta t$ is given by $f(t)*\Delta t$, then the probability that the pavement will fail on the interval from 0 to t is given by:

$$F(t) = \int_0^t f(x)dx \qquad \text{Eq. E-3}$$

The reliability function, expressing the probability that it survives to time t, is given by:

$$R(t) = 1 - F(t) \qquad \text{Eq. E-4}$$

Thus, the probability that the pavement will fail in the interval from t to $t+\Delta t$ is $F(t+\Delta t)-F(t)$, and the conditional probability of failure in this interval, given that the pavement survived to time t, is expressed by:

$$\frac{F(t+\Delta t)-F(t)}{R(t)} \qquad \text{Eq. E-5}$$

Dividing by Δt, one can obtain the average rate of failure in the interval from t to $t+\Delta t$, given that the pavement survived to time t:

$$\frac{F(t+\Delta t)-F(t)}{\Delta t}\left[\frac{1}{R(t)}\right] \qquad \text{Eq. E-6}$$

For small Δt, one can get the failure rate, which is:

$$Z(t) = \frac{f(t)}{R(t)} = \frac{f(t)}{1-F(t)} \qquad \text{Eq. E-7}$$

The failure rate is expressed in terms of the distribution of failure times. A typical failure rate curve is composed of three parts or can be grouped into three areas, as shown in figure E-3 and defined below.

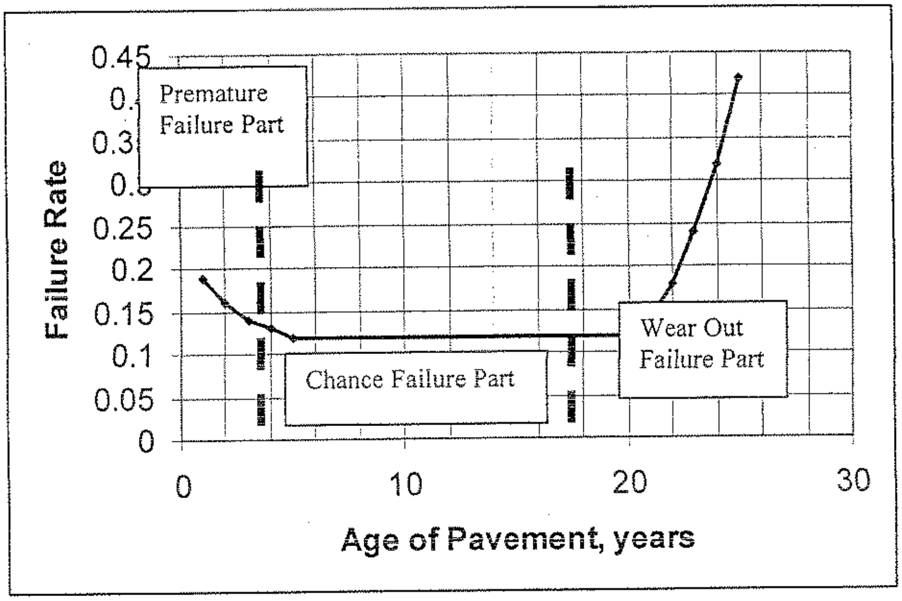


Figure E-3. Typical failure rate relationship for pavement structures.

1. The first part is characterized by a decreasing failure rate with time and is representative of the time period during which early failure or premature failures occur. This area or time typically represents pavements that were inadequately designed or built, using inferior materials.
2. The second part is characterized by a constant failure rate. A constant failure rate represents the time period when chance failures occur, or the failures occur at random with pavement age. In some survival methods, this area is referred to as the useful life of a pavement.
3. The third part is characterized by an increasing failure rate with time. This area or time represents the reverse of the first part, and when failure is a result of multi-distresses as related to a combination of parameters over time. As an example, exponential growth increases in traffic, past the design period from which thickness was determined.

The failure rate can be determined by organizing the performance data in terms of the distribution of pavement age exceeding a critical level (failure) versus the distribution of age for those pavements exhibiting a value lower than the critical value. Figure E-4 shows a typical probability of failure relationship from actual data included in the Long Term Pavement Performance (LTPP) database for International Roughness Index (IRI) values measured on flexible pavements in the GPS-1 and GPS-2 experiments.

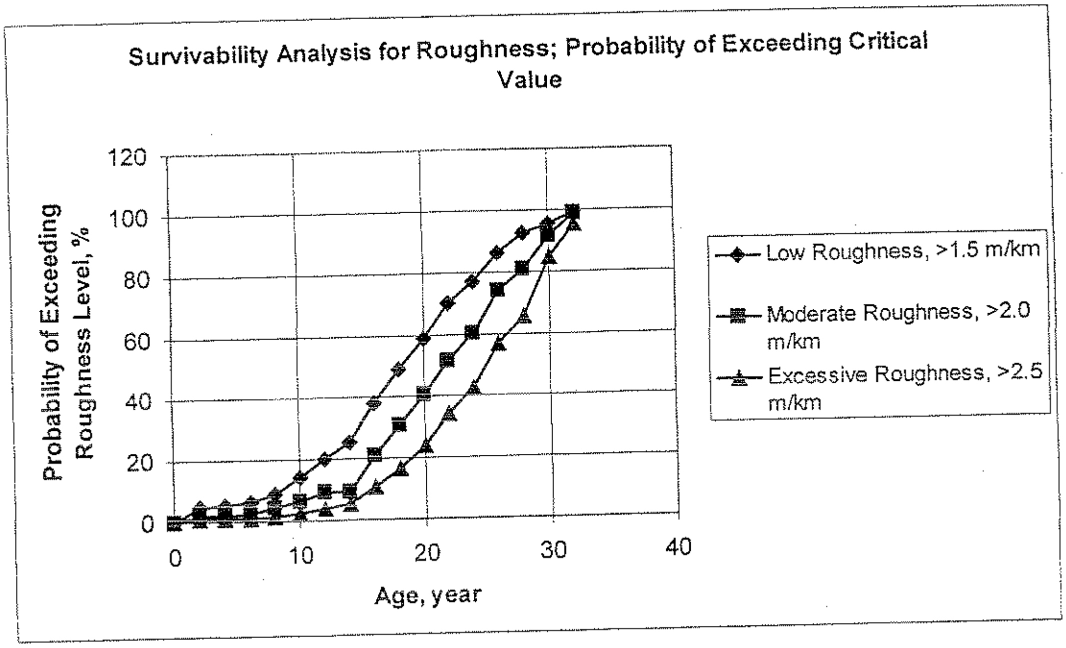


Figure E-4. Survival analysis or probability of exceeding a critical roughness magnitude.

Given the above definition of each parts of the probability of failure relationship with time, the failure rate can be defined as:

$$f(t) = Z(t)\left[e^{-\int_0^t Z(t)dx}\right] \qquad \text{Eq. E-8}$$

Assuming that the failure rate is constant within the second part and replacing *Z(t)* with α, the distribution of failure times is an exponential distribution as shown below.

$$f(t) = \alpha\left[e^{-\alpha t}\right] \qquad \text{Eq. E-9}$$

Many survival curves, or conversely the probability of failure, are based on the above relationships and assumptions. Unfortunately, the failure rate within the second part is not usually constant, and the failure rates for the first and third parts are not inversely proportional to one another. For these cases, which are typical for pavements, the failure rate can be estimated by the following relationship.

$$Z(t) = \alpha\beta t^{\beta-1} \qquad \text{Eq. E-10}$$

Thus,

$$f(t) = \alpha\beta t^{\beta-1}\left[e^{-\alpha t^{\beta}}\right] \qquad \text{Eq. E-11}$$

This density function is termed the Weibull distribution, and it is typically used in failure analyses. Use of the Weibull distribution permits the adjustment of the probability of failure based on new technologies and materials. This adjustment procedure is discussed below and is based on limited testing or evaluation of the new technologies and materials.

Adjustment of Survival Curves

The following provides concepts for adjusting survival curves to account for the use of new technologies and materials in life cycle cost analysis. The process assumes that the survival curve or probability of failure curve has been developed from actual performance data included in historical databases using traditional design procedures and materials, as shown in figure E-4. This process also assumes that limited laboratory and field testing is performed on the materials and pavement structures, and limited performance data is available from other sources. As noted above, parameters α and β of the Weibull distribution (see equation E-11) can be determined from existing data and then adjusted to account for the use of newer technologies and materials, similar to the example provided in the practical adjustment of the survival curves.

- Step 1—Separate the probability of failure curve into the three parts. Each part is handled separately in making adjustments to the relationship. In addition, each part of the curve will need to be assigned a specific type of distress that controls the failure definition. For example, the premature failures might be more related to rutting or thermal cracking for the first part, while fatigue cracking, smoothness, and/or PCI might be controlling the second part, and fatigue cracking or durability type distresses controlling the third part. This would be agency dependent, highway functional classification dependent, or other factors that existing technology does not properly consider.

- Step 2—Determine the adjustment that is to be made to the first part of the survival curve. These can be based on limited torture testing in the laboratory and on limited accelerated pavement testing. For this step, results from torture testing and accelerated pavement testing for conventional structures and materials are compared to those built or designed using the new technology. This testing comparison is used to determine the increase in age or time to reach the constant or uniform rate of increase in failures. This is just an adjustment in magnitude of age or shifting of the first part of the curve—the rate of change is not varied. The reason for this direct shift in age is that most of the premature failures are not dependent on time, but on other random factors that the existing technology does not consider. The new technology is assumed to adequately account for at least some of these random factors. The torture and accelerated pavement testing are used to confirm or validate that hypothesis and its magnitude.

- Step 3—Determine the adjustment that is to be made to the second part of the survival curve. This adjustment can be based on limited accelerated pavement testing and long-term field studies of the new technology used for other site factors (different climate, foundations, etc.). For this step, the accelerated pavement testing would compare the conventional structures and materials to those built or designed using the new technology and the longer-term field comparisons can be obtained from the literature and other databases. This testing comparison is used to determine any change in the rate of failure with age or time. In other words, the adjustment in magnitude of age can be time dependent—the exponent of equation E-11. The reason for this time-dependent shift in age is that the new technology may affect the slope of the chance failures, as well as a direct shift in the magnitude of age or time. The type of adjustment is dependent on whether the new technology is just materials or mixture design related with no change in the structural design procedure or a combination of both. This adjustment is more dependent on using engineering judgment because of the longer-term projections of failure and its definition.

- Step 4—Determine the adjustment that is to be made to the third part of the survival curve. This part of the curve is usually not adjusted but assumed to be the same as for the initial data. The shift is simply that part defined from the end of the second part. The reason for keeping this part of the curve the same is that longer-term predictions should only be accounted for with actual data. Thus, this part should only be adjusted when actual data become available.

- Step 5—Using the adjustments determined from Steps 2 and 3, calculate the new probability of failure relationship. This relationship should then be compared to the one developed from historical data to ensure engineering reasonableness.

- Step 6—The mean and standard deviation for the expected service life can then be determined for use in LCCA.

Summary

While it is very important to develop an initial set of survival curves for a given pavement "family," it is equally important to realize that this curve represents that population of pavements with its specific traffic, climate, design, materials, construction, and maintenance. This survival curve could be thought of as a benchmark curve.

As is normally the case, the highway agency has made many improvements to that "family" of pavements over the past several years, and the use of the benchmark survival curve may not be reasonable. An adjustment to this curve can be made to reflect the new technology improvements to design, construction, materials, and maintenance. This adjustment must consider the impact of the new technology to all types of failure mechanisms (distress, smoothness, etc.). The overall impact to the population of pavements built with this new technology will be to shift the survival curve to a longer life and perhaps also traffic carrying capacity but this shift will not be great because of so many factors that affect pavement performance. This topic is an area of very little research and much remains to be discovered to develop a reliable procedure to shift survival curve due to new technologies.

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Appendix F
Meeting Facilitator
Scope of Work

Meeting Facilitator
Scope of Work

General

The Ohio Department of Transportation (ODOT) is requesting letters of interest (LOI's) from qualified individuals to serve as a meeting facilitator. For purposes of this LOI, a facilitator is described as an individual who provides impartial management of meetings designed to enable participants with divergent views to focus on substantive issues and reach a common understanding of these issues. The facilitator will assist in developing an agenda for each meeting, assist in determining the appropriate length of the meeting, enforce ground rules of conduct, promote interaction and communication during meetings, and bring issues to closure. The facilitator will remain neutral relative to the content of the meeting in that they will not take sides or express a point of view during the meeting.

The individual selected will be asked to facilitate a series of meetings between ODOT and representatives of the portland cement concrete pavement and asphalt pavement construction industries. While ODOT has the responsibility of developing and implementing pavement selection, design, and specifications for construction and materials it is their desire to obtain the views of industry before making decisions. Conversely ODOT wishes to insure that industry understands the reasoning and support behind their decision making process.

The facilitator should be aware that there is a spirited level of competition between the asphalt and concrete paving industries. Both industries closely guard their existing market share and are always endeavoring to increase market share. This spirit of competition spilled into the political arena in 2003 with a legislative mandate that ODOT hire a neutral third party (NTP) to evaluate their pavement selection procedures. The nature and type of issues raised during the NTP's interviews with the paving industry, led to the NTP recommending that ODOT conduct a series of facilitated meetings with members of the paving industries.

Schedule

Approximately six 1- or 2-day meetings will be scheduled during a 12-month period commencing with the selection of the facilitator.

All meetings will be held at the ODOT headquarters in Columbus, Ohio

Selection Process

ODOT will evaluate the LOI and may directly select a facilitator or they may "short list" a number of respondents and request additional information. Interviews of the "short listed" individuals are optional. The selection criteria for the LOI are shown below:

Selection factors are as follows:

- Overall experience in facilitating meetings between groups with divergent points of view.
- Experience facilitating meetings between government agencies and stakeholder groups.
- Training, education, and certifications related to providing facilitation services
- Lack of detailed experience in the specific area of pavement engineering, design or construction.

Appendix G
Evaluation of the Future Maintenance Schedule

Evaluation of the Future Maintenance Schedule

At their November 18th meeting, the Pavement Selection Advisory Committee requested that the neutral third party (NTP) suggest an interim future maintenance schedule for ODOT. It was envisioned that this schedule would be used until ODOT could develop a new schedule based on survival curves. The NTP felt it was important that, where possible, the recommended schedule should reflect pavement performance and practices in Ohio. Because of time restraints, the NTP elected to focus on Interstate pavements; however, we believe the analysis approach used for interstate pavements can be duplicated for non-interstate routes with traffic less than 35 million rigid ESAL's.

To accomplish this task, the NTP requested the following information from ODOT:

1. During the past 5 years the percentage of mill and fill HMA overlays of Interstate asphalt pavements where full width milling, including the shoulder, was used. This should be broken down by functional overlays to correct surface distress and structural overlays.
2. For all functional HMA overlays constructed on Interstate asphalt pavements during the past 5 years, the time since the original construction of the pavement and (when applicable) the time since the most recently constructed prior overlay of the pavement. Also please provide the thickness of the overlay.
3. For all structural HMA overlays constructed on Interstate asphalt pavements during the past 5 years, the time since the original construction of the pavement and (when applicable) the time since the most recently constructed prior overlay of the pavement. Also please provide the thickness of the overlay.
4. For all structural HMA overlays constructed directly on PCC pavements during the past 5 years, time since the original construction of the pavement and the thickness of the overlay.

The information provided by ODOT in response to this request is included at the end of this appendix.

Maintenance Schedule for HMA Pavements

The data supplied by ODOT indicated that 12 HMA overlays were constructed on asphalt pavements during the last 5 years. This information was used to investigate three issues: 1) milling width, 2) overlay thickness, and 3) rehabilitation schedule.

Milling Width

The amount of milling required is an engineering decision based on the condition of the shoulder pavement. Table G-1 reflects the milling width used by ODOT during the past 5 years.

Table G-1. Interstate overlays.

District	County	Route	Proj. #	Structural	Functional	ML or Full Width	Thickness
2	LUC	475	358		X	Full Width	3.25
5	FAI	70	440		X	ML	1.5
5	LIC	70	316		X	ML (driving lane only)	1.5
5	LIC	70	401		X	ML +3'	1.5
5	LIC	70	493		X	ML	1.5
5	LIC	70	440		X	ML	1.5
6	DEL	71	722	X		Full Width	5.75
6	FRA	270	8000		X	ML + inside shoulder	1.5
6	FRA	71	722	X		Full Width	5.75
8	CLE	275	3012	X		Full Width	3.25
8	CLE	275	2	X		Full Width	3.25
8	CLE	275	172	X		Full Width	3.25

The data indicate that, typically, milling only the mainline is required for functional overlays and full-width milling is required at the time structural overlays are constructed. The average milled with for all of the functional overlays was 25 feet.

Based on a review of the data, the NTP recommends that milling of the mainline only be used for functional overlays and full-width milling be used for structural overlays.

Overlay Thickness

Observation of the data indicates that typically a 1.5-inch overlay is constructed when a functional pavement rehabilitation is required.

During the last 5 years there were five projects calling for structural overlays. Two projects totaling 15.72 miles required a 5.75-inch overlay, and 3 projects totaling 11.01 miles required a 3.25-inch overlay. The weighted average of the overlay thickness was 4.72 inches.

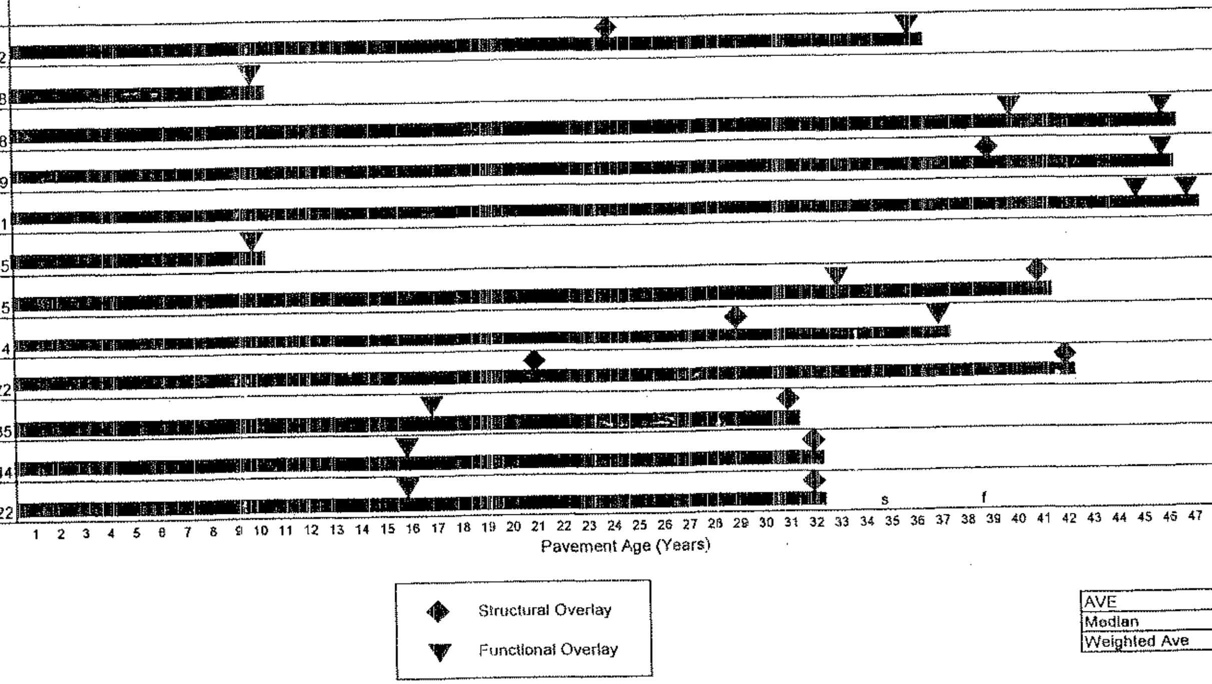
Based on a review of the data, an overlay thickness of 1.5 inches is used for functional overlays and an average of 4.75 inches is used for structural overlays.

Rehabilitation Schedule

Using the information supplied by ODOT relative to the pavement age at the time overlays were constructed during the last 5 years and the length of time since the previous overlay, a limited pavement history was developed for each of the sections. This history, shown in figure G-1, was used to develop a recommended rehabilitation schedule.

Figure G-1. Pavement history for HMA overlays constructed during the past 5 years.

District	County	Route	Proj. #	Length	Time to 1st Overlay	Time from Functional to Next overlay	Time from Structural to Next Overlay
2	LUC	475	358	3.72			12
5	FAI	70	440	2.38	10		
5	LIC	70	316	3.58		6	
5	LIC	70	401	5.09			7
5	LIC	70	493	6.41		2	
5	LIC	70	440	9.55	10		
6	DEL	71	722	11.5		8	
6	FRA	270	8000	3.14			8
6	FRA	71	722	4.22			21
8	CLE	275	3012	5.35	17	14	
8	CLE	275	2	4.44	16	16	
8	CLE	275	172	1.22	16	16	



	Time to 1st Overlay	Time from Functional to Next overlay	Time from Structural to Next Overlay
AVE	14	10	12
Median	16	11	8
Weighted Ave	13.1	9	12

Analysis of the data contained in figure G-1 indicates that the weighted average time to the first overlay (functional) is 13.1 years. The weighed average life of a functional overlay is 9 years. The weighted average life of a structural overlay is 12 years.

Based on this analysis, the indicated maintenance schedule would be to place the initial overlay (functional) at year 13, 2nd overlay (structural) at year 22, and third overlay (functional) at year 24.

Comparison of the NTP's analysis to ODOT's current schedule is provided in table G-2.

Table G-2. Comparison of HMA rehabilitation schedules.

NTP's Analysis	ODOT's Current Schedule
1. Year 13, 1.5" overlay with planing (mainline only)	1. Year 12, 1.5" overlay with planing (mainline and shoulder)
2. Year 22, 4.75" overlay with planing (mainline and shoulder)	2. Year 22, 3.25" overlay with planing (mainline and shoulder)
3. Year 34, 1.5" overlay with planing (mainline only)	3. Year 34, 1.5" overlay with planing (mainline and shoulder)

While the NTP's analysis used only a minimum amount of data, it tends to generally support the maintenance schedule currently used by ODOT.

Maintenance Schedule for Rigid Pavements

The data on overlaid rigid pavements were very limited; therefore, it was not possible for the NTP to draw any specific conclusions. The data tend to support the overly thickness being used according to ODOT's schedule.

The timing of ODOT's maintenance strategies was higher than the median for the States reviewed. It is difficult to draw conclusions from the median values of the other States reviewed because of differences in climate, designs, and materials. The NTP felt that Pennsylvania was the State most similar to Ohio in the review sample. Pennsylvania's schedule is shown on the next page. Since joint sealing is not normally performed on warranty pavement, the 10-year rehabilitation would not apply in Ohio.

Based on a review of practices of other States, particularly Pennsylvania, the NTP arrived at the rehabilitation schedule for rigid Interstate pavements shown in table G-3. ODOT's current schedule is shown for comparison. As in the case of HMA pavements, the NTP considers these to be minor modifications.

Table G-3. Comparison of PCC rehabilitation schedules.

NTP's Analysis	ODOT's Current Schedule
1. Year 20 - Concrete patch 2% of pavement area diamond grind	1. Year 22: Diamond grinding (mainline plus one foot of shoulder), full depth repair 4% of mainline surface area;
2. Year 30 - Concrete patch 5% of pavement area, 3.25" asphalt overlay.	Year 32: 3.25" asphalt overlay, full depth repair 2% of mainline surface area.

Pennsylvania's Rehabilitation Schedule for PCC Pavements

10 years - Clean and seal 25% of longitudinal joints
Clean and seal 5% of transverse joints, 0% if neoprene seals arc used
Seal coat shoulders, if Type 1 paved shoulders
20 years - Concrete patch 2% of pavement area
Diamond grind 50% of pavement area
Clean and seal all longitudinal joints, including shoulders
Clean and seal all transverse joints, 7% if neoprene seals are used
Maintenance and protection of traffic
User delay
30 years - Concrete patch 5% of pavement area
Clean and seal all joints
600-psy leveling course
3.5-in. or 4-in. bituminous overlay
Saw and seal joints in overlay
Type 7 paved shoulders
Adjust all guide rail and drainage structures
Maintenance and protection of traffic
User delay
35 years - Seal coat shoulders

Questions 1, 2, & 3 regarding asphalt interstates are answered below

NTP requested pavement information 11/20/03

District	County	Route	Begin log	End log	Length	Proj. #	Year	Activity	Thickness	Structural	Functional	ML or Full Width	Years Since Original Const.	Years Since Prior Overlay	Prior Overlay Thickness
2	LUC	475	5.25	8.97	3.72	358	2002	50	3.25		X	Full Width	36	12	3.25
5	FAI	70	0	2.38	2.38	440	1998	50	1.5		X	ML	10		
5	LIC	70	20.26	23.84	3.58	316	2000	50	1.5		X	ML (driving lane only)	46	6	1.5 ***
5	LIC	70	23.84	28.93	5.09	401	1999	50	1.5		X	ML	46	7	5.75
5	LIC	70	9.55	15.96	6.41	493	1999	50	1.5		X	ML	47	2	1.5
5	LIC	70	0	9.55	9.55	440	1998	50	1.5		X	ML	10		
6	DEL	71	0	11.5	11.5	722	1999	50	5.75	X		Full Width	41	0	1.25
6	FRA	270	33.86	37	3.14	8000	2000	50	1.5		X	ML + inside shoulder	37	8	6.25
6	FRA	71	25.68	29.9	4.22	722	1999	50	5.75	X		Full Width	42	1	3.75
8	CLE	275	0	5.35	5.35	3012	2000	50	3.25	X		Full Width	31	14	2.5
8	CLE	275	5.35	9.79	4.44	2	2002	50	3.25	X		Full Width	32	16	2.5
8	CLE	275	9.79	11.01	1.22	172	2002	50	3.25	X		Full Width	32	16	2.5

Question 4 regarding the 1st overlay of concrete interstates is answered below

District	County	Route	Blog	Elog	Length	Proj. #	Year	Activity	Thickness	Structural	Functional		Years Since Original Const.	Years Since Prior Overlay	Prior Overlay Thickness
12	CUY	90	9.7	13.41	3.71	180	1999	60	3.25	X			25		
10	NOB	77	11.22	18.92	7.7	94	1998	60	3.75	X			32		

Dave Miller:
Mainline plus 3 feet of inside shoulders.

Dave Miller:
1.5" mill and fill placed in 1998 to maintain traffic during multi-year construction. Prior overlay was 20 years earlier.

Dave Miller:
1.25" mill and fill placed in early 1999 to maintain traffic during multi-year construction. Prior overlay to that was 7 years earlier.