

Pavement Life-Cycle Cost Studies Using Actual Cost Data

A S Y N T H E S I S



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PAVEMENT LIFE-CYCLE COST STUDIES
USING ACTUAL COST DATA
A Synthesis

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EXECUTIVE SUMMARY

This synthesis presents the results of studies of interstate highways in three states which show the comparison of costs between hot mix asphalt (HMA) pavements and portland cement concrete (PCC) pavements.

The process used to determine the economical performance of pavements over time is called "Life-cycle Cost Analysis" (LCCA). There are two ways of using LCCA: (1) For the *prediction of future costs* of proposed pavements over a given period of time, using the best available information as to total costs and predicted performance; and (2) For the *determination of actual costs* of existing pavements over a given period of time based on historical data from agency records.

The three studies in this synthesis use the second way, which takes actual costs of all work performed to construct and maintain a pavement from agency records and the times at which the costs were incurred to determine the total cost of the pavements over time. In all cases, comparisons were made to the greatest extent possible of HMA and PCC pavements with similar traffic and comparable age.

There are many variables in the LCCA process, both in predicting future costs and in determining actual costs. These variables greatly influence the results of the analysis. The determination of actual pavement costs is highly dependent on the adequacy, or inadequacy, of records showing what was done to the pavement, when it was done, and how much it cost. This information is typically difficult to assemble, requiring diligent searching of agency construction and rehabilitation records. Inaccuracies or omissions in the records for these items will affect the accuracy of the results. In that light, the information provided in the three studies is unique and valuable due to the diligence of the authors in obtaining complete and accurate information.

The three studies were diverse in their approach to the question of which pavement type is more economical. The Ohio study examined five locations on four interstate highways where HMA and PCC pavements were constructed in close proximity and at approximately the same time. The costs were calculated per square yard of mainline pavement. The Kansas study looked at approximately 218 miles of PCC pavement and 262 miles of HMA pavement on rural interstate highways across the state. Comparative costs were calculated using the "four-lane mile of mainline pavement" as the unit of measure. The Iowa study examined three locations on one interstate route where HMA and PCC pavements were constructed adjacent to each other at nearly the same time. The comparison of costs was made using the "two-lane mile" as the unit of measure.

The Ohio study used the present worth method of costs wherein all of the costs during the analysis period of each project were discounted to the year of the original construction project. The adjacent HMA and PCC pavements were located on I-71 from central to northern Ohio, on I-75 and I-475 in the northwestern part of the state, and in two locations on I-275 in southwestern

Ohio. Calculations were made using both a 5.0% discount rate, which the Ohio DOT was using at that time, and a 2.5% discount rate to show the effect of a lower rate.

The Ohio results showed that in all cases the initial construction costs of HMA pavements were about 10 to 25 percent less than those of compared PCC pavements on the same route. The cost savings for the present worth values (or total discounted costs) of HMA compared to PCC pavements were even more dramatic, ranging from 13 percent to 107 percent, with most of the savings in the 25 percent to 70 percent range. The results are detailed in Table 1.

In the Kansas study, all of the compared pavements were not the same age, therefore equitable comparisons could not be made using the net present value (or worth) method. The comparisons were made using inflation adjusted dollars. An annual inflation rate of 3.5% was used, and all costs were carried forward to 2001 and referred to as "2001 dollars." A total of 218 miles of PCC pavement and 262 miles of HMA pavement on three interstate highways were evaluated. The HMA pavement on I-70 extends about 250 miles from the western border of the state to I-135 in central Kansas. The PCC pavement is in 3 locations: 95 miles on I-70 east of I-135; 68 miles on I-135 south of I-70; and 55 miles on I-35 in the eastern part of the state. Using an inflation rate of 3.5%, all costs were carried forward to 2001 and referred to as "2001 dollars."

The nine sections of HMA on I-70, one in each of nine counties and 249.7 miles in length, had an average life-cycle cost of \$1.89 million per 4-lane mile in 2001 dollars. The five sections of PCC on I-70, one in each of five counties and 95.1 miles in length, had an average life-cycle cost of \$3.22 million per 4-lane mile in 2001 dollars. On I-35, the 12.1 miles of HMA pavement in Coffey County had a life-cycle cost of \$1.39 million per 4-lane mile in 2001 dollars. The three sections of PCC pavement on I-35, in three counties and 35.5 miles in length, had an average life-cycle cost of \$3.43 million per 4-lane mile in 2001 dollars. There was no HMA pavement on I-135, but the 68.4 miles of PCC pavement in three counties had a life-cycle cost of \$2.89 million per 4-lane mile in 2001 dollars. Costs for each county are shown in Table 2.

The Iowa study determined the total life-cycle costs by calculating the present worth of costs of selected pavements discounted back to 1957 dollars using a discount rate of four percent. Three sections each of PCC and HMA pavement on I-80 in three counties between Des Moines and Iowa City were analyzed in the study.

In Iowa County—the one farthest east—the 4.58-mile PCC section had present worth costs of \$272,000 per 2-lane mile. The adjacent HMA section, 3.00 miles long, had present worth costs of \$157,528 by comparison. The 4.64-mile section of PCC pavement in Jasper County, the westernmost, showed total costs discounted to 1957 dollars of \$290,151 per 2-lane mile, while the adjacent 6.43 mile section of HMA pavement had total costs of \$179,136 per 2-lane mile. In Poweshiek County, the 9.15-mile PCC pavement section had present worth costs of \$186,471 per 2-lane mile for the eastbound lanes and \$189,253 per 2-lane mile for the westbound lanes. The adjacent 3.14-mile HMA pavement section, in comparison, had higher present worth costs amounting to \$199,473 per 2-lane mile. The costs are shown in Table 4.

The results of the studies show that HMA pavement was overall more economical in both initial construction cost and life-cycle costs than comparable PCC pavement. In Ohio, all five of the areas compared showed lower initial construction costs and life-cycle costs for HMA pavement. In Kansas, the 10 HMA and 11 PCC pavement sections evaluated on three interstate routes

showed that HMA was substantially more economical over the life of the pavement. Initial construction costs of nine HMA pavement sections in Kansas averaged less than those of five PCC pavement sections on I-70, but one HMA pavement section on I-35 had a higher initial construction cost than the average of three PCC pavement sections on the same route. In Iowa, two HMA pavement sections were substantially more economical over the life of the pavements than the comparable PCC sections, and one PCC section was slightly more economical in life cycle costs than the comparable HMA section.

PAVEMENT LIFE-CYCLE COST STUDIES
USING ACTUAL COST DATA
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INTRODUCTION

The performance and economy of highway pavements is a matter of critical importance to governmental agencies, highway engineers, paving contractors and others involved in the highway industry. The subject is also important to the citizen taxpayers, who want the best value for their tax dollars.

In that light, it is beneficial to know the economic value over time of pavements, generally called the "life-cycle costs" of pavements. In this synthesis, the results of studies of interstate highways in three states will be presented to show the comparison of life-cycle costs between hot mix asphalt (HMA) pavements and portland cement concrete (PCC) pavements.

There has historically been a difference of opinion as to whether hot mix asphalt (or *flexible*) pavements are more economical or less economical over time than portland cement concrete (or *rigid*) pavements. Each industry claims that its product is more economical or longer lasting, or both. Even experienced state highway agencies and highway engineers disagree on the subject. While the information presented here is not expected to settle the argument, it will show that careful, detailed studies in three states indicate that HMA pavements are more economical over time – that is, they have lower *life-cycle costs*.

The three studies examined here use actual costs from agency records and the times at which the costs were incurred to determine the total cost of the pavements over a period of time. This information is typically difficult to assemble, requiring diligent searching of agency construction and rehabilitation records. This makes these three studies unique and valuable. In all cases, comparisons were made to the greatest extent possible of HMA and PCC pavements with similar traffic and age.

DEFINITION OF ISSUE: LIFE-CYCLE COSTS

The process used to determine the economical performance of pavements is called "Life-cycle Cost Analysis" (LCCA). The subject is of such importance that the Federal Highway Administration has published an Interim Technical Bulletin (3) furnishing technical guidance and recommendations on best practices in conducting LCCA. There are two ways of using LCCA: (1) For the *prediction of future costs* of proposed pavements over a given period of time, using the best available information as to total costs and predicted performance; and (2) For the *determination of actual costs* of existing pavements over a given period of time based on historical data from agency records.

The prediction of future costs using LCCA can be used to make a comparison of costs between competing pavement designs, such as HMA versus PCC, or even two or more different HMA or PCC designs. Normally the procedure is used to compare HMA and PCC pavements designed to carry the predicted traffic load for an equal period of time. The results of an impartial LCCA will show which pavement type is most economical. This information can then be used to make a decision as to which pavement type is best for the agency or owner.

The predicted costs of a LCCA must be based on accurate unit costs of materials and construction, and on realistic cost estimates and timing of maintenance and rehabilitation procedures used during the pavement's life. The analysis takes the following costs into consideration: initial construction, routine and preventive maintenance, resurfacing, rehabilitation, reconstruction, and user costs; and it considers the salvage value of the pavement. Sometimes routine maintenance costs, user costs, and salvage value are not included, depending on agency procedures.

The LCCA procedure calls for the costs at the different times in the life of the pavement to be discounted to equate to dollar values at the beginning of the pavement's life. The resulting total cost over time is called the "net present value," also known as the "present worth of costs." The discounting of costs is based on a formula using a "discount rate," which converts costs during the life of a pavement to dollar values at the beginning of the pavement's life. The discount rate is generally defined as the difference between the interest rate on borrowed money for government bonds and the inflation rate. The Federal Highway Administration (FHWA) states that good practice suggests using a discount rate of 3 to 5 percent based on that definition and on a study of interest and inflation rates in the early and mid-1990's.

The period of time over which all of these costs are determined is called the "analysis period," and it usually ranges from 30 to 50 years. The period of time for which the initial pavement is designed is called the "performance period," or the "design period," and it usually varies between 20 and 30 years. The performance period is the time from completion of pavement construction to the time when the pavement is expected to reach its terminal serviceability and require rehabilitation or resurfacing. The timing for further rehabilitation activities is determined and applied to the project through the remainder of the analysis period.

The other use of LCCA, the determination of actual costs of existing pavements and the subsequent comparison of pavements of similar age and similar traffic loading, is accomplished through diligent search and compilation of agency information. Actual costs of the work performed on the pavements under study can then be discounted, normally to the beginning of the analysis periods if they are close in time. The total of these costs yields the net present value, i.e. the cost of each project in dollars at the beginning of its life. An alternate method is to adjust dollars forward to a common year using an appropriate inflation rate. This method can be useful particularly when the ages of compared pavements are not similar. Both of these procedures can be thought of as a "life-cycle cost *study*," because they are based on the determination of actual costs and information indicating when work on the pavement actually took place.

There are many variables in the LCCA process, both in predicting future costs and in determining actual costs. These variables greatly influence the results of the analysis. In the prediction of future costs, the use of *realistic* unit costs for materials and labor is critical, particularly in determining initial costs. The predicted frequency and extent of the various maintenance, rehabilitation, and reconstruction procedures and their resultant costs also will affect the outcome substantially. Routine maintenance costs, due to work usually performed by the agency, will normally have minimal effect on the total life-cycle costs.

The determination of actual pavement costs is highly dependent on the adequacy or inadequacy of records showing what was done to the pavement, when it was done, and how much it cost. Any inaccuracies or omissions in the records for these items will certainly skew the results. In addition, the construction of overlays or rehabilitation within boundaries other than the original sections of pavement makes it difficult to accurately determine the total cost of some pavement sections.

Different units of measure can be used to compare the costs of competing pavements. Probably the most basic unit is the square yard of mainline pavement. A lane-mile of pavement is a convenient method also of determining unit costs. For interstate and other four-lane pavements, the two-lane mile or four-lane mile of pavement can also be used as a unit of measure.

SCOPE OF THE STUDIES TO BE PRESENTED

The three studies presented in this synthesis examine the actual costs of HMA pavement sections versus PCC pavement sections over time. They were conducted on interstate pavements in Ohio, Kansas, and Iowa.

The Ohio study examined five locations on four interstate highways where HMA and PCC pavements were constructed in close proximity and at approximately the same time. The costs were calculated per square yard of mainline pavement. Initial construction, maintenance, resurfacing, rehabilitation, and reconstruction costs were considered, but user costs and salvage value were not considered. The net present value (NPV), or present worth (PW), of each pavement section was calculated using discount rates of 5.0% and 2.5% for comparison.

The Kansas study looked at rural interstate pavements across the state, approximately 218 miles of PCC pavement and 262 miles of HMA pavement. Comparative costs were calculated using the "four-lane mile of mainline pavement" as the unit of measure. Mainline pavement in this study is defined as the 24-foot wide travel lanes, shoulders, and ramps. It does not include bridges, bridge approach slabs, cross roads, drainage structures, rest areas, or other ancillary structures. Costs considered were those for initial construction, maintenance work, rehabilitation, and reconstruction. An annual inflation rate of 3.5% was used, and all costs were carried forward to 2001 and referred to as "2001 dollars".

The Iowa study examined three locations on Interstate Route 80 where HMA and PCC pavements were constructed adjacent to each other at nearly the same time. The comparison of costs was made using the "two-lane mile" as the unit of measure. The costs included were initial construction, contract maintenance, rehabilitation, and reconstruction costs. User delay costs and salvage, or residual, values were not taken into account. Cumulative costs of the pavements were calculated to obtain the present worth (or net present value) in 1957 dollars using a discount rate of four percent.

COST DETERMINATION PROCEDURES AND RESULTS OF STUDIES

Ohio Study

The Ohio study (5) was conducted in 1995 at the request of Flexible Pavements, Inc. (now Flexible Pavements of Ohio). The work consisted of obtaining the actual construction and maintenance costs of flexible pavements and adjacent rigid pavements constructed at five locations on the Interstate system in Ohio. Both pavement types were designed, constructed, and maintained to similar standards, and traffic loading is much the same on adjacent pavements. At the time of the study, pavements at the five locations had been in service from 19 to 38 years.

Project data was tabulated from plans and contract files made available by the Ohio Department of Transportation. This consisted of original construction project data and its costs and of contract maintenance activity costs by types of work through 1994. The total cost for each maintenance activity was discounted to the year of the original construction project using both a 5.0% and a 2.5% discount rate. The total present worth of project costs was then calculated for each discount rate. The total present worth of costs for each project was then divided by the corresponding area of the pavement in square yards to obtain the present worth of costs per square yard at each discount rate. The five percent rate was used because the Ohio DOT was using that rate for its cost analyses around the time many of these projects were being constructed. The two and one-half percent rate was used to show the effect of a lower rate.

The original pavement construction costs were determined for the mainline pavement layers above the subgrade. The cost of pavement drainage was not included, except on two I-275 projects where the flexible and the rigid pavements had different drainage designs. All other projects had similar, continuous drainage design. Contract maintenance activity costs incurred during the analysis period were included for items of work done to maintain, rehabilitate, or to reconstruct the mainline pavement.

This study investigated projects located as follows: (1) on Interstate 71 from Franklin County to Medina County, including sections in Delaware, Morrow, Richland, Ashland, and Wayne Counties; (2) on Interstate 75 in Hancock and Wood Counties; (3) on Interstate 275 in Hamilton County; (4) another section on Interstate 275 in Hamilton and Clermont Counties; and (5) on Interstate 475 in Lucas County.



Figure 1. Ohio Interstate Highways

The original construction costs and the maintenance costs over the lives of the pavements compiled in the report indicated that the HMA (flexible) pavements produced a significant economic advantage over the PCC (rigid) pavements. The cost advantage of HMA pavement would have been even greater if maintenance of traffic and user delay costs had been included. This is because the construction time required for maintenance, rehabilitation, and reconstruction of rigid pavements proved to be substantially longer than for flexible pavements.

Table 1 contains a summary of the comparison of project costs on interstate pavements in the five aforementioned areas of the state. The values are shown in dollars per square yard and include costs of maintenance, rehabilitation, and reconstruction at discount rates (DR) of 5.0% and 2.5%. The total present worth of costs, which includes the initial construction cost, is also shown for both discount rates. The costs are discounted to the year of the original construction project.

The section of I-75 in Wood County from milepost 14.91 to 19.92 received concrete rehabilitation with tied concrete shoulders added. Table 1 shows rehabilitation costs calculated both with and without tied shoulder costs. The flexible section, I-275 Hamilton 13.91 – 16.22, and the composite section, I-275 Hamilton 10.66 – 13.91, had higher initial construction costs because the cost of drainage was included. This was done because drainage on the two projects

was substantially different, while the other compared projects had essentially the same drainage treatment.

Pavement Type	Locations (Route, County, & Section)	Constr Year	Initial Constr Cost	Discounted Maint, Rehab & Reconst		Present Worth DR=5%	Present Worth DR=2.5%
				DR=5%	DR=2.5%		
Flexible	I-71 Franklin to Delaware	1958	5.44	2.48	4.07	7.92	9.51
Rigid	I-71 Delaware to Richland	1957-58	6.35	6.33	11.17	12.68	17.52
Rigid	I-71 Richland to Medina	1957-58	6.35	3.97	6.61	10.32	12.96
Flexible	I-75 Wood 0.77 - 5.06(SB)	1959	4.63	2.20	3.58	6.83	8.21
Rigid	I-75 Hancock 19.25 - 25.23	1956	5.78	3.75	7.36	9.53	13.14
Flexible	I-75 Wood 5.06 - 14.91	1966	5.16	1.82	2.89	6.98	8.05
Rigid	I-75 Wood 14.91 - 19.92 (Rehab w/tied shoulders)	1966	5.66	6.38	11.00	12.04	16.66
				9.12	15.55	14.78	21.21
Flexible	I-275 Hamilton 13.91 - 16.22	1975	10.62	1.37	2.17	11.99	12.79
Composite 3"AC/9"PCC	I-275 Hamilton 10.66 - 13.91	1975	12.81	2.27	3.58	15.08	16.39
Flexible	I-275 Hamilton 32.27 - 34.91	1968	4.94	2.26	3.86	7.20	8.80
Flexible	I-275 Clermont 0.00 - 10.98	1970	5.08	2.03	2.99	7.11	8.07
Rigid	I-275 Hamilton 30.96 - 32.27	1964	5.79	3.32	5.66	9.11	11.45
Flexible	I-475 Lucas 5.25 - 8.95	1966	5.62	2.64	4.08	8.26	9.70
Rigid	I-475 Lucas 0.09 - 5.25	1964/66	6.44	2.88	4.90	9.32	11.34

Costs are shown in \$ / sq. yd. "DR" stands for discount rate. The composite pavement consists of 3" of asphalt concrete over 9" of portland cement concrete.

Table 1. Comparison of Costs for Ohio Interstate Pavements

Ohio Study Conclusions

It can be seen from the values in Table 1 that the costs of initial construction for HMA pavements were consistently less than the initial construction costs of PCC pavements, ranging from approximately 10 percent to 25 percent less. The cost savings for the present worth values, both at 5 and 2.5 percent discount rates, were even more dramatic, ranging from 13 percent to 107 percent, with most of the savings in the 25 percent to 70 percent range. When the PCC rehabilitation with tied shoulders was considered, the cost savings for HMA were even greater. A graphical representation of the comparative project costs over time on Interstate Route 71 in Ohio is shown in Figure 2. The flexible pavement section from mileage 28.92 in Franklin County to mileage 11.50 in Delaware County (5.44 miles) is compared against the rigid pavement section from mileage 11.50 in Delaware County to mileage 0.00 in Richland County (6.35 miles).

Present Worth in 1960 of Total Contract Costs (5% Discount Rate)

Interstate 71

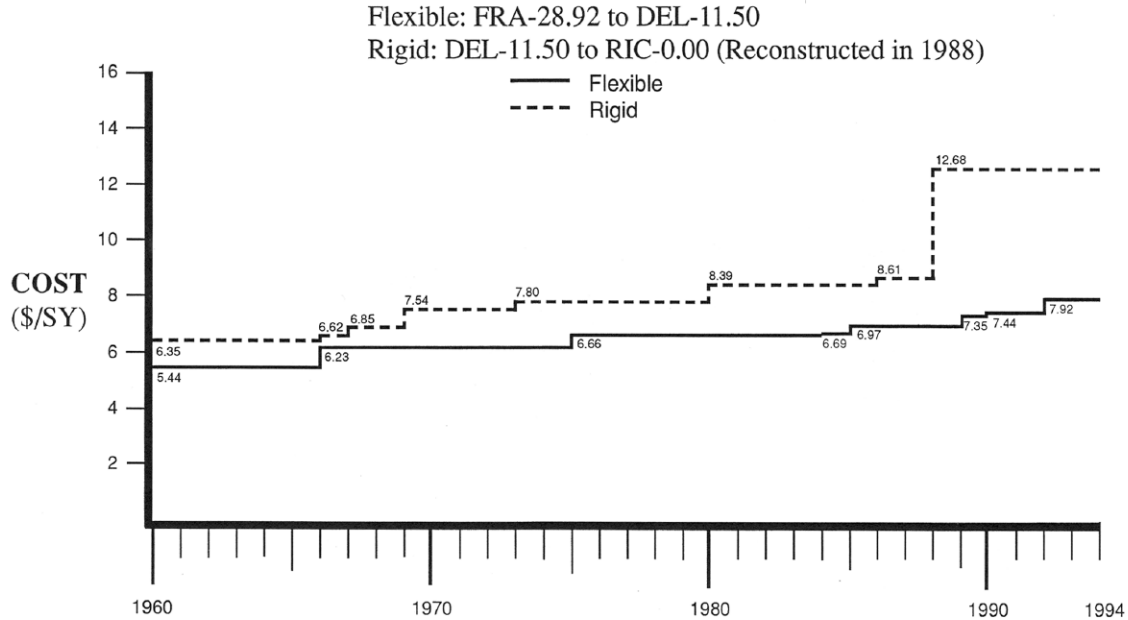


Figure 2. Comparative Costs on Interstate Route 71 in Ohio

This graphic clearly shows that the total life-cycle cost of flexible pavement began lower than that of rigid pavement and continued that way to the end of the analysis period, 34 years later. Similar graphics developed from the costs of the other pavements in the study showed similar results but are not shown here due to space limitations.

Kansas Study

The Kansas study is entitled "Evaluation of Expenditures on Rural Interstate Pavements in Kansas." It was written in 2002 by Stephen A. Cross, P.E., then Associate Professor, and Robert L. Parsons, Assistant Professor, University of Kansas. The purpose of the 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. The rural interstate pavements on I-35, I-70, and I-135 administered by the Kansas Department of Transportation (KDOT) are the ones which were chosen for evaluation. The interstate pavements administered by the Kansas Turnpike Authority (KTA) were not evaluated.

Approximately 218 miles of PCC pavement and 262 miles of HMA pavement were evaluated in this study. Most of the HMA pavement—250 miles of it—is on I-70 from the western border of the state to I-135. The PCC pavement is comprised of 95 miles on I-70 east of I-135, sixty-eight miles on I-135 south of I-70, and nearly 55 miles on I-35 in the eastern part of the state.

The cost comparisons were made for mainline paving only, which consisted of the 24-foot wide travel lanes, shoulders, and ramps. Not included were costs for bridges, bridge approach slabs, cross roads, drainage structures, rest areas, and other ancillary work. Costs included in the analysis were for original construction, maintenance work (minor and structural overlays), rehabilitation, and reconstruction. The expenditures for these work items were determined from contract bid sheets obtained from records of the Kansas DOT Bureau of Construction. The construction contracts usually do not cross county lines and the records are kept in each county. Two or more contracts were often required for original construction because of the large size of the counties.

Typical PCC pavement sections for original construction on all three interstate routes consisted of a 9-inch thick reinforced slab over a 4-inch aggregate base course. Lime stabilized subgrades were typically used and shoulders were either aggregate or HMA.

Typical HMA sections for I-70 were built using 15-inch Full-Depth Asphalt with HMA shoulders. The last three inches of the pavement were not placed at initial construction due to budgetary constraints but were planned for a later date. This procedure was characterized as planned stage construction (PSC). The HMA pavement on I-35 was constructed using 19.5-inch Full-Depth Asphalt. None of the I-135 pavement sections used HMA for mainline paving.

Maintenance work performed on the pavement was let either as a construction contract or as a maintenance contract. The costs of all construction and maintenance contracts related to mainline paving were included in the study. However, the cost of maintenance work performed by KDOT forces was not included because the records were not readily available and the cost was generally minimal compared to other costs.

Many of the PCC pavement sections had been reconstructed or were being reconstructed at the time of the study due to joint deterioration, faulting, or spalling. Expenditures for mainline paving reconstruction included the following costs: traffic control, pavement removal, subgrade compaction, subgrade stabilization, installing drainable base and edge drains, and paving the driving lanes, shoulders, and ramps. The reconstructed sections consisted of 11 to 12-inch thick PCC slabs—the earlier ones reinforced and the later ones plain—with tied concrete shoulders.

Four original HMA sections were reconstructed. One of these was a section that had been whitetopped and was later reconstructed with full-depth PCC. The other three sections were reconstructed using Full-Depth Asphalt. Mainline paving items used for determining the cost of HMA reconstruction were selected in the same manner as those used for calculating PCC pavement reconstruction.

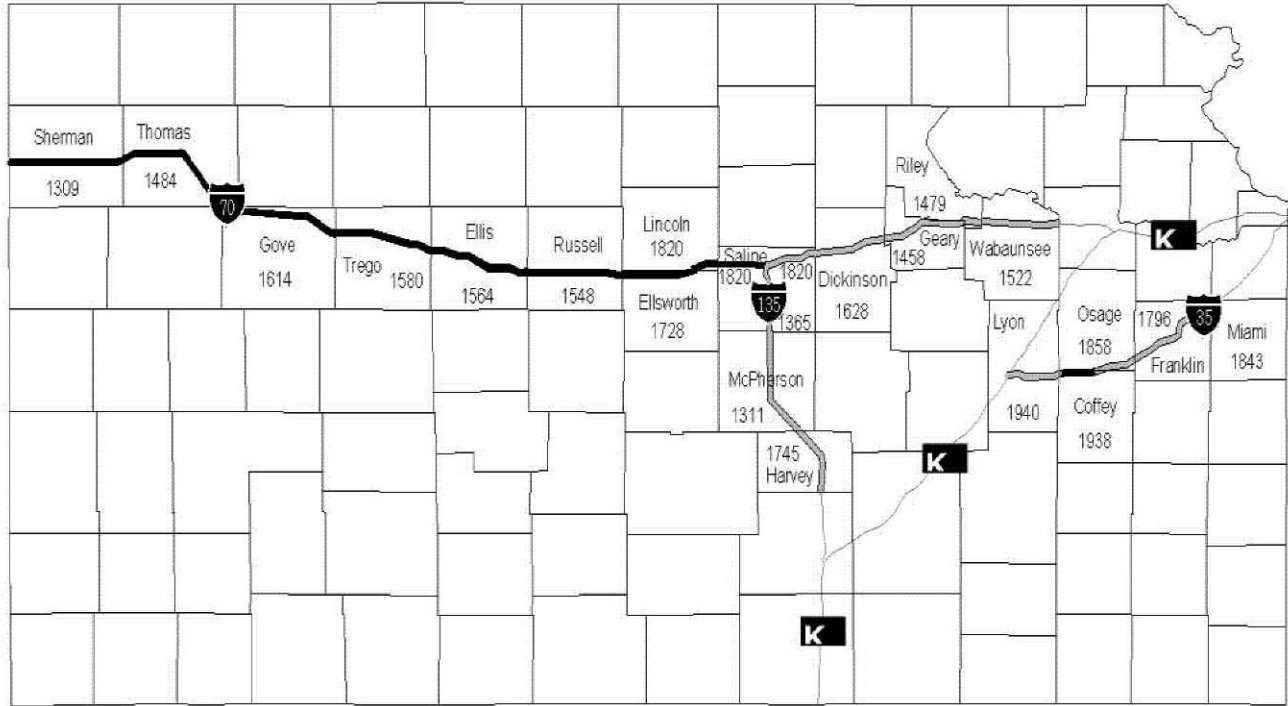


Figure 3. Location of Rural Interstate Pavements in Kansas with Average Daily Truck Traffic

Rehabilitation to correct distresses caused by thermal cracking has been performed on a majority of the HMA sections on I-70. Typically this consisted of injecting the thermal cracks with a fly ash slurry, cold milling four inches deep, cold-in-place recycling four inches deep, and placing six inches of HMA. Since the resulting thickness of the cold-in-place recycling was slightly more than the four inches scarified, the finished pavement ended up about 2.5 inches higher than the original profile. Thermal cracking had not occurred on the HMA portion of I-35 as of 2002, so that pavement was not rehabilitated. Expenditures for rehabilitation were determined using the costs of the same items as were used in reconstruction.

The total mainline expenditures, including change order costs, were used in performing this study. All sections evaluated in the study were on rural interstate pavements four lanes wide with two lanes in each direction. It was convenient therefore to summarize all expenditures for mainline paving on a cost per 4-lane mile basis for analysis. Expenditures were applied in the year the project was completed.

Since all of the pavements were not the same age, equitable comparisons could not be made using the net present value method. Therefore, the comparisons were made using inflation adjusted dollars. An annual inflation rate of 3.5% was used, and all costs were carried forward to

2001 and referred to as "2001 dollars." This inflation rate was obtained using guidance from the FHWA's *Publication No.FHWA-SA-98-079, Life-Cycle Cost Analysis in Pavement Design*. The FHWA recommends a discount rate of 3% to 5% based on rates of return on 10-year Treasury notes from 1991 to 1996. This same data indicates an inflation rate of 3% to 4% annually.

Table 2 shows the total costs per 4-lane mile in actual dollars and in 2001 dollars using a 3.5% inflation rate for I-35, I-135, and I-70. The 4-lane mile costs per county were determined by summing the total costs of the sections in each county and dividing by the length in miles.

County	Route	Pavement Type	Length (miles)	Year Opened	Costs/4-Lane Mile Actual Dollars (millions)	Costs/4-Lane Mile 2001 Dollars (millions)
Lyon-East	I-35	PCC	10.1	1977	\$3.70	\$4.66
Coffey	I-35	HMA	12.1	1973	\$0.68	\$1.39
Osage	I-35	PCC	11.3	1973	\$1.60	\$2.42
Franklin-W	I-35	PCC	14.1	1973	\$2.49	\$3.35
Saline	I-135	PCC	19.2	1965-66	\$3.02	\$3.93
McPherson	I-135	PCC	33.6	1969-72	\$1.79	\$2.62
Harvey	I-135	PCC	15.6	1971	\$1.53	\$2.20
Sherman	I-70	HMA	35.3	1969-70	\$1.46	\$2.32
Thomas	I-70	HMA	39.6	1966-69	\$1.05	\$1.76
Gove	I-70	HMA	37.5	1961-64	\$0.95	\$1.68
Trego	I-70	HMA	30.8	1960-65	\$0.86	\$1.55
Ellis	I-70	HMA	31.4	1965-66	\$1.29	\$1.98
Russell	I-70	HMA	30.0	1964-66	\$1.00	\$1.64
Ellsworth	I-70	HMA	23.2	1965	\$1.03	\$1.74
Lincoln	I-70	HMA	7.2	1964	\$0.93	\$1.71
Saline	I-70	HMA	14.7	1964	\$2.23	\$3.11
Saline	I-70	PCC	15.2	1962-65	\$1.18	\$2.22
Dickinson	I-70	PCC	24.1	1959-61	\$1.39	\$2.72
Geary	I-70	PCC	26.3	1959-65	\$2.44	\$3.58
Riley	I-70	PCC	5.9	1963	\$2.96	\$4.03
Wabaunsee	I-70	PCC	23.6	1959-63	\$2.87	\$3.79

Table 2. Total Costs per 4-Lane Mile Kansas Rural Interstate Highways

I-35

The pavement sections evaluated and compared on I-35 consist of 12.1 miles of HMA pavement in Coffey County and 35.5 miles of PCC pavement in the eastern half of Lyon County, the eastern part of Osage County, and the western half of Franklin County. The HMA pavement in Coffey County and the PCC pavement in Osage County and Franklin County were opened to traffic in 1973. The PCC pavement in Lyon County was opened to traffic in 1977. These are the only sections of pavement on I-35 where a direct comparison of costs was believed to be feasible. Two other sections, 19.2 miles of PCC pavement in the eastern half of Franklin County and in Miami County, were opened to traffic in 1959 and it was felt that the 14-year difference in ages was too great for direct comparison.

On I-35, the total costs in *actual dollars* for the HMA section (Coffey County) were \$677,000 per 4-lane mile. For the PCC sections the 4-lane mile total costs 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. When converted to *2001 dollars*, the total cost per 4-lane mile for the HMA section was \$1,393,000. For the PCC sections, the 2001-dollar costs 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.

I-135

The PCC pavement sections evaluated on I-135 consisted of 15.6 miles in Harvey County (not including the 4.5-mile section in the town of Newton), 33.6 miles in McPherson County, and 19.2 miles in Saline County. There were no HMA sections on I-135. Table 2 shows the total costs per 4-lane mile in actual dollars to be \$1.53 million, \$1.79 million, and \$3.02 million for Harvey, McPherson, and Saline Counties, respectively. The costs in 2001 dollars for the same counties are \$2.20 million, \$2.62 million, and \$3.93 million.

Of the 68.4 miles of that original PCC pavement, 40.8 miles (60%) have been reconstructed using PCC at a cost of \$2.15 million per 4-lane mile (\$2.26 million in 2001 dollars). In comparison, another 19.4 miles of the original pavement was rehabilitated using rubblization and an asphalt overlay and had an average cost of \$1.08 million per 4-lane mile (\$1.32 million in 2001 dollars). Only 8.2 miles of the original PCC pavement on these sections of I-135 have not been rehabilitated or reconstructed.

I-70

The rural Interstate sections evaluated and compared on I-70 consisted of 249.7 miles of HMA pavement and 95.1 miles of PCC pavement. The HMA sections were constructed between 1960 and 1970, and the PCC sections were constructed between 1959 and 1965. Table 2 shows the total costs per 4-lane mile in actual dollars and in 2001 dollars using a 3.5% inflation rate.

All of the HMA sections on I-70, except Sherman County and Saline County, had total life-cycle costs in 2001 dollars between \$1.55 million and \$1.98 million per 4-lane mile. The cost in Sherman County was driven up partly because the western 27.4 miles (77.6%) of the pavement were whitetopped and had a total cost in 2001 dollars of \$2.52 million per 4-lane mile. In contrast, the eastern-most 7.9 miles in Sherman County were rehabilitated using HMA and had a total cost in 2001 dollars of \$1.65 million per 4-lane mile. This resulted in an overall county cost of \$2.32 million per 4-lane mile in 2001 dollars. In Saline County, the two sections of HMA

pavement, totaling 14.7 miles, had to be reconstructed and resulted in a total cost per 4-lane mile of \$3.11 million in 2001 dollars.

The PCC pavement sections on I-70 had costs ranging from \$2.22 million in Saline County to \$4.03 million in Riley County per 4-lane mile in 2001 dollars. Figure 4 shows the total costs per 4-lane mile, adjusted for inflation to 2001 dollars, of all the HMA and PCC pavement sections on I-70 by county. These are the same total costs that are shown in Table 4, where all of the pavement sections are included.

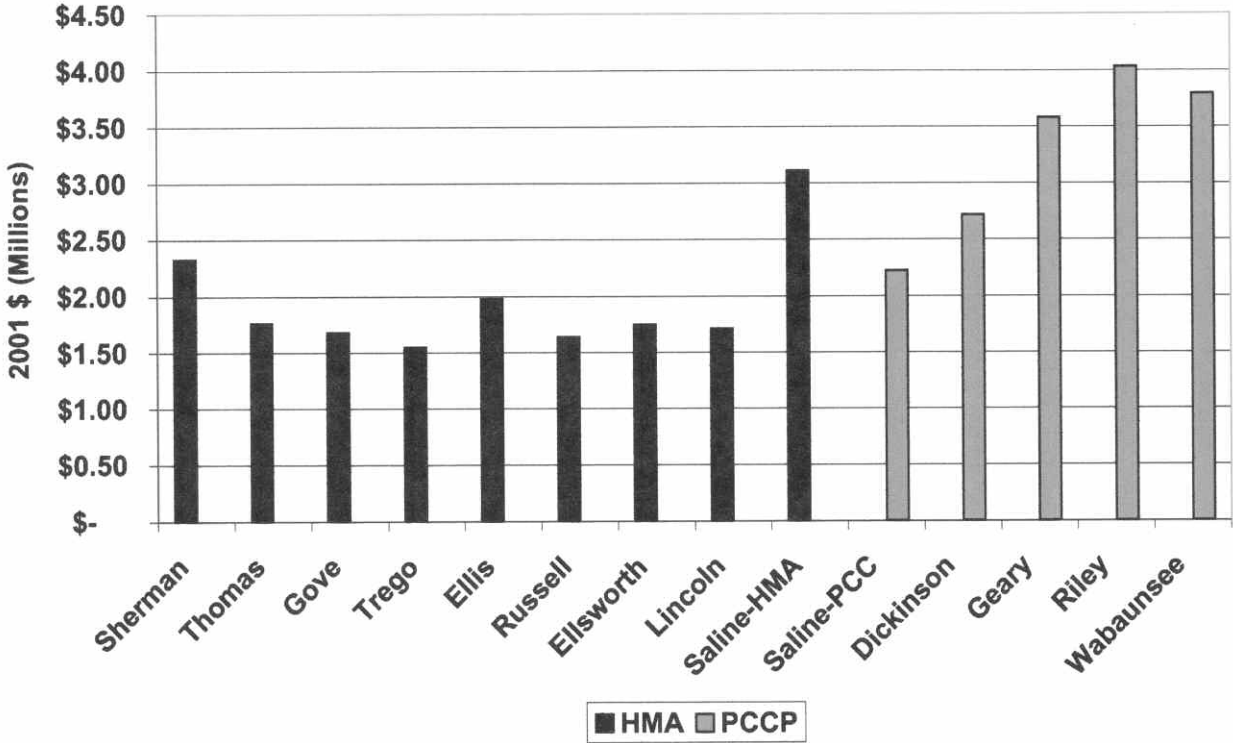


Figure 4. Total Costs per 4-Lane Mile in 2001 Dollars Interstate Route 70 in Kansas

Of the 249.7 miles of HMA pavement on I-70, 219.7 miles have been rehabilitated and 33.6 miles have been reconstructed. Most of the rehabilitated sections, 192.3 miles, were rehabilitated using HMA recycling and overlay procedures. The cost per 4-lane mile of the HMA rehabilitation was \$657,000 in 2001 dollars. The 27.4 miles of Sherman County sections 1 and 2 were rehabilitated using whitetopping at a cost per 4-lane mile of \$1,106,000 in 2001 dollars. The 33.6 miles of original HMA pavement which was reconstructed included 10.2 miles of whitetopped pavement that was reconstructed as full-depth PCC in 1999 and 2000. The remaining 23.4 miles of reconstructed HMA on I-70 consisted of a section Thomas County and both sections in Saline County. The reconstruction was performed using Full-Depth Asphalt at a cost of \$1,815,000 per 4-lane mile in 2001 dollars.

Of the 95.1 miles of PCC pavement on I-70, 52.3 miles (55%) have been reconstructed and none of the remaining pavement has been rehabilitated. The average cost per 4-lane mile of the reconstruction was \$2,103,000 in 2001 dollars, thus accounting for the higher life-cycle costs of PCC pavement shown in Table 2 and Figure 4.

All Sections

The average yearly cost per 4-lane mile for all the HMA and PCC pavement sections, by their age in years, was calculated using weighted averages of cost per mile for each of the analysis sections. There were 24 HMA pavement analysis sections totaling 261.8 miles, and 32 PCC sections totaling 218.2 miles. Figure 5 shows the average life-cycle cost at any given age of HMA and PCC rural interstate pavements in Kansas. At approximately 15 years the costs are equal, but then they diverge, with PCC becoming more expensive with time. This shows the importance of using an analysis period long enough to include at least one major rehabilitation or reconstruction for each type of pavement.

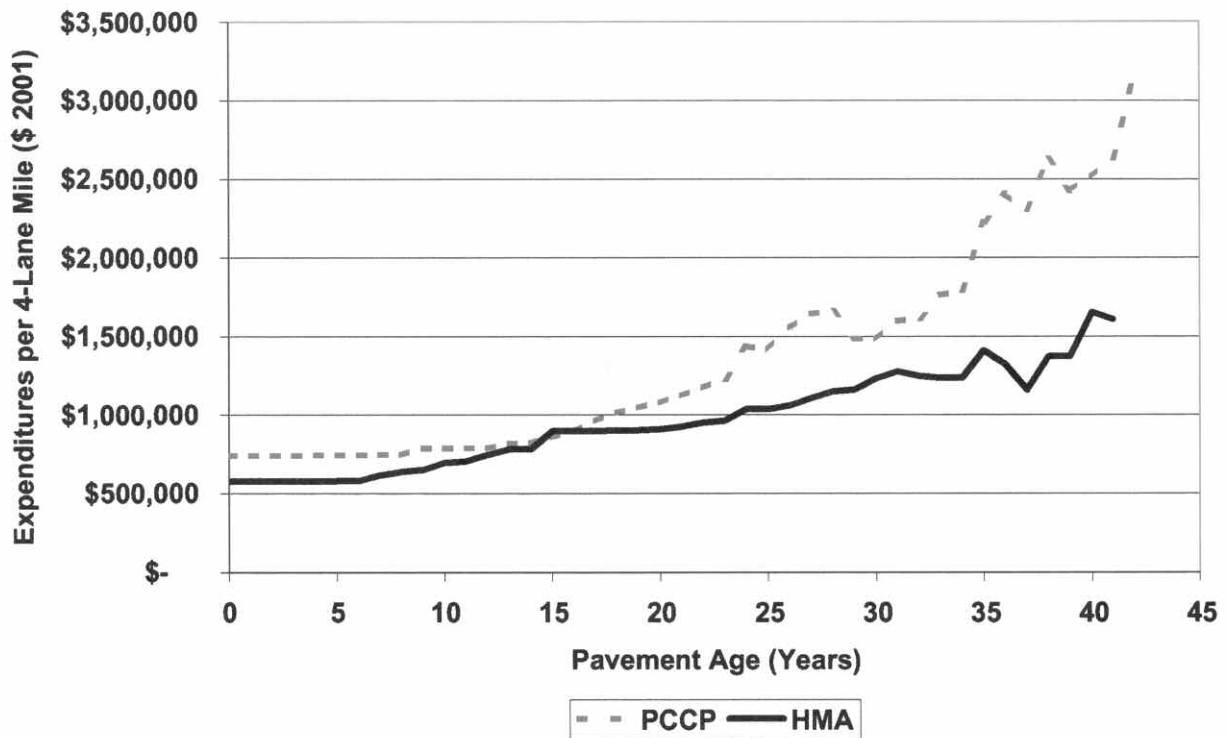


Figure 5. Average Life-Cycle Costs By Pavement Age, Adjusted for Inflation, of Rural Interstate Pavements in Kansas

The average original construction cost for PCC pavement was \$742,000 per 4-lane mile as compared to \$576,000 per 4-lane mile for HMA pavement. From the 6th to the 15th year, average annual expenditures were higher for HMA payment than for PCC pavement, due mainly to the planned stage construction overlays placed between years 7 and 13 on I-70. The average annual

expenditures during the next 27 years were \$63,000 per 4-lane mile for PCC pavement as compared to \$26,000 per 4-lane mile for HMA pavement.

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 had undergone rehabilitation or reconstruction—were 33 years for the HMA pavement sections and 34 years for the PCC sections. However, the costs were considerably different. Sixty-eight percent of the PCC pavement mileage studied was reconstructed at an average cost of \$2,037,000 per 4-lane mile, and 9% was rehabilitated at an average cost of \$1,321,000 per 4-lane mile. Nine percent of the HMA pavement mileage studied was reconstructed at an average cost of \$1,815,000, and 71% was rehabilitated using the HMA recycling and overlay procedure at an average cost of \$657,000 per 4-lane mile. The 10% of HMA pavement mileage rehabilitated using whitetopping cost an average of \$1,106,000 per 4-lane mile.

The performance of a realistic life-cycle cost analysis requires the input of data based on anticipated pavement service life. This information has not always been available. The FHWA recommends using reasonable assumptions of pavement life based on past performance and cost histories. This study determined pavement lives and cost data on rural interstate pavements in Kansas that provide recommendations for input parameters for future life-cycle cost analyses.

Kansas Study Conclusions

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

1. For the rural interstate pavements evaluated, total life-cycle costs in actual dollars and 2001 dollars were less for HMA pavements than for PCC pavements.
2. Original construction costs per 4-lane mile in 2001 dollars were less for HMA pavements than for PCC pavements: \$576,000 as compared to \$742,000.
3. From the 6th to the 15th year of the pavement's life, annual maintenance costs were slightly higher for HMA pavements, resulting in practically equal life-cycle costs at the end of that time. Annual expenditures over the next 25 years, however, were 2.4 times higher for PCC pavements than for HMA pavements: \$63,000 per 4-lane mile for PCC as 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.

Kansas Study Recommendations

Based on the results and limitations of this study, the following recommendations are warranted for pavement performance and treatment timing in life-cycle cost analysis for locations with similar materials and environment to Kansas. These recommendations are shown in Table 3.

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

*Thermal cracked HMA pavements only.

Table 3. Recommended Pavement Performance Input Parameters Used for Life-Cycle Cost Analysis in Kansas

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 3 are based on past performance and should be considered conservative values for use in life-cycle cost analysis.

Iowa Study

The Iowa research study (1) was conducted in 1998 by the Asphalt Paving Association of Iowa with the assistance of the Center for Transportation Research and Education. The objective of the study was to compare the performance of adjacent portland cement concrete (PCC) and hot mix asphalt (HMA) interstate pavement sections in Iowa using life-cycle cost analysis procedures. The decision to study pavements on the Interstate System was based on the knowledge that they are all typically designed, constructed, and maintained to similar standards, and that good original construction, maintenance, and rehabilitation records are kept.

Sections of PCC and HMA pavement on Interstate Route 80 in three counties between Des Moines and Iowa City were selected for analysis in this study. These sections, in Jasper, Poweshiek, and Iowa Counties, were selected because original construction of the PCC and HMA projects was completed during the same time period and the projects were adjacent to each other, thus assuring similar traffic loads. Care was taken not to select sections for study that would favor one pavement type over another.

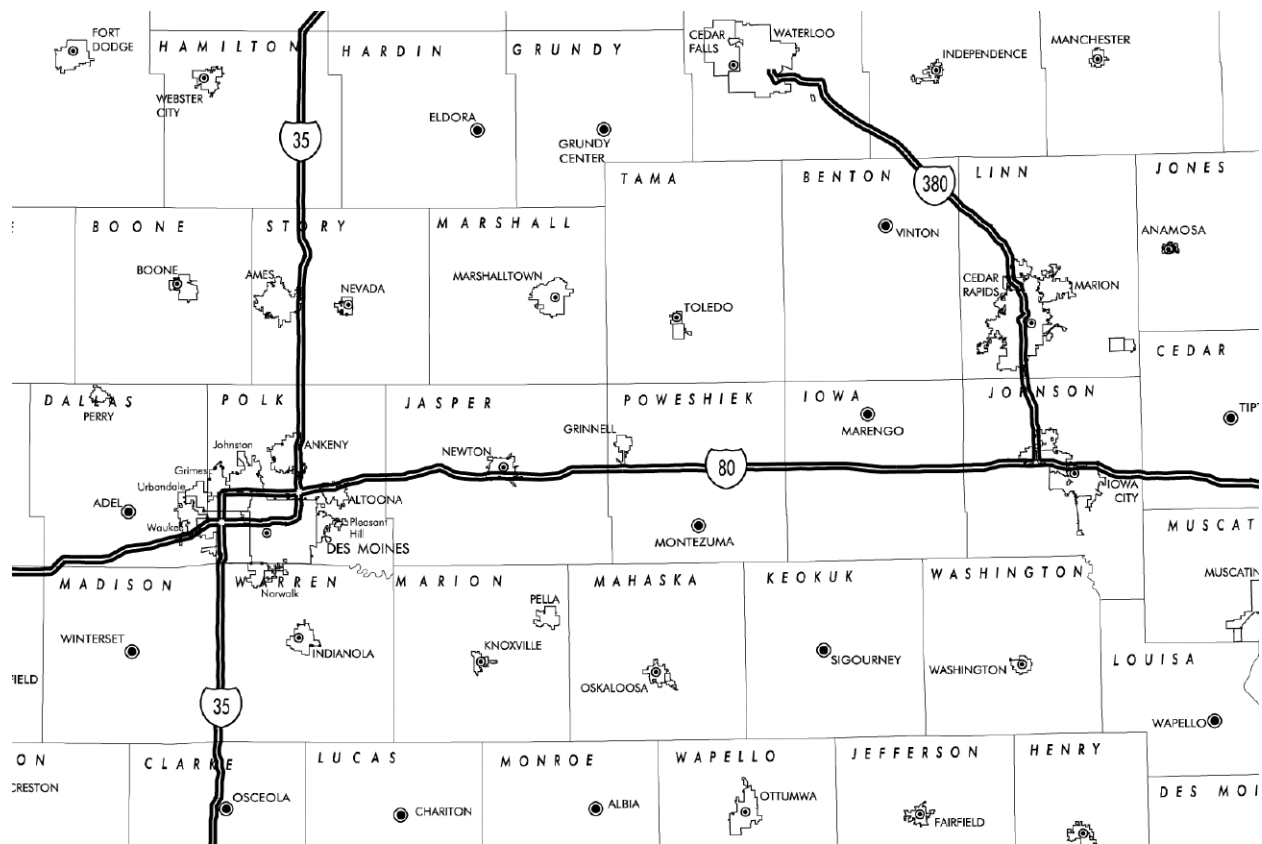


Figure 6. Map of East Central Iowa

The life-cycle cost study was conducted using the paving costs for initial construction, contract maintenance, overlays, rehabilitation, and reconstruction. The actual costs were obtained from Iowa Department of Transportation records by the Center for Transportation Research and Education, using great care to ensure accuracy. User costs and costs for routine maintenance performed by agency forces were not included, and salvage values were not considered. Costs for items not related to the pavement structure were not included in the study. All costs of the various pavement sections were discounted back to 1957, which was the earliest year that interstate sections in the original study were constructed. However, the sections built prior to 1962 were not included in the final report of the study because they were not considered representative of pavements in the state. A discount rate of four percent was used in order to be consistent with the discount rates used by the Iowa DOT. The costs are expressed in 1957 dollars per two-lane mile since all of the pavements analyzed were four-lane interstate.

The original HMA pavements were constructed using 6 inches of soil aggregate subbase, 14 inches of asphalt treated base, and 3 inches of hot mix asphalt surface course. The original plans called for 2 inches of HMA to be placed several years later as part of “stage construction.” The asphalt treated base was an asphalt-aggregate mixture of granular subbase and 10 inches of PCC reinforced with wire mesh and having doweled joints at 60-foot-plus spacing.

Traffic volumes were approximately the same in all sections of this study. The traffic at the time of the study was about 26,000 vehicles per day with 36 percent trucks. That equates to about 1.7 million equivalent single axle loads (ESALs) per year.

Table 4 summarizes the life-cycle costs determined for all the sections analyzed in this study. A discussion of these sections and their analysis follows, organized by each of the three counties.

County and Pavement Type	Section Length (miles)	Analysis Period	Life-Cycle Costs Per 2-Lane Mile (1957 Dollars)
Iowa			
HMA	3.00	1963-1996	\$157,528
PCC	4.58	1964-1996	\$272,000
Jasper			
HMA	6.43	1962-1964	\$179,136
PCC	4.64	1962-1964	\$290,151
Poweshiek			
HMA	3.14	1962-1992	\$199,473
PCC-EB	9.15	1963-1992	\$189,253
PCC-WB	9.15	1963-1992	\$186,471

Table 4. Life-Cycle Costs of HMA & PCC Pavements on I-80 in Iowa

Iowa County

The eastern-most sections of pavement studied were in Iowa County, just west of Iowa City. The PCC section, starting at milepost 221.35, extended 4.58 miles eastward. The HMA section was adjacent to the PCC section and measured 3.00 miles to its eastern terminus at milepost 228.93. The HMA project was constructed in 1963 and the PCC project in 1964. In 1968, a 2.3-inch overlay was placed on the HMA section to complete the planned stage construction.

The present worth, in 1957 dollars, of the HMA section of I-80 in Iowa County showed total cumulative costs in 1996 of \$157,528 per two-lane mile as compared to the PCC section costs of \$272,000 per two-lane mile. Figure 7 shows a graphical representation of the comparative costs over the life of the HMA and PCC pavements. But cost is not the only consideration. The Pavement Condition Rating (PCR), as shown in Figure 8, indicates that in 1996 the PCC pavement had a rating of 100 as compared to 79 for the HMA pavement. The PCC pavement, however, had been rebuilt that year, whereas the HMA overlay had been in place for four years. Just prior to the reconstruction, though, the PCR of the PCC pavement was below 30. Both pavements were performing well at the time of the rating in 1996, despite the lower score of the HMA pavement.

Interstate Route 80, Iowa County

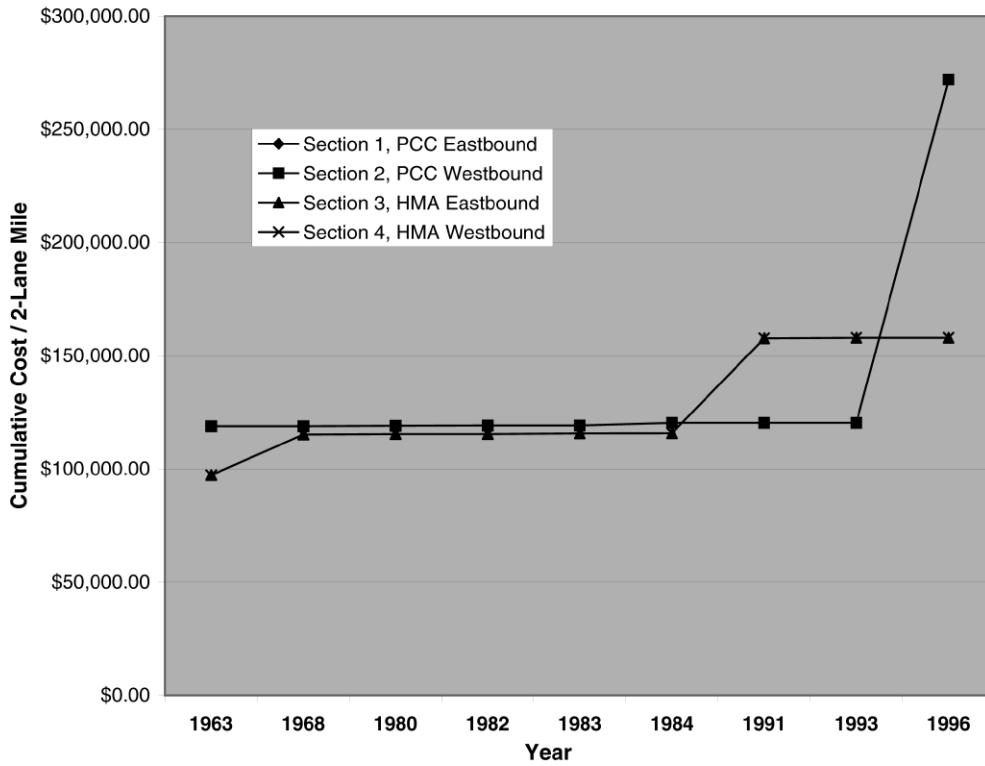


Figure 7. Total Cumulative (Life-Cycle) Costs, Iowa County, Iowa

Interstate Route 80, Iowa County

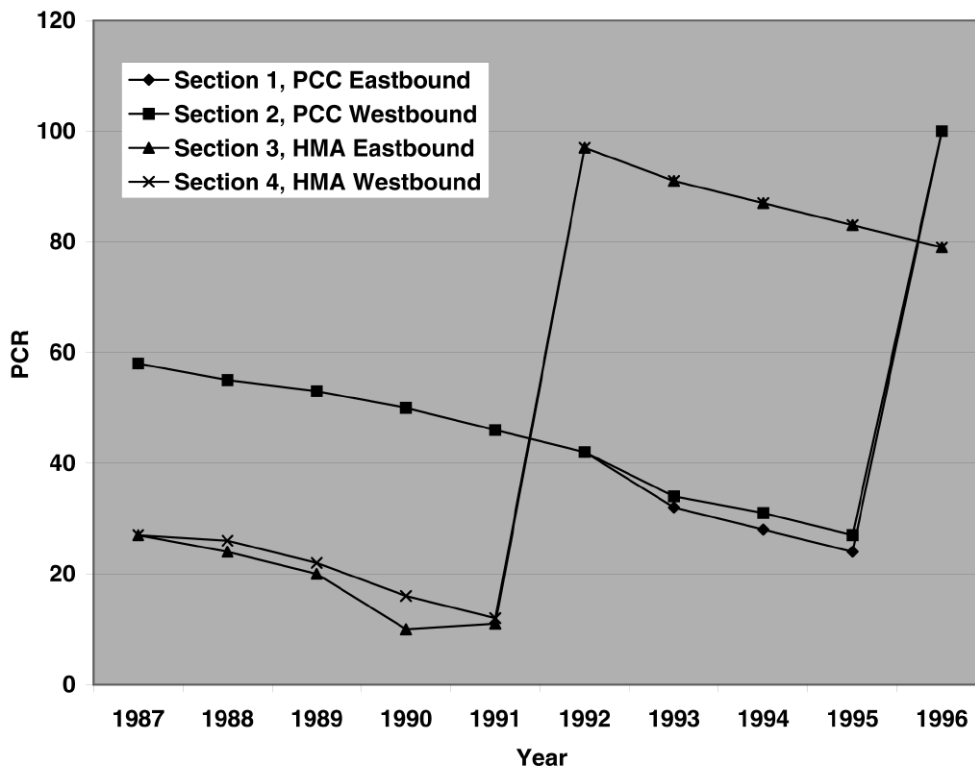


Figure 8. Pavement Condition Rating, Iowa County, Iowa

The original structure of the HMA pavement continued to provide good service with the addition of overlays, while the PCC pavement had to be completely replaced in 1996 in order to improve its condition. The difference in costs of the two pavements is attributable to the PCC reconstruction and indicates that asphalt pavement is more economical by \$114,472 per two-lane mile in 1996.

Jasper County

In Jasper County, a 4.64-mile section of PCC pavement starting about 30 miles east of Des Moines was studied and compared with an adjacent 6.43-mile section of HMA pavement. The present worth of costs in 1957 dollars per two-lane mile is \$179,136 for the HMA pavement section as compared to \$290,151 for the PCC section, as of 1994. That was the year in which the PCC pavement was reconstructed with 12 inches of plain concrete over the existing slab, which was broken up, had steel removed, was crushed, and re-laid as a thick aggregate base. The cumulative costs of the two pavements had been relatively close since the HMA pavement received its 2.3-inch stage construction overlay in 1968. When the HMA pavement was overlaid in 1984, its cumulative cost became about \$50,000 more than that of the PCC pavement. The reconstruction in 1994 brought the cumulative cost of the PCC pavement up to \$290,151.

The pavement condition rating of the PCC pavement rose to about 100 after it was reconstructed in 1994, compared with a PCR of about 50 for the HMA pavement in 1995. At that point the PCC pavement was performing better than the HMA pavement, which had thermal cracks at the time but no discernable rutting. Since the design life of the previous HMA overlay was 15 years, an overlay in 1999 would have raised the PCR to near 100 and increased the cumulative cost of the HMA section to \$210,961 per 2-lane mile in 1957 dollars. This compares at that point with a cost of more than the \$290,151 per 2-lane mile for the PCC pavement and a PCR probably still slightly less than 100. At that point, with the condition of both pavements about the same, the HMA pavement section would have been more economical than the PCC section by approximately \$79,190 per 2-lane mile.

Poweshiek County

The I-80 pavement sections in Poweshiek County, which lies between the other two counties, has 3.14 miles of HMA pavement adjacent to 9.15 miles of PCC pavement. Historically, PCC pavement has been less expensive to construct in this area, and the choice of these two sections was made in order to see the effect of that economic condition.

The initial construction cost of the PCC pavement, built in 1963, was some \$15,000 less expensive per 2-lane mile than the HMA pavement, which was built in 1962. The HMA section was overlaid in 1968 with 2.3 inches of HMA, and in 1984 it was milled to a depth of 2.2 inches and overlaid with 3.3 inches of HMA. As of 1992, the total cumulative life-cycle cost of the HMA section was \$199,473 per two-lane mile in 1957 dollars.

The westbound lanes of the PCC section were whitetopped with 4 inches of PCC in 1984 and the eastbound PCC lanes were reconstructed in 1985 using ten inches of plain concrete with doweled joints. As of 1992, the total cumulative life-cycle cost of the whitetopped westbound lanes was \$186,471 per 2-lane mile and that of the reconstructed eastbound lanes was \$189,253 per 2-lane mile, both expressed in 1957 dollars.

The pavement condition of both PCC and HMA shows a gradual decline from 1987 to 1996. The westbound PCC lanes, which had been whitetopped, had a PCR of 76 in 1987, whereas the reconstructed eastbound lanes were rated at 96, for an average of 86. By 1996 the average PCR of the PCC section was 58, but the whitetopped section was showing signs of failure, with a considerable number of areas having to be patched due to severe cracking. The HMA section had an average PCR of 89 in 1987 and decreased to an average of 47 by 1996.

The PCC showed a slightly lesser life-cycle cost as of 1992 and a slightly higher pavement condition rating as of 1996. However, if the analysis period is extended to the next overlay of the HMA section and to the reconstruction of the whitetopped section, both of which should occur near the same time, the cumulative life-cycle costs of the PCC pavement would certainly exceed those of the HMA pavement and the PCR of the two pavements would be close to equal.

Iowa Study Conclusions

The results of the study conducted on the PCC and HMA sections of I-80 indicate that: (1) the HMA sections provided more than 22 years of service without the need for reconstruction or rehabilitation; and (2) the HMA sections had a lesser rate of increase in cost for maintenance than the adjoining PCC pavements.

In the cases studied, two of the HMA sections – in Iowa and Jasper Counties – were significantly more economical in cumulative life-cycle costs than the adjacent PCC sections, and they performed as well or better than the PCC pavement. In Poweshiek County, the PCC pavement was slightly more economical in life-cycle costs and the pavement performed slightly better during the time of the study. However, a longer analysis period to include the next overlay of the HMA pavement and the reconstruction of the PCC pavement would probably change the results in Poweshiek County to favor HMA pavement.

SUMMARY AND CONCLUSIONS

By comparing the HMA and PCC sections of pavement in the three life-cycle cost studies presented here, a consistent and definitive result is obtained. The HMA pavement was overall more economical than PCC pavement in both initial construction cost and life-cycle cost.

In Ohio, all five areas of Interstate pavement studied showed HMA pavement to be more economical than PCC pavement. All of the compared pavements showed lower initial construction costs for HMA pavement than for PCC pavement by 10 to 25 percent. The net present value (NPV), or present worth (PW), of the pavement sections, calculated over analysis periods ranging from 20 to 39 years, showed that the HMA pavement in each area was more economical than its corresponding PCC pavement using both 2.5% and 5.0% discount rates. The NPV of HMA pavement was generally 25 percent to 70 percent more economical than PCC pavement.

The Kansas study of 21 pavement sections on three Interstate routes, I-70, I-35, and I-135, showed that HMA was substantially more economical than PCC over the life of these pavements. Direct comparisons between HMA and PCC pavements were made only on I-70 and I-35, since the three I-135 pavement sections were all PCC. While no direct comparisons were made between HMA and PCC initial construction costs, the average initial construction cost of nine HMA pavements on I-70 was approximately 25% lower than the average of the five PCC pavements on the same route. Even though the initial construction cost of the one HMA section on I-35 was about 10% higher than the average initial construction cost of the three PCC sections, the HMA pavement cost less over its life than the PCC pavement average. Life-cycle costs were evaluated from total expenditures carried forward to the year 2001 using an inflation rate of 3.5%, and referred to as "2001 dollars per 4-lane mile" of pavement. On I-35, the total expenditures per 4-lane mile in 2001 dollars for the three PCC sections varied from \$2.42 million to \$4.66 million, while the HMA section had a total cost of \$1.39 million. On I-70, the total expenditures per 4-lane mile in 2001 dollars for the five PCC sections ranged from \$2.22 million to \$4.03 million and averaged \$3.27 million, as compared to the nine HMA sections, which ranged from \$1.55 million to \$3.11 million and averaged \$1.94 million.

The Iowa study evaluated an area in each of three counties along I-80, each with one HMA and one PCC section. Two of the HMA sections were substantially more economical in life-cycle costs than the corresponding PCC section, and in the other county the PCC section was slightly more economical than the HMA section. The life-cycle costs were calculated from total costs over the analysis period and discounted at a rate of 4% back to 1957. The costs are expressed as "1957 dollars per 2-lane mile" of pavement. In Iowa County, the HMA pavement section was more economical than the PCC section by 42% as of 1996. In Jasper County, the HMA section cost 62% less than the PCC section as of 1994, the year the PCC section was reconstructed. In Poweshiek County, the life-cycle cost of the HMA section was 6% more than that of the PCC section as of 1992.

From the information and results shown in these three studies based on actual costs of constructing, maintaining, rehabilitating, and reconstructing interstate pavements in three states, it can be seen that hot mix asphalt pavement provides more cost-effective pavement with comparable performance when compared to portland cement concrete pavement.

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