Appendix C

Pavement Rehabilitation Example

The purpose of this Appendix is to demonstrate the step-by-step process for pavement evaluation and rehabilitation strategy selection which is presented in this *Guide for Selection of Pavement Rehabilitation Strategies*. The pavement rehabilitation example presented here is based on one given in Reference 1. Some of the data for this example were drawn from this source, and some other data were modified or invented. It is emphasized that neither the rehabilitation thickness designs nor the unit costs used in this example are necessarily those which would be used by the DOT of the State in which this project is located.

The rehabilitation selection process follows the following six steps presented in the Guide:

- **Step 1 – Data collection:** Gathering all of the information necessary to conduct an evaluation of the pavement's present condition and its rehabilitation needs.

- **Step 2 – Pavement evaluation:** Assessing the current condition of the pavement, identify the key types of deterioration present, identify deficiencies that must be addressed by rehabilitation, and identify uniform sections for rehabilitation and design over the project length.

- **Step 3 – Selection of rehabilitation techniques:** Identifying candidate rehabilitation techniques which are best suited to the correction of existing distress and achievement of desired improvements in the structural capacity, functional adequacy, and drainage adequacy of the pavement.

- **Step 4 – Formation of rehabilitation strategies:** Combining individual rehabilitation techniques into one or more rehabilitation strategy alternatives, developed in sufficient detail that the performance and costs of each may be confidently estimated.

- **Step 5 – Life-cycle cost analysis:** Comparing the monetary costs and benefits of the different rehabilitation strategy alternatives over a common analysis period.

- **Step 6 – Selection of rehabilitation strategy:** Considering monetary factors and nonmonetary factors together in selecting one pavement rehabilitation strategy from among the alternatives considered.

Step 1 – Data Collection

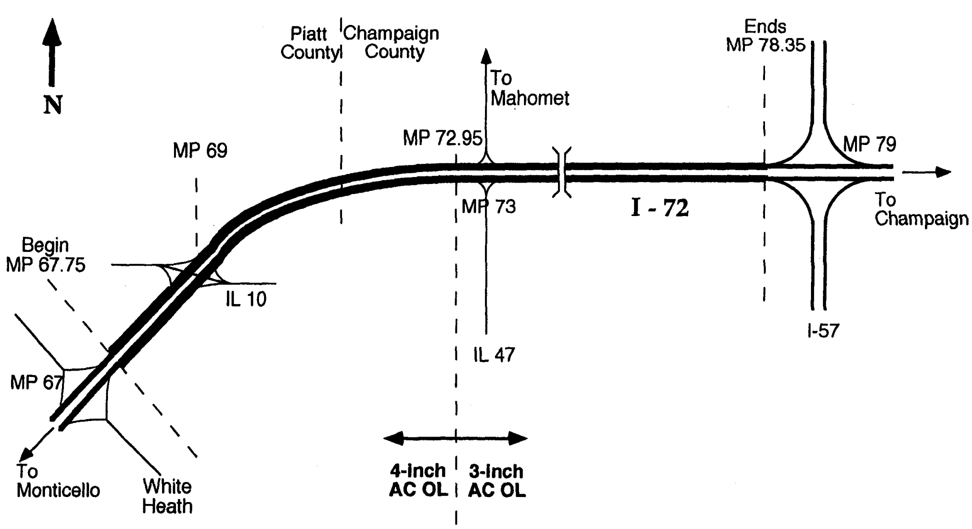
The activities involved in this step are shown below:

Step 1. Data Collection

Roadway Section Definition	Pavement Section Inventory	Traffic Analysis	Distress Survey	Nondestructive Deflection Testing
Materials Sampling and Testing	Profile and Roughness Measurement	Friction Measurement	Drainage Inspection	Other Nondestructive Testing

1a. Roadway Section Definition

The asphalt-overlaid concrete pavement used for this example is a section of Interstate 72 between Monticello and Champaign, Illinois. The portion of the highway addressed in this example runs eastbound and westbound, between mileposts 72.95 and 78.35. The layout of the project is illustrated below.



1b. Pavement Section Inventory

The original pavement was a 7-inch continuously reinforced concrete pavement with a 4-inch bituminous-aggregate mixture (BAM) base, constructed 23 years ago. The concrete aggregate source was a pit known for D-cracking aggregates. The pavement section has two traffic lanes in each direction, both 12 feet wide. The inner and outer shoulders are asphalt concrete and are 6 feet and 10 feet wide, respectively.

The pavement was overlaid after 13 years of service. Asphalt patching and longitudinal edgedrain installation were done at the time of the overlay. Between mileposts 67.66 and 72.95, a 4-inch asphalt overlay was placed. Between mileposts 72.95 and 78.35, a 3-inch asphalt overlay was placed. Only the latter half of the project, with the 3-inch overlay, is addressed in this example.

1c. Traffic Analysis

The existing overlay is estimated to have carried about 3.8 million ESALs in 10 years of service. The current truck traffic level corresponds to approximately 0.5 million rigid pavement ESALs annually, in one direction, in the outer traffic lane. The ESALs are estimated to be increasing at a compounded rate of 6 percent per year.

1d. Distress Survey

The eastbound and westbound directions are similar in their levels of distress. The project has about 62 medium- and high-severity distresses (potholes, reflected D-cracking failures, deteriorated transverse reflection cracks, and deteriorated asphalt patches), in the outer lane, in each direction, over its 5.4-mile length. Extensive D-cracking distress has reflected through to the pavement surface. The only materials-related distress in the asphalt concrete surface layer is some minor weathering. Rutting was measured with a South Dakota profiler. The average rut depth measured was 0.20 inches.

1e. Nondestructive Deflection Testing

Deflection testing was conducted using a Falling Weight Deflectometer. A target load of 9000 pounds was used with a 12-inch load plate, and deflection sensors spaced at 0, 12, 24, and 36 inches from the center of the load plate. Deflections were measured in the outer wheelpath, away from reflected joints and cracks. The pavement was tested at 500-foot intervals along its entire length, in the outer lane, in both directions.

The temperature of the asphalt concrete mix was measured three times during each day of testing. The mix temperature was recorded along with the time and the air and surface temperatures, in the FWD data file. These data were used to assign an elastic modulus to the asphalt concrete layer for each deflection basin measured.

The mean backcalculated dynamic k-value (modulus of subgrade reaction) was 270 psi/inch, which corresponds to a static k value of about 135 psi/inch. The mean backcalculated concrete modulus was 3.46 million psi. A high percentage of the deflection basins measured – 17 percent – yielded backcalculated concrete modulus values less than 2 million psi. These backcalculation results indicate the extent of the damage done by D-cracking.

1f. Materials Sampling and Testing

Several cores were obtained for examination and testing. In all but one case, the actual concrete thickness was greater than the design thickness of 7 inches. The average thickness of the concrete layer from the cores was 7.3 inches. The reinforcing steel was noted to be in good condition. In about half of the cores, the asphalt layer was bonded to the concrete layer, while in the other half it was not.

All of the asphalt concrete samples were subjected to diametral resilient modulus testing (ASTM D 4123) in the laboratory. The mean resilient modulus was 600 ksi at 70 degrees F and 275 ksi at 90 degrees F. These modulus values correspond to a testing frequency of 1.25 Hz.

Although sound concrete cores were recovered, the strength of the concrete layer was low. The mean split tensile strength was 372 psi, from which a modulus of rupture of 592 psi was estimated. The low strength of the concrete after 20 years is attributable to D-cracking damage.

No sound samples of the bituminous-aggregate mix base were recovered during coring. The base was observed to be largely deteriorated and mixed with subgrade soil. No laboratory testing was performed on the base materials.

The subgrade soil is a plastic clay, AASHTO classification A-6. Such soils typically have California Bearing Ratio (CBR) values in the range of about 5 to 15, and static k values between about 25 to 225 psi/inch, depending on the degree of saturation. The mean static k value estimated from the backcalculation results is within this range.

1g. Profile and Roughness Measurement

The pavement profile was measured with a South Dakota profiler An International Roughness Index (IRI) value of 3.0 m/km was obtained from profile measurements.

1h. Friction Measurement

Because the rehabilitation is expected to require resurfacing or reconstruction, no friction measurement was performed.

1i. Drainage Inspection

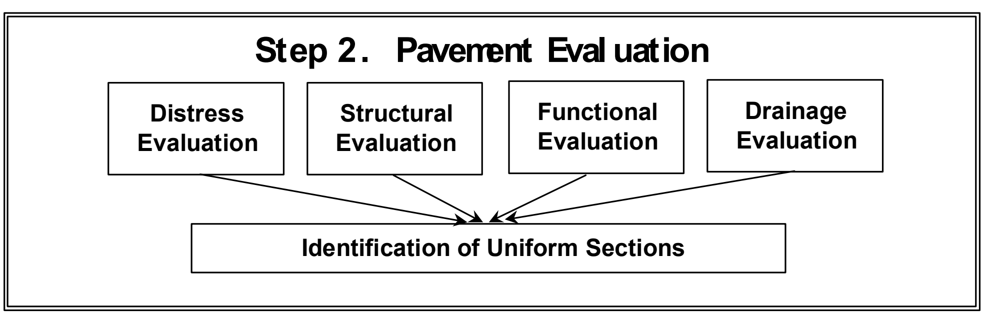
Visual inspection of the longitudinal edgedrain outlets indictates that the drains are functioning.

1j. Other Nondestructive Testing

No other nondestructive testing was done.

Step 2 – Pavement Evaluation

The activities involved in this step are shown below:



2a. Distress Evaluation

The extensive and severe distress present in the asphalt-overlaid concrete pavement today is the result of three factors:

- the extensive and severe D-cracking in the original concrete pavement,
- the reflection of this D-cracking distress through the first asphalt overlay, and
- the loss of continuity in the concrete slab, due to preoverlay repairs having been done with asphalt instead of continuously reinforced concrete. The latter type of repair was not feasible because of the extent of the D-cracking.

2b. Structural Evaluation

An asphalt-overlaid continuously reinforced concrete pavement is considered to require a structural improvement when it has 10 or more medium- or high-severity reflected cracks, punchouts, or failed patches per mile in the outer traffic lane. The project is considered to be in need of a structural improvement, because it has a total of 62 such distress occurrences, over a length of 5.4 miles, or 11.5 per mile.

2c. Functional Evaluation

The IRI level of 3.0 m/km is estimated to correspond to present serviceability index of about 2.3. A serviceability index of less than 2.5 for a route of this class is considered an indicator of functional deficiency.

2d. Drainage Evaluation

The pavement is considered to have adequate drainage.

2e. Identification of Uniform Sections

The evaluations of distress, structural condition, functional condition, and drainage condition indicate that the pavement section described can be considered one uniform section for purposes of rehabilitation strategy selection and design.

It should be noted, however, that the original construction section has already been divided into two sections for the purpose of this evaluation: the western half of the section, with the 4-inch overlay, and the eastern half of the section, with the 3-inch overlay.

Step 3 – Selection of Rehabilitation Techniques

The activities involved in this step are shown below:

Step 3. Selection of Rehabilitation Techniques			
Techniques Indicated by Structural Evaluation	Techniques Indicated by Functional Evaluation	Techniques Indicated by Distress Evaluation	Techniques Indicated by Drainage Evaluation

3a. Techniques Indicated by Structural Evaluation

The structural improvement options applicable to asphalt-overlaid concrete pavements are the following:

- Asphalt overlay (that is, a second asphalt overlay, on top of the existing asphalt overlay),
- Asphalt overlay of fractured concrete slab (after removal of the existing asphalt surface),
- Unbonded concrete overlay, and
- Reconstruction (in either asphalt or concrete).

3b. Techniques Indicated by Functional Evaluation

Although the pavement has unacceptably low serviceability, all of the structural improvement options listed in the previous step would correct this functional deficiency.

3c. Techniques Indicated by Distress Evaluation

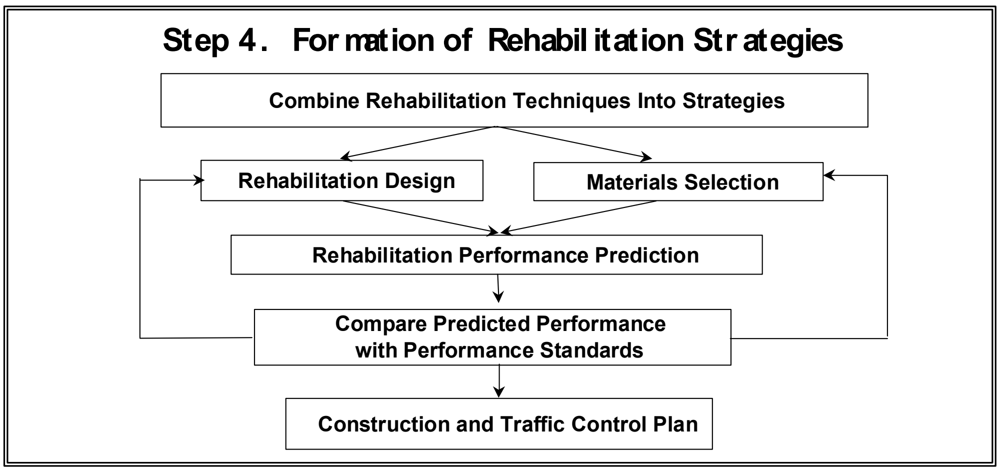
The principal distresses present are medium- and high-severity reflected cracks, punchouts, or failed patches. The repair options for such distresses are the four structural improvement options listed earlier, as well as full-depth repair. Given the extent and severity of the distress, full-depth repair alone without overlay is not considered an adequate repair option.

3d. Techniques Indicated by Drainage Evaluation

The drainage evaluation does not indicate that a drainage improvement is needed.

Step 4 – Formation of Rehabilitation Strategies

The activities involved in this step are shown below:



4a. Combine Rehabilitation Techniques Into Strategies

The rehabilitation strategy alternatives which represent feasible combinations of the individual techniques identified in Step 3 are the following:

- Asphalt overlay,
- Asphalt overlay with full-depth repair,
- Asphalt overlay with cold milling,
- Asphalt overlay with full-depth repair and cold milling,
- Asphalt overlay with hot surface recycling,
- Asphalt overlay with full-depth repair and hot surface recycling,
- Asphalt overlay of fractured concrete slab (after removal of existing asphalt surface),
- Unbonded concrete overlay,
- Unbonded concrete overlay with full-depth repair,
- Reconstruction in asphalt, and
- Reconstruction in concrete.

In reality, more permutations of the asphalt and unbonded concrete overlay alternatives exist, because varying amounts of full-depth repair between 0 and 100 percent could be selected. Given the severely deteriorated state of the original concrete slab, only alternatives involving no continuously reinforced concrete full-depth repair are considered feasible.

Among the rehabilitation strategy alternatives listed above, the following will be considered further in this example:

- Second asphalt overlay with cold milling,
- Asphalt overlay of fractured concrete slab (after removal of existing asphalt surface),
- Unbonded concrete overlay, and
- Reconstruction in asphalt, and
- Reconstruction in concrete.

4b. Rehabilitation Design

The thickness designs for the rehabilitation strategy alternatives listed above were developed using the 1993 *AASHTO Guide* [2] procedures for new design and overlay design. The initial and terminal serviceability levels used were 4.5 and 3.0. A design reliability level of 95 percent was selected. The drainage coefficients were set at 1.0 for all alternatives.

A reasonable service life range for the second asphalt overlay alternative is believed to be 8 to 15 years. The overlay was designed for 9 million rigid pavement ESALs over a 12-year design life. A value of 3.5 was used for the J load transfer factor, considering the deteriorated condition of the existing concrete slab. The concrete elastic modulus and subgrade k value inputs were selected based on the backcalculation results. An overall standard deviation of 0.39 was used. Given the severely deteriorated state of the existing concrete slab, it is not considered feasible to do continuously reinforced concrete full-depth repairs. Thus, a value of 0.85 was selected for the joints and cracks adjustment factor (F_{jc}), assuming no repair to the existing 62 potholes, deteriorated cracks, and failed patches per mile. A value of 0.80 was selected for the concrete durability factor (F_{dur}). A value of 0.97 was selected for the asphalt concrete quality adjustment factor (F_{ac}). It was assumed that 0.5 inch of the existing asphalt concrete surface would be removed by cold milling.

A reasonable service life range for the asphalt overlay-after-rubblizing alternative is believed to be 15 to 25 years. The overlay was designed for 7.75 million flexible pavement ESALs over a 15-year design life. The design subgrade resilient modulus was determined by dividing the estimated *in situ* resilient modulus (calculated from deflections measured 36 inches from the load plate) by a factor of 5. An overall standard deviation of 0.49 was used.

A reasonable service life range for the unbonded concrete overlay alternative is believed to be 20 to 30 years. The unbonded concrete overlay alternative was designed for 15.5 million rigid pavement ESALs over a 20-year design life. A value of 3.2 was used for the J load transfer, assuming that the overlay would be dowelled jointed concrete. Values of 4 million psi and 650 psi were used for the overlay concrete elastic modulus and modulus of rupture respectively. The design subgrade k value was the same as that used in the design of the asphalt overlay alternative, 135 psi/inch, based on the backcalculation results. A value of 0.95 was selected for the joints and cracks adjustment factor (F_{jcu}), assuming that no repair would be done to the existing 62 potholes, deteriorated cracks, and failed patches per mile. An overall standard deviation of 0.39 was used.

A reasonable service life range for reconstruction in asphalt is believed to be 20 to 25 years. The asphalt reconstruction alternative was designed for 10.5 million flexible pavement ESALs over a 20-year design life. The design subgrade resilient modulus was determined as described before for the rubblizing alternative. An overall standard deviation of 0.49 was used. It is assumed that the reconstructed pavement would be full-depth asphalt, over 6 inches of stabilized subgrade.

A reasonable service life range for reconstruction in concrete is believed to be 20 to 30 years. The concrete reconstruction alternative was designed for 15.5 million rigid pavement ESALs over a 20-year design life. A value of 3.2 was used for the J factor, assuming that the reconstructed pavement would be dowelled jointed concrete. Values of 4 million psi and 650 psi were used for the concrete elastic modulus and modulus of rupture respectively. The design subgrade k value was the same as that used in the design of the asphalt overlay alternative, 135 psi/inch, based on the backcalculation results. An overall standard deviation of 0.39 was used.

The thickness designs obtained for the alternatives considered are the following.

Alternative	Design Life	Required Thickness
Asphalt overlay with cold milling	12 years	9.75 inches
Asphalt overlay with rubblizing	15 years	12.25 inches
Unbonded concrete overlay	20 years	10.50 inches
Reconstruction in asphalt	20 years	15.00 inches
Reconstruction in concrete	20 years	12.50 inches

4c. Materials Selection

The State's conventional mixes for asphalt and concrete pavement layers are expected to be used.

4d. Rehabilitation Performance Prediction

According to the AASHTO procedures by which the rehabilitations were designed, the serviceability index of each alternative is expected to be 3.0 at the end of the initial design period. The rehabilitation alternatives were designed for different design periods, so some or all of them will require follow-up rehabilitation in order to filll out a common analysis period.

In addition, they are expected to require some maintenance. The three asphalt surface alternatives (asphalt overlay after cold milling, asphalt overlay after rubblizing, and reconstruction in asphalt) are expected to require some full- and/or partial-depth repair, and crack sealing. The two concrete surface alternatives (unbonded concrete overlay and reconstruction in concrete) are expected to require some full- and/or partial-depth repair and crack sealing.

4e. Comparison of Predicted Performance with Performance Standards

All of the alternatives are expected to be structurally adequate for their initial design periods, and to have a serviceability index of about 3.0 at the end of these periods. The follow-up rehabilitation activities are also assumed to be designed for a terminal serviceability index of 3.0. This presumes that adequate maintenance will be done during the performance period.

4f. Construction and Traffic Control Plan

The first alternative (asphalt overlay after cold milling) is the most expedient of the five, in that it does not involve either repair or removal of any pavement layers. However, the required thickness of the overlay dictates that it be placed in multiple lifts. It is anticipated that in each direction, traffic may be maintained in one lane at a time, and switched back and forth between lanes as needed to accommodate the placement of the overlay lifts of the traffic lanes and shoulders.

The rubblizing alternative requires removal of the existing asphalt concrete surface, which will leave exposed an old concrete slab which is far too deteriorated to safely and comfortably carry traffic. Therefore, it is proposed that the pavement be rehabilitated in one direction at a time, with traffic crossed over to opposing lanes in the opposite direction. This will permit the rapid removal of the existing asphalt concrete surface, rubblizing of the existing concrete slab, rolling the rubblized layer to compact it, and placement of the new asphalt concrete surface in lifts, in the traffic lanes and shoulders. The existing concrete slab is expected to be fairly easy to rubblize, considering its low strength and extensive D-cracking. Rehabilitation of the pavement by direction will require the scheduling of the use of the rubblizing equipment in two phases, several weeks apart.

The unbonded concrete overlay requires no repair. It does require require the placement of an inch of asphalt concrete layer as a separating and levelling course, placement of dowel baskets on this asphalt layer, at the planned locations of the transverse joints, placement of the concrete overlay slab in the traffic lanes and shoulders, and sawing and sealing of the transverse and longitudinal joints. It is proposed that these activities be conducted in one direction at a time, with traffic crossed over to opposing lanes in the opposite direction.

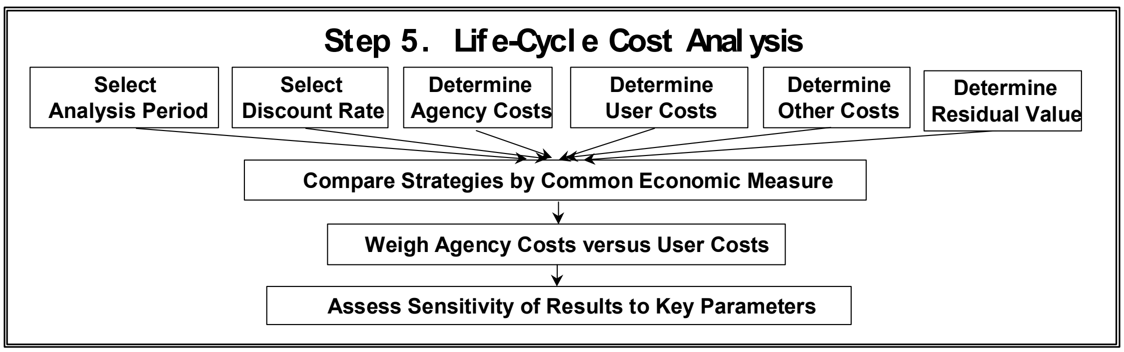
The asphalt reconstruction alternative requires demolition and removal of the existing pavement down to the subgrade, lime treatment of the subgrade, compacting and grading the treated subgrade, and placement of the full-depth asphalt pavement in multiple lifts, in the traffic lanes and shoulders. It is proposed that these activities be conducted in one direction at a time, with traffic crossed over to opposing lanes in the opposite direction.

The concrete reconstruction alternative requires demolition and removal of the existing pavement down to the subgrade, preparation of the subgrade (reworking, compacting, and grading), placement of a granular base layer, placement of dowel baskets on this base layer, at the planned locations of the transverse joints, placement of the concrete slab in the traffic lanes and shoulders, and sawing and sealing of the transverse and longitudinal joints. It is proposed that these activities be conducted in one direction at a time, with traffic crossed over to opposing lanes in the opposite direction.

All five of the alternatives are assumed to require reconstruction of the interchange at milepost 73 and reconstruction under the bridge a half mile west of that interchange.

Step 5 – Life-cycle Cost Analysis

The activities involved in this step are shown below:



5a. Select Analysis Period

An analysis period of 20 years is selected for the life-cycle cost analysis. This requires the assignment of follow-up rehabilitation treatments to the two alternatives with shorter design periods. The asphalt overlay alternative is assumed to require a 4.5-inch asphalt overlay with cold milling in year 12. The rubblizing alternative is assumed to require a 3-inch asphalt overlay with cold milling in year 15.

5b. Select Discount Rate

A discount rate of 4 percent is used in this example.

5c. Determine Monetary Agency Costs

The monetary agency costs considered for the purposes of this example are the following. The costs of reconstruction at the interchange and the bridge underpass within the project limits are included. All costs are per four-lane mile, including shoulders.

Initial Rehabilitation Construction Costs

Alternative 1:	Asphalt overlay with cold milling	$ 500,000
Alternative 2:	Asphalt overlay after rubblizing	$ 750,000
Alternative 3:	Unbonded concrete overlay	$ 900,000
Alternative 4:	Reconstruction in asphalt	$ 1,000,000
Alternative 5:	Reconstruction in concrete	$ 1,000,000

Follow-Up Rehabilitation Construction Costs during Analysis Period

Alternative 1:	Asphalt overlay with cold milling	$ 250,000 in year 12
Alternative 2:	Asphalt overlay after rubblizing	$ 200,000 in year 15
Alternative 3:	Unbonded concrete overlay	None
Alternative 4:	Reconstruction in asphalt	None
Alternative 5:	Reconstruction in concrete	None

Annual Maintenance Costs during Analysis Period

It is assumed that the following maintenance costs will be incurred in every year of the analysis period except the years in which rehabilitation is done (year 0 for all alternatives, as well as year 12 for Alternative 1 and year 15 for Alternative 2).

Alternative 1:	Asphalt overlay with cold milling	$ 30,000
Alternative 2:	Asphalt overlay after rubblizing	$ 25,000
Alternative 3:	Unbonded concrete overlay	$ 20,000
Alternative 4:	Reconstruction in asphalt	$ 15,000
Alternative 5:	Reconstruction in concrete	$ 15,000

Traffic Control Costs During Construction

It is assumed that the following traffic control costs will be incurred in the years in which rehabilitation is done (year 0 for all alternatives, as well as year 12 for Alternative 1 and year 15 for Alternative 2).

Alternative 1:	Asphalt overlay with cold milling	$ 20,000
Alternative 2:	Asphalt overlay after rubblizing	$ 25,000
Alternative 3:	Unbonded concrete overlay	$ 25,000

Alternative 4:	Reconstruction in asphalt	\$ 35,000
Alternative 5:	Reconstruction in concrete	\$ 35,000

The costs associated with design of the rehabilitation alternatives and administration of the rehabilitation project are assumed to be the same for all of the alternatives, and therefore need not be considered in the life-cycle cost analysis.

5d. Determine Monetary User Costs

User costs may be divided into those associated with the normal use of the roadway (in-service user costs) and those associated with periods of construction work (work zone user costs). For the purposes of this example, it is assumed that in-service user costs are the same for all of the alternatives. The work zone user costs are assumed to differ among the alternatives, because of the differences in timing of rehabilitation activities and construction durations. The following work zone user costs (including vehicle costs, delay costs, and accident costs) are assumed:

Alternative 1:	Asphalt overlay with cold milling	\$ 10,000 (years 0 and 12)
Alternative 2:	Asphalt overlay after rubblizing	\$ 12,000 (years 0 and 15)
Alternative 3:	Unbonded concrete overlay	\$ 12,000 (year 0)
Alternative 4:	Reconstruction in asphalt	\$ 15,000 (year 0)
Alternative 5:	Reconstruction in concrete	\$ 15,000 (year 0)

5e. Determine Other Monetary Costs

No other monetary costs are considered in this example.

5f. Determine Residual Value

It is assumed that all of the alternatives would have the same serviceability index (3.0). For the asphalt overlay and rubblizing alternatives, it is anticipated that the pavement will be reconstructed at the end of the analysis period, and that the pavement materials would not be recycled. The residual value of these two alternatives is therefore zero. Both of these alternatives have a cost associated with demolition and removal of the pavement at the end of the analysis period. The estimated cost of the demolition and removal is \$40,000.

The three remaining alternatives (unbonded concrete overlay, reconstruction in asphalt, and reconstruction in concrete) are presumed to have some residual value at the end of the analysis period, in terms of contribution to the structural capacity of a future overlay. For these three cases it is assumed that the cost of the next rehabilitation, at the end of the 20-year analysis period, is reduced as a result of resurfacing instead of reconstructing the pavement. A residual value of $300,000 is assumed for these three alternatives.

5g. Compare Strategies by Common Economic Measure

The five alternatives were compared in terms of their present worths (that is, in dollars in the year of the start of the analysis period). The calculation of the present worth of the agency costs and the user costs is shown below for each of the alternatives.

Alternative 1: Asphalt overlay with cold milling

Year	Agency Costs					User Costs
	Initial Rehabilitation	Follow-Up Rehabilitation	Maintenance	Traffic Control	Residual Value	
0	500,000			20,000		10,000
1			30,000			
2			30,000			
3			30,000			
4			30,000			
5			30,000			
6			30,000			
7			30,000			
8			30,000			
9			30,000			
10			30,000			
11			30,000			
12		250,000		20,000		10,000
13			30,000			
14			30,000			
15			30,000			
16			30,000			
17			30,000			
18			30,000			
19			30,000			
20			30,000		40,000	
Present Worth (4%)	500,000	156,149	388,972	32,492	18,255	16,246

Agency Costs	**1,095,869**
User Costs	**16,246**
Total Costs	**1,112,115**

Alternative 2: Asphalt overlay after rubblizing

Year	Agency Costs					User Costs
	Initial Rehabilitation	Follow-Up Rehabilitation	Maintenance	Traffic Control	Residual Value	
0	750,000			25,000		12,000
1			25,000			
2			25,000			
3			25,000			
4			25,000			
5			25,000			
6			25,000			
7			25,000			
8			25,000			
9			25,000			
10			25,000			
11			25,000			
12			25,000			
13			25,000			
14			25,000			
15		200,000		25,000		12,000
16			25,000			
17			25,000			
18			25,000			
19			25,000			
20			25,000		40,000	
Present Worth (4%)	750,000	111,053	325,877	38,882	18,255	18,663

Agency Costs	**1,244,067**
User Costs	**18,663**
Total Costs	**1,262,730**

Alternative 3: Unbonded concrete overlay

Year	Agency Costs					User Costs
	Initial Rehabilitation	Follow-Up Rehabilitation	Maintenance	Traffic Control	Residual Value	
0	900,000			25,000		12,000
1			20,000			
2			20,000			
3			20,000			
4			20,000			
5			20,000			
6			20,000			
7			20,000			
8			20,000			
9			20,000			
10			20,000			
11			20,000			
12			20,000			
13			20,000			
14			20,000			
15			20,000			
16			20,000			
17			20,000			
18			20,000			
19			20,000			
20			20,000		-300,000	
Present Worth (4%)	900,000	0	271,807	25,000	-136,916	12,000

Agency Costs	**1,059,890**
User Costs	**12,000**
Total Costs	**1,071,890**

Alternatives 4 and 5: Reconstruction (in asphalt or concrete)

Year	Agency Costs					User Costs
	Initial Rehabilitation	Follow-Up Rehabilitation	Maintenance	Traffic Control	Residual Value	
0	1,000,000			35,000		15,000
1			15,000			
2			15,000			
3			15,000			
4			15,000			
5			15,000			
6			15,000			
7			15,000			
8			15,000			
9			15,000			
10			15,000			
11			15,000			
12			15,000			
13			15,000			
14			15,000			
15			15,000			
16			15,000			
17			15,000			
18			15,000			
19			15,000			
20			15,000		-300,000	
Present Worth (4%)	1,000,000	0	203,855	35,000	-136,916	15,000

Agency Costs	**1,101,939**
User Costs	**15,000**
Total Costs	**1,116,939**

The present worths of the agency and user costs for the five alternatives are summarized below.

Alternative	Agency Costs	User Costs	Total Costs
1 – Asphalt overlay with cold milling	1,095,869	16,246	1,112,115
2 – Asphalt overlay with rubblizing	1,244,067	18,663	1,262,730
3 – Unbonded concrete overlay	1,059,890	12,000	1,071,890
4 – Reconstruction in asphalt	1,101,939	15,000	1,116,939
5 – Reconstruction in concrete	1,101,939	15,000	1,116,939

5h. Weigh Agency Costs Versus User Costs

If agency costs and user costs are weighted equally, the unbonded concrete overlay is the best buy, in terms of lowest present worth. In fact, in this particular example, Alternative 3 would have the lowest present worth no matter how the agency costs and user costs were weighted, because it has both the lowest agency costs and the lowest user costs.

In other situations, where one or more alternatives with lower agency costs have higher user costs and vice versa, the relative weights assigned to agency costs and user costs may become very important to the ranking of alternatives. This is especially true for higher traffic levels, very different performance curves among the alternatives, and/or very different frequencies of maintenance and rehabilitation intervention among the alternatives.

5i. Assess Sensitivity of Life-Cycle Cost Analysis to Key Parameters

The sensitivity of the life-cycle cost analysis results to the discount rate used is illustrated below. If a discount rate of 0 percent is used instead of 4 percent, the following costs are obtained:

Alternative	Agency Costs	User Costs	Total Costs
1 – Asphalt overlay with cold milling	1,400,000	20,000	1,420,000
2 – Asphalt overlay with rubblizing	1,515,000	24,000	1,539,000
3 – Unbonded concrete overlay	1,025,000	12,000	1,037,000
4 – Reconstruction in asphalt	1,035,000	15,000	1,050,000
5 – Reconstruction in concrete	1,035,000	15,000	1,050,000

Using a discount rate of 0 percent increases the calculated present worths, because future costs are weighted equally with present costs. The ranking of the alternatives does not change: the alternative with the lowest present worth is still Alternative 3.

If a discount rate of 9 percent is used instead of 4 percent, the following costs are obtained:

Alternative	Agency Costs	User Costs	Total Costs
1 – Asphalt overlay with cold milling	523,333	10,000	533,333
2 – Asphalt overlay with rubblizing	777,778	12,000	789,778
3 – Unbonded concrete overlay	927,222	12,000	939,222
4 – Reconstruction in asphalt	1,036,667	15,000	1,051,667
5 – Reconstruction in concrete	1,036,667	15,000	1,051,667

Using a discount rate of 9 percent decreases the calculated present worths, because future costs are weighted much less than present costs. The alternatives favored in this scenario are those with greater proportions of their costs deferred into the future. In this example, changing the discount rate from 4 percent to 9 percent changes the ranking of the alternatives: Alternatives 1 and 2 now have present worths lower than Alternative 3.

Step 6. Selection of Rehabilitation Strategy

The activities involved in this step are shown below:

Step 6. Selection of Rehabilitation Strategy

Weigh Monetary versus Nonmonetary Factors

↓

Select Rehabilitation Strategy

6a. Weigh Monetary versus Nonmonetary Factors

The calculated present worths could be weighted quantitatively against various nonmonetary factors of concern, or the nonmonetary factors could be considered subjectively. One issue relevant to the alternatives considered is that not all of the alternatives leave the agency with a pavement with the same residual value at the end of the analysis period. A potential disadvantage of the rubblizing alternative is the availability of the equipment needed for rubblizing. A disadvantage to the rubblizing and reconstruction alternatives is the potential for problems with the weak subgrade soil.

6b. Select Rehabilitation Strategy

Considering the results of the life-cycle cost analysis and the nonmonetary factors together, the unbonded overlay alternative is selected.

It is important to emphasize that this example is intended only to demonstrate the steps and calculations in the rehabilitation strategy selection process. The costs and other inputs used in this example do not necessarily represent the real values that a State DOT would assign to this project or other projects.

References for Appendix C

[1] Hall, K. T., Darter, M. I., and Petko, G. S., *Case Studies in Asphalt-Overlaid Concrete Pavement Evaluation and Rehabilitation*, Illinois Highway Research Report IHR 532-5, Federal Highway Administration Report No. FHWA-IL-UI-248, University of Illinois and Illinois Department of Transportation, 1995.

[2] American Association for State Highway and Transportation Officials, *Guide for Design of Pavement Structures*, Washington, D. C., 1993.