DEVELOPMENT AND SELECTION OF THE PREFERRED 4R STRATEGY

Gerald F. Voigt
American Concrete Pavement Association

M.J. Knutson, P.E.
American Concrete Pavement Association

INTRODUCTION

What are the R's?

Since 1976 the paving industry has been working under the initial guidelines as outlined in the Federal-Aid Highway Act. Provisions of this act expanded the definition of construction to include: resurfacing, restoration and rehabilitation, the original three R's. In 1981 the Highway Act was passed which added reconstruction, the fourth R. It seems simple, however the four R's by this definition have confused engineers and others since their inception.

In practice, the four R's are easily defined: Resurfacing, Restoration, Recycling and Reconstruction. Rehabilitation has been removed from the definition as found in the congressional act, because in reality it is a term which encompasses both resurfacing and restoration. Recycling, which was not present, has been added in our practical definition so as not to neglect the reuse of existing materials.

These two congressional bills, passed in 1976 and in 1981, have basically redirected the major efforts of our entire industry. Focus has been placed on the repair of existing pavements, not the construction of completely new routes. Why did this occur? What is the bottom line? The answer is simple and universal. MONEY! The reason the congress bothered to redefine pavement construction to include the "R words", was so that Federal Aid could be directed toward projects which involve our deteriorating roadway infrastructure.

PROJECT SURVEY

What information does one need to apply a 4R technique? That is a question which could be answered in many ways, but one must keep in mind that the best investment a person can make is an investment in information. As much information as possible will give the design engineer the proper knowledge of the deteriorated pavement to address the problems appropriately.

There are four basic types of data which are necessary in developing designs for almost all 4R options:

Design Data: The first information that should be collected by the engineer are the design parameters for the existing pavement. This data includes the pavement type, whether jointed plain undoweled concrete (JPCP), jointed plain doweled concrete (JDCP), jointed reinforced concrete (JRCP), continuously reinforced concrete (CRCP) or an asphalt concrete pavement (ACP). Detailed information about the components of the pavement are also very helpful, this should include: layer materials and strengths, joint design, shoulder design, drainage system design, initial design assumptions and parameters, and finally previous repair and maintenance activities.

Traffic Data: The rudiment used by all pavement engineers in pavement design has been to determine the amount of traffic to be carried before the pavement has reached a level of unacceptable structural or functional deterioration. In a rehabilitation evaluation, past, current and expected traffic growth is needed to determine the remaining life of the existing pavement and to design an effective rehabilitation option. Once the remaining life has been determined, the alternatives of appropriate and cost-effective rehabilitation options will be narrowed.

Environmental Data: Water, temperature, freeze-thaw (F-T) and their interaction with the materials and layers of the pavement system have had an impact on the quality of the riding surface and structural adequacy of the pavement. Knowledge of the drainage conditions and durability of the materials to F-T interaction will help design against these problems in the future.

Distress/Condition Data: The existing pavement has been subjected to traffic loadings and environmental effects since construction and opening to traffic. The present condition of the pavement components can give tremendous insight into the performance that may be expected in the future. A condition survey should report the type, severity and amount of each distress observed. The distress will then be characterized as load or climate related. Nondestructive testing (NDT) and destructive testing (cores) should be used to determine the condition below the surface (ie. structural & material) which is not detectable in a visual survey.

The objective of a project survey is to collect enough information to accurately determine the causes and extent of deterioration in order to give insight for the development of appropriate cost-effective rehabilitation (4R) strategies. However, the same amount of data is not required for all rehabilitation options. Table 1 shows the recommended data required for determining feasibility and developing designs for several 4R options.

EVALUATION

Evaluation combines all data collected on the pavement, in order to narrow the scope of effective solutions. According to the Federal Highway Administration (1)...

> "The goal of pavement evaluation is to design rehabilitation alternatives which address the CAUSES of the deterioration, not just the symptoms."

In other words, "Band-Aid" repairs are not the answer to providing solutions that will be truly effective in extending the structural and/or service life of an existing pavement. Deterioration should no longer simply be hidden; sound engineering and economics must be used to address the needs of the nation's pavement network.

Key questions must be addressed using an engineering analysis that is perhaps more complex than those to which pavement engineers are accustomed. This is because rehabilitation problems are complex with many variables and factors of influence. Several key questions are as follows (1):

1. Is the pavement structurally adequate for future traffic loadings?
2. Have any of the pavement layer materials deteriorated?
3. Are the drainage conditions adequate?
4. Is the pavement functionally adequate? (Ride quality, skid resistance)
5. Is the performance of the pavement uniform, or does it vary between lanes or directions?
6. Has past maintenance been applied or ignored? Could this have contributed to the present condition?

Evaluation in the truest form should not be based on assumed conditions or material strengths. These factors can be measured and determined from actual response to destructive and non-destructive testing methods. Perhaps current testing procedures can be improved to give more accurate results, but testing is surely a better system than a shot in the dark "guesstimate"!

4R OPTIONS

Restoration Alternatives

Restoration refers to the work required to bring the structural condition or rideability of a pavement to an acceptable condition. Most of these techniques are applied not only to repair deterioration in the existing pavement, but also to prevent the same deterioration from occurring in the future.

Some of the most common restoration techniques currently being applied are:

CONCRETE PAVEMENTS

1. Full-Depth concrete repair
2. Partial-Depth concrete repair
3. Joint & Crack Resealing
4. Slab Stabilization
5. Diamond Grinding
6. Pressure Relief Joint Construction
7. Load Transfer Restoration
8. Retrofitting Edge Support (PCC Shoulders)
9. Cross-Stitching

ASPHALT PAVEMENTS

1. Pothole Patching
2. Surface Treatments
   - o Friction Course
   - o Asphalt-Aggregate treatment
   - o Seal Coat
   - o Slurry Seal
   - o Road Oiling
3. Crack Sealing
4. Full-depth Material Repair
5. Partial-depth Material Repair

Each Restoration technique has unique design details and construction procedures. Comprehensive specifications and construction details are required for proper application of the technique by the contractor. These techniques can be applied as stand-alone procedures to repair a particular pavement ill, or may be used in conjunction with an overlay.

Resurfacing Alternatives

Overlays can provide two important functions. Through the provision of a new wearing course, overlays can improve: rideability, safety, skid-resistance, cross-section and surface material defects (ie. weathering and raveling). An increase in the structural capacity of the pavement can also be gained with the placement of an overlay.

Materials selected for the overlay may have a large impact on the thickness required to provide the needed structural capacity and/or extension of the service life of the pavement. The most common overlay alternatives are listed below.

CONCRETE PAVEMENTS

1. Bonded Concrete
2. Unbonded Concrete
3. Asphalt Concrete (without RCC)
2. Asphalt Concrete (with RCC)

ASPHALT PAVEMENTS

1. Asphalt Concrete (without RCC)
2. Asphalt Concrete (with RCC)
3. Unbonded Concrete

RCC = Reflective Crack Control

Each of the overlay techniques has unique characteristics which require an understanding of the engineering, in order that the overlay is applied effectively. Detailed construction guidelines and thorough specifi-

Table 1. Data Required for Determining Feasibility and Developing Designs for Repair/Preventative Methods for Concrete Pavements. (Ref 1).

DATA REQUIRED	FDR	PDR	OVL	DGR	REC	SLS	DRN	JTR	PRJ	LTR	STM
Pavt Design	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Traffic Load & Volume	Y		Y	Y	Y	D	Y	D	D	Y	Y
Distress	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Skid			D	D	D						D
Accident			D	D	D						
Age	D	D	D	D	D			D	D	D	D
Material Properties	D	D	Y	Y	Y	D	Y				
Subgrade			Y		Y	D	Y	Y			
Climate			Y		D	Y	Y	Y	D		
Vertical Clearance			Y		Y						
Geometrics			D		D						
NDT	D	D	D			Y					
Destructive Testing (coring)	Y	Y	Y	D	Y	D				D	
Roughness			D	D	D						D
Surface Profile				Y							
Previous Maintenance	D		D	D	D	D	D	D	D		
Pushing of Bridges								D	Y		
Utilities (underground)	D				D	D	D				
Original Data - Construction	D		D	D	D		D				
Traffic Control Options	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Drainage	D		Y	D	Y	D	Y	D			Y

KEY:

Y = Definitely Needed.
D = Desired but not Necessary.

FDR = Full-Depth Repair
PDR = Partial-Depth Repair
OVL = Overlay (Resurfacing)
DGR = Diamond Grinding

REC = Recycling
SLS = Slab Stabilization
DRN = Edge Drain Installation
JTR = Joint Resealing
PRJ = Pressure Relief Joints
LTR = Load Transfer Restoration
STM = Bituminous Surface Treatment

cations are required for proper construction by the contractor.

Overlays are almost never constructed without repair work done to the existing pavement prior to placement. It is important to overlay performance that the underlying (existing) pavement condition is uniform throughout the project length. In designing an overlay, the most important consideration is the evaluation of the existing pavement. The evaluation results will govern pre-overlay repair and often the type, and thickness of overlay to be applied.

Recycling Alternatives

Recycling refers to the reworking of one or more of the layers or shoulders in the pavement system. Deficiencies in layers below the surface may be treated using this technique. Each recycling technique has a somewhat different approach which may entail complete removal, partial removal, or just reworking the surface.

CONCRETE PAVEMENTS

1. Removal and reuse of old concrete as:
   - o Coarse aggregate in new PCC pavement reconstruction,
   - o Coarse aggregate in Econocrete base course,
   - o Aggregate in Cement Treated base course,
   - o Stockpile material for base, subbase, open-graded or asphalt mixes.
2. Shoulder Improvement - Including the replacement of existing shoulders with PCC shoulders.

ASPHALT PAVEMENTS

1. Surface Recycling - Removal to depths less than 1" through heater-scarification or milling.
2. In-place Recycling - Removal to depths greater than 1" reshaping and recompacting the material for use as a base course.
3. Central Plant Hot-Mix Recycling - Removal of the asphalt surface course, remixing at a plant and replacement and compaction on the pavement.

To be effective, all of these techniques require a very detailed material analysis.

Reconstruction Alternatives

Reconstruction involves complete removal of the pavement structure, typically to the base layer. The structure is then replaced with either virgin or recycled materials. The options available to the engineer in a reconstruction alternative are basically the same as for new construction projects (ie. construct PCC or AC pavement?).

OTHER NON-PAVEMENT CONSIDERATIONS

When working on rehabilitation and 4R type work, the engineer often gets so caught up in the development of appropriate strategies, that he may find himself neglecting some very significant factors that are not strictly related to the pavement. Such as (1,2):

1. Right-of-Way.
2. Environmental Concerns.
3. High-Accident locations.
4. Noise Barriers.
5. Lighting & Grade Requirements.
6. Geometrics.
7. User Delay.
8. Traffic Control.
9. Overhead Structures.
10. Structures on Grade.
11. Interchanges.
12. Median & Fill Slopes
13. Culvert Extensions.
14. Guard Rail Raising.
15. Sign Raising.

These factors alone may determine which 4R strategy will be the best solution. For example, when considering the strategy of an unbonded concrete overlay (7" thick) or an asphalt overlay (10" thick), select fill will be required to meet 6:1 side slopes as required under AASHTO guidelines. This will induce a significant cost to the strategies; in this case higher for the asphalt overlay than the unbonded overlay.

DEVELOPING 4R STRATEGIES

As discussed, each 4R technique will address a certain distress and perhaps several deterioration problems on an existing pavement. In addition, each technique may not only repair or prevent further deterioration caused by that particular distress, but may also retard the development of other distresses or deterioration as well (1,3). Table 2 lists critical distresses found on both Concrete and Asphalt pavements, and recommended treatments for these critical distresses to repair and prevent future occurrence. Of course the table is very general, but it does give basic candidate repair techniques for distresses that may be found in data collection procedures.

For any given pavement condition or level of deterioration, more than one repair/preventative technique may be required. Applying a combination of repair/preventative techniques to an existing pavement, which address all existing distress and will prevent future reoccurrence, is applying an appropriate 4R strategy. It is a 4R strategy that will give the engineer confidence that he has restored the pavement to an acceptable condition for a substantial period of time.

For any given project, several 4R strategies should be developed in order that no option is overlooked. **Narrow-mindedness in the development of <u>realistic</u> and <u>appropriate</u> strategies will eventually result in accelerated deterioration of our infrastructure and consequently waste of limited funds.**

CHOOSING THE PREFERRED 4R STRATEGY

Figure 1 shows the step-by-step process that should be followed in a 4R analysis to determine the preferred alternative. The ultimate basis for choosing the preferred strategy once several appropriate strategies have been developed is cost. A cost analysis should consider all items, including scheduled maintenance, resurfacing and rehabilitation over the life of the alternative. In the past, many governmental agencies have based their decision making on initial cost. This however did not take into account the long-term performance of pavement alternatives and the effects that economic forces have on the cost of these alternatives.

Table 2 - Critical Distresses & Possible Treatments

DISTRESS/ PROBLEM	REPAIR METHODS	PREVENTATIVE TREATMENTS
JOINTED CONCRETE PAVEMENTS:		
Pumping	• Slab Stabilization • Full-Depth Repair	• Joint Rout & Reseal • Load Transfer Restoration • Edge Drains • Edge Support (Tied PCC Shoulders)
Faulting	• Diamond Grinding • Bonded Overlay • Unbonded Overlay • AC Overlay	• Slab Stabilization • Joint Rout & Reseal • Load Transfer Restoration • Edge Drains • Edge Support (Tied PCC Shoulders)
Slab Cracking	• Full-Depth Repair • Recycle Lane	• Slab Stabilization • Load Transfer Restoration • Bonded Overlay • Unbonded Overlay • AC Overlay
Joint Spalling	• Partial-Depth Repair • Full-Depth Repair	• Joint Rout & Reseal
"D"-Cracking	• Partial-Depth Repair • Full-Depth Repair	• Full-Depth Repair
Blow-up	• Full-Depth Repair	• Pressure Relief Joints • Joint & Crack Resealing
Polishing/ Scaling	• Diamond Ginding	• Concrete Sealer • Bonded Overlay • Asphalt Overlay
Structural Deficiency	• Slab Stabilization • Load Transfer Restoration • Full-Depth Repair • Replace/Recycle Lane	• Bonded Overlays • Unbonded Overlays • Edge Support (Tied PCC Shoulders
CONTINUOUSLY REINFORCED PAVEMENTS:		
Punchouts & Pumping	• Slab Stabilization • Full-Depth Repair	• Slab Stabilization
Faulting	• Full-Depth Repair • Bonded Overlay • Unbonded Overlay • AC Overlay	• Slab Stabilization • Edge Drains
Crack Deterioration	• Full-Depth Repair • Recycle Lane	• Slab Stabilization
"D"-Cracking	• Partial-Depth Repair • Full-Depth Repair	• Full-Depth Repair
Polishing/ Scaling	• Diamond Ginding	• Bonded Overlay • AC Overlay
Structural Deficiency	• Slab Stabilization • Full-Depth Repair	• Bonded Overlays • Unbonded Overlays • Replace/Recycle Lane

Table 2 (Continued) - Critical Distresses & Possible Treatments

DISTRESS/ PROBLEM	REPAIR METHODS	PREVENTATIVE TREATMENTS
ASPHALT PAVEMENTS:		
Rutting	• AC Overlay	• Whitetopping PCC Overlay • AC Overlay
Fatigue Cracking	• Remove & Replace	• Whitetopping PCC Overlay • AC Overlay
Polishing Aggregate	• Surface Treatment • AC Overlay	• Whitetopping PCC Overlay • AC Overlay
Potholes	• Cold Patch • Full-Depth Replace. • Partial-Depth Replace.	• Whitetopping PCC Overlay • AC Overlay
Raveling/ Weathering	• Surface Treatment • AC Overlay	• Whitetopping PCC Overlay • AC Overlay
Stripping	• Surface Treatment • AC Overlay	• Recycling • AC Overlay
Structural Deficiency	• Whitetopping • AC Overlay	• Whitetopping PCC Overlay • AC Overlay • Recycling

Of course in a few cases non-monetary factors will predetermine the selection despite the results from a cost analysis. Still in other cases non-monetary factors will play a smaller role in determining the preferred alternative. **In most cases however, money is the bottom line!** With this in mind, some detailed discussion of life-cycle cost analysis is warranted.

Life-Cycle Cost Analysis

"The most effective method of measuring the cost-effectiveness of alternate 4R or initial project designs is life-cycle cost analysis (LCA). Using this method of measuring equates present and future cost streams of each alternative by taking into account the effects of inflation and interest rates on the project (strategy) expenses over the life of the project (strategy). Because of this, however, LCA requires that the engineer step out of his realm of engineering, and make assumptions about the future performance of interest rates and inflation." (3,4) The assumptions made by the engineer can have a great effect on the results of the economic analysis.

However, there is an answer to avoiding this problem, because the history of economics shows that despite the large fluctuations that occur in individual interest rates or rates of inflation, the differential between the two remains constant over time (4). This difference between the interest rate and the inflation rate is called the discount rate or the real interest rate. The significance of the relative constancy of the real interest rate is that the engineer will not need to base his analysis on some assumed interest and inflation values, rather he can concentrate on the appropriate value for the differential (real interest rate) over the life of the alternative.

Why use the Real Interest Rate?

Why not just choose the prevailing interest and inflation rates? In doing this the engineer is vulnerable to biasing the results in favor of one alternative over another. This is illustrated using four example cases in Table 3 (4).

When a higher than appropriate interest rate or a lower than appropriate inflation rate is used (ie. a high real interest rate), the economic analysis will bias toward the alternative with lower initial costs and higher future costs and in turn, penalize the alternative with the higher initial cost. The reverse is true when using a low real interest rate. This is illustrated in example cases 2 and 3 included in Table 3.

Note the relative insignificant difference in the cost advantage in example cases 1 and 4 as compared to that between example cases 2 and 3. In both 1 and 4, the approximate real interest rate was the same (3%). This illustrates that the absolute values of interest and inflation are less significant than the relative difference between them (the real interest rate) (4).

Selecting the Real Interest Rate

With the previous discussion in mind, how does the engineer select the real interest rate? The following factors should be considered (4):

Financing (the interest rate): Selection should be based on the cost of funds to the agency that will finance and maintain the project. If the project is undertaken by a state or local government, then the appropriate interest rate would be the municipal bond rate. If a private firm is financing a substantial portion of the

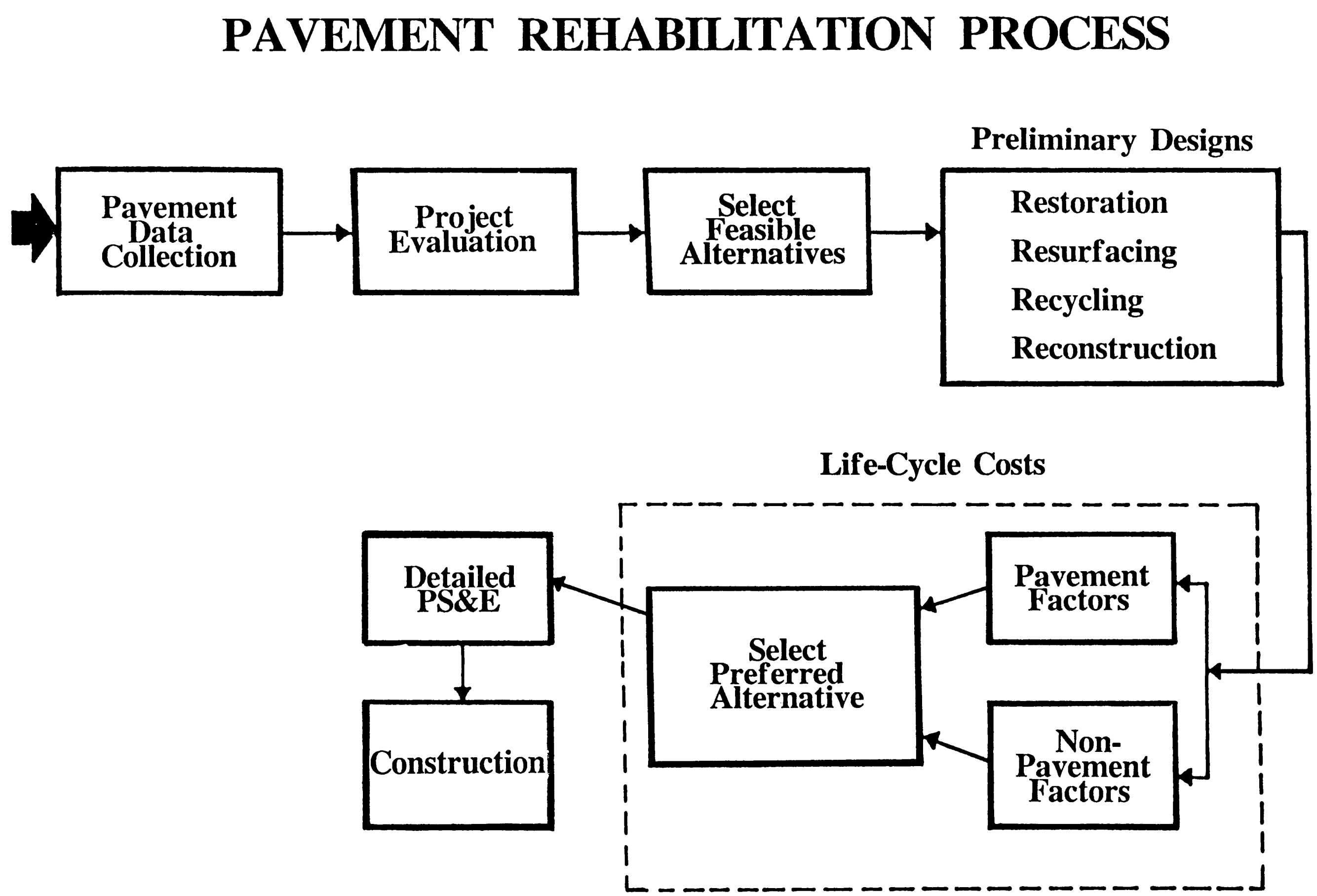

Figure 1. The Pavement Rehabilitation Process (Ref 1.)

Table 3. Example Life-Cycle Cost Analysis Under Different Interest/Inflation Rate Assumptions.

	Case 1	Case 2	Case 3	Case 4
INTEREST RATE	7%	11%	7%	14%
INFLATION RATE	4%	4%	6%	11%
APPROXIMATE REAL INTEREST RATE	3%	7%	1%	3%
CONCRETE (PCC)				
Initial Cost ($400,000)	$400,000	$400,000	$400,000	$400,000
Annual Maintenance ($500)	10,235	6,805	13,134	10,463
EFFECTIVE COST	410,235	406,805	413,134	410,463
ASPHALT (AC)				
Initial Cost (325,000)	325,000	325,000	325,000	325,000
Annual Maintenance (1,000)	20,469	13,610	26,268	20,926
Resurfacing (100,000 in Yr 15)	67,157	40,174	87,682	68,842
EFFECTIVE COST	412,627	378,784	438,950	414,768
COST ADVANTAGE: PCC OVER AC	2,392	(28,021)	25,816	4,305

project, the prime rate would be a good indicator. Federal involvement would use the rate for long-term U.S. Treasury obligations (4).

Industry (the inflation measure): Selection should be based on the trends for price movements of the industry, if the there is a good reason to believe that the price changes will differ significantly from the general prices over the analysis period. "The use of the Department of Labor's "Producer Price Index" (PPI) is an acceptable practice in absence of clear evidence that specific commodity prices movements will differ significantly from general price movements" (4).

Analysis Period: The real interest rate should be representative of the long-term average differential between the interest rate that reflects the borrower's costs of funds, and the inflation measure indicative of the industry. This period must encompass the span under which the strategies will be compared. A 30-year, or more, design life should be used for new pavements. The life expected from a rehabilitation alternative is not quite that easily assumed. The interaction between each technique and the existing pavement will dictate the life of the strategy.

Table 4 summarizes the historic differentials of three interest rates with the PPI. To avoid biasing results, the engineer should choose the real interest rate which reflects the general trends of the funding agency. The average values given in the table will provide the most accurate analysis of differing 4R strategies and other highway designs, because the values reflect the long-term trends and the long-term analysis period.

In the examples presented at the end of this paper, the rates given in Table 4 will be employed. A breakdown of the expected life for each technique is summarized in Table 5. Other factors which will be used in this analysis are the following:

Present Worth: Present Worth is merely the sum of all costs over the project life in today's dollars. This is based on the quantity for initial construction multiplied by the current rate for each item. Of course future costs for maintenance or any rehabilitation that may accompany the alternative, are discounted to account for the decreased value of the dollar in future years.

Equivalent Uniform Annual Cost (EUAC): The equivalent uniform annual cost spreads the present worth of all items, including initial and staged construction items, and planned maintenance, to an annual cost over the life of the alternative.

Table 4. Thirty Year Average Historical Real Interest Rates.

	STATE AGENCIES	FEDERAL AGENCIES	PRIVATE SECTOR
	REAL MUNICIPAL BOND RATE (AAA) (%)	REAL L-T TREASURY BILL RATE (5)	REAL PRIME RATE (%)
1977-1986	2.77%	5.42%	6.67%
1967-1976	-1.11	-0.26	0.85
1957-1966	2.22	3.02	3.58
30 YEAR AVERAGE: 1957-1986	1.25	2.84	3.57
RECOMMENDED REAL INTEREST RATE	1-2%	2-3%	3-4%

* All figures based on annual averages using the annual average change in the Producer Price Index as the inflation indicator.

COST DATA - PREFERRED ALTERNATE SELECTION

Construction cost data for the items included in any 4R strategy should be relatively easy to determine. Bid tabs, and index costs can be used to get the current rates. The examples were developed using costs from the "Summary of Awarded Contract Prices - 1987" from the Iowa Department of Transportation (6). Costs that are not taken from that reference are noted. These costs are listed in Table 6.

Maintenance costs are very difficult to determine, because most agencies do not keep maintenance records for surface repair. Maintenance items for PCC pavements include: joint and crack sealing, blowup repairs, occasional full-depth or partial-depth patches, striping and shoulder blading etc.. For AC pavements items include crack sealing, pothole repair, occasional patching, striping and shoulder blading etc. Most agencies also use seal coats and other surface treatments; these are not included as maintenance items. Maintenance costs accelerate with age, and are plotted on Figure 2 using data kept in several county agencies in Iowa. (2)

EXAMPLES

The examples show typical solutions for several jointed concrete pavements in need of some form of rehabilitation. The cases presented are not intended to indicate that any one method is better or worse than the others. This presentation will just indicate how the analysis for proper 4R strategy selection should be conducted given a deteriorated pavement and some cost data. The life expectancies for each alternative as shown in Table 5 and the cost data given in Figure 6 will be used.

The solutions rendered under this analysis will be based on hypothetical pavement conditions; the strategies are not developed based on application of a strategy at the most appropriate time or stage of deterioration. The examples are for existing interstate roadways, however the same principles apply to all highways no matter what functional classification. Tables 7, 8 and 9 show the life-cycle cost analysis performed for one mile sections of each alternate under cases 1, 2 and 3 respectively.

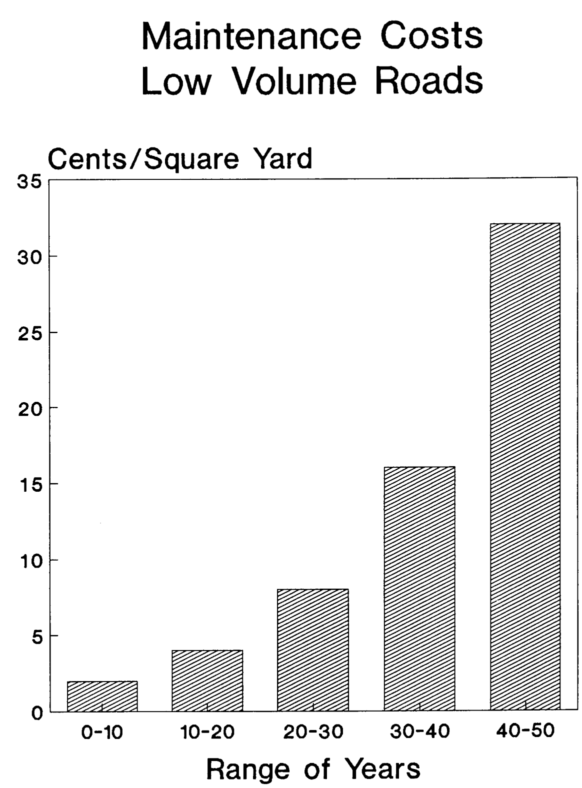

Figure 2. Maintenace Costs for Typical Rural Secondary Roadways (Ref.2).

Table 5 - Expected Life for Repair/Preventative Techniques

Restoration PCC	
• Diamond Grinding:	10 years with concurrent CPR work.
• Full-Depth Repair:	10 years
• Partial-Depth Repair:	10 years
• Slab Stabilization:	no practical limit
• Load Transfer Restoration:	8-10 years
• Edge Drains:	no practical limit
• Joint Resealing:	10-15 years
• Crack Sealing	10 years
Restoration AC	
• Slurry Seal:	3-6 years (ref. 5)
• Asphalt-Aggregate Surface Treatment	3-6 years (ref. 5)
• Crack Sealing	3-5 years (ref. 5)
• Patching	5-7 years
Resurfacing	
The average life for asphalt overlays is as follows:	
• Interstate	8-12 years
• Primary	10-15 years
• Secondary	10-15 years
• Municipal Streets	10-20 years
The average life for concrete overlays is as follows (2):	
• Bonded Overlay	15-20 years (design dependant)
• Unbonded Overlay	30 years (design dependant)
Recycling & Reconstruction	
The expected life of a recycling or reconstruction alternative will correspond to the design life used in the design procedure. A 30 year, or more, design life should be used for all new pavement designs.	

All of the life data shown has been extracted from reference 2 except where noted.

Table 6 - Average Cost Data (1987) (Ref.6)

SURFACE (New or Overlay):		
Pavement, Slipform, Furnish & Place	\$1.40 - \$1.80/SY-IN	
Doweled Joints @ 20 ft.	\$1.25/SY	
Pavement, PCC Slipform, Furnish Only	\$28.00 - \$38.00/CY	
Pavement, PCC Slipform, Place Only	\$2.75 - \$4.00/SY	
Asphalt Surface Material, Class A (Use 6% Asphalt Cement @ \$135.00/Ton)	\$22.00 - \$32.00/Ton	
Asphalt Binder Material, Class A (Use 6% Asphalt Cement @ \$135.00/Ton)	\$22.00 - \$24.00/Ton	
BASE (New):		
Aggregate Base Course	\$6.45/Ton	
Asphalt Treated, Class 1	\$16.00/Ton	
Slipform, Econocrete	\$1.00 - 1.20/SY-IN	
RESTORATION (PCC):		
Full-Depth Repair, PCC	\$65.00/SY	
Partial-Depth Repair, PCC	\$16.50/SF	
Diamond Grinding	\$2.25/SY	
Load Transfer Rest. (Retrofit Dowel Bars)	\$65.00 Each *	
Pressure Relief Joint	\$25.00/LF	
PCC Joint Rout & Seal	\$1.00/LF	
PCC Crack Rout & Seal	\$0.75/LF	
Slab Stabilization (Subsealing)	\$1.25/SY	
RESTORATION (AC):		
ACC Patch	\$76.00/Ton	
Slurry Seal	\$1.00 - \$3.00/SY	(Ref. 5)
Asphalt-Aggregate Surface Treatment	\$1.00 - \$3.00/SY	(Ref. 5)
AC Crack Sealing	\$0.75 - \$1.25/LF	(Ref. 5)
Tack Coat/Prime Coat	\$0.80/Gallon	
RESTORATION (MISCELLANEOUS):		
Surface Preparation, 1/4" Nominal	\$1.00/SY	
Asphalt Cold Milling	\$1.50/SY	
Edge Drains	\$3.50/LF	
RECYCLING:		
Concrete Removal & Crushing	\$3.00 - \$5.00/SY	
Asphalt Surface Removal	\$1.00 - 2.00/SY	
Credit PCC	\$8.00/Ton	
SHOULDERS:		
Shoulders, Granular	\$8.85/Ton	
Aggregate for Shoulder Fillets	\$9.00/Ton	
AC Shoulder Wedge	\$13.00/Ton	
MISCELLANEOUS:		
Select Granular Fill (Trucked)	\$6.00/CY	
Ditch Grading/Shaping	\$300.00/Station	
Subgrade Preparation (Blading-Grading)	\$0.20/SY	
Base Preparation	\$0.30/SY	
Culvert Extension	\$500.00 Each	
24" Concrete Roadway Culvert	\$25.00/LF	
Remove & Replace 24" Concrete Aprons	\$195.00 Each	
Delineators (Remove & Replace)	\$10.50 Each	
Signs (Adjust)	\$200.00 Each	
Steel Guard Rail Beam (Remove & Replace)	\$5.00/LF	
Guard Rail Posts	\$45.00 Each	
Guard Rail Anchors	\$200.00 Each	
Bridge Approach Removal	\$15.00/SY	
Raising Interstate Bridges	\$80,000.00 - \$120,000 Each	
Traffic Control	\$1000.00-\$12,500.00 Per Mile	

CASE 1 - EXISTING INTERSTATE PAVEMENT

Design Data:

Pavement Type:	JRCP
Age:	23 years
Geometrics:	4-lane (divided)
Joint Spacing:	50 feet
Reinforcing:	dowel/mesh
Surface Thickness:	10 inches
Base:	4 inches (granular)
Subgrade:	Fine-grained, clay
	Lane Width: 12 feet
Shoulders:	Bituminous Outer 10 ft
	Bituminous Inner 4 ft

Condition Evaluation A - Case 1:

- Joints are deteriorated in outer lane (some medium severity spalling.
- Minor surface scaling over areas on both the inner and outer lanes.
- Medium severity faulting in the outer lane (greater than 0.1").
- Pumping is extensive. Drainage needs improvement.
- Minor slab cracking, but not seriously deteriorated.
- Asphalt shoulders are in fatigued and some raveling is evident.
- Truck traffic to jump by a projected at 20% due to opening of new factory adjacent to the roadway.

Alternative 4R strategies Case 1:

Alternative A – Restoration using CPR.
10 year expected life.
Real Interest Rate used 2.5%.

- Full-Depth Repair – 15% of the joints
- Partial-Depth Repair – 10% of the joints
- Slab Stabilization – 50% of outer lane
- Diamond Grinding – both lanes
- Edge Drains – along outer lane only
- Asphalt shoulder removal
- Retrofit Full-Depth Tied PCC Shoulders
- Reseal joints & cracks – all transverse and longitudinal

Alternative B – Resurfacing (Bonded Overlay).
20 years expected life.
Real Interest Rate used 2.5%.

- Full-Depth Repair – 10% of the joints
- Partial-Depth Cold-Milling (at spalled joints)
- Edge Drains – along outer lane only
- 4" PCC Overlay
- 6" Tied PCC Shoulders (remove 2" existing AC shoulders)

Alternative C – Resurfacing (Staged AC Overlay).
20 year expected life.
Real Interest Rate used 2.5%.

- Full-Depth Repair – 10% of the joints
- Edge Drains – along outer lane only
- 6" Asphalt surface
- 6" Asphalt shoulders
- 4" Overlay in year 10

CASE 2 - EXISTING INTERSTATE PAVEMENT

Design Data:

Pavement Type:	JRCP
Age:	30 years
Geometrics:	4-lane divided
Jointing:	50 feet
Reinforcement:	Dowel/mesh
Surface Thickness:	10 inches
Base:	4 inches (granular)
Subgrade:	Fine-grained, clay
Lane Width:	12 feet
Shoulders:	Bituminous Outer 10 feet
	Bituminous Inner 4 feet

Condition Evaluation B - Case 2:

- Joint deterioration is extensive in both lanes.
- Medium to High severity faulting (greater than 0.2")
- Outer lane is cracked extensively. (greater than 1000' per mile)
- Inner lane cracking not as serious (approximately 500' per mile)
- Asphalt shoulders fatigued and in very poor condition.

Alternative 4R strategies Case 2:

Alternative A – Resurfacing (Unbonded PCC Overlay).
Expected Life: 30 years
Real Interest Rate: 2.5%

- Full-Depth Repair – 10% of the joints
- 4" Edge Drain – along outer lane only
- 8" PCC Overlay & PCC Shoulders

Alternative B – Resurfacing (Staged AC Overlay).
Expected Life: 30 years
Real Interest Rate: 2.5%

- Full-Depth Repair – 20% of the joints
- 4" Edge Drain – along outer lane only
- 9" Asphalt surface & 9" Asphalt shoulders
- Overlay year 10 and Year 20 – 4" thickness (2" Cold-Milling)

Alternative C – Reconstruction (Recycle PCC)
Expected Life: 30 years
Real Interest Rate: 2.5%

- Reconstruct 10" PCC Jointed Plain Pavement
- Doweled Joints at 20 feet
- 4" Edge Drains – along both lanes
- 10" Tied PCC shoulders

CASE 3 - EXISTING INTERSTATE PAVEMENT

Design Data:

Pavement Type:	JRCP
Age:	33 years
Geometrics:	4-lane divided
Jointing:	50 feet
Reinforcement:	Dowel/Mesh
Surface Thickness:	10 inches
Base:	4 inches (granular)
Subbase:	none
Subgrade:	Fine-grained, clay
Lane Width:	12 feet
Shoulders:	Bituminous Outer 10 feet Bituminous Inner 4 feet

Condition Evaluation C - Case 3:

- Joint deterioration is extensive in both lanes.
- Faulting is serious in the outer lane (greater than 0.3").
- Pumping is extensive in the outer lane.
- Corner breaks on 50% of the joints.
- Subbase saturated.
- Shoulders are in fair condition.

Alternative 4R strategies Case 3:

Alternative A -- Recycling - Concrete Inlay
30 year design
Real Interest Rate: 2.5%

- Pavement Removal
- Granulaı Subbase
- 11.5" PCC Pavement
- 6" Tied PCC Shoulders
- 4" Edge Drain -- along both lanes

Alternative B -- Recycling - Asphalt Inlay Staged
30 year design
Real Interest Rate: 2.5%

- Pavement Removal
- 13" AC Pavement
- 4" AC Overlay to be applied at year 10 & year 20
- 2" AC Surface cold-milling removal in conjunction with overlays.
- 4" Edge Drain -- along both lanes

RESULTS

The results of the life-cycle cost analysis of our three examples are presented in Figures 3, 4 and 5. Both the initial cost and the equivalent uniform annual cost are shown. Please note that a real interest rate of 2.5 percent was used for these cases. Detailed information and the development of these strategy cost numbers are included in the Appendix.

Case 1: This case analyzed the rehabilitation of a 23 year old concrete pavement expecting a large increase in truck traffic due to the opening of a factory adjacent to the roadway. The most cost-effective strategy to improve the structural capacity, on an annual cost basis, is through the placement of a 4" bonded concrete overlay. On an initial cost basis however, this alternative is the most costly.

Case 2: The 30 year old concrete pavement analyzed under this scenerio, is rehabilitated most cost-effectively using an unbonded concrete overlay. The cost for the unbonded overlay is less than the reconstruction alternate; this is because the existing pavement provides good support for the overlay--reducing required slab thickness--and no costs are incurred for pavement removal and reworking base layers. The AC overlay did not prove to be cost-effective.

Case 3: In this case, the restoration or resurfacing of a 33 year old concrete pavement was not expected to be cost effective, therefore two inlay/recycling alternatives were considered. The best strategy, on an annual cost basis, is the PCC inlay including tied PCC shoulders. However strictly on an initial cost basis the PCC inlay is nearly 1.5 times the cost of the staged asphalt inlay strategy. This is because much of the total cost for the staged asphalt overlay strategy is future cost for overlays and maintenance that would be necessary for the alternative to meet its expected life.

<u>Unless analyzed on an annual cost basis, these future costs would not be taken into account, and the taxpayers would not only pay a higher price for that particular project, but also for future projects that might be deferred due to lack of adequate funds.</u>

The solutions rendered under these case studies illustrate the importance of considering all costs both **initial** and **future**, and equally as important, all items whether **directly** related to the pavement or **not directly** related to the pavement. All items will have an influence on the cost of a 4R strategy, and ultimately the choice of a 4R strategy.

FINAL STEPS

Once a life-cycle cost analysis has determined the most cost-effective solution, the next step is to prepare the contract plans and documents. A very detailed Project Survey and Evaluation is needed to lo-

Table 7a. Per Mile Cost Estimate Spreadsheet for Case 1 Alternative A.

CASE 1 -- Interstate
Alternative A -- Restoration (CPR)

Expected Life (year): 15
Real Interest Rate: 2.5

ITEM	COST	UNITS	TOTAL PER LANE	% OF LANE	# OF LANES	TOTAL QUANTITY	TOTAL COST/MILE	YEAR APPLIED	PRESENT WORTH
Full-Depth Repair	$65.00	SY	848	15	2	254.4	$16,536		$16,536
Partial-Depth Repair	$16.50	SF	954	10	2	190.8	$3,148		$3,148
Diamond Grinding	$2.25	SY	7040	100	2	14080.0	$31,680		$31,680
PCC Joint Rout & Seal - Transverse	$1.00	LF	1272	100	2	2544.0	$2,544		$2,544
- Centerline	$1.00	LF	5280	100	1	5280.0	$5,280		$5,280
- Shoulder	$1.00	LF	10560	100	1	10560.0	$10,560		$10,560
PCC Crack Rout & Seal	$0.75	LF	954	100	2	1908.0	$1,431		$1,431
Slab Stabilization	$1.25	SY	7040	50	1	3520.0	$4,400		$4,400
Edge Drains	$3.50	LF	5280	100	1	5280.0	$18,480		$18,480
Asphalt Shoulder Removal - Outer	$2.00	SY	5867	100	1	5867.0	$11,734		$11,734
Asphalt Shoulder Removal - Inner	$2.00	SY	3520	100	1	3520.0	$7,040		$7,040
10", PCC Shoulders Furnish - Outside	$35.00	CY	1630	100	1	1630.0	$57,050		$57,050
10", PCC Shoulders Furnish - Inside	$35.00	CY	978	100	1	978.0	$34,230		$34,230
10", PCC Shoulders Placement - Outside	$2.50	SY	5867	100	1	5867.0	$14,668		$14,668
10", PCC Shoulders Placement - Inside	$2.50	SY	3520	100	1	3520.0	$8,800		$8,800
Traffic Control	$7,500.00	MILE	1	100	1	1.0	$7,500		$7,500

Present Worth: $235,081
Initial Cost: $235,081
EUAC: $18,987

Table 7b. Per Mile Cost Estimate Spreadsheet for Case 1 Alternative B.

CASE 1 -- Interstate
Alternative B -- Bonded PCC Overlay

Expected Life (year): 20
Real Interest Rate: 2.5

ITEM	COST	UNITS	TOTAL PER LANE	% OF LANE	# OF LANES	TOTAL QUANTITY	TOTAL COST/MILE	YEAR APPLIED	PRESENT WORTH
4" PCC Bonded Overlay, Furnish	$35.00	CY	782	100	2	1564.0	$54,740		$54,740
4" PCC Bonded Overlay, Placement	$2.75	SY	7040	100	2	14080.0	$38,720		$38,720
2", Cold-Milling, Outside	$1.50	SY	5867	100	1	5867.0	$8,801		$8,801
2", Cold-Milling, Inside	$1.50	SY	3520	100	1	3520.0	$5,280		$5,280
6", PCC Shoulders Furnish - Outside	$35.00	CY	978	100	1	978.0	$34,230		$34,230
6", PCC Shoulders Furnish - Inside	$35.00	CY	587	100	1	587.0	$20,545		$20,545
6", PCC Shoulders Placement - Outside	$2.75	SY	5867	100	1	5867.0	$16,134		$16,134
6", PCC Shoulders Placement - Inside	$2.75	SY	3520	100	1	3520.0	$9,680		$9,680
Slab Stabilization	$1.25	SY	7040	50	1	3520.0	$4,400		$4,400
Edge Drains	$3.50	LF	5280	100	1	5280.0	$18,480		$18,480
Full-Depth Repair	$60.00	SY	848	10	2	169.6	$10,176		$10,176
Cold-Milling - Partial-Depth	$4.00	SY	283	10	2	56.6	$226		$226
Surface Preparation	$1.25	SY	7040	100	2	14080.0	$17,600		$17,600
Guard Rail Beam (Remove & Replace)	$5.00	LF	500	100	1	500.0	$2,500		$2,500
Guard Rail Posts (Remove & Replace)	$45.00	EACH	88	100	1	88.0	$3,960		$3,960
Guard Rail Anchors (Remove & Replace)	$200.00	EACH	4	100	1	4.0	$800		$800
Traffic Control	$12,500.00	MILE	1	100	1	1.0	$12,500		$12,500
RESEAL JOINTS & CRACKS YEAR 10:									
PCC Joint Rout & Seal - Transverse	$1.00	LF	1272	100	2	2544.0	$2,544	10	$1,987
- Centerline	$1.00	LF	5280	100	1	5280.0	$5,280	10	$4,125
- Shoulder Long.	$1.00	LF	10560	100	1	10560.0	$10,560	10	$8,249
- Shoulder Transv.	$1.00	LF	2968	100	1	2968.0	$2,968	10	$2,319
PCC Crack Rout & Seal	$0.75	LF	954	100	2	1908.0	$1,431	10	$1,118
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	10	$781

Present Worth: $277,351
Initial Cost: $258,772
EUAC: $17,791

Table 7c. Per Mile Cost Estimate Spreadsheet for Case 1 Alternative C.

CASE 1 -- Interstate — Expected Life (year): 20
Alternative C -- Asphalt Overlay — Real Interest Rate: 2.5

ITEM	COST	UNITS	TOTAL PER LANE	% OF LANE	# OF LANES	TOTAL QUANTITY	TOTAL COST/MILE	YEAR APPLIED	PRESENT WORTH
3", Asphalt Surface, Mainline	$24.00	TONS	1163	100	2	2326.0	$55,824		$55,824
3", Asphalt Binder, Mainline	$22.00	TONS	1126	100	2	2252.0	$49,544		$49,544
Tack Coat, Mainline	$0.80	GALLONS	352	100	2	704.0	$563		$563
3", Asphalt Level/Binder, Outer Shoulder	$22.00	TONS	938	100	1	938.0	$20,636		$20,636
3", Asphalt Level/Binder, Inner Shoulder	$22.00	TONS	562	100	1	562.0	$12,364		$12,364
3", Asphalt Surface, Outer Shoulder	$24.00	TONS	968	100	1	968.0	$23,232		$23,232
3", Asphalt Surface, Inner Shoulder	$24.00	TONS	580	100	1	580.0	$13,920		$13,920
Tack Coat, Shoulders	$0.80	GALLONS	470	100	1	470.0	$376		$376
Full-Depth Repair	$60.00	SY	848	10	1	84.8	$5,088		$5,088
Slab Stabilization	$1.25	SY	7040	50	1	3520.0	$4,400		$4,400
Edge Drains	$3.50	LF	5280	100	1	5280.0	$18,480		$18,480
Guard Rail Beam (Remove & Replace)	$5.00	LF	500	100	1	500.0	$2,500		$2,500
Guard Rail Posts (Remove & Replace)	$45.00	EACH	88	100	1	88.0	$3,960		$3,960
Guard Rail Anchors (Remove & Replace)	$200.00	EACH	4	100	1	4.0	$800		$800
Traffic Control	$10,000.00	MILE	1	100	1	1.0	$10,000		$10,000
OVERLAY YEAR 10:									
2", Cold-Milling (Entire Surface)	$1.50	SY	23467	100	1	23467.0	$35,201	10	$27,499
2", Asphalt Surface, Mainline	$24.00	TONS	775	100	2	1550.0	$37,200	10	$29,061
2", Asphalt Binder, Mainline	$22.00	TONS	750	100	2	1500.0	$33,000	10	$25,780
Tack Coat, Mainline	$0.80	GALLONS	352	100	2	704.0	$563	10	$440
2", Asphalt Level/Binder, Outer Shoulder	$22.00	TONS	625	100	1	625.0	$13,750	10	$10,741
2", Asphalt Level/Binder, Inner Shoulder	$22.00	TONS	375	100	1	375.0	$8,250	10	$6,445
2", Asphalt Surface, Outer Shoulder	$24.00	TONS	645	100	1	645.0	$15,480	10	$12,093
2", Asphalt Surface, Inner Shoulder	$24.00	TONS	387	100	1	387.0	$9,288	10	$7,256
Tack Coat, Shoulders	$0.80	GALLONS	470	100	1	470.0	$376	10	$294
Engineering (@ 10 percent)							$15,311	10	$11,961
Traffic Control	$5,000.00	MILE	1	100	1	1.0	$5,000	10	$3,906
CRACK SEALING:									
AC Crack Sealing (Year = 5)	$1.00	LF	475	100	2	950.0	$950	5	$840
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	5	$884
AC Crack Sealing (Year = 15)	$1.00	LF	475	100	2	950.0	$950	15	$656
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	15	$690

Present Worth: $360,231
Initial Cost: $221,687
EUAC: $23,108

Table 8a. Per Mile Cost Estimate Spreadsheet for Case 2 Alternative A.

CASE 2 -- Interstate
Alternative A -- Unbonded PCC Overlay

Expected Life (year): 30
Real Interest Rate: 2.5

ITEM	COST	UNITS	TOTAL PER LANE	% OF LANE	# OF LANES	TOTAL QUANTITY	TOTAL COST/MILE	YEAR APPLIED	PRESENT WORTH
8" PCC Unbonded OL, Furnish/Mainline	$35.00	CY	1564	100	2	3128.0	$109,480		$109,480
8" PCC Unbonded OL, Placement/Mainline	$2.75	SY	7040	100	2	14080.0	$38,720		$38,720
8" PCC Unbonded OL, Furnish/Shoulder	$35.00	CY	2086	100	1	2086.0	$73,010		$73,010
8" PCC, Placement/Inner Shoulder	$2.75	SY	3520	100	1	3520.0	$9,680		$9,680
8" PCC, Placement/Outer Shoulder	$2.75	SY	5867	100	1	5867.0	$16,134		$16,134
Full-Depth Repair	$60.00	SY	848	10	2	169.6	$10,176		$10,176
1", Asphalt Concrete Bond Breaker	$22.00	TON	375	100	2	750.0	$16,500		$16,500
Tack Coat	$0.80	GALLON	352	100	2	704.0	$563		$563
Edge Drains	$3.50	LF	5280	100	1	5280.0	$18,480		$18,480
Guard Rail Beam (Remove & Replace)	$5.00	LF	500	100	1	500.0	$2,500		$2,500
Guard Rail Posts (Remove & Replace)	$45.00	EACH	88	100	1	88.0	$3,960		$3,960
Guard Rail Anchors (Remove & Replace)	$200.00	EACH	4	100	1	4.0	$800		$800
Delineators (Rem. & Reinstall)	$10.50	EACH	21	100	1	21.0	$221		$221
Mileposts (Rem. & Reinstall)	$50.00	EACH	1	100	1	1.0	$50		$50
Signs (Rem. & Reinstall)	$200.00	EACH	2	100	1	2.0	$400		$400
24" Concrete Culvert (Extend)	$25.00	LF	40	100	1	40.0	$1,000		$1,000
24" Dia. Concrete Apron (Rem. & Replace)	$120.00	EACH	5	100	1	5.0	$600		$600
Bridge Raising/Interchange Work	$100,000.00	MILE	1	100	1	1.0	$100,000		$100,000
Select Fill (Trucked)	$8.00	CY	6520	100	1	6520.0	$52,160		$52,160
Traffic Control	$12,500.00	MILE	1	100	1	1.0	$12,500		$12,500
RESEAL JOINTS & CRACKS YEAR 15:									
PCC Joint Rout & Seal - Transverse	$1.25	LF	3168	100	2	6336.0	$7,920	15	$5,468
- Centerline	$1.25	LF	5280	100	1	5280.0	$6,600	15	$4,557
- Shoulder	$1.25	LF	10560	100	1	10560.0	$13,200	15	$9,114
PCC Crack Rout & Seal	$1.00	LF	150	100	2	300.0	$300	15	$207
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	15	$690

Present Worth: $486,971
Initial Cost: $466,934
EUAC: $23,266

Table 8b. Per Mile Cost Estimate Spreadsheet for Case 2 Alternative B.

Page 1

CASE 2 -- Interstate — Expected Life (year): 30
Alternative B -- ACC Overlay, Staged — Real Interest Rate: 2.5

ITEM	COST	UNITS	TOTAL PER LANE	% OF LANE	# OF LANES	TOTAL QUANTITY	TOTAL COST/MILE	YEAR APPLIED	PRESENT WORTH
3", Asphalt Surface, Mainline	$24.00	TONS	581	100	2	1162.0	$27,888		$27,888
6", Asphalt Binder, Mainline	$22.00	TONS	2251	100	2	4502.0	$99,044		$99,044
Tack Coat, Mainline	$0.80	GALLON	352	100	2	704.0	$563		$563
6", Asphalt Level/Binder, Outer Shoulder	$22.00	TONS	1876	100	1	1876.0	$41,272		$41,272
6", Asphalt Level/Binder, Inner Shoulder	$22.00	TONS	1126	100	1	1126.0	$24,772		$24,772
3", Asphalt Surface, Outer Shoulder	$24.00	TONS	968	100	1	968.0	$23,232		$23,232
3", Asphalt Surface, Inner Shoulder	$24.00	TONS	580	100	1	580.0	$13,920		$13,920
Tack Coat, Shoulders	$0.80	GALLON	470	100	1	470.0	$376		$376
Full-Depth Repair	$60.00	SY	848	20	1	169.6	$10,176		$10,176
Edge Drains	$3.50	LF	5280	100	1	5280.0	$18,480		$18,480
Guard Rail Beam (Remove & Replace)	$5.00	LF	500	100	1	500.0	$2,500		$2,500
Guard Rail Posts (Remove & Replace)	$45.00	EACH	88	100	1	88.0	$3,960		$3,960
Guard Rail Anchors (Remove & Replace)	$200.00	EACH	4	100	1	4.0	$800		$800
Delineators (Rem. & Reinstall)	$10.50	EACH	21	100	1	21.0	$221		$221
Mileposts (Rem. & Reinstall)	$50.00	EACH	1	100	1	1.0	$50		$50
Signs (Rem. & Reinstall)	$200.00	EACH	2	100	1	2.0	$400		$400
24" Concrete Culvert (Extend)	$25.00	LF	40	100	1	40.0	$1,000		$1,000
24" Dia. Concrete Apron (Rem. & Replace)	$120.00	EACH	5	100	1	5.0	$600		$600
Bridge Raising/Interchange Work	$100,000.00	EACH	1	100	1	1.0	$100,000		$100,000
Select Fill (Trucked)	$8.00	CY	7335	100	1	7335.0	$58,680		$58,680
Traffic Control	$10,000.00	MILE	1	100	1	1.0	$10,000		$10,000
OVERLAY YEAR 10:									
2", Cold-Milling	$1.50	SY	23467	100	1	23467.0	$35,201	10	$27,499
2", Asphalt Surface, Mainline	$24.00	TONS	775	100	2	1550.0	$37,200	10	$29,061
2", Asphalt Binder, Mainline	$22.00	TONS	750	100	2	1500.0	$33,000	10	$25,780
Tack Coat, Mainline	$0.80	GALLON	352	100	2	704.0	$563	10	$440
2", Asphalt Level/Binder, Outer Shoulder	$22.00	TONS	625	100	1	625.0	$13,750	10	$10,741
2", Asphalt Level/Binder, Inner Shoulder	$22.00	TONS	375	100	1	375.0	$8,250	10	$6,445
2", Asphalt Surface, Outer Shoulder	$24.00	TONS	645	100	1	645.0	$15,480	10	$12,093
2", Asphalt Surface, Inner Shoulder	$24.00	TONS	387	100	1	387.0	$9,288	10	$7,256
Tack Coat, Shoulders	$0.80	GALLON	470	100	1	470.0	$376	10	$294
Engineering (@ 10 percent)							$15,311	10	$11,961
Traffic Control	$5,000.00	MILE	1	100	1	1.0	$5,000	10	$3,906

Page 1 Present Worth: $573,408
Page 1 Initial Cost: $437,934
Page 1 EUAC: $27,396

Table 8b. Per Mile Cost Estimate Spreadsheet for Case 2 Alternative B. (CONTINUED)

Page 2

CASE 2 -- Interstate
Alternative B -- ACC Overlay, Staged

Expected Life (year): 30
Real Interest Rate: 2.5

ITEM	COST	UNITS	TOTAL PER LANE	% OF LANE	# OF LANES	TOTAL QUANTITY	TOTAL COST/MILE	YEAR APPLIED	PRESENT WORTH
OVERLAY YEAR 20:									
2", Cold-Milling	$1.50	SY	23467	100	1	23467.0	$35,201	20	$21,482
2", Asphalt Surface, Mainline	$24.00	TONS	775	100	2	1550.0	$37,200	20	$22,702
2", Asphalt Binder, Mainline	$22.00	TONS	750	100	2	1500.0	$33,000	20	$20,139
Tack Coat, Mainline	$0.80	GALLON	352	100	2	704.0	$563	20	$344
2", Asphalt Level/Binder, Outer Shoulder	$22.00	TONS	625	100	1	625.0	$13,750	20	$8,391
2", Asphalt Level/Binder, Inner Shoulder	$22.00	TONS	375	100	1	375.0	$8,250	20	$5,035
2", Asphalt Surface, Outer Shoulder	$24.00	TONS	645	100	1	645.0	$15,480	20	$9,447
2", Asphalt Surface, Inner Shoulder	$24.00	TONS	387	100	1	387.0	$9,288	20	$5,668
Tack Coat, Shoulders	$0.80	GALLON	470	100	1	470.0	$376	20	$229
Engineering (@ 10 percent)							$15,311	20	$9,344
Traffic Control	$5,000.00	MILE	1	100	1	1.0	$5,000	20	$3,051
CRACK SEALING:									
AC Crack Sealing (Year = 5)	$1.00	LF	475	100	2	950.0	$950	5	$840
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	5	$884
AC Crack Sealing (Year = 15)	$1.00	LF	475	100	2	950.0	$950	15	$656
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	15	$690
AC Crack Sealing (Year = 25)	$1.00	LF	475	100	2	950.0	$950	25	$512
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	25	$539

Page 1	Present Worth:	$573,408
Page 1	Initial Cost:	$437,934
Page 1	EUAC:	$27,396
Page 2	Present Worth:	$109,954
Page 2	Initial Cost:	
Page 2	EUAC:	$5,253
	Present Worth:	$683,362
	Initial Cost:	$438,093
	EUAC:	$32,649

Table 8c. Per Mile Cost Estimate Spreadsheet for Case 2 Alternative C.

CASE 2 -- Interstate
Alternative C -- Reconstruction (Full-Width PCC)

Expected Life (year): 30
Real Interest Rate: 2.5

ITEM	COST	UNITS	TOTAL PER LANE	% OF LANE	# OF LANES	TOTAL QUANTITY	TOTAL COST/MILE	YEAR APPLIED	PRESENT WORTH
Removal & Crushing PCC	$5.00	SY	7040	100	2	14080.0	$70,400		$70,400
Shoulder Removal (Outer)	$5.00	SY	5867	100	1	5867.0	$29,335		$29,335
Shoulder Removal (Inner)	$5.00	SY	3520	100	1	3520.0	$17,600		$17,600
Rework Existing Base Course	$0.30	SY	23467	100	1	23467.0	$7,040		$7,040
Excavation	$8.00	CY	130	100	1	130.0	$1,040		$1,040
Aggregate for Base Course Repair (20%)	$6.45	TONS	2607	20	1	521.4	$3,363		$3,363
Base Coarse Aggregate for 2' widening	$6.45	TONS	132	100	1	132.0	$851		$851
4" Open-graded Base layer	$8.00	TONS	2737	100	1	2737.0	$21,896		$21,896
Pavement, Slipform 10"	$18.00	SY	15253	100	1	15253.0	$274,554		$274,554
Pavement, Slipform 10", Outer Shoulder	$18.00	SY	5867	100	1	5867.0	$105,606		$105,606
Pavement, Slipform 10", Inner Shoulder	$18.00	SY	3520	100	1	3520.0	$63,360		$63,360
Doweled Joints @ 20 feet	$1.25	SY	15253	100	1	15253.0	$19,066		$19,066
Edge Drains	$3.50	LF	5280	100	2	10560.0	$36,960		$36,960
Guard Rail Beam (Remove & Replace)	$5.00	LF	500	100	1	500.0	$2,500		$2,500
Guard Rail Posts (Remove & Replace)	$45.00	EACH	88	100	1	88.0	$3,960		$3,960
Guard Rail Anchors (Remove & Replace)	$200.00	EACH	4	100	1	4.0	$800		$800
Delineators (Rem. & Reinstall)	$10.50	EACH	21	100	1	21.0	$221		$221
Mileposts (Rem. & Reinstall)	$50.00	EACH	1	100	1	1.0	$50		$50
Signs (Rem. & Reinstall)	$200.00	EACH	2	100	1	2.0	$400		$400
Traffic Control	$12,500.00	MILE	1	100	1	1.0	$12,500		$12,500
CREDIT FOR RECYCLING:									
Used as Coarse Aggregate in PCC	($8.00)	TON	2589	100	2	5178.0	($41,424)		($41,424)
RESEAL JOINTS & CRACKS YEAR 15:									
PCC Joint Rout & Seal - Transverse	$1.25	LF	3168	100	2	6336.0	$7,920	15	$5,468
- Centerline	$1.25	LF	5280	100	1	5280.0	$6,600	15	$4,557
- Shoulder	$1.25	LF	10560	100	1	10560.0	$13,200	15	$9,114
PCC Crack Rout & Seal	$1.00	LF	150	100	2	300.0	$300	15	$207
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	15	$690

Present Worth: $650,116
Initial Cost: $659,098
EUAC: $31,061

Table 9a. Per Mile Cost Estimate Spreadsheet for Case 3 Alternate A.

CASE 3 -- Interstate
Alternative A -- Recycle/PCC Inlay w/ PCC Shoulders

Expected Life (year): 30
Real Interest Rate: 2.5

ITEM	COST	UNITS	TOTAL PER LANE	% OF LANE	# OF LANES	TOTAL QUANTITY	TOTAL COST/MILE	YEAR APPLIED	PRESENT WORTH
Removal & Crushing PCC	$5.00	SY	7040	100	2	14080.0	$70,400		$70,400
Rework Existing Base Course	$0.30	SY	7040	100	2	14080.0	$4,224		$4,224
Aggregate for Base Course Repair (35%)	$6.45	TONS	2607	35	1	912.5	$5,885		$5,885
Pavement, Slipform 11.5" Furnish & Place	$20.70	SY	7040	100	2	14080.0	$291,456		$291,456
Doweled Joints @ 20 feet	$1.25	SY	7040	100	2	14080.0	$17,600		$17,600
Asphalt Cold-Milling, (Shoulders)	$1.50	SY	9387	100	1	9387.0	$14,081		$14,081
Pavement, Slipform Outer Shoulder, 6"	$10.80	SY	5867	100	1	5867.0	$63,364		$63,364
Pavement, Slipform Inner Shoulder, 6" (Furnish & Place)	$10.80	SY	3520	100	1	3520.0	$38,016		$38,016
Edge Drains	$3.50	LF	5280	100	2	10560.0	$36,960		$36,960
Guard Rail Beam (Remove & Replace)	$5.00	LF	500	100	1	500.0	$2,500		$2,500
Guard Rail Posts (Remove & Replace)	$45.00	EACH	88	100	1	88.0	$3,960		$3,960
Guard Rail Anchors (Remove & Replace)	$200.00	EACH	4	100	1	4.0	$800		$800
Delineators (Rem. & Reinstall)	$10.50	EACH	21	100	1	21.0	$221		$221
Mileposts (Rem. & Reinstall)	$50.00	EACH	1	100	1	1.0	$50		$50
Signs (Rem. & Reinstall)	$200.00	EACH	2	100	1	2.0	$400		$400
Traffic Control	$12,500.00	MILE	1	100	1	1.0	$12,500		$12,500
CREDIT FOR RECYCLING:									
Used as Coarse Aggregate in PCC	($8.00)	TON	2589	100	2	5178.0	($41,424)		($41,424)
RESEAL JOINTS & CRACKS YEAR 15:									
PCC Joint Rout & Seal - Transverse	$1.25	LF	10560	100	2	21120.0	$26,400	15	$18,228
- Centerline	$1.25	LF	5280	100	1	5280.0	$6,600	15	$4,557
- Shoulder	$1.25	LF	10560	100	1	10560.0	$13,200	15	$9,114
PCC Crack Rout & Seal	$1.00	LF	250	100	2	500.0	$500	15	$345
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	15	$690

Present Worth: $553,927
Initial Cost: $520,992
EUAC: $26,465

Table 9b. Per Mile Cost Estimate Spreadsheet for Case 3 Alternate B.

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CASE 3 -- Interstate — Expected Life (year): 30

Alternative B -- Recycle/AC Inlay — Real Interest Rate: 2.5

ITEM	COST	UNITS	TOTAL PER LANE	% OF LANE	# OF LANES	TOTAL QUANTITY	TOTAL COST/MILE	YEAR APPLIED	PRESENT WORTH
Removal & Crushing PCC	$5.00	SY	7040	100	2	14080.0	$70,400		$70,400
Rework Existing Base Course	$0.30	SY	7040	100	2	14080.0	$4,224		$4,224
Aggregate for Base Course Repair (35%)	$6.45	TONS	2607	35	1	912.5	$5,885		$5,885
Prime Coat, Mainline	$0.80	GALLON	4224	100	1	4224.0	$3,379		$3,379
4", Asphalt Surface, Mainline	$24.00	TONS	1549	100	2	3098.0	$74,352		$74,352
9", Asphalt Level/Binder, Mainline	$22.00	TONS	3377	100	2	6754.0	$148,588		$148,588
2", Asphalt Level/Binder, Outer Shoulder	$22.00	TONS	625	100	1	625.0	$13,750		$13,750
2", Asphalt Level/Binder, Inner Shoulder	$22.00	TONS	375	100	1	375.0	$8,250		$8,250
1", Asphalt Surface, Outer Shoulder	$24.00	TONS	323	100	1	323.0	$7,752		$7,752
1", Asphalt Surface, Inner Shoulder	$24.00	TONS	194	100	1	194.0	$4,656		$4,656
Tack Coat, Shoulders	$0.80	GALLON	470	100	1	470.0	$376		$376
Edge Drains	$3.50	LF	5280	100	2	10560.0	$36,960		$36,960
Guard Rail Beam (Remove & Replace)	$5.00	LF	500	100	1	500.0	$2,500		$2,500
Guard Rail Posts (Remove & Replace)	$45.00	EACH	88	100	1	88.0	$3,960		$3,960
Guard Rail Anchors (Remove & Replace)	$200.00	EACH	4	100	1	4.0	$800		$800
Delineators (Rem. & Reinstall)	$10.50	EACH	21	100	1	21.0	$221		$221
Mileposts (Rem. & Reinstall)	$50.00	EACH	1	100	1	1.0	$50		$50
Signs (Rem. & Reinstall)	$200.00	EACH	2	100	1	2.0	$400		$400
Traffic Control	$10,000.00	MILE	1	100	1	1.0	$10,000		$10,000
CREDIT FOR RECYCLING - PCC									
Used as Aggregate in AC	($8.00)	TON	2589	100	2	5178.0	($41,424)		($41,424)
OVERLAY YEAR 10:									
2", Cold Milling	$1.50	SY	23467	100	1	23467.0	$35,201	10	$27,499
2", Asphalt Surface, Mainline	$24.00	TONS	775	100	2	1550.0	$37,200	10	$29,061
2", Asphalt Level/Binder, Mainline	$22.00	TONS	750	100	2	1500.0	$33,000	10	$25,780
Tack Coat	$0.80	GALLON	352	100	2	704.0	$563	10	$440
2", Asphalt Level/Binder, Outer Shoulder	$22.00	TONS	625	100	1	625.0	$13,750	10	$10,741
2", Asphalt Level/Binder, Inner Shoulder	$22.00	TONS	375	100	1	375.0	$8,250	10	$6,445
2", Asphalt Surface, Outer Shoulder	$24.00	TONS	645	100	1	645.0	$15,480	10	$12,093
2", Asphalt Surface, Inner Shoulder	$24.00	TONS	387	100	1	387.0	$9,288	10	$7,256
Tack Coat, Shoulders	$0.80	GALLON	470	100	1	470.0	$376	10	$294
Engineering (@ 10 percent)							$15,311	10	$11,961
Traffic Control	$5,000.00	MILE	1	100	1	1.0	$5,000	10	$3,906

Page 1	Present Worth:	$490,553
Page 1	Initial Cost:	$355,079
Page 1	EUAC:	$23,437

Table 9b. Per Mile Cost Estimate Spreadsheet for Case 3 Alternate B. (CONTINUED)

Page - 2

CASE 3 -- Interstate — Expected Life (year): 30

Alternative B -- Recycle/AC Inlay — Real Interest Rate: 2.5

ITEM	COST	UNITS	TOTAL PER LANE	% OF LANE	# OF LANES	TOTAL QUANTITY	TOTAL COST/MILE	YEAR APPLIED	PRESENT WORTH
OVERLAY YEAR 20:									
2", Cold Milling	$1.50	SY	23467	100	1	23467.0	$35,201	20	$21,482
2", Asphalt Surface, Mainline	$24.00	TONS	775	100	2	1550.0	$37,200	20	$22,702
2", Asphalt Level/Binder, Mainline	$22.00	TONS	750	100	2	1500.0	$33,000	20	$20,139
Tack Coat	$0.80	GALLON	352	100	2	704.0	$563	20	$344
2", Asphalt Level/Binder, Outer Shoulder	$22.00	TONS	625	100	1	625.0	$13,750	20	$8,391
2", Asphalt Level/Binder, Inner Shoulder	$22.00	TONS	375	100	1	375.0	$8,250	20	$5,035
2", Asphalt Surface, Outer Shoulder	$24.00	TONS	645	100	1	645.0	$15,480	20	$9,447
2", Asphalt Surface, Inner Shoulder	$24.00	TONS	387	100	1	387.0	$9,288	20	$5,668
Tack Coat, Shoulders	$0.80	GALLON	470	100	1	470.0	$376	20	$229
Engineering (@ 10 percent)							$15,311	20	$9,344
Traffic Control	$5,000.00	MILE	1	100	1	1.0	$5,000	20	$3,051
CRACK SEALING:									
AC Crack Sealing (Year = 5)	$1.00	LF	475	10	2	95.0	$95	5	$84
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	5	$884
AC Crack Sealing (Year = 15)	$1.00	LF	475	100	2	950.0	$950	15	$656
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	15	$690
AC Crack Sealing (Year = 25)	$1.00	LF	475	100	2	950.0	$950	25	$512
Traffic Control	$1,000.00	MILE	1	100	1	1.0	$1,000	25	$539

Page 1	Present Worth:	$490,553
Page 1	Initial Cost:	$355,079
Page 1	EUAC:	$23,437
Page 2	Present Worth:	$109,198
Page 2	Initial Cost:	
Page 2	EUAC:	$5,217
	Present Worth:	$599,752
	Initial Cost:	$355,079
	EUAC:	$28,655

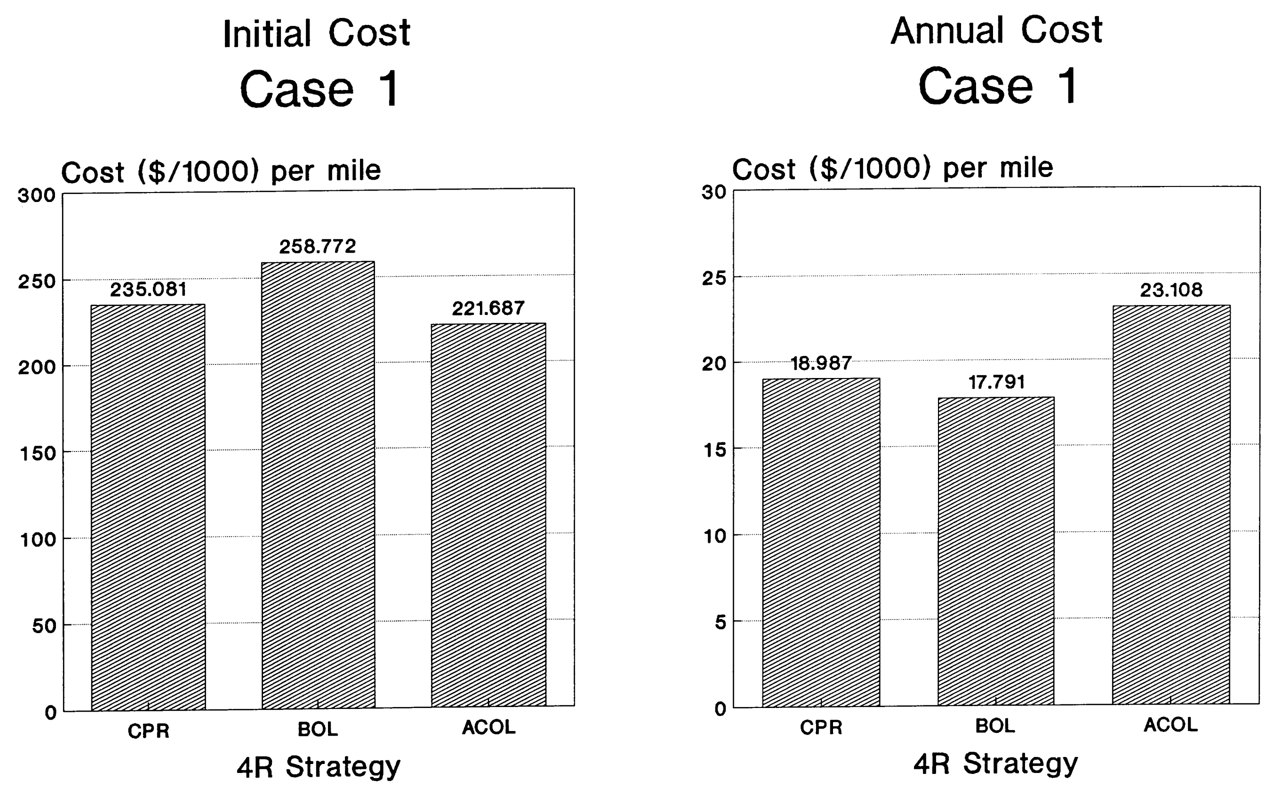

Figure 3. Initial and Annual Cost Comparisons for Case 1.

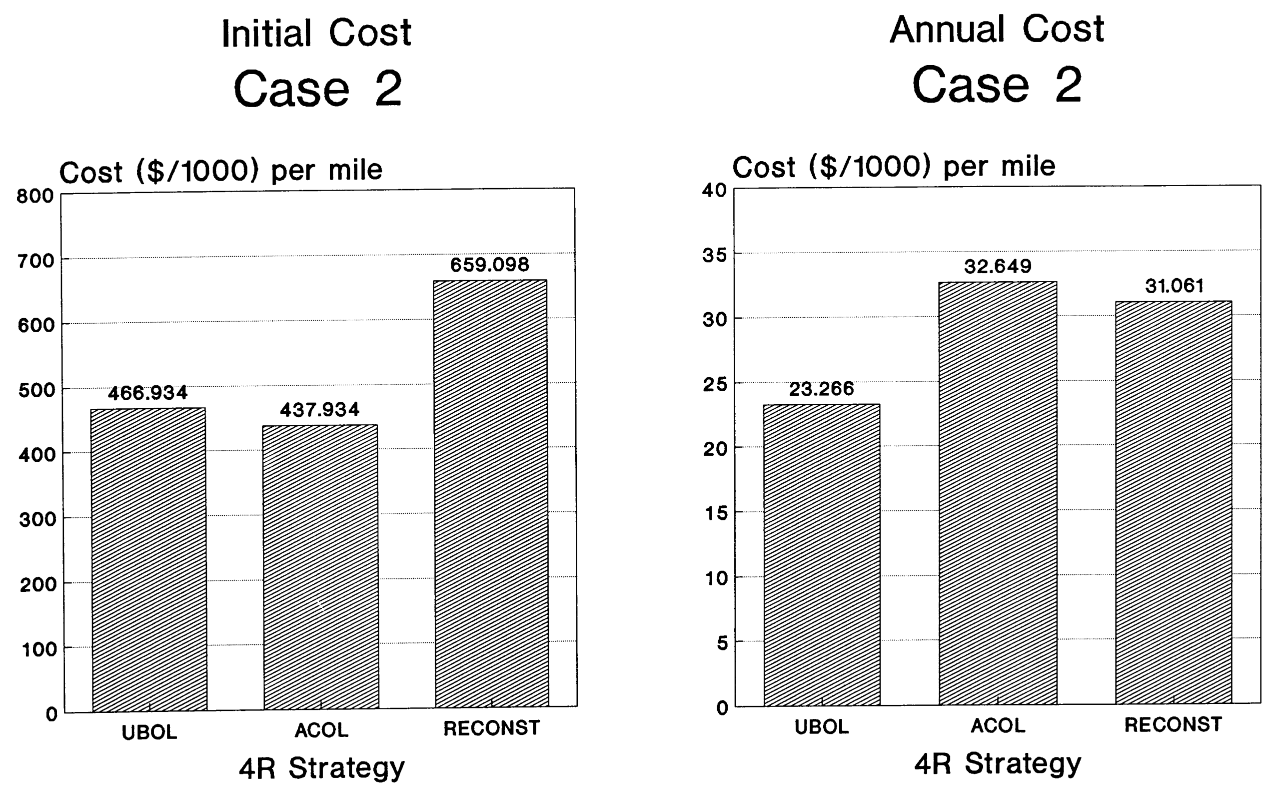

Figure 4. Initial and Annual Cost Comparisons for Case 2.

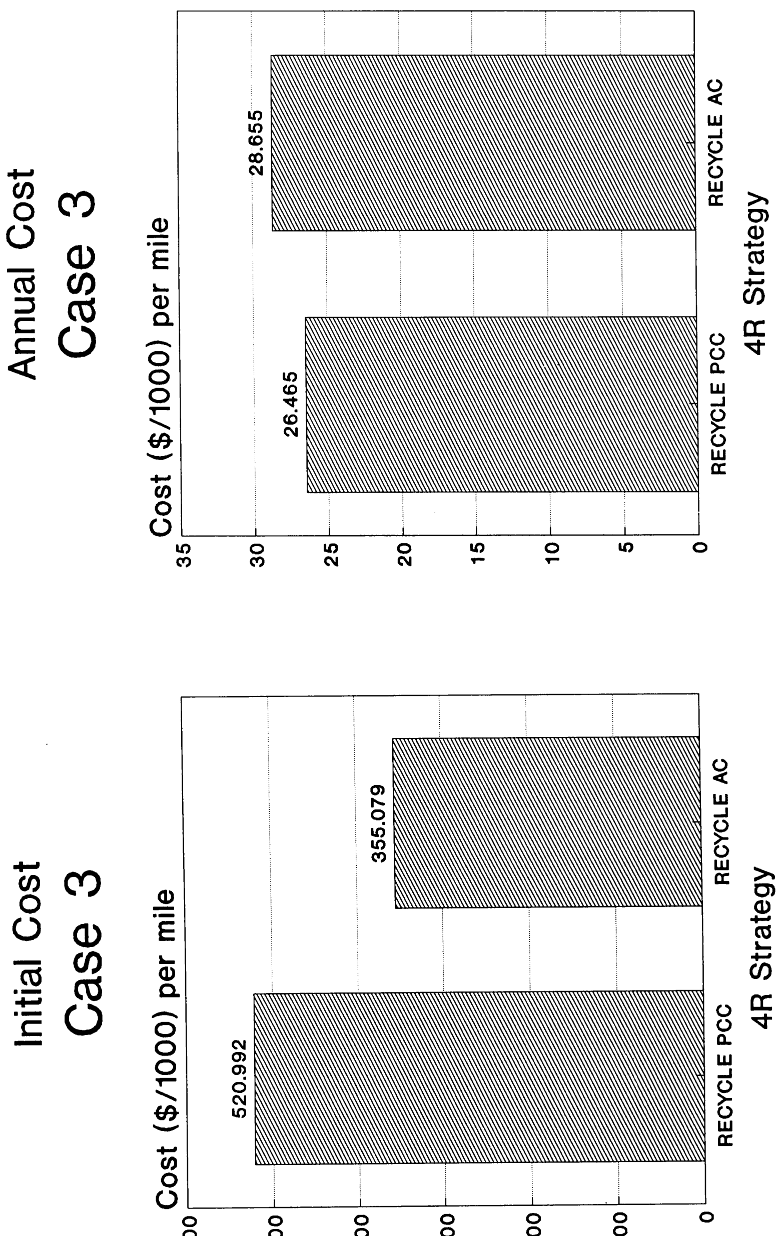

Figure 5. Initial and Annual Cost Comparisons for Case 3.

cate patching and other improvement areas on the plans. The final step after plan preparation is construction.

CONCLUSIONS

In recent years the highway industry has turned its focus on the rehabilitation of our existing infrastructure. Engineering solutions for pavement problems have been developed and can be constructed effectively. Unfortunately choosing the proper 4R strategy to apply to an existing roadway can be a tough problem. The pavement rehabilitation process can be summarized in 6 steps.

1. Pavement Data Collection.
2. Project Evaluation.
3. Selection of Feasible Alternatives.
4. Preparation of Preliminary Designs.
5. Life Cycle Cost Analysis.
6. Preparation of Detailed Plans
7. Implementation.

In most cases, the choice of 4R strategy, like most choices involving money, will boil down to the price-tag. The key to determining the most cost-effective solution is: applying a proper life-cycle cost analysis, choosing the appropriate interest rate for the funding agency, considering all 4R options, and considering non-pavement related factors.

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