Long-term Benefits of Microsurfacing Applications in Indiana – Methodology and Case Study

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ABSTRACT
Microsurfacing is a relatively new technology. As such, there is great interest in assessing its efficacy as a preventive maintenance treatment. This paper investigates the long-term benefits of microsurfacing applications at various highway sections in Indiana. The measures of effectiveness (MOE) used are treatment life, increase in average condition, and area bounded by the treatment performance curve. Each MOE was expressed separately in terms of three performance indicators – surface roughness (IRI), Pavement Condition Rating (PCR), and Rutting (RUT). The results show that for each MOE and performance indicator, the treatment effectiveness is influenced by climate, traffic loading, and highway class. The results also show that the effectiveness of microsurfacing is most perceptible when rutting is used as the performance indicator. When treatment service life is used as the MOE, microsurfacing effectiveness ranges from 2–10 years (on the basis of the IRI performance indicator); at least 15 years (on the basis of rutting); and 4–15 years (on the basis of PCR). When the increase in pavement condition is used as the MOE, the treatment is seen to offer 7–27% and 90–96% reductions in surface roughness and rutting, respectively, and a 2–7% increase in PCR. Finally, when the area enclosed by the microsurfacing performance curve is used as the MOE, it is seen that this treatment offers benefits of 30–258 IRI-years, 15–67 RUT-years, and 18–56 PCR-years (IRI in inches per mile, RUT in inches, and PCR in units on a 0-100 scale). The case study results generally demonstrate that microsurfacing is a promising treatment in addressing rutting and in extending pavement life in general.
INTRODUCTION
Microsurfacing treatments involve the laying of a mixture of crushed mineral aggregate, polymer-modified asphalt emulsion, mineral filler, water, and an additive to control hardening of the mixture. A self-propelled pug mill mixes the components and lays the mix immediately after mixing – no compaction of the microsurfacing layer is required (1). A microsurfacing layer may be as thin as 3/8 inch (9.5 mm) and is capable of filling wheel ruts up to 1.5 inches (38 mm) or 2 inches (50 mm) deep. Unlike localized treatments such as crack sealing and bump grinding, microsurfacing belongs to a certain category of pavement treatments which includes seal coating and thin HMA overlays. These treatments cover the entire width of the carriageway with an aggregate-bituminous mix. Like all other pavement treatments, microsurfacing is categorized in different ways by different agencies, depending on the purpose of the application, the hierarchy of the supervising jurisdiction, the expenditure involved, and other factors. For the purposes of the present study, microsurfacing is described as a preventive maintenance activity, a categorization that is consistent with most nationwide studies (2).

Microsurfacing treatments have typically been applied with the objective of correcting surface ruts and improving surface friction and skid resistance. The treatment has been found to perform well for 5–7 years after application given favorable conditions (3). After nine years of experimental use in the State of Oklahoma, it was concluded that microsurfacing significantly corrects and retards pavement rutting, improves friction, and fills alligator and depression cracks (1). Microsurfacing practice is relatively new in Indiana, but some districts in Indiana that have applied this treatment have indicated that it has significantly improved pavement condition and extended the life of recipient pavements by at least 3 years (4). A study in Indiana showed that microsurfacing treatments have an average cost of $21,630 per lane-mile (with standard deviation of $3,654) in Year 1995 dollars (5). Using projections from the Federal Aid Highway Construction Price Index trends, this corresponds to approximately $26,800 in Year 2006 dollars.

Unlike short-term treatment effectiveness that mainly refers to the sudden improvement in pavement condition just upon treatment, long-term effectiveness refers to the treatment benefits measured over the entire life of the treatment. Long-term effectiveness could be viewed as the time taken by the pavement to revert to its pre-treatment pavement condition or the improvement in pavement condition over treatment life relative to the pre-treatment condition. Values of long-term effectiveness are generally preferred over those of the short-term because a good short-term performance (such as a sudden jump in condition) may not necessarily translate into superior sustained performance over the long term, particularly when exposed to traffic loading and climatic effects.

The long-term effectiveness of pavement treatments including microsurfacing is of great interest to pavement managers seeking cost-effective solutions to pavement preservation. Models that estimate the effectiveness of such treatments are useful in pavement engineering and management (including life-cycle cost analysis) and highway needs assessment studies. With the knowledge of the effectiveness of a treatment in terms of service life for example, it is possible to determine the times at which subsequent activities would be necessary at a future time. Then, with treatment cost models, it is possible to estimate the future cost of a treatment when it is due. With such knowledge of cost and effectiveness of such maintenance treatments, it is possible to draw up more reliable schedules for pavement maintenance and rehabilitation and to develop more realistic budgets for pavement preservation. Furthermore, effectiveness models help provide a methodology by which pavement and maintenance managers can compare the benefits of alternative treatments that differ by material type, new layer thickness, procedure, environment, jurisdiction, or even by source of the work (in-house versus by-contract, or between contractors).

METHODOLOGY FOR THE ANALYSIS
In evaluating the long-term effectiveness of any pavement treatment, issues that need to be addressed include selection of appropriate measures of effectiveness (MOE) and performance indicators, calculating the MOEs in terms of the performance indicators, and expressing the treatment effectiveness either as average values or as functions of pavement attributes (existing pavement thickness and quality, functional class, environment,
pre-treatment pavement condition, etc.) and treatment attributes (treatment thickness and quality, workmanship quality, etc.).

Performance Indicators
In selecting an appropriate index for treatment effectiveness evaluation, it is vital to consider what the treatment in question is meant to achieve in terms of pavement performance/condition, and how such performance/condition is measured. In the context of microsurfacing, application is typically intended to correct rutting, shallow surface depressions, and surface irregularities in general. Therefore, the ideal performance indicator for measuring microsurfacing effectiveness should be an index that can directly capture any change in the extent and severity of such defects. As such, the present study utilizes the Rutting performance indicator. The paper investigates the use of the International Roughness Index (IRI) and Pavement Condition Rating (PCR) as viable performance indicators for investigating microsurfacing effectiveness. IRI is a measure of pavement ride quality and measures the pavement roughness in inches per mile units, and a higher IRI indicates a rougher pavement. Rutting is a measure of the average depths of longitudinal troughs in the pavement wheel paths. Pavement Condition Rating (PCR) is a measure of the pavement surface distresses (including transverse cracking, longitudinal cracking, and block cracking) on a scale that ranges from 0 (failed pavement) to 100 (excellent). Besides the fact that Rutting (and probably to a lesser extent, IRI and PCR) are appropriate indicators for assessing distresses reductions associated with microsurfacing applications, they were selected also because (i) they are generally representative of user perception of road quality, (ii) they typically serve as a basis for agency repair decisions, (iii) data is collected regularly for these performance indicators for the entire state highway network in Indiana.

Measures of Effectiveness (MOE)
In the present paper, the long-term effectiveness of microsurfacing was evaluated using three measures:
- Treatment service life (extended pavement life),
- Increased average pavement condition over the treatment life,
- Increased area under performance curve due to treatment.

Each measure of effectiveness can be expressed in terms of a performance indicator (IRI, RUT or PCR). A description of each measure of effectiveness and its use in past pavement research is herein provided.

Effectiveness Estimation Methodology
Figure 1 illustrates the three measures that could be used to assess the effectiveness of a pavement treatment. For the abscissa of the graph, the paper uses pavement age (in years) as the time-related variable over which the pavement performance is monitored, but the concepts may readily be applied when accumulated loading or climatic effects are used in lieu of pavement age. In assessing the long-term effectiveness of a treatment, it is useful to derive a pavement performance curve for the treatment. Some agencies have developed treatment-specific performance curves for a number of rehabilitation or maintenance treatments (6, 7, 8, 9, 10). During the life of the treatment, there should be no other treatment of similar or higher level than the treatment in question, otherwise the life of the treatment can be considered to have ended at that point. Where no treatment performance curves exist or where data are insufficient to develop one, individual annual values of performance may be plotted for each pavement, and used for the analysis.

This paper utilizes microsurfacing performance models developed in a previous study. The models were based on performance data from pavement sections to which the treatment was applied. Together with the threshold condition, these models helped determine the measures of effectiveness, namely: service life (when the pavement reaches’ the established threshold); average pavement condition over the service life; and area bounded by the performance curve.

An alternative to using a single performance curve for all pavements sections that received the treatment would be to plot the performance trends for each individual pavement section, determine the measures of treatment effectiveness (increased service life, increased average condition, and area-enclosed-
by-curve) for each pavement, then examine how each measure of effectiveness varies by pavement and treatment attributes.

Insert Figure 1

The immediate increase in performance (PCR increase or IRI and RUT reductions) upon microsurfacing treatment (illustrated in Figure 1 as $DF$) is a necessary aspect of the analysis. These are expressed either as average values or as functions of pavement and treatment attributes such as pre-treatment pavement condition ($12, 13$). For microsurfaced pavements in Indiana, a recent Indiana study modeled such immediate increases in performance as follows ($11$):

IRI reduction:  
$$DF = 11.50 + e^{0.0187 \times IRI_{ini}}$$  

RUT reduction:  
$$DF = 0.030 + 2.481 \times RUT_{ini}^2$$

PCR increase:  
$$DF = 227.89 - 49.19 \times \ln(PCR_{ini})$$

$IRI_{ini}$, $RUT_{ini}$, and $PCR_{ini}$ are the initial (pre-treatment) pavement surface roughness (IRI in in/mile), rut depth (RUT in inches) and pavement condition rating (PCR units), respectively.

Estimation of Treatment Life

The treatment life of a treatment can be determined using any one of the following approaches:

(i) Reviewing historical contract records and determining the amount of time elapsed between time of microsurfacing application and the subsequent application of a treatment of similar or higher level. In the case of microsurfacing, “higher level” treatments may include functional or structural overlays and pavement replacement. In this approach, a performance curve is not needed – past records of pavement treatment contracts at a section are simply used to determine the number of years between the dates of successive treatment applications.

(ii) Collecting field data from several microsurfaced pavement sections to develop microsurfacing performance curves for each individual microsurfaced section or a single curve for all microsurfaced sections. Then the plot is extrapolated to determine the amount of time that passes (or is expected to pass) between the treatment and the time the treated pavement reverts to an established threshold. Depending on agency practice, the threshold may be the average initial condition of all treated pavement or a pre-specified condition trigger established in the agency’s design manual. Instead of time (years), accumulated traffic loading or climate effects could be used. In this approach (unlike Approach (i)), a performance curve is needed.

In this paper, the latter approach was used: microsurfacing performance curves were developed from field data, and the average initial (pre-treatment) pavement condition for all the microsurfaced pavement sections was used as the threshold. It is vital to note that such treatment thresholds are typically a reflection of past practice, can vary significantly from one pavement to another, and may also be influenced by considerations other than engineering need.

The general form of the post-treatment performance models developed for pavements that had received the microsurfacing treatment is as follows ($10$):

$$y = e^{(A + \beta_1 \cdot AATA \times t + \beta_2 \cdot ANDX \times t)}$$  

Where

$y$ = Value of pavement performance/condition indicator (IRI, RUT or PCR) for a treated pavement section in a given year,
AATA × \(t\) = The product of average annual truck traffic volume (in millions) and time since the microsurfacing treatment, \(t\). Used to represent the accumulated average annual daily truck traffic experienced by the treated pavement section at a given year,

ANDX × \(t\) = The product of average annual freeze index (in thousands) and time since the microsurfacing treatment, \(t\). Used to represent the accumulated annual freeze index experienced by the treated pavement section at a given year,

\(A\) = Constant term, and

\(\beta_i\) = Estimated coefficients for model explanatory variables.

When the performance reaches a critical threshold value \(y_c\), the corresponding value of \(t\) is the treatment service life, \(t_c\), and is found either graphically or using the following equation:

\[
t_c = \frac{\ln y_c - A}{\beta_2 \times AATA + \beta_3 \times ANDX}
\]  

Separate microsurfacing performance curves were developed for each performance indicator (IRI, PCR and RUT). As such, separate service lives of the treatment were derived for each indicator.

Agencies that prefer to use Approach (ii) for determining the service life of their treatments but have treatment performance curves different from Equation (4) may simply use a similar algebraic manipulation to derive the expression for service life. This is possible if the performance curve is (or can be) expressed in terms of pavement age (time).

The general concept of treatment life as a measure of treatment effectiveness has been used extensively in past research as a measure of effectiveness of pavement repair activities (2, 3, 14, 15).

**Increased Average Pavement Condition over Treatment Life**

A simple approach to estimating the average pavement condition over the life of microsurfacing treatment is to carry out annual field measurements of IRI, RUT and PCR until such time that the pavement condition falls below a specified threshold. An alternative approach is to develop performance models using data from a collection of treated pavements and then using such models to estimate the average value of the ordinate (condition) over the treatment life. The latter approach was used in the study.

For a given pavement section that received the treatment, the average pavement condition over the service life, \(PERF_{AVG}\), can be determined as follows:

\[
PERF_{AVG} = \frac{1}{t_c} \left( y_0 + y_1 + \ldots + y_c \right)
\]  

Where \(y_0\) = Pavement condition just after treatment,

\(y_c\) = Pavement condition at the time when pavement condition reaches the threshold,

\(y_1, y_2, \ldots, y_{c-1}\) = Pavement condition values at intervening years,

\(t_c\) = Service life.

The increase in average pavement condition due to the microsurfacing treatment can then be found by finding the percentage change in average condition relative to the condition before treatment.

\[
Effectiveness_{APC} = 100 \times \left( \frac{PERF_{AVG} - PERF_{INT}}{PERF_{INT}} \right)
\]  

Where

\[
\text{Effectiveness}_{APC} = \text{Treatment effectiveness measured as an increase in average pavement condition},
\]

\[
\text{PERF}_{INI} = \text{Initial (pre-treatment) condition of pavement in terms of the performance indicator (IRI, PCR or RUT)},
\]

\[
\text{PERF}_{AVG} = \text{The average condition of pavement (averaged over entire actual or extrapolated service life) in terms of the performance indicator (IRI, PCR or RUT)}.
\]

The use of post-treatment average pavement condition as a measure of treatment effectiveness is seen in some previous studies (16, 17). Agencies that wish to measure their treatment effectiveness in terms of increased average pavement condition can simply collect post-treatment field data and average such values from time of treatment until the service life is reached. Alternatively, agencies can use data points that have been estimated on the basis of performance models developed from field data.

**Increased Area-Bounded-by-Performance Curve due to Treatment**

Probably the most conceptually superior of all measures of long-term effectiveness, the area bounded by the performance curve and the threshold line embodies both concepts of average pavement condition and the service life. A simple approach for determining the area under the performance curve is to carry out field monitoring of pavement condition for each of several pavement sections that received the treatment, plotting a graph of the condition measurements versus time, determining the area bounded by the curve and threshold line for each pavement, and finding the average of these areas from time of treatment to the time the pavement condition reaches a specified threshold. Alternatively, a single pavement performance curve could be developed using data from treated similar pavement sections and finding (using calculus or manual means) the required area bounded by the performance curve. For non-increasing performance indicators such as PCR, the area bounded by the curve and the horizontal line projected from the threshold condition level (i.e., the area under the curve) is the measure of treatment effectiveness (Figure 1). For non-decreasing indicators such as IRI and rutting, the effectiveness, or the area bounded by the curve and the horizontal line projected from the threshold condition level, is the area over the curve.

As seen in Figure 1, the treatment effectiveness (area bounded by the curve) can be defined as follows (11):

(i) For non-decreasing performance indicators such as IRI and RUT (where effectiveness is represented by the area over the curve):

\[
2 \times \left\{ (\text{DF} \times t_e) - \int_0^{t_e} (e^{A + t(AAATA + \beta_i \times \text{ANDX})}) \, dt \right\}
\]

Where

\[
\text{DF} = \text{Difference between initial and post-treatment pavement condition},
\]

\[
t_e = \text{Treatment service life is the upper limit of the integration},
\]

\[
A = \text{A constant term},
\]

\[
AAATA = \text{Average annual daily truck traffic experienced by the pavement section in millions},
\]

\[
\text{ANDX} = \text{Average annual freeze index (ANDX) experienced by the pavement section in thousands},
\]

\[
\beta_i = \text{Estimated coefficients for model explanatory variables}.
\]
(ii) For non-increasing performance indicators such as PCR (where effectiveness is represented by the area under the curve):

\[ 2 \times \int_0^{t_c} (e^{(A + \beta_1 \times A_ATA + \beta_2 \times A_NDX)}) \, dt \]

(9)

Where terms have their usual meanings.

For pavements in each road class that received the treatment, microsurfacing effectiveness in terms of condition-years were thus calculated on the basis of IRI, PCR, and RUT.

A review of a sample of past literature shows that the area-bounded-by-the-curve concept has seen widespread application (2, 18, 19, 20) particularly to serve as a surrogate for reduced vehicle operating costs to represent a benefit of pavement rehabilitation or maintenance.

**DATA COLLECTION AND COLLATION FOR CASE STUDY**

For demonstrating the study methodology, the present paper utilized data for pavement sections that received microsurfacing treatment in Indiana between 1994 and 2001 (Table 1). Data included pavement identification and referencing, condition, traffic volume, climate characteristics and maintenance history data. The contract datafile provided information on contract location, type of pavement treatment, and dates of letting and completion. The pavement condition data-file included yearly pavement condition data (IRI, Rut Depth, and PCR). Traffic data used for the study included traffic volume (AADT), and truck percentages. Traffic volumes were available from annual Indiana County Flow Map publications and Vehicle Classification Reports. Primary climate data were collected from the National Oceanic and Atmospheric Administration and processed to derive secondary climate indicators such as number of freeze-thaw cycles and freeze index. The freeze index was found to vary from a state of relatively low freeze in southern Indiana to one of relatively high freeze in northern Indiana (5). For each county containing a microsurfaced pavement under study, the freeze index was calculated using methodologies described in available literature (21, 22) and temperature data, and were used to classify counties in order of climate severity (high and low). Using appropriate data management tools, data from different databases sources with different referencing systems were reconciled. Also the following categories were established: High traffic loading pavements – ESALs exceeding 1 million, Low traffic loading pavements – ESALs not exceeding 1 million, High climate severity pavements – annual freeze index exceeding 60 degree-days, Low climate severity pavements – annual freeze index not exceeding 60 degree-days.

The pavement condition thresholds used in the present paper are simple averages of pre-treatment pavement condition at various road sections in Indiana within the study period, and are as follows:

- Interstates: IRI – 93.35 in/mile, RUT – 0.1 inches, PCR – 89.54 PCR units,
- Non-Interstates: IRI – 116.39 in/mile, RUT – 0.19 inches, PCR – 90.99 PCR units.

Insert Table 1

**FINDINGS FROM THE STUDY**

**Preliminary Results – Microsurfacing Performance Curves**

Microsurfaced Pavement Performance as a Function of Accumulated Loading and Climate Severity:

The microsurfacing performance models that were developed in a previous research project in Indiana (10) for each family of pavements were of the general functional form shown as Equation (1). The actual models are presented in Table 2.
Final Results – Microsurfacing Long-term Effectiveness Values

The results of the case study are presented in Table 3 and Figure 2. These show the effectiveness of microsurfacing treatments for each measure of effectiveness, performance indicator, and highway class. The values shown do not reflect actual (field measured) effectiveness exhibited by actual pavements in each combination of functional class/traffic loading/climate regime, but rather reflects the values of effectiveness for given levels of these variables that were “simulated” on the basis of the microsurfacing performance curve and performance thresholds. It may be recalled that the performance models were a function of traffic and climate, among others, and the performance thresholds were a function of highway class. However, the same methodology could easily be applied to sections where actual field measurements are available for each combination of these categories.

Microsurfacing Effectiveness on the Basis of Treatment Life

For each highway class and for various combinations of climate and traffic loading regimes, the life of microsurfacing treatments was estimated in terms of time (years), separately for each performance indicator IRI, RUT, and PCR. The results are illustrated in Figure 2a. The service lives were determined on the basis of performance models developed from in-service pavements and performance thresholds established from historical practice.

The results suggest that microsurfacing treatment offers an average service life of approximately 5 years when IRI is used as a measure of effectiveness, 7 years on the basis of PCR, and 24 years on the basis of rutting, thus suggesting that the long-term effectiveness of the treatment is most perceptible when viewed from perspective of rut correction. This provides corroboration to previous research findings (1, 3) and supports the hypothesis that microsurfacing significantly corrects and retards pavement rutting.

The study results also provide some indication that the variation in effectiveness of microsurfacing treatments in terms of service life could be explained by levels of traffic loading and climate severity, and highway class, and the variation across such factors is most visible when rutting is used as the performance indicator. It is seen that the service life afforded by microsurfacing treatments at non-Interstate pavements exceeds that at Interstate pavements: on the basis of IRI, service life is 6 vs. 4 years; on the basis of rutting, service life is 27 vs. 22 years; on basis of PCR, service life is 7 vs. 8 years. Overall, this result seems to be consistent with the findings of at least one previous researcher who indicated that microsurfacing performs well for 5-7 years after application given favorable conditions (3). The study findings also provide the intuitive result that for any given highway class and performance indicator, microsurfacing treatment service life is longer in cases of low severity climate and low traffic loading compared to severe climate and high traffic loading conditions.

Which factor plays a greater role in reducing the microsurfacing treatment service life – traffic loading or climate? The study results seem to roughly provide a rather approximate insight into this issue. On the basis of rutting, moving from mild climate to relatively severe climate seems to have a more deleterious effect on the longevity of microsurfaced pavements compared to moving from low traffic to relatively high traffic levels. While it may be correctly argued that this is a scaling issue, the general pattern of the trends seems to be obvious. This result is consistent for both Interstate and non-Interstate pavements. The relatively greater damage of increasing climate compared to increasing traffic loading, however, is not so obvious when IRI and PCR are used as performance indicators.

Another interesting result pertains to the relative effectiveness of microsurfacing treatments between pavements of the two highway class. The results show that the service life of this treatment at non-Interstate sections exceed those of their Interstate counterparts by 36% when IRI is used as performance indicator and 18% on the basis of rutting, but is 24% lower than their Interstate counterparts when PCR is used as the performance indicator. This probably explains why the application of microsurfacing treatments seems to be more preferable for non-Interstate compared to Interstate pavements.
Microsurfacing Effectiveness on the Basis of Increased Average Pavement Conditions
Table 2 and Figure 2b show that microsurfacing treatments offer a 6-27\% decrease in IRI, a 92-96\% reduction in rutting, and a 2-7\% increase in PCR, depending on the highway class, traffic loading level and climate severity. In terms of this MOE, microsurfacing effectiveness seems to be, by far, most perceptible when rutting is used as a performance indicator and relatively less perceptible when IRI and PCR are used.

In terms of increased average pavement condition relative to initial condition, the results provide relatively little insight into the relative effects of increasing traffic load and climate severity on the effectiveness of microsurfacing treatments. In terms of this measure of treatment effectiveness, non-Interstate pavements fare better than their Interstate counterparts on the basis of rutting and IRI, while Interstate pavements fare only slightly better in terms of PCR.

Microsurfacing Effectiveness on Basis of Area Bounded by the Performance Curve
In Table 2 and Figure 2c, the effectiveness of microsurfacing treatments are shown in terms of area enclosed by the post-treatment performance curve. The figure shows that depending on the levels of traffic loading and climate severity, highway class, the treatment yields an effectiveness value (area) of approximately 31-258 IRI years, 0.6-4.1 RUT-years, and approximately 18-56 PCR-years. The results show that when traffic level increases from low to high, the effectiveness (area bounded by the curve) slumps sharply, irrespective of the type of performance indicator used. When climate severity increases from low to high, a similar drop in effectiveness is observed for all three performance indicators.

From the perspective of highway class, there seem to be significant differences in microsurfacing effectiveness on the basis of rutting and IRI: the microsurfacing treatment seems to be more effective (offers a greater area under the rutting and IRI performance curves) at non-Interstate pavements compared to Interstate pavements, for any combination of loading and climate regimes.

General Discussion – Differences in Microsurfacing Effectiveness Perceptions
The study results yield some thought-provoking insights into the benefits of microsurfacing treatments from the perspectives of different MOE, different performance indicator, and different highway classes, as illustrated in Figure 2.

With regard to MOE, it is seen that when service life or area-bounded-by-the-curve is used as the measure of effectiveness, there seem to be relatively wide differences in the treatment effectiveness across highway class and climate/traffic regimes. On the other hand, there are relatively little differences in effectiveness observed across such attributes when increase in average pavement condition is used as a measure of treatment effectiveness.

With regard to the performance indicators, the effectiveness of microsurfacing appears to be most visible when rutting is used to indicate pavement performance. In terms of rutting performance, the treatment is shown to exhibit much higher service life and increase in pavement condition compared to the other performance indicators. In past research, there have been specific allusions to the therapeutic effect of microsurfacing on rutted pavements \(1, 3\).

Examination of the effectiveness results by highway class shows that irrespective of MOE used and traffic/climate regime, non-Interstates stand to gain relatively higher benefits from such treatments than their Interstate counterparts when IRI and Rut are used as performance indicators. When PCR is used as a performance indicator, microsurfacing appears to be only slightly more effective at Interstates.

Finally, it is worth mentioning that values of microsurfacing effectiveness may vary from one agency to another due to differences in agency-specific conditions and practices such as pavement performance curves and established thresholds for treatment applications.
SUMMARY AND CONCLUSIONS

In this paper, a methodology for determining the long-term effectiveness of microsurfacing treatments using three measures of effectiveness is presented. The measures of effectiveness are: (i) service life was determined on the basis of performance models developed from in-service pavements and performance thresholds established from historical practice, (ii) average condition of the pavement sections after microsurfacing treatment, found by simply averaging the values of the pavement condition from time of treatment to the end of service life using the performance plots, and expressed as a percentage of the condition at the time of treatment, (iii) area bounded by the treated pavement performance curve and the threshold line, in condition-year units. For each measure of treatment effectiveness, three pavement performance indicators are separately used: IRI, RUT, and PCR. Using data from microsurfaced pavements in Indiana, a case study is used to demonstrate the methodology.

The results show that microsurfacing offers average approximate service lives of 5 years when IRI is used as a measure of effectiveness, over 10 years on the basis of rutting, and 7 years on the basis of PCR. On the basis of IRI and rutting, microsurfacing generally appears to offer a greater service life when applied at non-Interstate compared to Interstate pavements. The results also provide an insight into the relative effects of increases in traffic loading vis-à-vis increase in climate severity on the service life of microsurfacing treatments: on the basis of rutting, increasingly severe climate seems to have a more deleterious effect on post-microsurfacing pavement longevity compared to increasingly severe traffic conditions. The seemingly greater damage of climate relative to traffic, however, is not so obvious when IRI and PCR are used as performance indicators. The service life of microsurfacing at non-Interstate sections exceeds those of their Interstate counterparts when IRI and Rutting are used as performance indicator but is lower than their Interstate counterparts when PCR is used.

When the increase in average pavement condition (relative to initial condition) is used as the measure of long-term effectiveness, it is seen that the treatment offers a 6-27% decrease in IRI, a 92-96% reduction in rutting, and a 2-7% increase in PCR, depending on the highway class, traffic loading level and climate severity. The analysis also showed that in terms of increased average pavement condition, the treatment effectiveness is most perceptible when rutting is used as a performance indicator. Investigation of microsurfacing treatment effectiveness in terms of area enclosed by the performance curve after treatment showed similar trends to those of service life.

From the study results, it is seen that perceptions of the treatment effectiveness (and variations thereof) can be influenced by the specific measure of effectiveness that is selected for the study. When service life and area-bounded-by-the-curve are used as the measures of effectiveness, there seem to be relatively wide differences in the treatment effectiveness across highway class and climate/traffic regimes. On the other hand, there are little differences observed across such attributes when increase in average pavement condition is used as the MOE. Furthermore, the choice of performance indicator can also affect the perceived effectiveness of microsurfacing treatments – the highest effectiveness (longer service life and greater increases in pavement condition) is observed when rutting is used as the performance indicator. The highway class at which the treatment is applied can also influence the conclusions. The study results show that when IRI and Rut are used as performance indicators, non-Interstates are generally perceived to gain relatively greater benefits from microsurfacing treatments compared to their Interstate counterparts, irrespective of traffic/climate regime.

For any measure of effectiveness, highway class and performance indicator, the treatment service life is longer (as expected) in cases of mild climate and low traffic conditions compared to severe climate and high traffic loading conditions.

The study results can have important implications in the design of pavement preservation strategies and overall pavement management. The results suggest that there may be a need for the Indiana Department of Transportation to review relevant portions of its design manual that deal with the specification of expected service life of microsurfacing treatments. As the present study is based on a rather small sample, any design manual revisions could be carried out after more exhaustive investigations that would involve a larger number of microsurfaced pavements. Furthermore, the microsurfacing service life values obtained in the present study could be helpful in the design of preventive maintenance strategies for life-cycle cost analyses.
Other highway agencies with established performance indicators, performance curves and application thresholds for microsurfacing treatment may use the study methodology described in this paper to ascertain the effectiveness of the treatment on the basis of any of the three MOEs described in this paper. Agencies with no microsurfacing performance curve may use direct field measurements of the performance indicators, and may carry out the analysis for each individual pavement.

Finally, future work in this area could include other performance indicators such as surface friction, to assess the skid resistance benefits of microsurfacing treatments.

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This work was supported by the Joint Transportation Research Program (JTRP) administered by the Indiana Department of Transportation and Purdue University. The paper evolved from a 1999 to 2002 project which evaluated the impact of maintenance on capital improvement. Professor Kumares C. Sinha, Olson Distinguished Professor of Civil Engineering and Director of the JTRP, is especially acknowledged for his support. Messrs. Mr. John Weaver of the Indiana Department of Transportation (INDOT), David Holtz, William Flora, and Hadi Yamin of INDOT Program Development Division, and Messrs. Mark Burton and Dennis Belter of INDOT Operations Support Division, are also acknowledged for their immense assistance in data acquisition and other areas of the study.

The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policies of the Federal Highway Administration and the Indiana Department of Transportation, nor do the contents constitute a standard, specification, or regulation.

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<th>To (Milepost)</th>
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<th>District</th>
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<th>Nr. of Lanes</th>
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### Table 1 (continued). List of Pavement Sections that Received Microsurfacing Treatment 1994-2001

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Table 2. Pavement Performance Models for Microsurfacing Treatment in Indiana (10)

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Table 3. Long-term Treatment Effectiveness of Microsurfacing

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<td>High Traffic Low Climate</td>
<td>44.94 IRI-yrs</td>
<td>122.72 IRI-yrs</td>
<td>1.11 RUT-yrs</td>
<td>2.63 RUT-yrs</td>
</tr>
<tr>
<td>Low Traffic High Climate</td>
<td>49.71 IRI-yrs</td>
<td>135.73 IRI-yrs</td>
<td>0.71 RUT-yrs</td>
<td>1.70 RUT-yrs</td>
</tr>
<tr>
<td>High Traffic High Climate</td>
<td>31.47 IRI-yrs</td>
<td>85.93 IRI-yrs</td>
<td>0.58 RUT-yrs</td>
<td>1.38 RUT-yrs</td>
</tr>
</tbody>
</table>