EXECUTIVE SUMMARY

EVALUATION OF EXPENDITURES ON RURAL INTERSTATE PAVEMENTS IN KANSAS

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or the policies of the State of Kansas.

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INTRODUCTION

The National Highway System (NHS) Designation Act of 1995 required state DOTs to conduct a life-cycle cost analysis on NHS projects costing $25 million or more. The 1998 Transportation Equity Act for the 21st Century (TEA-21) removed the requirement for LCCA on high cost NHS projects. However, the Federal Highway Administration (FHWA) still recommends LCCA and has a policy statement recommending the use of good practice, rather than specifying a single LCCA method.

One of the most comprehensive tools for LCCA is *Publication No. FHWA-SA-98-079, Life-Cycle Cost Analysis in Pavement Design.* The FHWA publication recommends procedures for conducting LCCA of pavements using Monte Carlo simulation procedures to account for the uncertainties associated with LCCA inputs.

The final results from any LCCA procedure, regardless of sophistication, is no better than the input variables. To that end, the purpose of this study was to evaluate the historical expenditures for rural interstate pavements in Kansas and to provide historical performance and cost data to evaluate the assumptions associated with LCCA input parameters currently used in Kansas.

SCOPE

This study involved the evaluation of rural interstate pavements on I-35, I-135 and I-70 in Kansas that are administered by the Kansas Department of Transportation (KDOT). The sections of interstate pavement administered by the Kansas Turnpike Authority (KTA)

were not evaluated. The rural interstate sections evaluated on I-35 consisted of the section from the intersection of US-50 in Lyon County near the Emporia city limits to the west Johnson County line. The rural interstate sections evaluated on I-135 consisted of the section from the intersection with I-70 to the north Sedgwick County line. A 4.5-mile section through the city of Newton in Harvey County was excluded. The counties evaluated on I-70 included the section from the west Shawnee County line to the Colorado State line, excluding Logan County. The section of I-70 through Logan County is less than one mile long. Figure 1 shows the location of the counties and routes evaluated with the heavy commercial vehicles per county.

ANALYSIS PROCEDURE

Mainline Paving

Expenditures were determined for mainline paving only. Mainline paving is defined, for the purpose of this study, as the 24-foot wide travel lanes, shoulders and ramps. Excluded from mainline paving were bridges, bridge approach slabs, cross roads, drainage structures, rest areas, and other ancillary work or structures.

Expenditures were classified as original construction, maintenance work (minor and structural overlays), rehabilitation and reconstruction. Expenditures for the above actions were determined from contract bid sheets obtained from the Kansas DOT Bureau of Construction records. Construction contracts generally do not cross county lines and the records are stored by county. Due to the size of the counties, two or more contracts were often required for original construction. Later maintenance, rehabilitation and reconstruction contracts did not necessarily follow the original construction sections. Therefore, the analysis was performed on a section by section basis within each county.

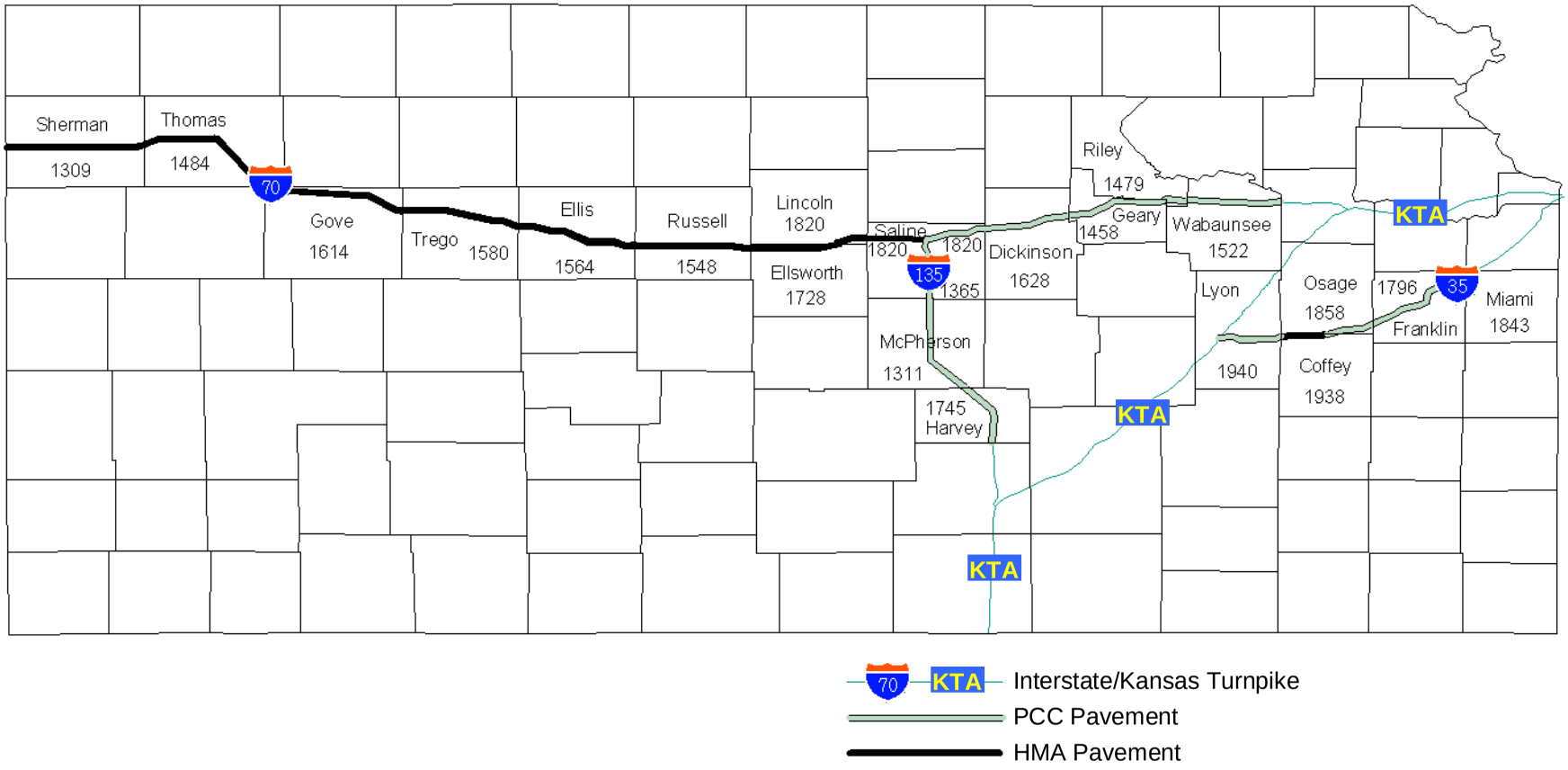

Figure 1: Location of Rural Interstate Pavements in Kansas with Average Daily Truck Traffic.

The only requirements for section boundaries were that all miles in each section have the same original construction date and, if reconstructed or rehabilitated, the same reconstruction or rehabilitation dates.

Original Construction

Typical Portland cement concrete (PCC) pavement sections for original construction consisted of a 9-inch thick slab over a 4-inch thick aggregate base. Lime stabilized subgrades were used on the majority of the pavements. Shoulders were either aggregate or hot mix asphalt (HMA).

Typical HMA sections for I-70 consisted of 15 inches of full depth HMA with HMA shoulders. The final three inches of the pavement were not placed initially due to budgetary constraints but were planned for a later date. The authors have referred to this as planned staged construction (PSC). The HMA pavement on I-35 was placed full depth and was 19.5 inches thick.

Separate contracts were generally let for grading and drainage, bridges and for paving. The contracts for bridges and grading and drainage were not included in the expenditures for mainline paving. The cost of grading and drainage is a function of topography and not the pavement type. Other items excluded from mainline paving included drainage structures, bridge approach slabs, guardrail fence and signing.

Change orders for original construction were low, generally less than 5%. However, change orders could not be ignored because some later maintenance contracts, entirely related to mainline paving, had change order amounts that exceeded the original bid price. The bid item sheets had the total cost of change orders but did not specify the items to which they were applied. Total mainline paving expenditures were determined

by applying the ratio of total expenditures to bid price for the entire contract to the sum of the mainline paving bid items. For example, if the change orders were 5% of the original bid price, the bid mainline paving expenditures were increased 5% to determine the total mainline paving expenditures.

Maintenance Work

Maintenance work was either let as a construction contract or as a maintenance contract. All construction and maintenance contracts relating to mainline paving were included. The majority of the construction/maintenance contracts were exclusively for mainline paving items. State supplied maintenance was not included because the records are not readily available and the cost is generally considered minimal on a per mile basis.

Reconstruction / Rehabilitation

Reconstruction

Many of the PCC pavement sections have been or are currently being reconstructed. The major distress was reported as joint deterioration due to D-cracking, faulting or spalling. As with new construction, only mainline paving items were included in the analysis. Mainline paving items for reconstruction included traffic control, rock excavation (removing existing PCC pavement), recompacting the subgrade, subgrade stabilization, installing drainable base and edge drains, and paving the driving lanes, shoulders and ramps. All reconstructed sections consisted of 11-12 inch thick PCC slabs with tied concrete shoulders. Drainage structures, bridges and bridge approach slabs were excluded from mainline paving items.

There were four original HMA sections that were reconstructed. One of the sections was a whitetopped section that was reconstructed in full depth PCC. The other

three sections were HMA sections that were reconstructed using full depth HMA. Mainline paving items for HMA reconstruction were determined in the same manner as for reconstruction of PCC pavements.

Rehabilitation

The majority of the HMA sections on I-70 have undergone rehabilitation to correct distress caused by thermal cracking. Rehabilitation typically consisted of injecting the thermal cracks with a type C fly ash slurry, cold milling to a depth of four inches, cold in-place recycling to a depth of four inches and placing six inches of HMA. Thermal cracking has not occurred on the HMA section on I-35. There were two PCC sections that were rehabilitated using rubblization. Mainline paving items for rehabilitation were determined in the same manner as for reconstruction.

Mobilization was a separate line item for later construction contracts, including all reconstruction and rehabilitation projects. Mobilization was apportioned to mainline paving using the ratio of mainline paving to total bid price, excluding mobilization from both items. For example, if the total bid price minus mobilization was $1,000,000 and the mainline paving expenditures minus mobilization was $750,000, then 75% of the mobilization cost was added to the mainline paving expenditures to determine total mainline expenditures. Detailed lists of items included in mainline paving are presented in the final report by the authors.

Cost per 4-Lane Mile

The analysis was performed using the total mainline expenditures for the project (bid total + change orders). The mainline bid totals were used for projects that were not finalized. All sections of rural interstate pavements evaluated were four lanes wide, two

lanes in each direction. Therefore, all expenditures for mainline paving were adjusted to a cost per 4-lane mile basis for analysis. That is, all costs were converted to a cost per centerline mile of 4-lane pavement. Expenditures were applied in the year the project was completed.

A portion of the original PCC sections on I-70 utilized the recently constructed alignment of US-40 for two of their four lanes. This was true for all 5.9 miles of Riley County, 2.5 miles of the 26.3 miles in Geary County and 5.8 of the 23.6 miles in Wabaunsee County. To account for this, the expenditures per 2-lane mile were doubled to estimate the 4-lane mile cost. This adjustment affected 14.2 miles of the 219 miles of PCC pavement evaluated.

Most maintenance contracts did not correspond to the pavement analysis sections. If the pavement analysis section fell completely within the maintenance contract, the cost per 4-lane mile of the maintenance treatment is the same as for the section. The total expenditure for the pavement analysis section would be the per mile cost multiplied by the length of the section. If the maintenance contract covered only a portion of the pavement analysis section, then the expenditures were apportioned to the section. The total expenditures for the pavement analysis section would be the per mile cost of the contract multiplied by the length of the action in the pavement analysis section. The cost per 4-lane mile would be the total cost in the section divided by the length of the section. For example, a 25-mile maintenance contract for $250,000 that covered 12 miles of a 15-mile pavement analysis section would have a per mile cost of $10,000. The total expenditures in the pavement analysis section would be $10,000 per mile x 12 miles or

$120,000. The cost per 4-lane mile in the pavement analysis section would be $120,000 ÷ 15 miles, or $8,000 per 4-lane mile.

Analysis Methodology

All of the pavements were not the same age. Therefore, comparisons were made using inflation adjusted dollars. An annual inflation rate of 3.5% was used, and all costs were brought forward to 2001 and referred to as 2001 dollars. This inflation rate was obtained from the FHWA, in *Publication No. FHWA-SA-98-079 Life-Cycle Cost Analysis in Pavement Design.* The FHWA recommends a discount rate of 3-5% based on rates of return on 10-year treasury bonds from 1991-1996. This corresponds to an inflation rate of 3-4% annually.

FINDINGS

Summary findings for the sections of I-35, I-135 and I-70 are provided below. Detailed analyses on a section-by-section basis are available in the final report. The detailed analyses list all contract expenditures for each county in graphical and tabular form. General descriptions of the pavement sections are provided as well.

Table 1 shows the counties evaluated, the route, length of route in each county, original pavement type, year 2000 traffic data and dates of original construction. The traffic data was obtained from KDOT's *Pavement Management System 2000 NOS Condition Survey* and their *2000 Traffic Flow Map*. The traffic data reported is the one-way traffic and includes the annual average daily traffic (AADT), heavy commercial vehicles and ESALs. The ESALs are the daily 18-kip single axle loads in the design lane. ESALs are calculated for the pavement based on the current surface type. Figure 1 also shows the average one-way heavy commercial vehicles in each county.

Table 1. Rural Interstate Pavements in Kansas.

County	Route	Pavement Type	Year Opened	Length (miles)	1-Way Traffic AADT	1-Way Traffic Heavy Commercial Vehicles	1-Way Traffic ESALs*
Lyon-East	I-35	PCCP	1977	10.8	7580	1940	1739
Coffey	I-35	HMA	1973	12.1	6345	1938	1204
Osage	I-35	PCCP	1973	11.3	5589	1858	1510
Franklin-West	I-35	PCCP	1973	14.1	5721	1813	1625
Franklin-East	I-35	PCCP	1959	16.4	8836	1778	1269
Miami	I-35	PCCP	1959	2.8	9565	1843	1236
Saline	I-135	PCCP	1966-67	19.2	7380	1365	829
McPherson	I-135	PCCP	1969-72	33.6	5413	1311	967
Harvey	I-135	PCCP	1971	15.6	7860	1745	1284
Sherman	I-70	HMA	1969-70	35.3	4116	1309	1128
Thomas	I-70	HMA	1966-69	39.6	4504	1484	1034
Gove	I-70	HMA	1961-64	37.5	4507	1614	1228
Trego	I-70	HMA	1960-65	30.8	5021	1580	1149
Ellis	I-70	HMA	1965-66	31.4	5870	1564	1177
Russell	I-70	HMA	1964-66	30.0	5287	1548	1069
Ellsworth	I-70	HMA	1965	23.2	5456	1728	1295
Lincoln	I-70	HMA	1964	7.2	6190	1820	1017
Saline	I-70	HMA	1964	14.7	6310	1820	1084
Saline	I-70	PCCP	1962-65	15.2	7735	1820	1291
Dickinson	I-70	PCCP	1959-61	24.1	7332	1628	1393
Geary	I-70	PCCP	1959-65	26.3	6963	1458	1261
Riley	I-70	PCCP	1963	5.9	8035	1479	989
Wabaunsee	I-70	PCCP	1959-63	23.6	8878	1522	945

* Based on Current Surface Type

As originally built there were approximately 219 miles of PCC pavement and 262 miles of HMA pavement. Included in these totals are 27.4 miles of a PCC overlay of HMA pavement (whitetopping), of which 10.3 miles were subsequently reconstructed

with PCC pavement, all in Sherman County. McPherson County has 19.7 miles of rubblized PCC pavement.

As shown in Table 1, the PCC pavement sections carry more traffic and ESALs than the HMA sections. The 2000 AADT, weighted on a per-mile basis, was 7,120 vehicles for the PCC pavement sections and 5,085 vehicles for the HMA sections. The ESALs were 1,230 for PCC and 1,140 for HMA. The ESALs can be misleading because several of the PCC sections are covered with an HMA overlay and the ESALs are determined based on current surface type. The pavements carried virtually the same heavy commercial vehicles, 1580 for HMA and 1600 for PCC, on a weighted per mile basis. The difference in heavy commercial vehicles between the PCC and HMA sections is less than 1.3%. Therefore, the effect of traffic on the difference in performance between the pavement types is minimal.

I-35

The pavement sections evaluated on I-35 consist of 12.1 miles of HMA in Coffey County and 55.4 miles of PCC pavement in the eastern half of Lyon, Osage, Franklin and Miami Counties. The pavement sections from the eastern Lyon County line to Ottawa, Kansas were opened to traffic on the same day in 1973. This section includes the HMA section (Coffey County) and two PCC sections, Osage County and the western half of Franklin County. The eastern half of Lyon County was opened to traffic in 1977, four years later. These are the only sections of pavement on I-35 where a direct comparison of expenditures was feasible. The remainder of I-35, between Ottawa and the Johnson County line, includes two PCC sections that were opened to traffic in 1959, the eastern portion of Franklin County and Miami County. Direct comparisons between these

sections and the HMA section are problematic due to the 14-year difference in age and were not made.

The original construction of the PCC pavements from Emporia to Ottawa (Lyon-E, Osage, and Franklin-W) consisted of a 9-inch thick reinforced PCC slab over an aggregate base on a lime stabilized subgrade. The pavement had HMA shoulders. The PCC pavement sections from Ottawa to the Johnson County line did not contain a lime stabilized subgrade and had aggregate shoulders. The HMA section (Coffey County) consisted of 19.5 inches of HMA with HMA shoulders over a lime stabilized subgrade.

Table 2 shows the total expenditures per 4-lane mile in actual dollars and in 2001 dollars using a 3.5% annual inflation rate. The expenditures per county were determined by summing the total expenditures of the analysis sections for each county. Figures 2 and 3 are comparisons of the actual and inflation adjusted total expenditures, respectively, for the five PCC sections and the HMA section (Coffey County). Figure 4 is a comparison of the inflation-adjusted expenditures per year, by age of the pavement, for each analysis section.

All of the pavements in the Emporia to Ottawa section are 28 years old with the exception of Lyon County, which is 24 years old, allowing a direct comparison. Total expenditures in actual dollars for the HMA section (Coffey County) were $677,000 per 4-lane mile. The total expenditures per 4-lane mile for the PCC sections were $3,696,000 for the eastern half of Lyon County, $1,604,000 for Osage County and $2,490,000 for the western half of Franklin County. Total expenditures per 4-lane mile in 2001 dollars for the HMA section were $1,393,000. The total expenditures per 4-lane mile in 2001

Table 2. Total Expenditures per 4-Lane Mile.

County	Route	Pavement Type	Year Opened	Total Expenditures / 4-Lane Mile	
				Actual Dollars (Millions)	2001 $
Lyon-East	I-35	PCCP	1977	$3.87	$4.66
Coffey	I-35	HMA	1973	$0.68	$1.39
Osage	I-35	PCCP	1973	$1.60	$2.42
Franklin-West	I-35	PCCP	1973	$2.49	$3.35
Franklin-East	I-35	PCCP	1959	$2.55	$3.62
Miami	I-35	PCCP	1959	$0.75	$1.76
Saline	I-135	PCCP	1966-67	$3.02	$3.93
McPherson	I-135	PCCP	1969-72	$1.79	$2.62
Harvey	I-135	PCCP	1971	$1.53	$2.20
Sherman	I-70	HMA	1969-70	$1.46	$2.32
Thomas	I-70	HMA	1966-69	$1.05	$1.76
Gove	I-70	HMA	1961-64	$0.95	$1.68
Trego	I-70	HMA	1960-65	$0.86	$1.55
Ellis	I-70	HMA	1965-66	$1.29	$1.98
Russell	I-70	HMA	1964-66	$1.00	$1.64
Ellsworth	I-70	HMA	1965	$1.03	$1.74
Lincoln	I-70	HMA	1964	$0.93	$1.71
Saline	I-70	HMA	1964	$2.23	$3.11
Saline	I-70	PCCP	1962-65	$1.18	$2.22
Dickinson	I-70	PCCP	1959-61	$1.39	$2.72
Geary	I-70	PCCP	1959-65	$2.44	$3.58
Riley	I-70	PCCP	1963	$2.96	$4.03
Wabaunsee	I-70	PCCP	1959-63	$2.87	$3.79

dollars for the PCC sections were $4,662,000 for the eastern half of Lyon County, $2,419,000 for Osage County and $3,347,000 for the western half of Franklin County. The total expenditures for Osage, Franklin and Miami Counties will soon increase significantly because the remainder of the PCC sections are scheduled for reconstruction.

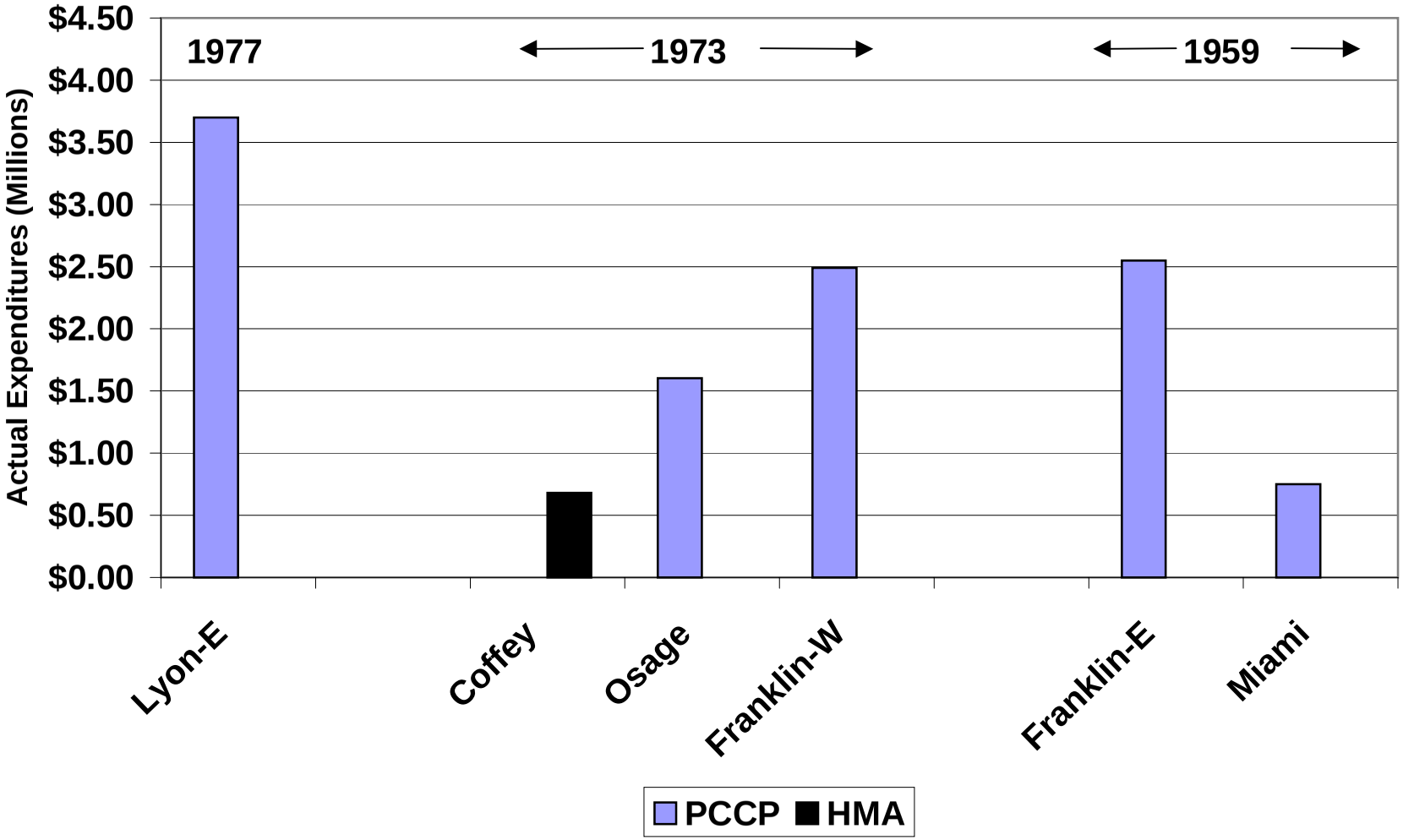

Figure 2. Actual Expenditures Per 4-Lane Mile, I-35

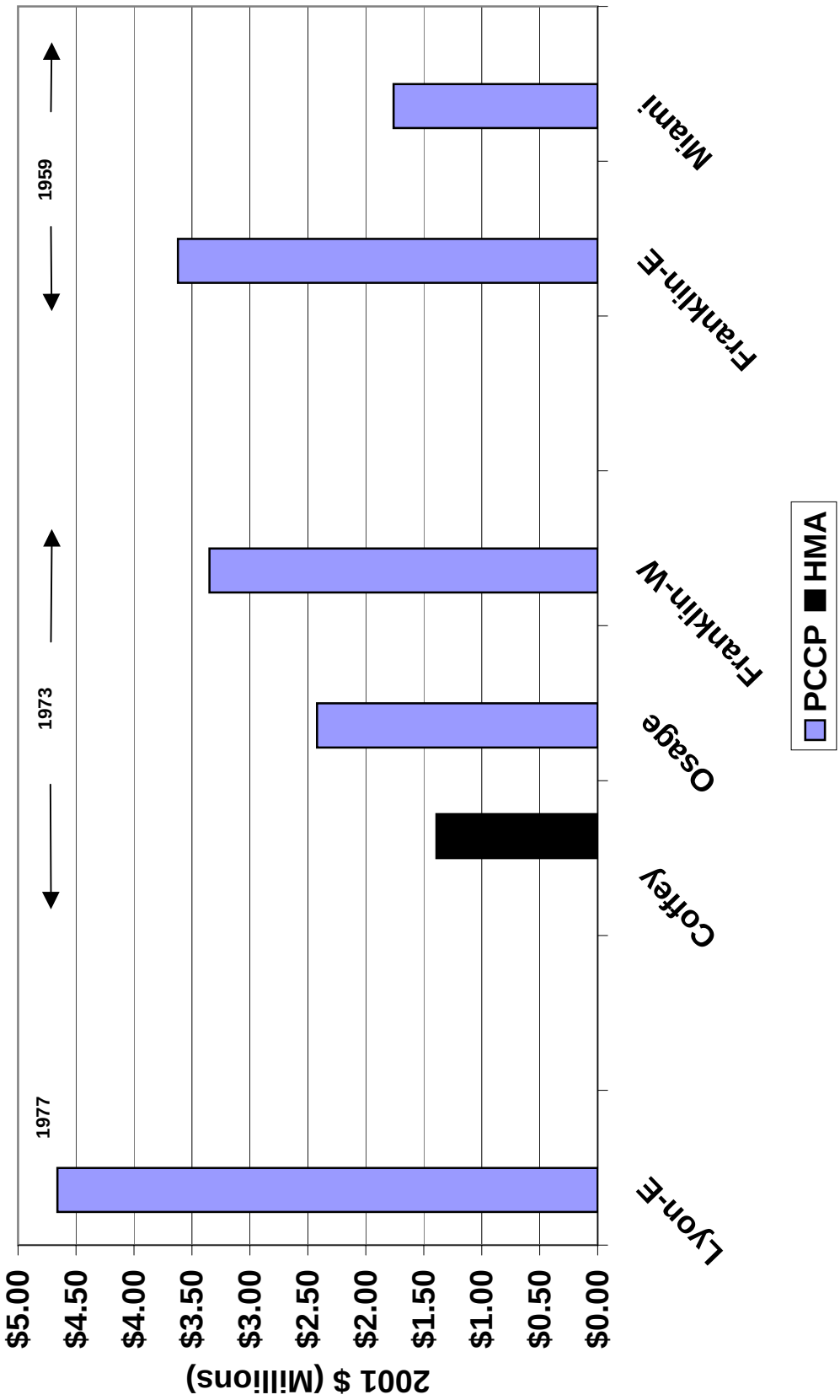

Figure 3. Inflation Adjusted Total Expenditures per 4-Lane Mile, I-35

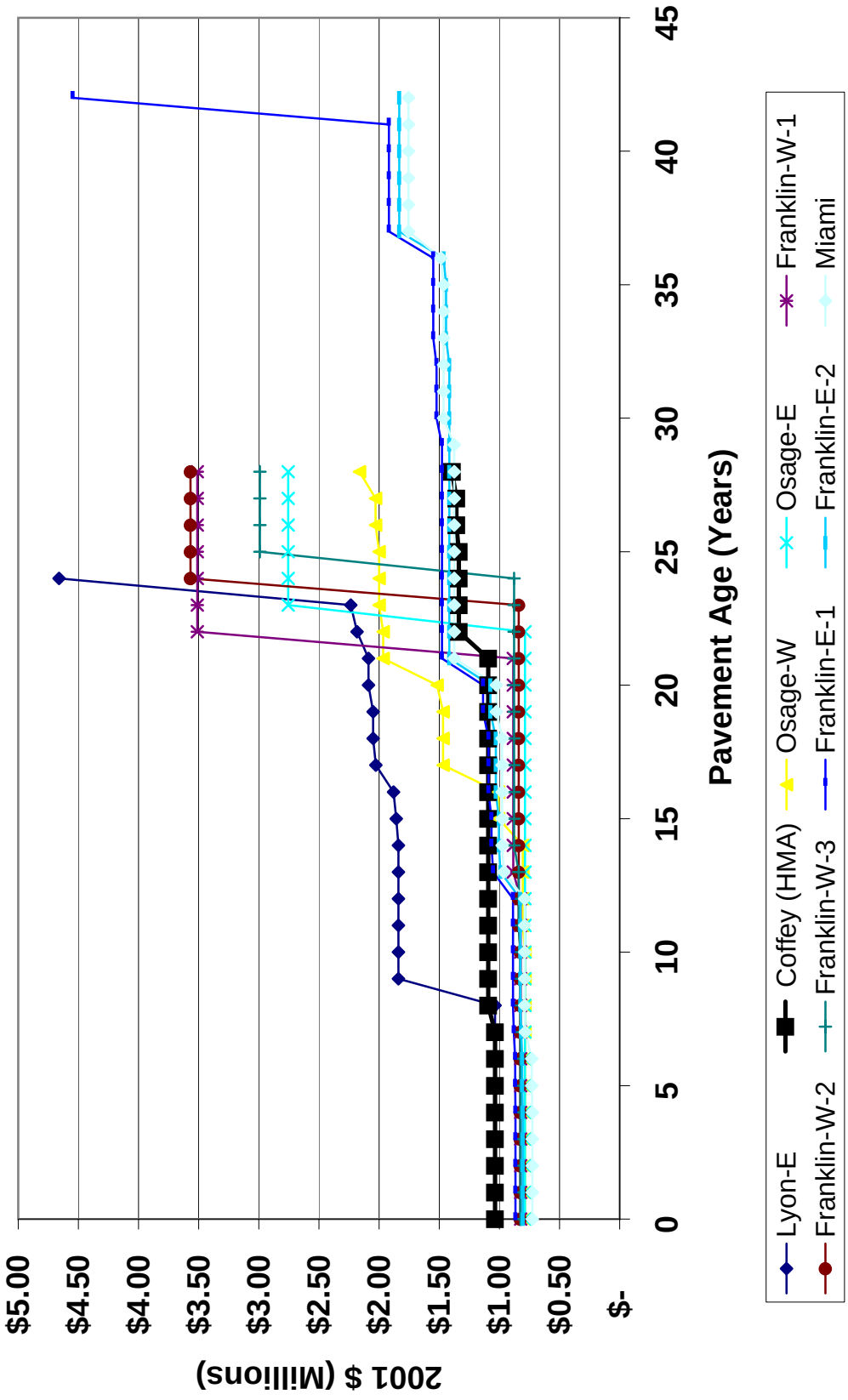

Figure 4. Inflation Adjusted Expenditures per 4-Lane Mile, by Pavement Age, I-35 Sections.

The HMA section (Coffey County) was the only HMA section evaluated that did not experience thermal cracking. Total maintenance expenditures were $281,000 per 4-lane mile ($357,000 in 2001 dollars) or less than $13,000 per year per 4-lane mile in 2001 dollars. The maintenance consisted of a machine laid seal after eight years, a three-inch overlay after 22 years and a bituminous seal after 28 years. Of the 55.4 miles of original PCC pavement on I-35, less than 27% are still in service. The 14.9 miles that are currently in service are scheduled for reconstruction.

I-135

The pavement sections evaluated on I-135 consisted of Harvey County, excluding the 4.5-mile section in Newton, McPherson County and Saline County. McPherson County was opened to traffic in two sections, one in 1969 and the other in 1972. Harvey County was opened to traffic in 1971 and Saline County in 1966 and 1967. There were no HMA sections on I-135. Table 2 shows the total expenditures for the PCC pavement sections in actual and 2001 dollars. Figure 5 is a comparison of the total expenditures in actual and 2001 dollars, by county, and figure 6 is a comparison of the inflation-adjusted expenditures per year, by age of the pavement, for each analysis section.

Of the 68.4 miles of original PCC pavements, 40.8 miles (60%) have been reconstructed at a cost of $2,152,000 ($2,257,000 in 2001 dollars) per 4-lane mile. I-135 contains the only sections of PCC pavement that have been rehabilitated. There are 19.4 miles of rubblized PCC pavement in McPherson County. The average cost of rehabilitation (rubblization) was $1,075,000 ($1,321,000 in 2001 dollars) per 4-lane mile. There are only 8.6 miles (12.6%) of original PCC pavement on I-135 that have not been reconstructed or rubblized.

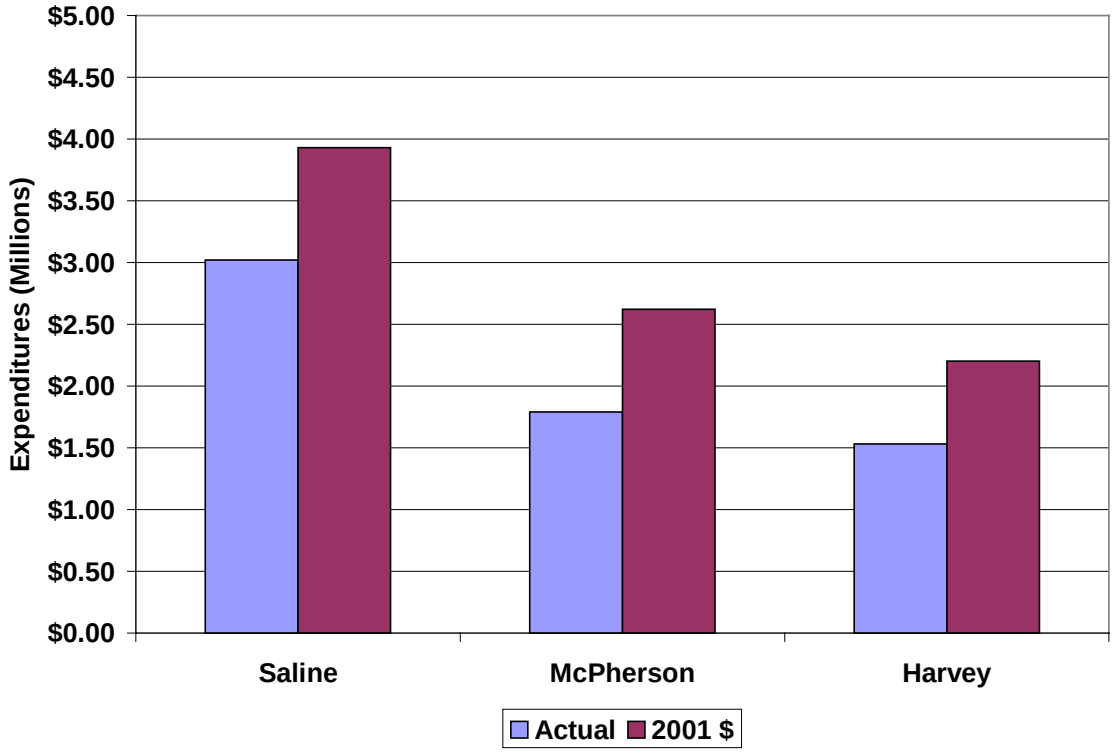

Figure 5. Expenditures Per 4-Lane Mile, I-135

I-70

Of the rural interstate sections evaluated on I-70, there are 249.7 miles of HMA pavement and 95.1 miles of PCC pavement. The HMA sections were constructed between 1960 and 1970. The PCC sections were constructed between 1959 and 1965. A portion of the original PCC sections on I-70 utilized the recently constructed alignment of US-40 for two of their four lanes. This was true for all 5.9 miles of Riley County, 2.5 miles of the 26.3 miles in Geary County and 5.8 of the 23.6 miles in Wabaunsee County. To account for this the expenditures per 2-lane mile were doubled to estimate the 4-lane mile cost.

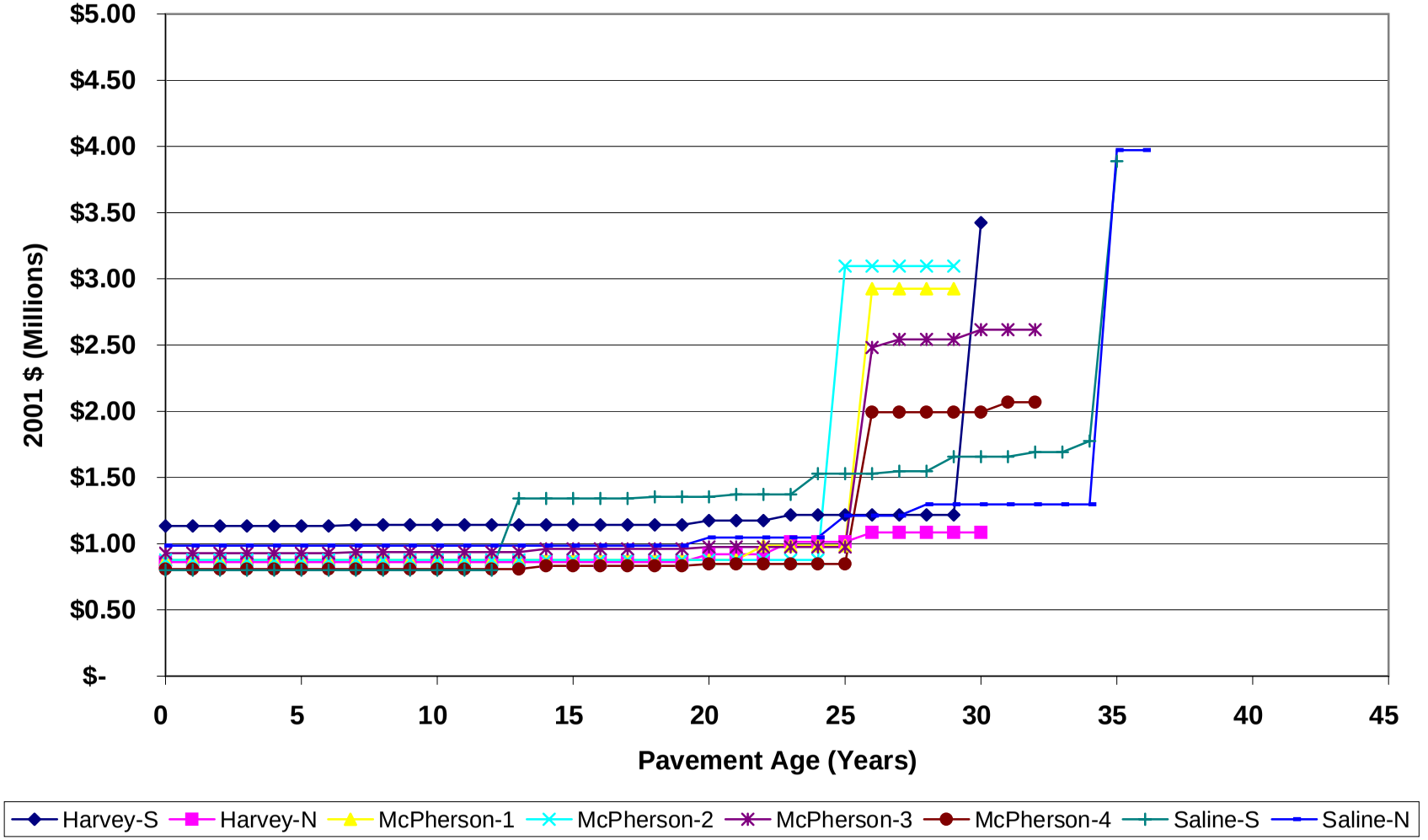

Figure 6. Inflation Adjusted Expenditures per 4-Lane Mile, by Pavement Age, I-135 Sections

Table 2 shows the total expenditures per 4-lane mile in actual dollars and in 2001 dollars using a 3.5% annual inflation rate. Figures 7 and 8 are comparisons of the actual and inflation adjusted total expenditures per 4-lane mile, respectively, for the PCC and HMA sections, by county. The expenditures per county were obtained by taking a weighted average on a per mile basis of the analysis sections in each county.

All HMA sections, with the exception of Sherman County and Saline County, have had total expenditures in actual dollars between $0.86 million and $1.29 million per 4-lane mile. The western 27.4 miles of Sherman County were rehabilitated using whitetopping. The total expenditures for the western portion of Sherman County were $1,608,000 per 4-lane mile in actual dollars and $2,518,000 in 2001 dollars. The HMA portion of Saline County, two sections totaling 14.7 miles, was reconstructed and had total expenditures of $2,227,000 per 4-lane mile in actual dollars and $3,105,000 in 2001 dollars. The PCC pavement sections had total expenditures between $1.18 million and $2.96 million per 4-lane mile in actual dollars and $2.22 million to $4.03 million in 2001 dollars.

Figures 9 and 10 are a comparison of the inflation-adjusted expenditures per year, by age of the pavement, for each analysis section for the HMA and PCC sections, respectively. As shown in figure 9, there are four HMA sections with expenditures exceeding $2.5 million per 4-lane mile, these are the four reconstructed sections. Figure 10 shows that there were only four PCC pavement sections with expenditures less than $2 million per 4-lane mile. These four sections (28.4 miles) are the only sections of PCC pavement on I-70 that have not been reconstructed.

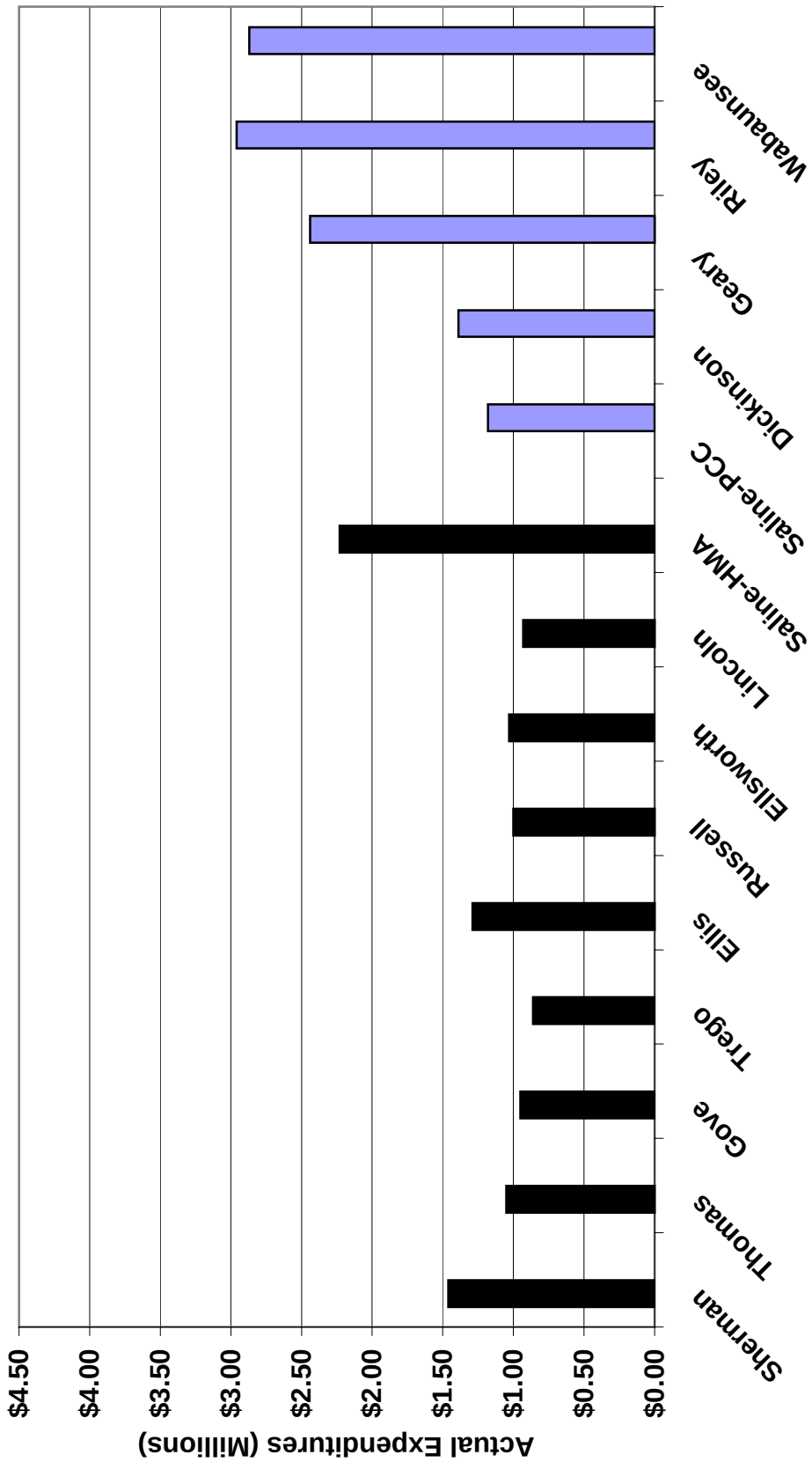

Figure 7. Actual Expenditures per 4-Lane Mile, I-70

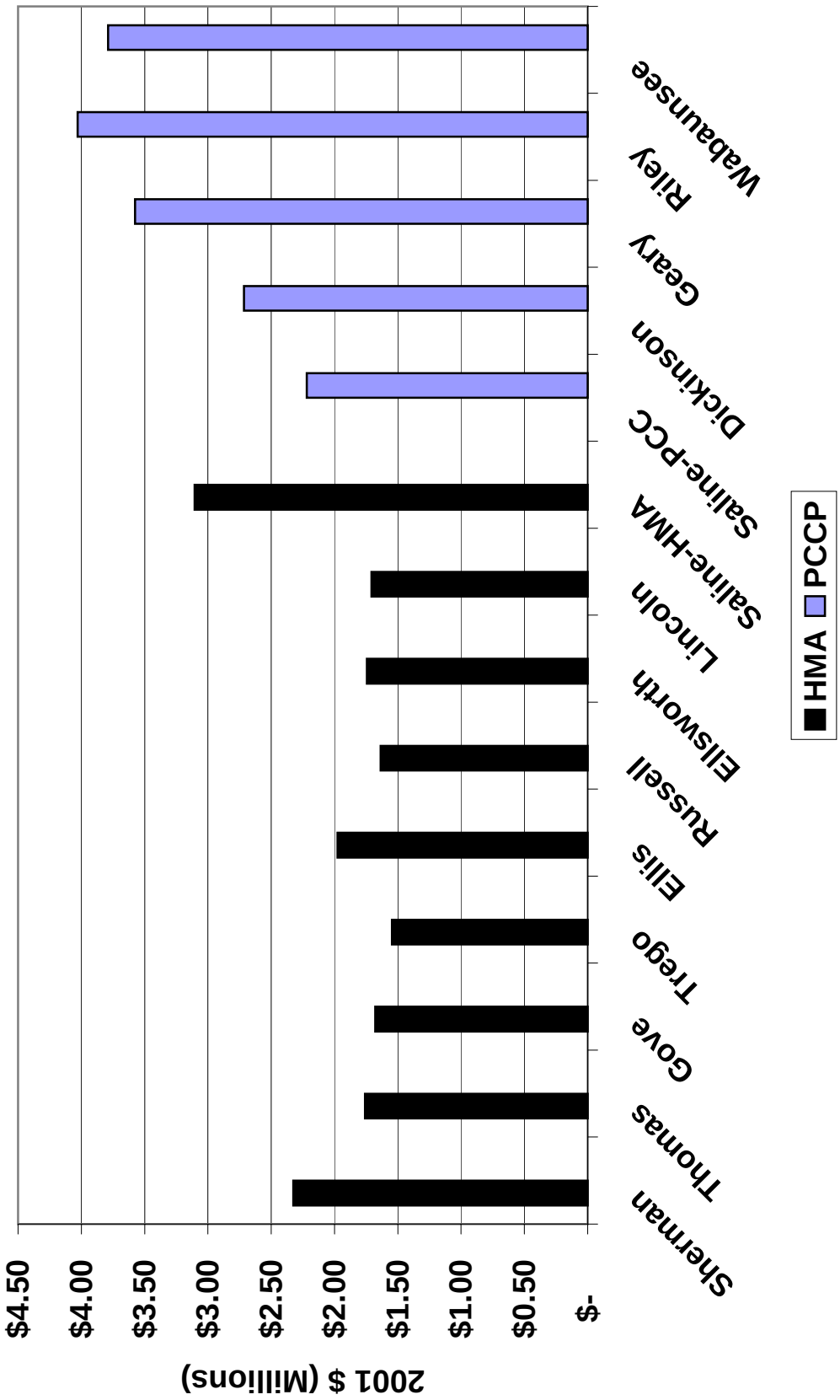

Figure 8. Inflation Adjusted Total Expenditures per 4-Lane Mile, I-70

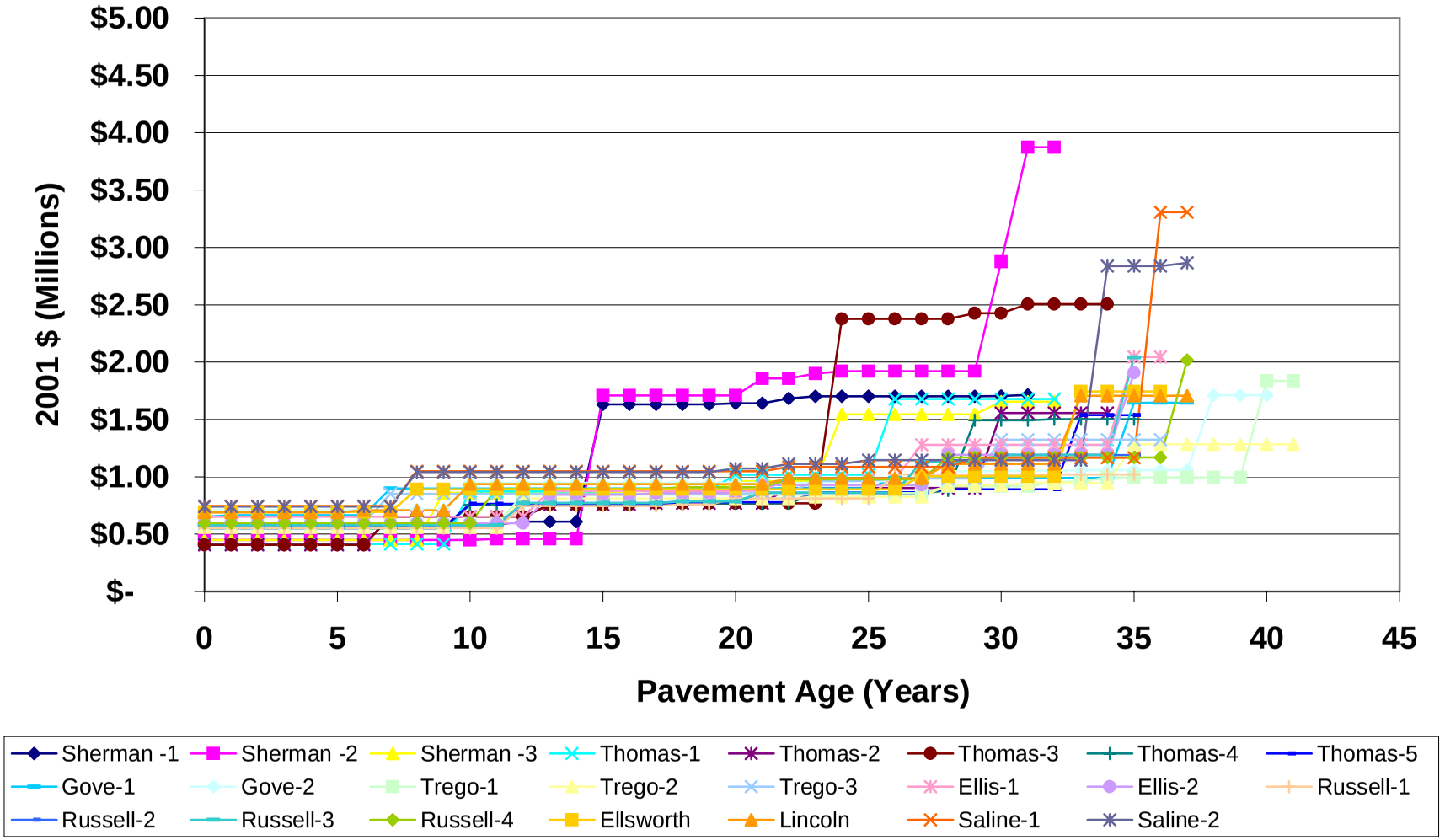

Figure 9. Inflation Adjusted Expenditures per 4-Lane Mile, by Pavement Age, I-70 HMA Sections

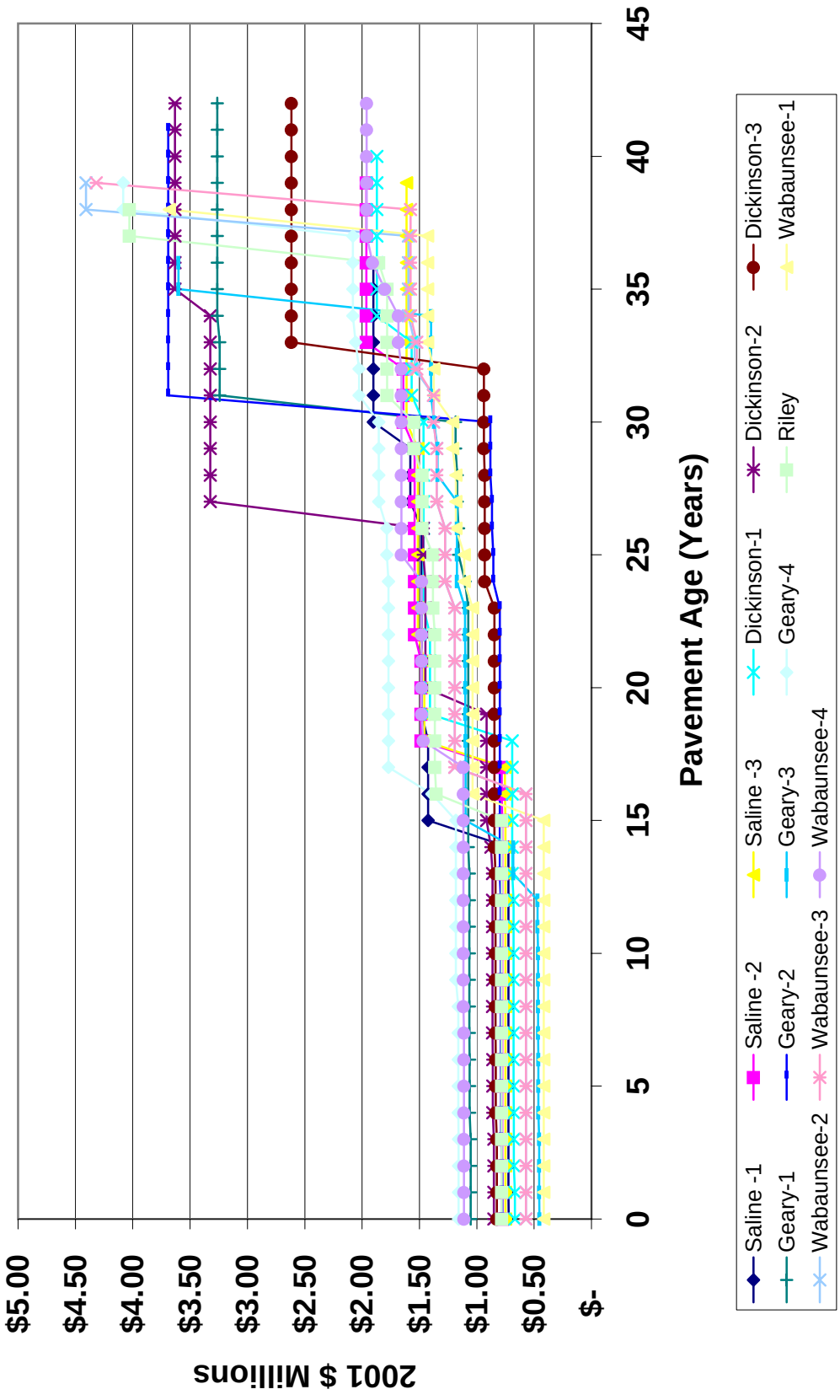

Figure 10. Inflation Adjusted Expenditures per 4-Lane Mile, by Pavement Age, I-70 PCC Sections

Of the 249.7 miles of HMA pavement on I-70, 219.70 miles have been rehabilitated and 33.6 miles were reconstructed. The majority of the rehabilitated sections, 192.3 miles, were rehabilitated using HMA recycling procedures previously described. The cost per 4-lane mile of the HMA recycling was $657,000 in 2001 dollars. There were 27.4 miles that were rehabilitated using whitetopping, Sherman sections 1 and 2. The whitetopping was performed in 1984 and 1985 at a cost of $1,106,000 per 4-lane mile in 2001 dollars. Of the four sections (33.6 miles) of reconstructed original HMA pavement, there were 10.2 miles (Sherman-2) of whitetopped pavement that was reconstructed in full depth PCC in 1999 and 2000. The remaining three sections (23.4 miles) of reconstructed HMA on I-70 included both sections of Saline County and section 3 in Thomas County. The reconstruction was performed using HMA at a cost of $1,815,000 per 4-lane mile in 2001 dollars.

There are 95.1 miles of PCC pavement on I-70, of which 52.3 (55%) have been reconstructed. None of the PCC pavement sections on I-70 have undergone rehabilitation. The average cost per 4-lane mile of the reconstruction was $2,103,000 in 2001 dollars.

Average Expenditures by Pavement Type

The average yearly expenditure per 4-lane mile by pavement age was determined by taking weighted averages per mile of each pavement analysis section. There were 24 HMA pavement analysis sections ranging in length from 4.0 to 23.2 miles and 32 PCC pavement analysis sections ranging in length from 1.9 to 13.1 miles. Pavement analysis sections were selected to give each section a discrete beginning and reconstruction or rehabilitation date. Pavement sections ranged in age from 28 to 41 years for HMA and

24 to 42 years for PCC. For calculations in excess of 28 years of age for HMA and 24 years of age for PCC, the total miles of pavement were reduced accordingly. Figure 11 shows the average inflation adjusted expenditures per year, by age of the pavement sections, for both PCC and HMA pavements.

The plots in figure 11 represent the average life-cycle cost of HMA and PCC rural interstate pavements in Kansas. The data indicates equal life-cycle cost at approximately 15 years. After fifteen years the costs diverge with the PCC sections becoming increasingly more expensive with time. The FHWA recommends (*Publication No. FHWA-SA-98-079 Life-Cycle Cost Analysis in Pavement Design)* analysis periods long enough to include one major rehabilitation for each pavement type. Figure 11 shows the consequences of analysis periods that do not include the cost of major rehabilitation or reconstruction of PCC pavements.

As shown in figure 11, a definite increase in expenditures for PCC pavements occurs at approximately 14 years of age. The HMA section shows little expenditures during the first six years then a steady increase in expenditures through year 41. Therefore, two linear regression curves were determined for each pavement type, one from 0-14 years and another from 15-42 years for PCC and from 0-6 and 7-41 years for HMA. The results are shown in figure 12. The slopes of the regression curves represent the annual expenditures per 4-lane mile.

Average original construction costs for PCC pavements were higher than HMA pavements, $742,000 to $576,000 per 4-lane mile, respectively. Annual expenditures per year over the first 14 years life were higher for HMA pavements. This is due to the PSC overlays placed between year 7 and 13 on I-70. Annual expenditures over the next 27

Figure 11. Inflation Adjusted Life-Cycle Cost Performance for Kansas Rural Interstate Pavements

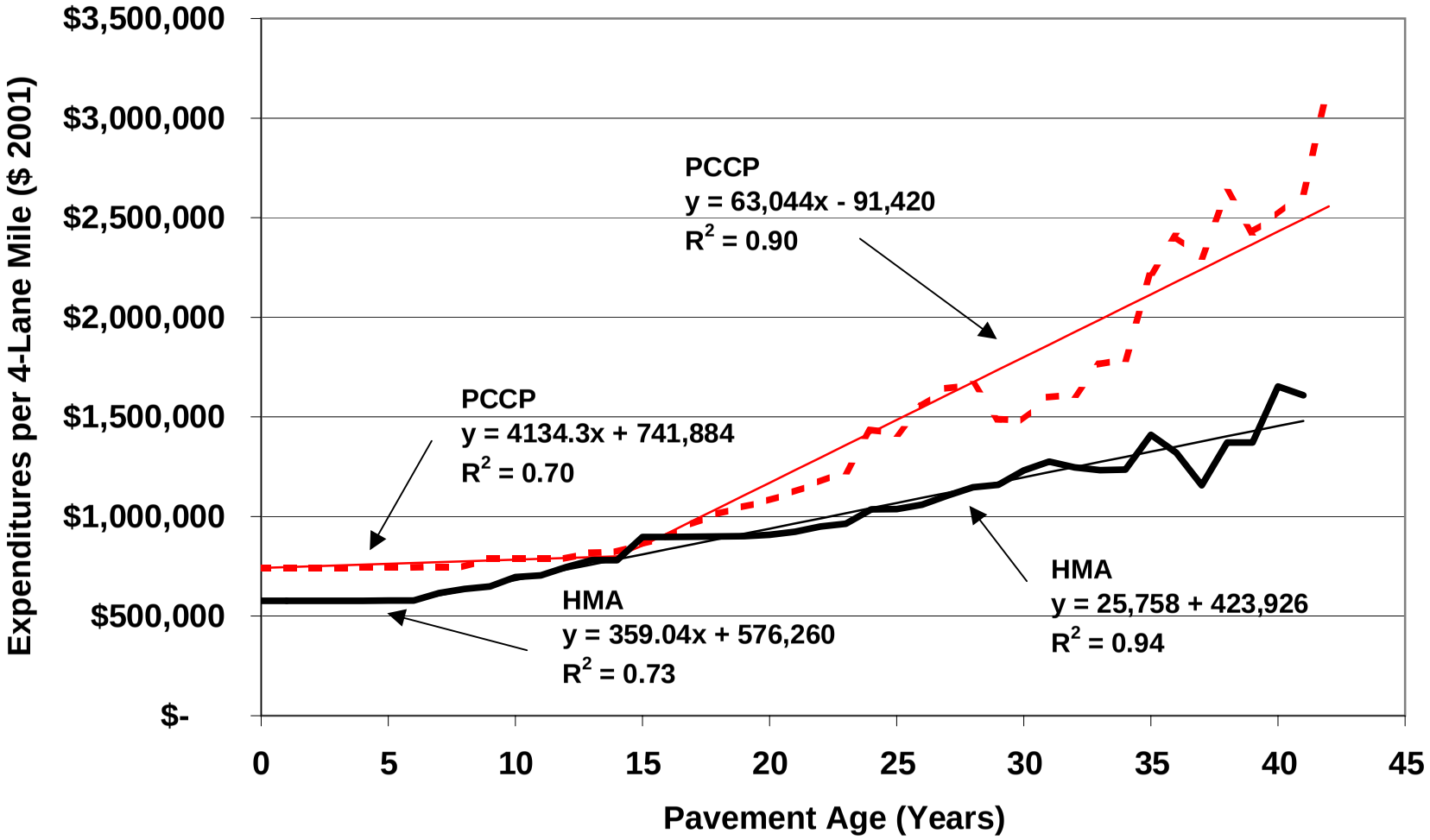

Figure 12. Regression Curves for Life-Cycle Cost Performance

years were 2.4 times higher for PCC pavements than HMA pavements, $63,000 per year per 4-lane mile compared to $26,000 per year per 4-lane mile for HMA.

The majority of the PCC pavement sections have been reconstructed. However, even assuming future maintenance expenditures revert to the earlier level of $4,000 per year for the PCC pavements and expenditures remain at the higher level of $26,000 per year for the HMA pavements, it would take 48 years for total expenditures to be equal. This assumes that all of the PCC pavement sections, including those that have not been reconstructed, will perform similar to a 0-14 year old pavement over the next 48 years and that the HMA sections will continue to require rehabilitation costs.

Pavement Performance

Life-cycle cost analysis requires input parameters of anticipated pavement performance. The FHWA recommends using reasonable assumptions of pavement performance based on past performance and cost histories. The performance and cost data obtained from this study was analyzed to provide recommendations for input parameters for life-cycle cost analysis. The analysis was performed using weighted averages per mile of pavement based on the 32 individual PCC pavement analysis sections and the 24 HMA pavement analysis sections.

Service Life

Service life is defined as number of years from original construction until a major treatment was required. Major treatments are defined as reconstruction or rehabilitation. Of the 218.9 miles of PCC pavement evaluated, 148.0 miles (68%) were reconstructed and 19.4 miles (9%) were rehabilitated (rubblization). Of the 261.8 miles of HMA evaluated, 192.3 miles (73%) were rehabilitated using HMA recycling and 27.4 miles

(10%) were rehabilitated using whitetopping. There were 23.4 miles of HMA pavement that were reconstructed and 10.2 miles of whitetopped pavement that were reconstructed in full depth PCC.

Figure 13 shows the percent of miles in service without reconstruction or rehabilitation, by year, for each pavement type. The performance lives of the two pavement types were very similar. The average service life in years, or the time until 50% of the miles of had undergone rehabilitation or reconstruction, were 33 years for the HMA pavement sections and 34 years for PCC sections. However, the costs were considerably different. Sixty-eight percent of the miles of PCC pavement were reconstructed at a cost of $2,037,000 per 4-lane mile and 9% were rehabilitated at a cost of $1,321,000 per 4-lane mile. The cost of reconstructing the 23.4 miles (9%) of HMA pavement was $1,815,000. Seventy-three percent of the miles of HMA pavement were rehabilitated using HMA recycling at a cost of $657,000 per 4-lane mile. The 27.4 miles (10%) of whitetopping cost $1,106,000 per 4-lane mile. Table 3 shows the original construction costs and reconstruction or rehabilitation costs by pavement type.

HMA Overlay

As previously discussed the HMA sections on I-70 were built using planned staged construction (PSC). However, it is generally agreed that a maintenance action was required at the time the PSC was placed. Figure 14 presents the percent of miles still in service, by pavement age, until the PSC and second HMA overlay were placed for HMA pavement sections and the first and second HMA overlays for PCC pavement sections. Fifty percent of the HMA miles received the first HMA overlay after 10 years with a

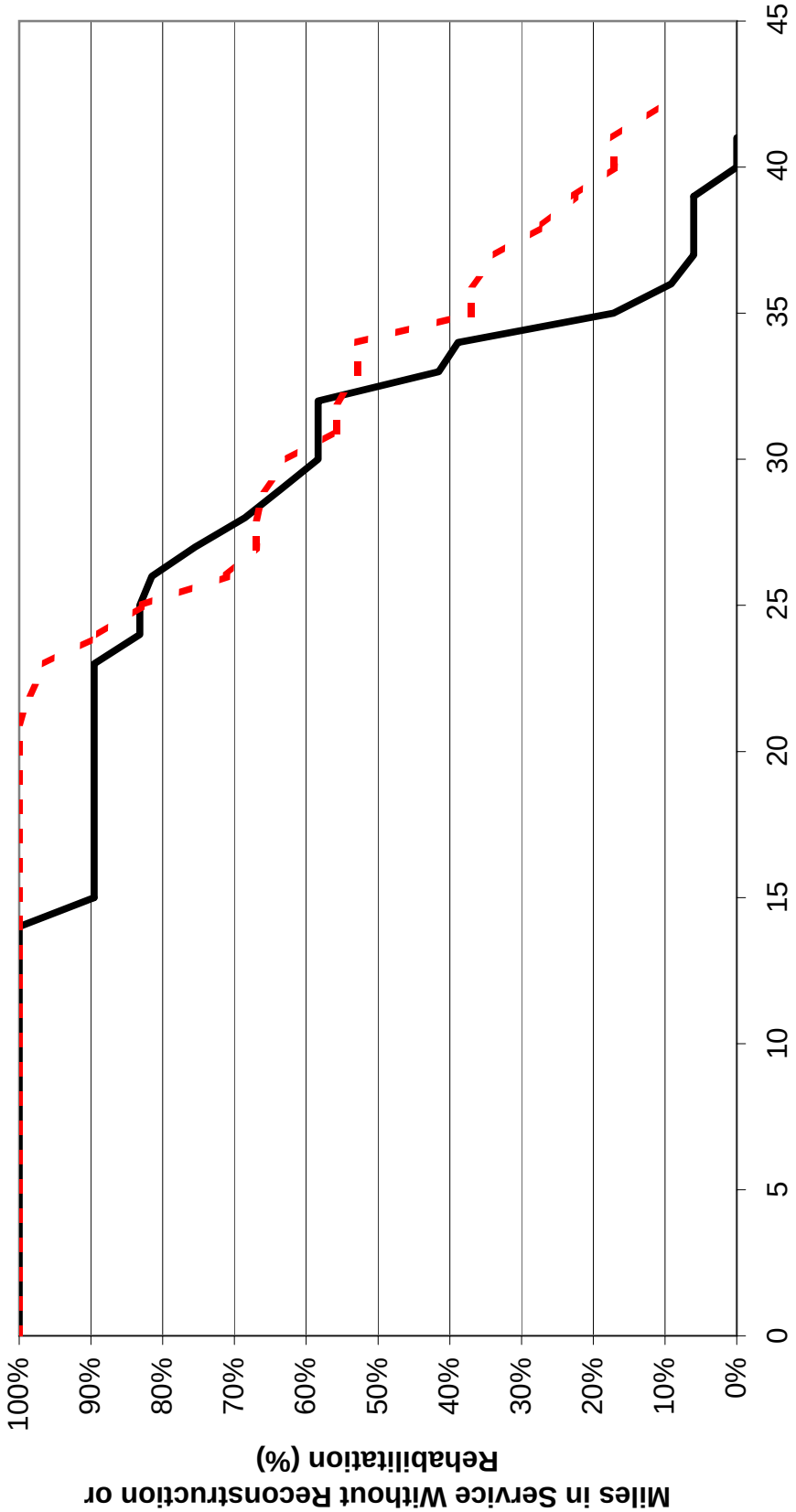

Figure 13. Performance History Curves for Service Life

Table 3. Average Expenditures for Rural Interstate Pavements, 2001 Dollars

	HMA		PCC	
	Miles (%)	Cost	Miles (%)	Cost
Original Construction	100	$ 576,000	100	$ 742,000
Reconstruction	9*	$ 1,815,000*	68	$ 2,037,000
Rehabilitation				
HMA Recycling	73	$ 657,000		N/A
Whitetopping	10	$ 1,106,000		N/A
Rubblization		N/A	9	$ 1,321,000

N/A = Not Applicable * Full Depth HMA

range of seven to 13 years for the PSC on I-70, to a maximum of 22 years for Coffey County, which was not built using PSC. A second overlay was placed 27 years after original construction with a range of 17 to 37 years (not every section has received a second HMA overlay).

After 18 years, 50% of the PCC pavement sections had received an HMA overlay. The range was 13 to 42 years (not every section has received an HMA overlay). Fifty percent of the miles of PCC pavements received a second HMA overlay 31 years after original construction or 13 years after the first HMA overlay. The range was 17 to 42 years from original construction.

First Minor Maintenance Treatment

Minor maintenance treatments were differentiated from HMA overlays for this study. Minor maintenance treatments for PCC pavements consisted of mudjacking slabs, crack

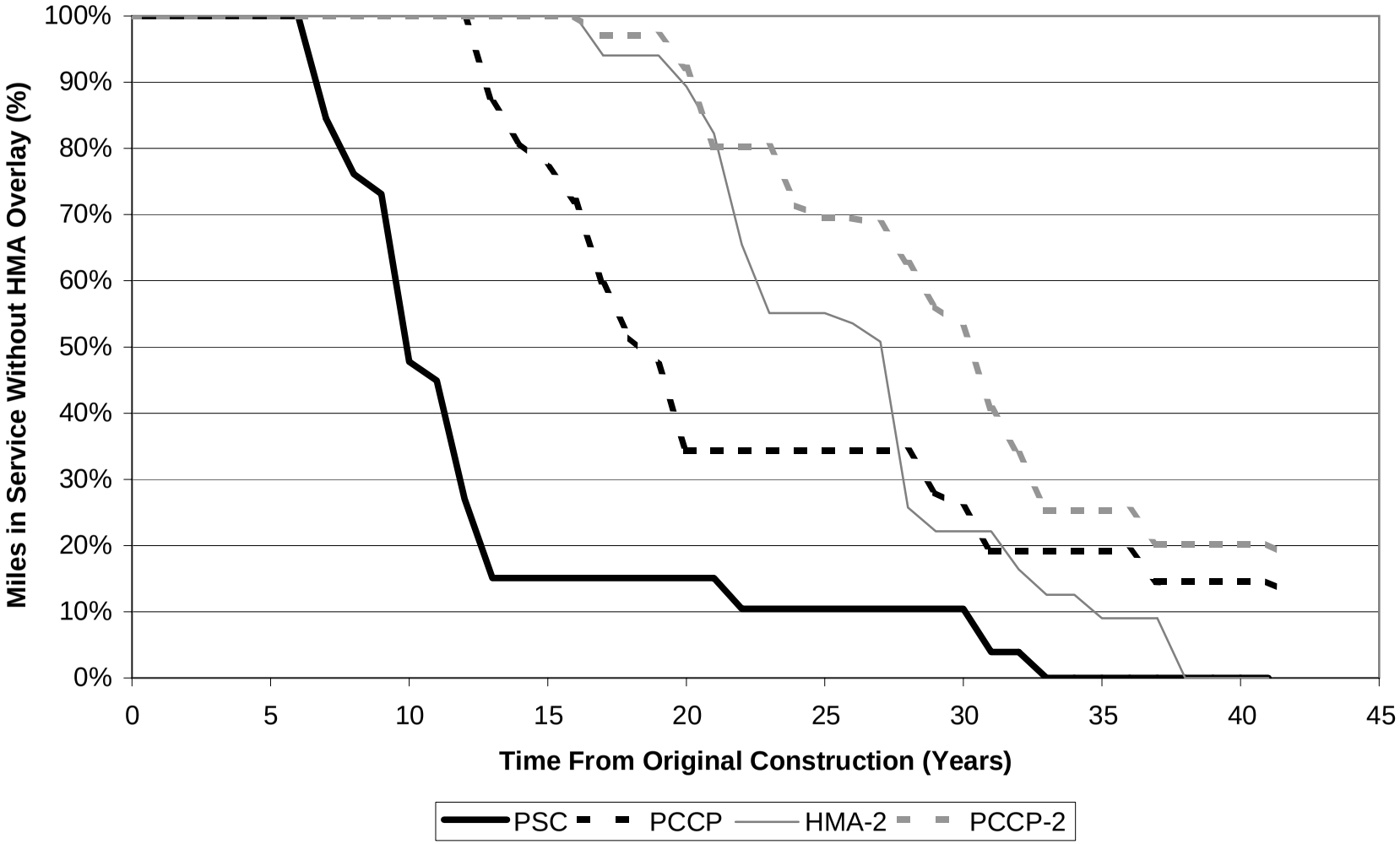

Figure 14. Performance History Curves for HMA Overlays

sealing and PCC patches. Minor maintenance work on HMA pavements consisted of cold milling, applying seal coats, crack sealing and surface recycling.

Figure 15 shows the percentage of miles still in service, by age, until the first minor maintenance treatment. The PSC placed on the HMA sections is shown on the plot for clarity. Fifty percent of the PCC pavements had received a minor maintenance treatment after nine years. The range was one to 29 years. The HMA sections on I-70 received a PSC after 10 years. Fifty percent of the HMA miles lasted 18 years before requiring a minor maintenance treatment or eight years after the PSC overlay. The range was five to 37 years. If the whitetopped sections are excluded, this drops to 27 years.

CONCLUSIONS

Based on the results of this study the following conclusions are warranted.

1. For the rural interstate pavements evaluated, total expenditures in actual dollars and 2001 dollars were less for HMA pavements than PCC pavements.
2. Original construction costs per 4-lane mile in 2001 dollars were less for HMA pavements than PCC pavements, $576,000 to $742,000, respectively.
3. During the first 15 years of a pavement's life, annual maintenance costs were slightly higher for HMA pavements, resulting in equivalent life-cycle costs. Annual expenditures over the next 25 years were 2.4 times higher for PCC pavements than HMA pavements, $63,000 per 4-lane mile for PCC compared to 26,000 for HMA.
4. HMA and PCC pavements had similar average service lives until rehabilitation or reconstruction, 33 and 34 years for HMA and PCC, respectively. Reconstruction costs for PCC pavements averaged $2.04 million per 4-lane mile compared to rehabilitation costs of $0.66 million per 4-lane mile for HMA pavements.

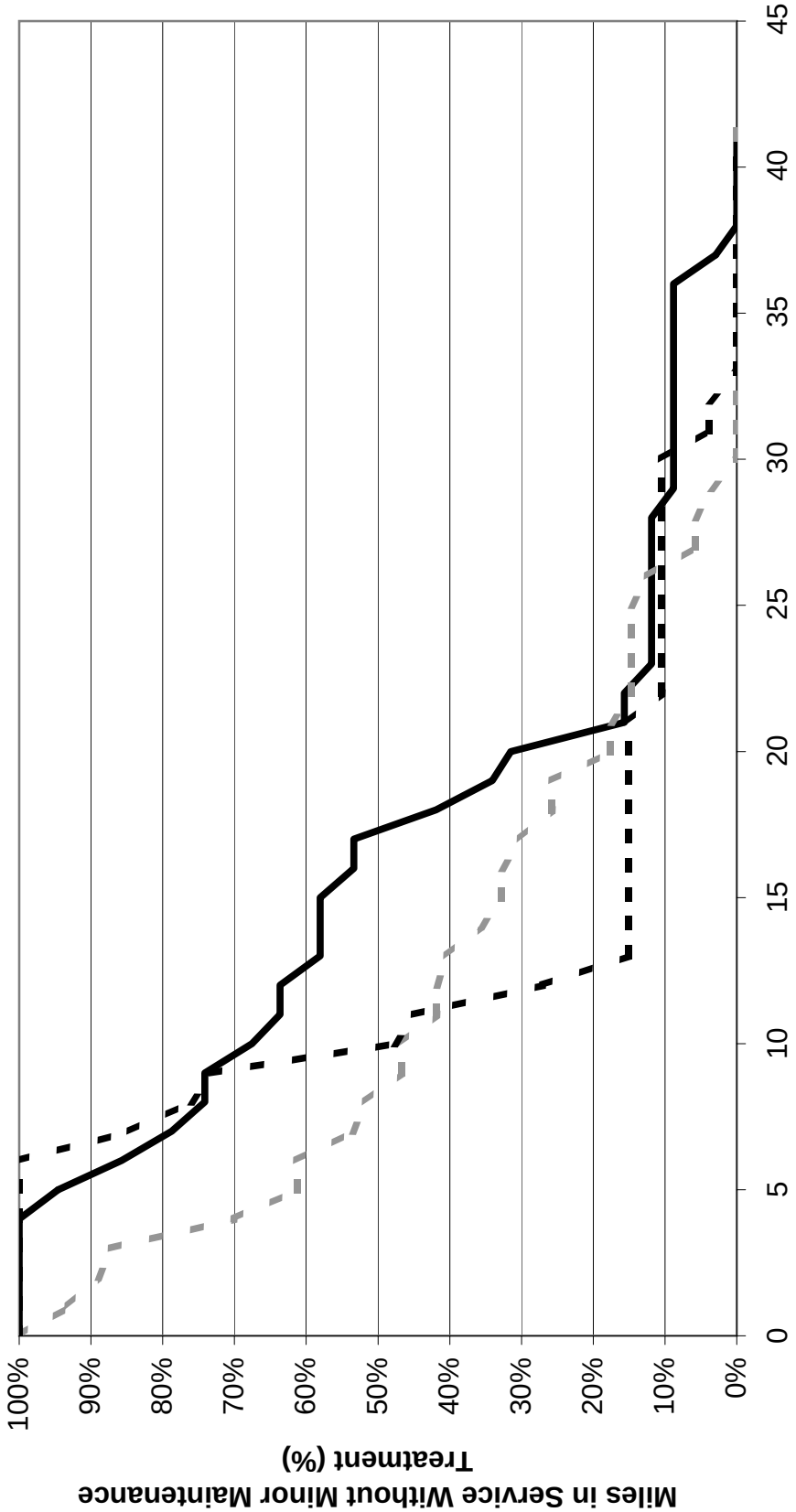

Figure 15. Performance History Curves for First Minor Maintenance Treatment

RECOMMENDATIONS

Based on the results and limitations of this study, the following recommendations for pavement performance for use in life-cycle cost analysis in areas with similar materials and environment to Kansas are warranted. The recommendations are shown in table 4. Both pavement types were originally constructed using the best available materials, methods and procedures available at the time of construction. The major reported modes of pavement distress were thermal cracking for HMA pavements and joint deterioration due to D-cracking, faulting and spalling for PCC pavements. These distress mechanisms have been addressed by changes in material specifications, design procedures and construction methods. The recommendations shown in table 4 are based on past performance and should be considered conservative values for use in life-cycle cost analysis.

HMA Pavements

HMA pavements should last a minimum of 8-12 years past original construction without any maintenance. Pavements built utilizing planned staged construction typically received a planned overlay after 10 years. Seventeen years after original construction, seven years after the PSC, a seal or cold milling was typically performed. An HMA overlay was typically placed an average of 27 years after original construction. Rehabilitation on pavements with thermal cracking occurred after 33 years. Rehabilitation consisted of milling four inches, cold in-place recycling four inches and placing six inches of HMA.

Table 4. Recommended Input Parameters for Life-Cycle Cost Analysis in Kansas.

Treatment	Action	Treatment Life		
		Average	Maximum	Minimum
		(years)		
HMA Pavements				
1st	HMA Overlay	10	22	7
2nd	Seal	18	27	5
3rd	HMA Overlay	27	37	17
4th	Rehabilitation*	33	40	15
PCC Pavements				
1st	Seal / Patch	9	29	1
2nd	HMA Overlay	18	42	13
3rd	HMA Overlay	31	42	17
4th	Reconstruction	34	42	22

* Thermal cracked HMA pavements only.

PCC Pavements

The average time until the first minor maintenance treatment for a PCC pavement was nine years. After this time slab repair, consisting of patching, mudjacking or crack sealing was required. An HMA overlay was placed an average of 18 years after original construction followed by a second HMA overlay at 31 years. Complete reconstruction occurred, on average, after 34 years.

Thirty-five percent of the PCC pavements had a service life of less than 30 years and 63% had a service life of less than 35 years. None of the PCC pavements evaluated are expected to exceed a 45-year service life before complete reconstruction is required. Exceedingly long service lives for Kansas PCC pavements do not appear warranted.

Average yearly maintenance expenditures for PCC pavements during the first 15 years were slightly less than HMA pavements. During the next 25 years, yearly expenditures for PCC pavements were 2.4 times higher than HMA pavements. Historically, PCC pavements have required less maintenance than HMA pavements during the first 15 years but considerably more maintenance during the next 25 years. If long service lives are expected for PCC pavements, considerable maintenance cost during the last 25 years of the pavement's life should be considered.