

Case Study Comparisons of the Life-Cycle Costs of HMAC and PCC Pavements on Lower Volume Roads

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ABSTRACT

The costs of pavement construction, maintenance and rehabilitation are primary factors considered by most local agencies in the selection of pavement type (i.e., asphalt concrete [AC] or portland cement concrete [PCC]) for new construction. The optimal use of agency funds for any given project can only be determined through an economic analysis of all associated agency costs and the performance of the pavement. Life-cycle cost analyses were performed on AC and PCC highway pavements in Olmsted and Waseca counties of Minnesota. The Means Heavy Construction Historical Cost Index and Minnesota Department of Transportation (Mn/DOT) Surfacing Indices were used to convert all expenditures over time into equivalent “constant dollar” values.

Direct comparisons were made on roadway sections with similar traffic volumes, ages and environmental conditions. For Olmsted county, the favored pavement type depended somewhat on the cost indices that were used in the analysis; however, index selection had no effect on the outcome for the Waseca county comparisons. When the results were normalized for traffic volumes (i.e., cost per lane-mile per million vehicles carried), PCC pavements were clearly more cost-effective in all cases for Olmsted county and for all but one case for Waseca county, regardless of the cost indices that were used. A graph of average cumulative maintenance costs over time indicates that PCC pavements generally incurred significantly lower maintenance and rehabilitation costs than AC roadways in both Waseca and Olmsted counties.

INTRODUCTION

Problem Statement

The costs of pavement construction, maintenance and rehabilitation are primary factors considered by most local governmental agencies in the selection of pavement type (i.e., asphalt concrete [AC] or portland cement concrete [PCC]) for new construction. Initial cost of construction is clearly an important and sometimes overriding consideration in pavement type selection. However, the optimal use of agency funds for any given project can only be determined through an economic analysis of all associated agency costs and the performance of the pavement.

Unfortunately, the costs of pavement maintenance and rehabilitation are often difficult to determine due to the use of local agency work crews rather than outside contracts. Furthermore, the performance of local agency pavements is not routinely monitored in an objective manner. Thus, it has historically been difficult to obtain valid comparisons of the complete costs and performances associated with AC and PCC pavements constructed to serve similar traffic flows in comparable environments. This has resulted in the selection of pavement types for local roads based on initial costs alone or on anecdotal evidence and other subjective criteria.

There is a need to perform case studies of pavements constructed by local road agencies to provide objective assessments of the true agency costs of constructing, maintaining and rehabilitating typical AC and PCC local highway pavements. Only by documenting the actual costs of constructing and maintaining different types of pavement structures over their performance lives can highway agency engineers make well-informed decisions concerning pavement type selection.

Research Objective

The objective of this research study was to perform and document comparisons of the agency costs associated with AC and PCC pavements constructed and maintained by local highway and road agencies (i.e., township, city and county highway departments) in Minnesota.

Research Benefits

The case studies performed under this study provide objective assessments of the true agency costs of constructing, maintaining and rehabilitating typical AC and PCC local highway pavements in Minnesota. This information will be of great use to highway agency engineers in making well-informed pavement type selection decisions in a manner that improves the use of agency funds and increases the service life and overall performance of the highway pavement network.

DATA ACQUISITION AND REDUCTION

Study Project Selection Criteria

The following project selection criteria were established to ensure that subsequent comparisons of project performance and economics would be valid.

- The initial cost of construction and a complete history of maintenance and rehabilitation activities must be available for all selected study projects.
- Selected pairs of study projects must have been constructed at approximately the same time (within a year or two) with the intent of serving comparable volumes and types of traffic.
- Selected pairs of study projects must have been constructed in similar climates over similar roadbed soils.
- Projects selected for comparison should have been in service for at least 10 years.

Selection and Description of Study Projects

The Olmsted and Waseca County (Minnesota) Highway Departments were selected as the first and second sources of data, respectively, for this study because of their reputation for maintaining detailed records of pavement costs and pavement maintenance/rehabilitation activities, their use of both AC and PCC pavements, and their expressed willingness to participate in this project.

The project team met with the Olmsted and Waseca County Highway Department staffs during the falls of 1998 and 1999, respectively. During these meetings, County State Aid Highways (CSAHs) meeting the selection criteria described above were identified. Tables 1 and 2 list the roadways identified for consideration in Olmsted and Waseca counties, respectively.

These CSAHs were subdivided into project study sections with relatively uniform properties with respect to the following parameters:

- Pavement Type
- Time Since Construction
- Geometry
- Structural Characteristics
- Present Condition
- Traffic Characteristics

The creation of these project study sections (also called “uniform sections”) was done to facilitate comparisons of project cost and performance data.

Tables 1 and 2 list the uniform pavement sections that were identified and selected by the project team, and provide details concerning the section length, actual or projected life, surface type, major rehabilitation activities and traffic volumes for each section. Twenty-eight uniform sections from Olmsted county and thirty-five uniform sections from Waseca county were considered in the final project analyses.

Initial Construction Costs

Initial construction cost data were found on contract vouchers. State Aid Project (SAP) numbers were used to differentiate between different construction projects. The vouchers also included project locations and boundaries, descriptions of the work performed (e.g., grading, base or surface construction), comments, and itemized lists of expenses (i.e., descriptions, unit prices, quantities and total costs for each pay item). Care was taken to ensure that the quantities and total costs collected were “certified to date” and were not the bid quantities and costs. It was also important to identify and collect cost and quantity data from the final contract voucher.

For the purposes of this project, initial construction costs included only the costs associated with construction above the finished grade (i.e., costs associated with base and surfacing construction, and maintenance costs required during the life of the pavement to improve pavement serviceable/ride quality).

This was done to allow direct comparisons of the costs associated with different projects without considering construction costs that are related more to site conditions than pavement type (e.g., varying amounts of cut and fill, debris removal, etc.). Table 3 presents representative lists of items that were specifically included in and excluded from the cost analyses in this study. Complete listings of the included and excluded costs are provided in the project final reports (1,2).

Overall construction costs were assigned to uniform sections proportionately by section length and numbers of lanes. Details concerning the estimation of construction costs and the distribution of those costs over the uniform sections are provided in the project final reports (1,2).

Overlay Costs

Asphalt concrete overlay projects were generally contracted out and were assigned SAP numbers. The costs associated with these activities were easily tracked and distributed over each section in the manner described for initial pavement construction costs. Table 3 presents a description of the costs associated with bituminous overlays that were included in the cost analysis.

Maintenance Costs

Table 3 also presents a listing of the types of maintenance costs collected from each county. Details describing these activities, along with the costs per lane mile, are provided in the project final reports (1,2).

Olmsted County

Olmsted county pavement maintenance records are kept in maintenance log books. These records go back to 1947 and consist primarily of maps that highlight or label the locations of maintenance activities, but present little cost or quantity information. Actual maintenance labor and equipment costs (along with some material costs) for 1991 – 1998 were found in accounting ledgers. These costs were used as the basis for estimating maintenance costs for the study.

Waseca County

Waseca county pavement maintenance records are kept in the “Waseca County Annual Reports.” These reports go back to the 1960s and consist primarily of maps that highlight or label the location of current and future maintenance activities. In addition, these reports include a table containing total costs for routine

maintenance, repairs and replacements, betterments and special work for each roadway, but present no quantity information. Actual maintenance labor and equipment costs (along with some material costs) for 1991 – 1999 were found in accounting ledgers. These costs were used as the basis for estimating maintenance costs for the study.

Determination of Maintenance Material Costs

When maintenance cost records included only labor costs, estimates of the cost of maintenance materials were based on the assumption that the cost of materials for a specific maintenance activity could be estimated as percentage of the cost of labor for that activity. Ratios of material costs to labor costs were computed for activities for which the material and labor costs were known. The Olmsted county staff provided estimates of the average material and labor costs for items such as hand patching, blade patching, filling/sealing cracks, and seal coating. Waseca county records were not sufficient to allow the county staff to provide estimates of the maintenance material costs, so these costs could not be included in the life-cycle cost analyses for Waseca county, resulting in the use of lower estimated maintenance costs for that county.

Distribution of Maintenance Costs over Uniform Sections

Whenever possible, maintenance costs were assigned to uniform sections in the manner described previously for initial construction costs (i.e., proportionate with section length). However, maintenance activity locations were generally given broadly, and the exact locations of maintenance activities were often unknown. Olmsted and Waseca county personnel assisted in determining the locations of the maintenance activities; the costs of maintenance activities prior to 1991 and after 1998/99 were assumed to be evenly distributed over entire maintenance sections.

Backcasting/Forecasting Maintenance Costs

It was necessary to forecast maintenance costs through the end of the projected life of each pavement section. In some cases, it was also necessary to “backcast” maintenance costs during periods for which no records exist. Backcasting and forecasting of maintenance costs was performed using a graph that plotted average cumulative maintenance costs per lane mile (1998 dollars) versus the number of years since construction or last major rehabilitation activity (i.e., overlay). Figure 1 illustrates the graph generated for this

purpose for both Olmsted and Waseca county AC and PCC pavements. This graph was developed using the 1991-1999 maintenance data described previously. The development and use of this graphs is described in the project final reports (1,2). This figure shows that the average cumulative maintenance costs for Waseca county's AC and PCC pavements significantly exceeds those incurred for similar pavement types in Olmsted county. Waseca county AC maintenance costs tend to increase at an earlier time and a faster rate than do those of Olmsted county. This significant difference can be attributed to the different maintenance practices performed by each county. Waseca county typically seal coats their AC pavements 1 or 2 years after construction and builds a minimal number of overlays, if any, on the roadways prior to complete reconstruction, thereby requiring more maintenance to keep the road functional. In addition, Waseca county repairs and "crackfills" their concrete roads more often than does Olmsted county, which is reflected in the difference in their PCC maintenance costs.

Cost Indices

A key component of most economic analyses is the conversion of expenditures incurred at different times into equivalent "constant dollar" values. The assumed "time value of money" can significantly affect the results of the analysis. For example, many economists use "discount rates" that adjust cash flows based on the difference between treasury bill interest rates and the rate of inflation. Numerous consumer and industrial cost indices are also available and can be used in cost analyses.

It was determined that the Means Heavy Construction Historical Cost Index was an appropriate index for use in this study. Indices were published for 1949 to 1998 (and for 1999 when the Waseca study was performed), and were estimated through 2028 using averages of index values for previous years (e.g., the 1988 – 1998 average was used for projections between 1998 and 2003, the 1983 – 1998 average was used for projections between 2003 and 2008, etc.). Details concerning the use of the Means Index are presented in the project final reports (1,2).

Additional indices were obtained from the Minnesota Department of Transportation (Mn/DOT) cost estimating unit. These construction indices were divided into categories for three types of construction: excavation, structures and surfacing. The Surfacing Index category was further subdivided into Bituminous

Surfacing and Concrete Surfacing Indices, which were available for the period 1967 to 1998 (and for 1999 when the Waseca county study was performed). Indices for years prior to 1967 were estimated using index value average trends for subsequent years (e.g., the 1962 – 1966 indices were based on the average of the first 10 years available [1968 – 1979], the 1957 – 1961 indices were based on the average of the first 15 years available [1968 to 1983], etc.).

Large differences were sometimes observed between the Means Heavy Construction Indices and the Mn/DOT surfacing indices, so each project was analyzed using two techniques. In the first, the Means Index was used to adjust all cost items (i.e., maintenance, base construction, surfacing, overlays, etc.). In the second, the Means Index was used to adjust only maintenance and base construction costs and the Mn/DOT Surfacing indices were used to adjust surfacing costs. Results obtained using both of these analyses are summarized in the project final reports (1,2) and in this paper.

Traditional economic analyses often make use of a discount rate, which is defined as the difference between the investment (or interest) rate and the inflation rate. A typical value for the discount rate, based on 30-year averages of treasury bill returns and inflation, is approximately 3.5 percent. This compares favorably with the average rates of increase of the Means and Mn/DOT surfacing indices used in this study (3.93 percent for the Olmsted county sections and 3.30 percent for the Waseca county sections), and suggests that the results of the analyses performed in this study would probably not change significantly when using more traditional analysis techniques.

Traffic Data

Two-way average daily traffic (ADT) volume maps were available for Olmsted and Waseca county highways for 3-6 year intervals from 1936 – 1994 and 1969 – 1995, respectively. In addition, unpublished data were obtained from Mn/DOT for Olmsted county 1998 and Waseca county 1999 traffic counts. These data were used to estimate the ADT for each uniform section, as described in the project final reports (1,2).

Graphs of 1-way ADT versus time were constructed for each uniform section. These graphs were used to project future traffic levels and to estimate accumulated traffic since construction or major

rehabilitation. Accumulated traffic estimates were used to normalize pavement costs for traffic volume, as described later in this paper.

Pavement Performance

Pavement quality indices (PQI), a form of performance rating, were found for 1994, 1995 and 1997 for Olmsted county. These ratings were derived from a condition survey performed by Olmsted county technicians and/or engineers. A summary of these ratings is presented in the project final report (1). Performance ratings could not be found for any Waseca county study sections.

Plots of PQI versus pavement age can be used to project pavement performance and to plan rehabilitation activities. They can also be used to normalize cost data with respect to pavement performance (e.g., to compute costs per unit of performance-time). However, the PQI is a subjective rating that is not highly precise, and only three data points were available to establish a performance trend for Olmsted county uniform sections, so these data were not considered sufficient for performance projection or cost normalization. Waseca county has not collected performance data for any of their roadways, so performance trends could not be constructed for Waseca county uniform sections.

Mn/DOT inspected the Olmsted county projects using a PaveTech van in 1997. A copy of the results of this survey is included as an appendix to the final report (1). In addition, the project team visually assessed the current condition of each pavement section and estimated pavement ride quality during visits to the Olmsted county project sites in June 1999. The results of the project team assessments are presented in the project final report (1).

DATA ANALYSES

Techniques

There are many different techniques for analyzing and comparing cost data. These include net present cost/worth, equivalent uniform annual cost/worth, rate of return, benefit/cost ratio and others. When used properly, all of these techniques will consistently rank alternate construction or rehabilitation options in the same order (or will always identify the same option as being the most cost-effective). Some of these types of analyses are easily misused and can lead to incorrect conclusions. It can also be argued that public agencies

incur only costs and do not derive an easily quantifiable benefit, which leaves a benefit/cost ratio analysis open to interpretation (or manipulation). These considerations are discussed at length in any number of papers and books and are not discussed further here (or in the final reports (1,2)).

For the purposes and scope of this study, the project team determined that the most appropriate analyses were the net present cost (NPC) and equivalent uniform annual cost (EUAC) approaches.

Net Present Cost (NPC)

The NPC approach converts all costs incurred over the project life into equivalent values of today's currency (1998, for this study) and then sums these "converted" or adjusted costs to produce a single cost for the option.

The Means Heavy Construction Cost Indices and Mn/DOT Surfacing Indices were used to convert costs into equivalent values of 1998 currency through the following expression:

$$\text{Year A Value of Cost Incurred in Year B} = (\text{Index for Year A} / \text{Index for Year B}) \times \text{Cost in Year B}$$

The following example illustrates the conversion of the cost of bituminous surfacing in 1967 to present (1998) costs using Means and Mn/DOT Indices.

□ Uniform Section:	"R/R Tracks to CR119S, CSAH 9"
□ Bituminous Surfacing Cost (1967 Dollars):	\$5,466.82/Lane Mile
□ Means Heavy Construction Indices:	115.1 (1998) 23.5 (1967)
□ Mn/DOT Bituminous Surfacing Indices:	124.06 (1998) 31.2 (1967)

Means Index:

$$1967 \text{ Bituminous Surfacing Cost in 1998 Dollars} = (\$5,466.82) \times (115.1/23.5) = \underline{\$26,775.79/\text{lane mile}}$$

Mn/DOT Bituminous Surfacing Index:

$$1967 \text{ Bituminous Surfacing in 1998 Dollars} = (\$5,466.82) \times (124.06/31.2) = \underline{\$21,737.62/\text{lane mile}}$$

Equivalent Uniform Annual Cost (EUAC)

The EUAC approach is often used in economic analyses when comparisons are being made between alternatives with different lives. The EUAC is the cost which, if incurred annually over the life of the project, yields the same present worth of costs as the actual expenses at the times they are incurred. Therefore, if the project is continued for more than one cycle, the equivalent annual cost for the next cycle and all succeeding cycles would be exactly the same as for the first, assuming all cash flows were the same for each period (3).

The capital recovery factor is used to determine the EUAC of each cost item given that the NPC of the item is already known. The capital recovery factor is expressed as follows:

$$\text{Capital Recovery Factor (A/P, i, n)} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where:

A/P = ratio of the EUAC to the NPC

i = percent annual increase in Means Heavy Construction Cost Indices or Mn/DOT Surface Indices

n = analysis period, years.

The percent increase in Means Heavy Construction Indices or Mn/DOT Surface Indices (i) can be estimated as the average percent increase over the years representing the life of the pavement. Therefore, the EUAC of the bituminous surfacing in the previous example would be calculated as follows:

□ Uniform Section: “R/R Tracks to CR119S, CSAH 9”

□ Life: 1967-2006

Mean’s Index EUAC:

□ Avg. Increase in Means Heavy Construction Indices (1967-2006):	4.6%
□ Net Present Cost (1998 Dollars, Means Index):	\$26,775.79/lane mile

$$\text{Capital Recovery Factor} = \frac{0.046(1 + 0.046)^{39}}{(1 + 0.046)^{39} - 1} = 0.05563$$

$$\text{Bituminous Surface EUAC} = \$26,775.79 \times 0.05563 = \underline{\$1,489.54/\text{lane mile/year}}$$

Mn/DOT Index EUAC:

- Avg. Increase in Mn/DOT Bituminous Surface Indices (1967-2006): 4.45%
- Net Present Cost (1998 Dollars, Mn/DOT Index): \$21,737.62/lane mile

$$\text{Capital Recovery Factor} = \frac{0.0445(1 + 0.0445)^{39}}{(1 + 0.0445)^{39} - 1} = 0.05447$$

$$\text{Bituminous Surface EUAC} = \$21,737.62 \times 0.05447 = \underline{\$1,184.05/\text{lane mile/year}}$$

Salvage Year

In addition to cost data and an analysis technique, economic analyses also require the selection of an analysis period, which is often selected to coincide with the performance life of the option being studied. For the purposes of this study, the Olmsted and Waseca county engineering staff provided estimates of the year during which each study section would require major rehabilitation or reconstruction. This year (called the “salvage year”) was used to determine the expected life of each pavement section (in years) and was used as the end point for cost analyses. The interest rate (*i*) was estimated as the average percent increase over the years representing the life of the pavement. It was further assumed that each pavement section would have no residual value (either positive or negative) at the salvage year.

Results

Tables 4 and 5 summarize the results of the economic analyses for the Olmsted and Waseca county uniform sections included in this study. The tables are divided into two major case headings – one which uses only Means Heavy Construction Indices, and one which uses Mn/DOT Surfacing Indices, as discussed previously. Under each index case heading, costs are presented in terms of EUAC per lane mile and EUAC per lane mile per million vehicles (i.e., normalized for traffic volume). Cost data associated with concrete pavement sections are shaded in gray.

The most accurate comparisons of AC and PCC pavement cost data are generally obtained when construction year, cumulative traffic and environmental conditions are comparable. While environmental conditions throughout Olmsted and Waseca county are reasonably constant, it was difficult to identify sets of AC and PCC pavements sections with comparable construction dates and cumulative traffic volumes for the purposes of direct comparisons. For example, several Olmsted county AC and PCC pavement sections were constructed in the mid-1970s, but the traffic volumes carried by these sections varied widely.

Olmsted County

Three direct comparisons were made using the following uniform sections:

Case 1. PCC (section 11) vs. AC (section 2)

Case 2. PCC (section 9) vs. AC (sections 13 and 14)

Case 3. PCC (section 10) vs. AC (section 1)

Case 1

Table 4 shows that, when using the Mn/DOT Surfacing Indices, the PCC sections (11 and 12) built in 1983 have an average EUAC of approximately \$6500 per lane mile per year, while the AC section (2) built in 1984 has an EUAC of approximately \$6900 per lane mile per year. The traffic volume for the PCC sections ranged from 11.2 to 11.7 million vehicles and was 11.5 million vehicles for the AC section. When traffic is factored in, the PCC sections have an average EUAC of \$574 per lane mile per year per million vehicles, while the AC section has an EUAC of \$597 per lane mile per year per million vehicles. In these cases, the PCC generally appears to be slightly more cost effective. Similar conclusions can be drawn using the Means cost index analyses.

Case 2

A similar comparison can be made using the PCC section (9) constructed in 1987 and AC sections (13 and 14) constructed in 1984 with traffic volumes ranging from 5.2 to 1.8 million vehicles, respectively. Using the Mn/DOT Surfacing Indices, the PCC section has an EUAC of approximately \$6300 per lane mile per year, while the AC sections have an average EUAC of \$5800 per lane mile per year. Using the Means Indices, the

PCC section has an EUAC of approximately \$6000 per lane mile per year, while the AC sections have an average EUAC of \$6600 per lane mile per year.

When traffic is factored in, the PCC section is consistently more cost-effective (i.e., an EUAC of \$1200 per lane mile per year per million vehicles, while the AC sections have an average EUAC of \$3600 per lane mile per year per million vehicles, using the Mn/DOT Surfacing Indices).

Case 3

Using the Mn/DOT cost index analyses, it can be seen that the PCC section (10) built in 1983 has an EUAC of approximately \$6600 per lane mile per year. The AC section (1) built in 1984 has an EUAC of approximately \$6700 per lane mile per year. The traffic volumes for the PCC and AC sections were 9.1 and 7.9 million vehicles, respectively. When traffic is factored in, the PCC section has an EUAC of \$720 per lane mile per year per million vehicles, while the AC section has an EUAC of \$852 per lane mile per year per million vehicles, suggesting that the PCC appears to be slightly more cost-effective. Similar conclusions can be drawn using the Means cost index analyses.

Waseca County

Three direct comparisons were made using the following uniform sections:

Case 1. PCC (sections 5 and 6) vs. AC (section 7)

Case 2. PCC (sections 3 and 4) vs. AC (sections 1 and 18)

Case 3. PCC (section 34) vs. AC (sections 25 and 26)

Case 1

Table 5 shows that, when using the Mn/DOT Surfacing Indices, the PCC sections (5 and 6) built in 1975 have an average EUAC of \$7405 per lane mile per year, while the AC section (7) built in 1974 has an EUAC of \$8684 per lane mile per year. The traffic volume for the PCC sections ranged from 3.3 to 3.6 million vehicles and was 3.2 million vehicles for the AC section. When traffic is factored in, the PCC sections have an average EUAC of \$2179 per lane mile per year per million vehicles, while the AC section has an

EUAC of \$2766 per lane mile per year per million vehicles. In these cases, the PCC appears to be more cost effective. Similar conclusions can be drawn using the Means Cost Index analyses.

Case 2

Using the Mn/DOT Cost Index analyses, it can be seen that the PCC sections (3 and 4) built in 1976 have an average EUAC of \$6679 per lane mile per year. The AC sections (1 and 18) built in 1977 have an average EUAC of \$4681 per lane mile per year. The traffic volume for the PCC sections was 2.8 million vehicles; traffic ranged from 1.3 to 3.0 million vehicles for the AC sections. When traffic is factored in, the PCC sections have an average EUAC of \$2399 per lane mile per year per million vehicles, while the AC sections have an average EUAC of \$2248 per lane mile per year per million vehicles. In these cases, the AC appears to be slightly more cost-effective. Similar results are obtained when using the Means Cost Index analyses.

Case 3

Using the Mn/DOT Cost Index analyses, it can be seen that the PCC section (34) built in 1980 has an EUAC of \$5415 per lane mile per year. The AC sections (25 and 26) built in 1980-82 have an average EUAC of \$6616 per lane mile per year. The traffic volume for the PCC section was 3.8 million vehicles; traffic volumes ranged from 2.6 to 2.7 million vehicles for the AC sections. When traffic is factored in, the PCC section has an EUAC of \$1429 per lane mile per year per million vehicles, while the AC sections have an average EUAC of \$2506 per lane mile per year per million vehicles. In these cases, the PCC appears to be much more cost-effective. Similar results are obtained when using the Means Cost Index analyses and factoring in traffic volumes.

General Cost Comparisons by Pavement Type

It is possible to make very broad-based comparisons of the costs generally associated with the construction of AC and PCC pavements in each county. For the 28 pavement sections in Olmsted County considered in this study and using the Mn/DOT Surfacing Indices, the 14 PCC pavements had an average EUAC of \$8412 per lane mile per year (\$776 per lane mile per year per million vehicles) while the 14 AC pavements had an average EUAC of \$7903 per lane mile per year (\$1858 per lane mile per year per million

vehicles). For the 35 pavement sections considered for the Waseca county study and using the Mn/DOT Surfacing Indices, the 14 PCC pavements had an average EUAC of \$6982 per lane mile per year (\$1528 per lane mile per year per million vehicles) while the 21 AC pavements had an average EUAC of \$6410 per lane mile per year (\$3815 per lane mile per year per million vehicles).

While such gross analyses provide interesting information, it must be recognized that they may well be comparisons of “apples and oranges” and that factors other than pavement surface type (e.g., traffic, pavement age, foundation support, etc.) are uncontrolled and are likely to bias the results of the analysis. The most valid analyses will result from comparisons of pavement sections that are selected to control as many factors as possible, as was done in the case studies described previously.

CONCLUSIONS

The following conclusions are based on the analyses documented in this report for the 28 and 35 uniform sections selected from Olmsted and Waseca counties in Minnesota, respectively.

- Several useful analysis techniques and tools were developed during the course of this study, including:
 - development of a graph of cumulative maintenance cost versus time for AC and PCC pavements in Olmsted and Waseca counties in Minnesota;
 - innovative yet rational techniques for estimating missing maintenance cost information, as well as for backcasting and forecasting maintenance costs; and
 - innovative techniques for performing economic analyses on public works projects through the use of industry-specific cost indices instead of economy-wide inflation and discount rates that may be biased by factors that do not directly influence heavy construction costs.

These techniques and tools will facilitate additional work done in this area. In addition, they may be useful in the development of Olmsted and Waseca county maintenance budgets and documenting resource needs.

- Of the 28 uniform sections considered for Olmsted county, 8 were used in 3 direct comparisons of pavements with comparable age and traffic; similarly 13 of the 35 uniform section considered for Waseca county were used in 3 direct comparisons.

- For Olmsted county, the favored pavement type depended somewhat on the cost indices that were used in the analysis; the index selection generally had no effect on the outcome for the Waseca county comparisons.
- When the results were normalized for traffic volumes (i.e., cost per lane-mile per million vehicles carried), PCC pavements were clearly more cost-effective in all cases for Olmsted county and for all but one case for Waseca county, regardless of the cost indices that were used.
- Insufficient data were available to normalize the results for ESALs or other measures of heavy traffic effects. However, it is believed that such normalization would further favor PCC pavements because the sections that were subjected to higher proportions of heavy commercial traffic in Olmsted and Waseca county had been constructed using PCC.
- Insufficient data were available to normalize the results for performance or ride quality.
- Maintenance costs for AC are significantly greater than those for PCC over the pavement life in both Olmsted and Waseca counties.

RECOMMENDATIONS

- Additional maintenance cost data should be collected to supplement data currently used to develop the graph of “average cumulative maintenance costs versus years since last rehabilitation.”
- Additional cost, traffic and performance data should be collected from other city, township and county highways to facilitate further direct comparisons between PCC and AC pavement sections.
- Highway agencies should be encouraged to routinely collect and store accurate information concerning pavement construction, maintenance and rehabilitation costs, traffic volume and composition, and pavement performance. Furthermore, the practice of discarding old cost, traffic and performance information should be abandoned because the analysis of this information represents our best chance for improving the effectiveness of our decision-making processes.

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REFERENCES

1. Embacher, R. A., and M. B. Snyder. *A Comparison of Life-Cycle Costs of Asphalt Concrete and Portland Cement Concrete Pavements in Olmsted County, Minnesota*. Final Report to Concrete Paving Association of Minnesota. University of Minnesota Department of Civil Engineering. Minneapolis, Minnesota. January 2000.
2. Embacher, R. A., and M. B. Snyder. *A Comparison of Life-Cycle Costs of Asphalt Concrete and Portland Cement Concrete Pavements in Waseca County, Minnesota*. Final Report to Concrete Paving Association of Minnesota. University of Minnesota Department of Civil Engineering. Minneapolis, Minnesota. September 2000.
3. Blank, L. T., and A. J. Tarquin. *Third Edition: Engineering Economy*. McGraw Hill, Incorporated. 1989.

TABLE 1 Study Project Uniform Section Descriptions (Olmsted County)

Section No./Uniform Section	Section Length (km)	Actual or Projected Life*	Surface Type	Major Rehabilitation	1-Way Traffic Volume (Million Vehicles)
CSAH 4					
1. CSAH 5 to CSAH 3S	3.4	1984-2011	AC	'98 OL	7.86
2. CSAH 3S to CSAH 3N	2.8	1984-2011	AC	'98 OL	11.53
3. CSAH 3N to 60 Ave. NW	1.2	1977-2009	PCC		11.59
4. 60 Ave. NW to 50 Ave. NW	2.2	1977-2009	PCC		14.46
5. 50 Ave. NW to CSAH 22	1.2	1977-2009	PCC		16.5
6. CSAH 22 to R/R Tracks	1.0	1977-2009	PCC		24.55
7. CR151 to 19 th St. NW	1.0	1972-2009	AC	'89	36
8. 19 th St. NW to 21 st Ave.	0.8	1972-2009	AC	'89	25.78
CSAH 5					
9. CSAH 3 to CSAH 16	12.9	1987-2012	PCC		5.22
10. CSAH 16 to CSAH 4	3.2	1983-2012	PCC		9.11
11. CSAH 4 to 23 St. NW	1.2	1983-2012	PCC		11.17
12. 23 St. NW to 13 St. NW	1.6	1983-2012	PCC		11.7
13. US14 to Frontier Road	0.8	1984-1999	AC		2.28
14. Frontier Road to CSAH 25	5.5	1984-1999	AC		1.24
CSAH 9					
15. 19 th Ave. SE to CSAH 22	1.6	1969-2009	AC	'88 OL	50.59
16. CSAH 22 to R/R Tracks	2.2	1969-2006	AC	'88 OL	19.31
17. R/R Tracks to CR119S	3.5	1967-2006	AC	'74 OL, '88 OL	13.96
18. CR119S to TH42	8.1	1974-2001	PCC		7.63
19. TH42 to CSAH 7S	1.6	1979-1993	AC		1.86
20. TH42 to CSAH 7S	1.6	1994-2024	PCC		8.78
21. CSAH 7S to CSAH 10	7.2	1994-2024	PCC		5.5
22. 0.5 Mi. E. CSAH 7S to CSAH 7N	2.4	1974-1993	AC		2.62
23. CSAH 7N to CR132	0.9	1974-1993	AC		2.22
24. CR132 to CSAH 10	3.2	1979-1993	AC		1.7
25. CSAH 10 to County Line	4.8	1979-1996	AC		1.7
26. CSAH 10 to County Line	4.8	1998-2028	PCC		6.24
CSAH 22					
27. US63 to CSAH 2	2.6	1989-2019	PCC		79.8
28. CSAH 2 to CSAH 9	3.1	1989-2019	PCC		79.83

*Pavement section life projections are estimates provided by the Olmsted County Highway Department.

TABLE 2 Study Project Uniform Section Descriptions (Waseca County)

Section No./Uniform Section	Section Length (km)	Actual or Projected Life*	Surface Type	Major Rehabilitation	1-Way Traffic Volume (Million Vehicles)
CSAH 1					
1. S. County Line - TH30	7.9	1977-2002	AC		1.3
CSAH 2					
2. W. County Line - CSAH 3	4.8	1983-1999	AC		2.53
3. CSAH 3 - CSAH 33	3.2	1976-2001	PCC		2.75
4. CSAH 33 - CSAH 17	3.6	1976-2001	PCC		2.82
5. CSAH 17 - 85th St.	2.0	1975-2001	PCC		3.26
6. 85th St. - CSAH 27	4.0	1975-2001	PCC		3.55
CSAH 3					
7. S. County Line - TH30	4.8	1974-2003	AC		3.14
8. N. Limits Waldorf - CSAH 4	1.2	1983-2002	AC		3.19
9. CSAH 4 - CSAH 9	8.1	1991-2026	PCC		13.47
10. CSAH 9 - CSAH 2	6.9	1985-2020	PCC		9.54
11. CSAH 2 - S. Limits Janesville	3.2	1983-2018	PCC		16.43
12. 412 Ave. - CSAH 5	6.0	1987-2022	PCC		13.88
CSAH 4					
13. CSAH 3 - CSAH 11	5.6	1981-2002	AC		1.76
14. CSAH 11 - CSAH 12	1.6	1981-2002	AC		1.75
15. CSAH 12 - CSAH 29	3.5	1981-2002	AC		1.92
16. CSAH 29 - 0.5 Mi. NE	0.8	1983-2002	AC		1.58
17. 0.5 Mi. NE CSAH 29 - CSAH 23	6.2	1983-2002	AC		1.68
18. East County Line	2.9	1977-2010	AC	'95 OL	2.96
CSAH 5					
19. CSAH 19 - CSAH 17	0.4	1992-2028	PCC		7.91
20. CSAH 17 - S. JCT. CSAH 35	4.2	1992-2028	PCC		8.31
CSAH 35					
21. N. JCT. CSAH 5 - 403 Ave.	7.0	1997-2012	AC		0.84
22. 403 Ave. - S. JCT. CSAH 5	2.0	1997-2012	AC		0.82
CSAH 8					
23. CSAH 12 - TH13	1.0	1992-2007	AC		0.52
CSAH 9					
24. W. County Line - CSAH 3	5.6	1990-2005	AC		1.5
25. CSAH 3 - 70 St.	5.6	1982-2010	AC	'95 OL	2.62
26. 70 St. - 75 St.	0.8	1981-2010	AC	'95 OL	2.66
27. 75 St. - CSAH 29	0.8	1970-2010	AC	'81 OL, '95 OL	3.35
28. CSAH 29 - CR75	0.6	1970-2010	AC	'95 OL	3.54
29. CR75 - CSAH 26	4.8	1970-2010	AC	'95 OL	3.34
CSAH 17					
30. US14 - 0.25 Mi. S. CSAH 5	2.2	1995- 2030	PCC		2.49
CSAH 19					
31. CSAH 3 - OLD CSAH 17	5.2	1992-2027	PCC		2.59
CSAH 20					
32. CR 56N - CR 56S	0.8	1971-2007	AC	'92 OL	2.29
33. CR 56S - E. County Line	4.7	1971-2007	AC	'92 OL	1.39
CR 57					
34. CSAH 27 - CR57N	1.6	1980-2015	PCC		3.79
35. CR57N - CSAH 4	1.6	1980-2015	PCC		7.6

*Pavement section life projections are estimates provided by the Waseca County Highway Department.

TABLE 3 Cost Items Included in and Excluded from Cost Analysis

Items Included in Cost Analysis
<ul style="list-style-type: none"> ▪ AC Surfacing (bituminous material for prime/tack coat and mixture, wearing and leveling course mixture, deductions for paving changes/errors, striping)
<ul style="list-style-type: none"> ▪ Base Construction (crushed rock base, aggregate base class 2 and/or 5, road-mixed bituminous surface [aggregate, bituminous material for prime/tack coat and mixture])
<ul style="list-style-type: none"> ▪ Bituminous Overlay (pavement profiling, bituminous material for prime/tack coat and mixture, wearing and leveling course mixture, base course, adjustment of gage valve, adjustment of frame and ring castings, temporary lane marking, seal coat, sawing bituminous pavement, remove bituminous pavement, mill bituminous surface, bituminous material for fog seal, traffic control, ride/density incentive, deductions for paving changes/errors, striping, cold recycle-inplace bituminous mixture)
<ul style="list-style-type: none"> ▪ Maintenance costs (hand patching, blade patching, repair/crackfill, pavement markings, seal coating, mudjacking, repairing frost boils, repairing mud pockets)
<ul style="list-style-type: none"> ▪ PCC Surfacing (concrete pavement standard width, expansion joint, dowel bars/dowel bar assemblies, concrete curing compound, ride/smoothness/water-cement ratio incentive, deductions for paving changes/errors, water-reducing agent, traffic control, extra cement-high early, permanent terminal header, striping)
Select Items Excluded from Cost Analysis
<ul style="list-style-type: none"> ▪ Common Laborers (Perform undocumented miscellaneous tasks)
<ul style="list-style-type: none"> ▪ Drainage Systems
<ul style="list-style-type: none"> ▪ Dust Treatments (Influenced by variability of moisture during construction)
<ul style="list-style-type: none"> ▪ Easements
<ul style="list-style-type: none"> ▪ Engineering (Costs influenced by complexity of project)
<ul style="list-style-type: none"> ▪ Motor Grader/Scraper/Dozer (Used for shaping ditches and grading/excavation work)
<ul style="list-style-type: none"> ▪ Material Testing (Dependent on site/project)
<ul style="list-style-type: none"> ▪ Shouldering Items (Shouldering type is not dependent on pavement type)
<ul style="list-style-type: none"> ▪ Subgrade Preparation Items (Costs related to site condition)
<ul style="list-style-type: none"> ▪ Approaches/Entrances (Influenced by number of intersecting roadways with the uniform section)

TABLE 4 Effects of Pavement Type on Life Cycle Costs (Olmsted County)

Uniform Section	Section No.	Life	Surface Type	1-Way Traffic Volume (Million Vehicles)	Using Means Heavy Construction Cost Indices for ALL Items			Using Mn/DOT HWY Construction Cost Indices and Means Heavy Construction Cost Indices for Maintenance Items		
					EUAC/Lane Mile (based on NPC @ t = 1998)	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle	EUAC/Lane Mile (based on NPC @ t = 1998)	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle
CSAH 4										
CSAH 5 to CSAH 3S	1	1984-2011	AC	7.86	\$7,605	\$968	\$6,697	\$852		
CSAH 3S to CSAH 3N	2	1984-2011	AC	11.53	\$7,866	\$682	\$6,886	\$597		
CSAH 3N to 60 Ave. NW	3	1977-2009	PCC	11.59	\$7,504	\$647	\$7,843	\$677		
60 Ave. NW to 50 Ave. NW	4	1977-2009	PCC	14.46	\$7,563	\$523	\$7,903	\$547		
50 Ave. NW to CSAH 22	5	1977-2009	PCC	16.5	\$7,519	\$456	\$7,859	\$476		
CSAH 22 to R/R Tracks	6	1977-2009	PCC	24.55	\$7,680	\$313	\$8,020	\$327		
CR151 to 19 th St. NW	7	1972-2009	AC	36	\$12,127	\$337	\$11,380	\$316		
19 th St. NW to 21 st Ave.	8	1972-2009	AC	25.78	\$12,044	\$467	\$11,297	\$438		
CSAH 5										
CSAH 3 to CSAH 16	9	1987-2012	PCC	5.22	\$6,064	\$1,162	\$6,257	\$1,199		
CSAH 16 to CSAH 4	10	1983-2012	PCC	9.11	\$6,402	\$703	\$6,562	\$720		
CSAH 4 to 23 St. NW	11	1983-2012	PCC	11.17	\$6,402	\$573	\$6,563	\$588		
23 St. NW to 13 St. NW	12	1983-2012	PCC	11.7	\$6,389	\$546	\$6,580	\$560		
US14 to Frontier Road	13	1984-1999	AC	2.28	\$6,579	\$2,885	\$5,839	\$2,561		
Frontier Road to CSAH 25	14	1984-1999	AC	1.24	\$6,562	\$5,292	\$5,823	\$4,696		

TABLE 4 Effects of Pavement Type on Life Cycle Costs (Olmsted County) (Continued)

Uniform Section	Section No.	Life	Surface Type	1-Way Traffic Volume (Million Vehicles)	Using Means Heavy Construction Cost Indices for ALL Items			Using Mn/DOT HWY Construction Cost Indices and Means Heavy Construction Cost Indices for Maintenance Items		
					EUAC/Lane Mile (based on NPC @ t = 1998)	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle	EUAC/Lane Mile (based on NPC @ t = 1998)	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle	
CSAH 9										
19 th Ave. SE to CSAH 22	15	1969-2009	AC	50.59	\$12,736	\$252	\$12,803	\$253		
CSAH 22 to R/R Tracks	16	1969-2006	AC	19.31	\$10,540	\$546	\$10,617	\$550		
R/R Tracks to CR119S	17	1967-2006	AC	13.96	\$11,455	\$821	\$10,524	\$754		
CR119S to TH42	18	1974-2001	PCC	7.63	\$8,761	\$1,148	\$7,181	\$941		
TH42 to CSAH 7S	19	1979-1993	AC	1.86	\$8,029	\$4,317	\$7,080	\$3,806		
TH42 to CSAH 7S	20	1994-2024	PCC	8.78	\$8,413	\$958	\$9,729	\$1,108		
CSAH 7S to CSAH 10	21	1994-2024	PCC	5.5	\$8,381	\$1,524	\$9,696	\$1,763		
0.5 Mi. E. CSAH 7S to CSAH 7N	22	1974-1993	AC	2.62	\$4,550	\$1,736	\$3,470	\$1,325		
CSAH 7N to CR132	23	1974-1993	AC	2.22	\$7,430	\$3,347	\$6,211	\$2,798		
CR132 to CSAH 10	24	1979-1993	AC	1.7	\$7,413	\$4,361	\$6,423	\$3,778		
CSAH 10 to County Line	25	1979-1996	AC	1.7	\$6,493	\$3,819	\$5,588	\$3,287		
CSAH 10 to County Line	26	1998-2028	PCC	6.24	\$10,479	\$1,679	\$10,426	\$1,671		
CSAH 22										
0.5 Mi. SE US62 to CSAH 2	27	1989-2019	PCC	79.8	\$9,561	\$120	\$11,064	\$139		
CSAH 2 to CSAH 9	28	1989-2019	PCC	79.83	\$10,605	\$133	\$12,109	\$152		

TABLE 5 Effects of Pavement Type on Life Cycle Costs (Waseca County)

Uniform Section	Section No.	Life	Surface Type	1-Way Traffic Volume (Million Vehicles)	Using Means Heavy Construction Cost Indices for ALL Items			Using Mn/DOT HWY Construction Cost Indices and Means Heavy Construction Cost Indices for Maintenance Items		
					EUAC/Lane Mile (based on NPC @ t = 1998)	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle	EUAC/Lane Mile (based on NPC @ t = 1998)	EUAC/Lane Mile (based on NPC @ t = 1998)	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle	
CSAH 1										
S. County Line - TH30	1	1977-2002	AC	1.3	\$2,898.92	\$2,229.94	\$3,088.85	\$2,376.04		
CSAH 2										
W. County Line - CSAH 3	2	1983-1999	AC	2.53	\$6,260.32	\$2,474.43	\$5,875.14	\$2,322.19		
CSAH 3 - CSAH 33	3	1976-2001	PCC	2.75	\$6,893.45	\$2,506.71	\$6,744.20	\$2,452.44		
CSAH 33 - CSAH 17	4	1976-2001	PCC	2.82	\$6,768.51	\$2,400.18	\$6,613.23	\$2,345.12		
CSAH 17 - 85th St.	5	1975-2001	PCC	3.26	\$7,158.74	\$2,195.93	\$7,404.86	\$2,271.43		
85th St. - CSAH 27	6	1975-2001	PCC	3.55	\$7,158.74	\$2,016.55	\$7,404.86	\$2,085.88		
CSAH 3										
S. County Line - TH30	7	1974-2003	AC	3.14	\$8,711.47	\$2,774.35	\$8,683.95	\$2,765.59		
N. Limits Waldorf - CSAH 4	8	1983-2002	AC	3.19	\$9,369.83	\$2,937.25	\$7,868.43	\$2,466.59		
CSAH 4 - CSAH 9	9	1991-2026	PCC	13.47	\$6,133.87	\$455.37	\$6,845.05	\$508.17		
CSAH 9 - CSAH 2	10	1985-2020	PCC	9.54	\$6,222.96	\$652.30	\$7,612.25	\$797.93		
CSAH 2 - S. Limits Janesville	11	1983-2018	PCC	16.43	\$6,827.51	\$415.55	\$7,644.77	\$465.29		
412 Ave. - CSAH 5	12	1987-2022	PCC	13.88	\$5,418.65	\$390.39	\$6,048.53	\$435.77		
CSAH 4										
CSAH 3 - CSAH 11	13	1981-2002	AC	1.76	\$6,718.90	\$3,817.56	\$6,200.21	\$3,522.85		
CSAH 11 - CSAH 12	14	1981-2002	AC	1.75	\$4,194.24	\$2,396.71	\$4,038.82	\$2,307.90		
CSAH 12 - CSAH 29	15	1981-2002	AC	1.92	\$5,028.75	\$2,619.14	\$4,617.21	\$2,404.80		
CSAH 29 - 0.5 Mi. NE	16	1983-2002	AC	1.58	\$6,645.42	\$4,205.96	\$6,498.05	\$4,112.69		
0.5 Mi. NE CSAH 29 - CSAH 23	17	1983-2002	AC	1.68	\$6,421.44	\$3,822.29	\$6,359.44	\$3,785.38		
East County Line	18	1977-2010	AC	2.96	\$5,804.45	\$1,960.96	\$6,272.79	\$2,119.19		
CSAH 5										
CSAH 19 - CSAH 17	19	1992-2028	PCC	7.91	\$5,781.31	\$730.89	\$7,671.07	\$969.79		
CSAH 17 - S. JCT. CSAH 35	20	1992-2028	PCC	8.31	\$5,781.31	\$695.70	\$7,671.07	\$923.11		

TABLE 5 Effects of Pavement Type on Life Cycle Costs (Waseca County) (Continued)

Uniform Section	Section No.	Life	Surface Type	1-Way Traffic Volume (Million Vehicles)	Using Means Heavy Construction Cost Indices for ALL Items			Using Mn/DOT HWY Construction Cost Indices and Means Heavy Construction Cost Indices for Maintenance Items		
					EUAC/Lane Mile (based on NPC @ t = 1998)	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle	EUAC/Lane Mile (based on NPC @ t = 1998)	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle	EUAC/Lane Mile (based on NPC @ t = 1998)	EUAC/Lane Mile (based on NPC @ t = 1998) / Million Vehicle
CSAH 35										
N. JCT. CSAH 5 - 403 Ave.	21	1997-2012	AC	0.84	\$5,988.00	\$7,128.57	\$6,932.89	\$8,253.44		
403 Ave. - S. JCT. CSAH 5	22	1997-2012	AC	0.82	\$6,164.33	\$7,517.48	\$7,246.05	\$8,836.65		
CSAH 8										
CSAH 12 - TH13	23	1992-2007	AC	0.52	\$5,092.56	\$9,793.39	\$5,912.04	\$11,369.30		
CSAH 9										
W. County Line - CSAH 3	24	1990-2005	AC	1.5	\$6,716.49	\$4,477.66	\$7,018.75	\$4,679.16		
CSAH 3 - 70 St.	25	1982-2010	AC	2.62	\$6,898.46	\$2,633.00	\$6,632.92	\$2,531.65		
70 St. - 75 St.	26	1981-2010	AC	2.66	\$7,389.21	\$2,777.90	\$6,598.19	\$2,480.52		
75 St. - CSAH 29	27	1970-2010	AC	3.35	\$9,061.54	\$2,704.94	\$8,470.10	\$2,528.39		
CSAH 29 - CR75	28	1970-2010	AC	3.54	\$7,354.37	\$2,077.51	\$7,111.88	\$2,009.01		
CR75 - CSAH 26	29	1970-2010	AC	3.34	\$6,917.99	\$2,071.26	\$6,669.18	\$1,996.76		
CSAH 17										
US14 - 0.25 Mi. S. CSAH 5	30	1995-2030	PCC	2.49	\$6,084.41	\$2,443.54	\$7,261.75	\$2,916.37		
CSAH 19										
CSAH 3 - OLD CSAH 17	31	1992-2027	PCC	2.59	\$6,020.99	\$2,324.71	\$7,968.06	\$3,076.47		
CSAH 20										
CR 56N - CR 56S	32	1971-2007	AC	2.29	\$6,527.24	\$2,850.33	\$6,259.91	\$2,733.58		
CR 56S - E. County Line	33	1971-2007	AC	1.39	\$6,530.05	\$4,697.88	\$6,262.82	\$4,505.62		
CR 57										
CSAH 27 - CR57N	34	1980-2015	PCC	3.79	\$6,153.80	\$1,623.69	\$5,414.54	\$1,428.64		
CR57N - CSAH 4	35	1980-2015	PCC	7.6	\$6,179.65	\$813.11	\$5,441.14	\$715.94		

FIGURE 1 Effect of Time on Olmsted and Waseca County Cumulative Maintenance Costs

