FINAL REPORT

EFFECTIVENESS OF CRACK SEALING ON
PAVEMENT SERVICEABILITY AND LIFE

Submitted By

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Effectiveness of Crack Sealing on Pavement Serviceability and Life

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Crack Sealing, Pavement Performance, Pavement Serviceability, Life, Cost-effectiveness, Performance-effectiveness

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DISCLAIMER

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EFFECTIVENESS OF CRACK SEALING ON
PAVEMENT SERVICEABILITY AND LIFE

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Problem
Sealing cracks in pavements with an asphalt surface is a preventive maintenance activity performed by most highway agencies including the Ohio Department of Transportation (ODOT). A range of materials and methods are in use within Ohio for this purpose. The choice of a specific material/method depends on the county manager’s understanding of the historical performance of various materials, pavement type (flexible or composite), regional conditions, availability of funds, and so on.

Sealing cracks may minimize water infiltration, prevent pumping and avoid the need for premature base and pavement repair. However, crack sealing may also have a negative effect on a pavement, namely, tracking of sealing material by tire action, reduced skid resistance, a rougher pavement etc. Crack sealing is beneficial if pavement life is increased while maintaining serviceability. Within ODOT, the primary concern is to investigate and document the effectiveness of crack sealing with respect to: (i) economic benefits, (ii) maintaining and/or improving serviceability, and (iii) extending pavement life.

This study was carried out to establish a field experiment to statistically evaluate the effectiveness of ODOT’s current crack sealing practices on pavement serviceability and life. The report provides a complete description of the experimental plan, testing, evaluation and proposed analysis procedures.
Objectives
To design and develop a project to statistically evaluate the cost-effectiveness of ODOT’s current crack sealing program.

Description
In this study, the effectiveness of crack sealing of flexible and composite pavements will be determined through a series of well-controlled field evaluations conducted over a period of nearly ten years. The experimental plan has been carefully designed to obtain statistically valid conclusions. The design of experiment included several tasks namely, identification of experimental variables, determining the required sample size, defining a measure of effectiveness, selecting test sections, conducting field studies, determining type and frequency of data to be collected, and developing a database. The data collected would be used by the ODOT to address the following specific issues:

- Do existing crack sealing practices within ODOT enhance pavement performance?
- Are crack sealing practices cost beneficial?
- What is the optimum timing for treatment?

Based on an evaluation of crack sealing practices in Ohio, a review of published literature, and a discussion with ODOT’s engineers, the primary design factors selected for the field experiment were pavement type, type of aggregate in the surface layer and Pavement Condition Rating (PCR) level. In addition, environmental conditions, functional classification, crack sealing material type and placement procedures were considered as secondary variables.

An interactive database has been developed to assist the ODOT in (i) data gathering, (ii) data storing, (iii) data processing, and (iv) data analysis. This database termed ODOT - ECS (Ohio Department of Transportation - Database to Evaluate Crack Sealing Practices in Ohio) is a comprehensive MS Windows-based software developed in MS Visual Basic and MS Access. This research will help ODOT to objectively assess the effectiveness of its crack sealing practices.

Conclusions & Recommendations
Final conclusions on the effectiveness of ODOT’s current crack sealing practices can be reached after applying the suggested analysis procedures to the data collected according to the guidelines developed in the study. However, it is strongly recommended that an analysis and an interim report be prepared for the data up to 2005.

Implementation Potential
For the crack sealing program in the State of Ohio, this study will help establish ‘what’ (with respect to the type of material and method) and ‘when’ (with respect to age and/or condition of pavement) it is most cost-effective to seal a pavement with the objective of improving its condition and extending its life.
EFFECTIVENESS OF CRACK SEALING ON
PAVEMENT SERVICEABILITY AND LIFE

1. DESCRIPTION OF THE PROBLEM

Sealing cracks in pavements with an asphalt surface is a preventive maintenance activity performed by most highway agencies including the Ohio Department of Transportation (ODOT). A range of materials and methods are in use within Ohio for this purpose. The choice of a specific material/method depends on the county manager’s understanding of the historical performance of various materials, pavement type (flexible or composite), regional conditions, availability of operating funds, and so on.

The SPS-3 and SPS-4 studies of the Strategic Highway Research Program (SHRP) were setup to establish a good pavement preservation program in each state. Though the SPS-3 and SPS-4 studies have yielded good information, more research is needed to provide additional data to augment the SHRP studies and to ultimately provide answers to the performance and cost-effectiveness of crack sealing and other pavement preservation strategies [1].

Sealing cracks may reduce water infiltration, prevent pumping and avoid the need for premature base and pavement repair. Crack sealing may also affect the pavement in many ways such as, tracking of sealing material by tire action, reduced skid resistance, and a rougher pavement. Crack sealing is beneficial if pavement life is increased while maintaining serviceability. The serviceability of a pavement is its ability to serve the anticipated traffic during the design period. Within ODOT, the primary concern is to investigate and document the effectiveness of current crack sealing program with respect to: (i) economic benefits, (ii) maintaining and/or improving serviceability, and (iii) extending pavement life.

In March 2000, ODOT commissioned the University of Cincinnati (UC) to ‘design a project to statistically verify the effectiveness of ODOT’s current force account crack sealing program on pavement condition and life’. During the period 2000 through 2002, the UC
researchers have worked with ODOT engineers, highway managers and county managers to initiate this project, setup test sections, conduct preliminary pavement condition evaluations, and establish guidelines for further monitoring. Field verification of effectiveness is being made by studying the performance of crack sealing on bituminous surfaced pavements (flexible pavements as well as composite pavements with an asphalt layer on jointed reinforced concrete slabs). The ODOT would continue to collect the data until significant changes in pavement condition are observed. Conclusions could then be made by analyzing the long-term data collected by ODOT.

2. **OBJECTIVES AND SCOPE**

The objective of the study is to “design and develop a project to statistically evaluate the cost-effectiveness of ODOT’s current crack sealing program”. The researchers, over a period of two years, have developed a controlled experimental plan with guidelines for long term monitoring that is necessary for analyzing the cost-effectiveness of crack sealing and its effect on pavement condition and pavement serviceability over time.

The primary focus of this research is to evaluate the effectiveness of crack sealing materials and application methods commonly practiced by ODOT maintenance crews. Hence, this study does not concentrate on material selection and application methods, but rather the effectiveness of sealing in general. However, efforts have been made to include the most commonly used materials and application methods as an additional variable. An overview of the research approach is presented in Figure 1. As noted in Figure 1, the scope of this research included setting up test and control sections, conducting preliminary studies, and developing a plan for the long term monitoring of these sections. The data collected would be used by the ODOT to address the following specific issues:

- Do existing crack sealing practices within ODOT enhance pavement performance?
- Are crack sealing practices cost beneficial?
- What is the optimum timing for treatment?
Figure 1. Overview of Research Approach
This research can help ODOT in objectively assessing the effectiveness of its crack sealing practices. The study can also lead to the development of deterioration curves which can provide answers to the above questions. This report provides a complete description of the experimental plan, testing, evaluation and analysis procedures designed to address the key issues outlined above.

3. REVIEW OF EXISTING CRACK SEALING PRACTICES IN OHIO

To begin with, the researchers designed a survey form in cooperation with ODOT’s engineers. The survey form is provided in Appendix A. This survey form was mailed to all eighty-eight county managers and twelve District highway managers to query them on the materials used for crack sealing, application methods, type of crack sealed, time of sealing, their willingness to participate in this study, and so on. Forty six counties responded to the survey. A summary of the responses can be seen in Appendix B. In general, the following observations were made:

1. The counties perform crack sealing during the Fall, Winter and Spring months.

2. An air compressor is commonly used for pavement surface preparation.

3. The pavement temperature when the seal is applied varies in general from 40°F to 100°F.

4. The counties ‘mostly clean’ the pavement surface and keep the surface ‘dry’ before placing the crack seal.

5. The counties treat cracks of all severity (low, moderate and high). However, a greater number of counties treat only ‘moderate’ cracks.

6. The types of cracks sealed include alligator, edge, block, longitudinal, reflection, and transverse cracks.

7. A range of materials are used for crack sealing. MC-3000 is the most widely used material.

8. Routing is not done prior to crack sealing.

9. The finished sealant is predominantly ‘level with surface’ or ‘overband’.
10. The counties perform crack sealing using their own forces. The counties rarely out source this work to contractors.

The primary advantages of the survey was in helping the researchers better understand the existing crack sealing practices in Ohio. This information was used to develop a realistic plan for the field experiment and to define the exact scope of the field study, namely the number of test variables to be included, total number of test sections required, availability of sections, and so on.

4. STATISTICAL DESIGN OF EXPERIMENT

If an experiment is to be performed properly, a scientific approach to planning the experiment must be employed. The ‘statistical design of experiment’, refers to the process of planning the experiment so that the appropriate data to be analyzed by statistical methods will be collected, resulting in valid and objective conclusions. The statistical approach to experimental design is necessary so that meaningful conclusions can be drawn from the data. When the problem involves data that are subject to experimental errors, statistical methodology is the only objective approach to analysis. Thus, there are two aspects to any experimental problem: the design of the experiment and the statistical analysis of the data [2, 3, 4].

In this study, the effectiveness of crack sealing of flexible and composite pavements will be determined through a series of well-controlled field evaluations conducted over a period of five years or more. To use a statistical approach in designing and analyzing this experiment, it is necessary for everyone involved in the experiment to have a clear idea in advance of exactly what is to be studied, how the data are to be collected, and at least a qualitative understanding of how these data are to be analyzed. In general, the design of experiment includes the following tasks:

1. Recognition of and statement of the problem
2. Choice of factors, levels, and ranges
3. Selection of the response variable(s)
4. Choice of experimental design

5. Performing the experiment

6. Statistical analysis of the data

7. Conclusions and recommendations

Note: ‘*’ represents pre-experimental planning.

The details of activities performed under each task are presented in the following sections.

4.1 Recognition of and Statement of the Problem

Determination of the most cost effective time and treatment is the most difficult problem that a pavement engineer encounters. The most cost effective treatment is dependent on the pavement condition while the most cost effective time to treat a pavement is dependant on the type of treatment involved. In other words, the two factors that play a critical role in sealing pavements with asphalt surface are ‘type of action’ and ‘time of action’. Therefore, for the crack sealing program to be successful in Ohio, it is important to investigate ‘what’ treatment (with respect to type of material and method to be used) and ‘when’ (with respect to age and/or condition of pavement) it is most cost effective to improve the pavement condition and extend its life.

In order to develop all ideas about the objectives of the experiment and to solicit input from all concerned parties, a team approach was implemented.

The researchers requested the Office of Pavement Engineering to form a Technical Evaluation Team. The technical evaluation team thus formed was composed of members representing the following ODOT departments:

- ODOT’s Office of Pavement Engineering
  - Pavement Research Section
  - Pavement Design Section
The role of the district offices and the counties was to provide information regarding pavement sections that are available for crack sealing, assist in setting up the test sections, perform crack sealing according to the guidelines developed by the researchers and maintain the test sections during the life of the project. The role of the Offices of Pavement Engineering and Materials Management was to: (i) help the researchers coordinate the works with district offices and counties, (ii) provide any necessary data available with ODOT, as identified by the researchers, and (iii) review and approve the research approach. The team served as a knowledge source, provided guidelines, monitored the progress, and acted as a sounding board to the researchers.

4.2 Choice of Factors, Levels and Ranges

The primary objective of the design of the experiment is to make sure that the factors included in the field evaluation are appropriate for demonstrating the effect of crack sealing on pavement condition, service life and life cycle costs. Once the factors are selected, the ranges over which these factors will be varied should be established. It is also important to identify and include an adequate number of test sections that is sufficient to allow the performance of required statistical analysis.

When considering the factors that may influence the performance of a process, the experimenter usually discovers that these factors can be classified as either design factors or nuisance factors [2]. The design factors are the factors which exercise considerable influence on the outcome, and are actually selected for study in the experiment. Nuisance factors, on the other
hand, may have small to large effects that must be accounted for, yet may not be of interest in the context of the present experiment.

In the beginning, the following factors were considered:

- Pavement type
- Pavement condition rating prior to crack sealing
- Type of aggregate in the surface layer
- Temperature zone
- Traffic loading
- Age
- Layer properties
- Prior maintenance
- Near future maintenance and rehabilitation needs
- Functional classification
- Treatment material properties
- Quality of the treatment construction or application
- Environmental conditions at the time of treatment application

Although all of these factors are likely to impact the performance of crack sealed pavements to various degrees, all of them were not considered as design factors in the experiment. The primary reasons for doing so were: time and monetary constraints (using a reasonable number of sections and conducting the study within a manageable time frame) and, lack of available candidate sections.
Based on a review of crack sealing practices in Ohio, followed by discussions with the technical evaluation team, pavement type (two levels), PCR prior to crack sealing (three levels), and type of aggregate in surface layer (two levels) were considered as ‘design factors’ for selecting the test sections.

Thus temperature zone, functional classification (which may also account for the traffic), treatment material type and placement procedures were considered as nuisance factors. These factors are ‘controlled nuisance factors’ meaning, their levels have been set by the researchers, as shown in Table 1. The temperature zone was varied over two-levels (North of I-70 and South of I-70), treatment materials over four-levels (ODOT Type II, Type III and Type IV, regular emulsion), and pavement surface preparation over two-levels (‘none’ and ‘other’ techniques). Type II crack sealant is a mixture of certified binder meeting PG64-22 and polyester fibers. Type III crack sealant is a mixture of binder meeting PG64-22 and polypropylene fibers. Type IV crack sealant is a prepackaged, pre-approved mixture of modified binder with a minimum two percent polyester fibers (recycled fibers not permitted) [5].

Figure 2 depicts the experimental design setup. A matrix of design factors showing the levels used in the experiment is presented in Table 2. A group number was assigned to each set of factors. For example, group number 1 consists of test sections in flexible pavements with limestone aggregate in the surface layer, and a PCR less than 75. Thus there are 12 groups, as shown in Table 2.
### Table 1. Design Factors, Nuisance Factors and their Levels

<table>
<thead>
<tr>
<th>Design Factors</th>
<th>Number of Levels</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement type</td>
<td>2</td>
<td>Flexible and Composite</td>
</tr>
<tr>
<td>Pavement Condition Rating (PCR) of existing pavement</td>
<td>3</td>
<td>&lt;75, 75-85, &gt;85</td>
</tr>
<tr>
<td>Type of aggregate in the surface layer</td>
<td>2</td>
<td>Lime Stone and Gravel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nuisance Factors</th>
<th>Number of Levels</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature zone</td>
<td>2</td>
<td>North of I-70 and South of I-70</td>
</tr>
<tr>
<td>Functional Classification</td>
<td>3</td>
<td>IR, US, SR</td>
</tr>
<tr>
<td>Treatment Material Type</td>
<td>3</td>
<td>ODOT Types II, III and IV</td>
</tr>
<tr>
<td>Pavement surface preparation</td>
<td>2</td>
<td>None/Others</td>
</tr>
</tbody>
</table>
Figure 2. Schematic Illustration of Process Model
Table 2. Matrix of Design Factors

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>FLEXIBLE</th>
<th></th>
<th></th>
<th>COMPOSITE</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate in Surface Layer</td>
<td>LIME STONE</td>
<td>GRAVEL</td>
<td></td>
<td>LIME STONE</td>
<td>GRAVEL</td>
<td></td>
</tr>
<tr>
<td>PCR of Existing Pavement</td>
<td>&lt;75 75-85 &gt;85</td>
<td>&lt;75 75-85 &gt;85</td>
<td>&lt;75 75-85 &gt;85</td>
<td>&lt;75 75-85 &gt;85</td>
<td>&lt;75 75-85 &gt;85</td>
<td></td>
</tr>
<tr>
<td>Group Number</td>
<td>1 2 3</td>
<td>4 5 6</td>
<td>7 8 9 10 11 12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.3 Selection of the Response Variable

A response variable is a performance indicator. It is a measure of the effectiveness of crack sealing. Several performance indicators are available to study changes in pavement condition. The choice of a specific indicator depends primarily on the agencies’ pavement evaluation practices and pavement preservation policies. Three key measures commonly employed to define the condition of the pavement are:

- Surface distress
- Roughness
- Surface friction

The surface distress survey is helpful to observe the variation of overall pavement condition. The distress manuals developed by SHRP, ODOT and other agencies list various types of distresses commonly observed on asphalt pavement surfaces and a procedure to measure them [6, 7]. Roughness is a measure of the longitudinal profile of the pavement surface that affects ride quality. Roughness is measured using a profiler and expressed as International Roughness Index (IRI). An evaluation of the entire test pavement is required to measure IRI. [8]. ODOT has conducted skid resistance testing on state system roads in Ohio since the mid 1970's in response to FHWA’s recommendation that each state DOT create a skid testing program. All skid testing is conducted in accordance with ASTM specification E-274. During a test sequence, water is pumped onto the pavement directly in front of the test trailer wheel. A hydraulic braking system is used to lock the test wheel. After the test wheel is locked and has been sliding for a suitable distance, the horizontal and vertical forces on the wheel and hub assembly are measured. A heavy duty computer in the tow vehicle measures and averages these forces. The Skid Number is calculated by dividing the horizontal force by the vertical force, then multiplied by 100.
The performance indicators available at ODOT are Pavement Condition Rating (PCR), Roughness (IRI), and Skid Number (SN). Two important issues were considered in the selection of the response variables for the present study, namely:

1. The response variables should truly represent changes in pavement condition (or performance) due to crack sealing;

2. The data required to measure (or compute/estimate) the response variables should be readily available at ODOT; if additional information is required, the additional data collection efforts should be reasonable.

The ODOT’s Pavement Design and Rehabilitation Manual [9] considers the use of PCR as a rating index to trigger maintenance and rehabilitation actions. PCR is a rating system based on a visual inspection of pavement distress. The PCR provides an index reflecting the composite effects of varying distress types, severity and extent upon the overall condition of the pavement. Its value ranges from 0 to 100, with 100 being the best. A General Query Language algorithm has been developed which helps the counties develop a first cut list of candidate projects based on individual distress, in conjunction with PCR [10]. However, the District Pavement Review Team would further evaluate the candidate projects based on PCR, Ride Number, Structural Deduct, and the pavement history to arrive at an optimal district preventive maintenance program. Structural deduct is a part of PCR, and includes distresses which may be related to the structural integrity of the pavement.

Roughness is an indicator of functional performance. The ODOT’s Pavement Management Division collects the roughness data annually in 0.10 mile intervals and reports in terms of IRI.

Although it would be of interest to use SN also as a response variable, only limited skid data is available with ODOT. Based on suggestions by the technical evaluation team, SN will be used to study the effect of crack sealing on frictional characteristics, only where adequate data is available.
Thus the response variables used in this study are:

- PCR,
- IRI, and
- SN (limited study).

A discussion on the adequacy of these response variables and the need to develop a new response variable is presented in Section 6.0.

4.4 Choice of Experimental Design

The choice of an experimental design depends on the following:

- consideration of sample size (number of replicates),
- the selection of a suitable run order for the experimental trials, and
- the determination of whether or not blocking or other randomization restrictions are involved.

If there were one or several factors under investigation, and the primary goal of the experiment is to make a conclusion about one a-priori important factor, (in the presence of, and/or in spite of the existence of the other factors), and the question of interest is whether or not that factor is "significant", (i.e., whether or not there is a significant change in the response for different levels of that factor), then we have a comparative problem and we need a comparative design solution.

The three basic principles of experimental design are replication, blocking, and randomization [2].

By replication, we mean repetition of the basic experiment. The experimenter would need to determine the number of times each treatment (combination) is to be observed - that is, how
many replications are to be performed. The purpose of replication is twofold. First, it serves to average out random sources of error, thereby lowering the error of the means which exemplify the results. Second, and more important, it supplies an estimate of error, without which it is impossible to evaluate the significance of the effects. Replication reflects sources of variability both between runs and within runs.

Blocking means that treatment comparisons must be made across homogeneous experimental units. Blocking is an explicit recognition by the experimenter of the presence of one or more nuisance factors affecting the response. The model that the experimenter uses to represent the data that come from an experiment with blocking will explicitly take into account potential block differences, and the analysis compares treatments only on uniform experimental material. More generally, the statistical procedures appropriate for experiments with blocking come to conclusions by accumulating evidence of treatment differences from the results of smaller experiments among uniform material that make up the entire experiment.

The third aspect of choice of experimental design is the determination of the manner in which the treatment combinations are randomized to the experimental units. Randomization prevents unrecognized factors from systematically confounding the results.

In summary, the completed experiment is specified by its treatment design, amount of replication (to achieve the experiment’s goals), use of blocking (to “balance” the effects of unrecognized nuisance factors), and manner of randomization of treatments to experimental units. The choice of these elements also helps determine the appropriate model for describing the experimental response.

These basic principles of statistical design of experiments have been adhered to in setting up this experiment. Replication has been performed by including multiple sections with the same treatment. Blocking has been effectively used to include nuisance factors, yet confound their effects. The role of randomization in this experiment is extremely important. By randomizing,
the effect of any nuisance factor that may influence the observed response variable is approximately balanced out.

### 4.4.1 Determining Sample Size

The next question is, “how many samples have to be tested in order to establish the significance of a definite difference, \( d \), between two sample means?” This question comes about because differences which are practically important are not in general statistically significant differences. One can always obtain greater precision in a mean by replicating it more and more. The sample size selected in this study should be sufficient to allow ODOT to perform a statistical analysis of the effect of the sealing operation on pavement condition and life.

Determining sample size is a very important issue because samples that are too large may waste time, resources and money, while samples that are too small may lead to inaccurate results.

Suppose one is willing to allow a margin of error \( d \), and a risk factor \( \alpha \) that the estimate of \( m \) will be off by a value \( d \). Since the sampling distribution of mean is “normal” for four or more measurements from almost every population distribution likely to be met in practice, one can ascertain the required sample size \( n \) if an estimate of the standard deviation of the population \( \sigma \) is available. The sample size can be obtained using the expression [11, 12]:

\[
    n = \left( \frac{z_{\alpha/2}^2 \cdot \sigma^2}{d^2} \right)
\]

The values for \( z_{\alpha/2}^2 \) can be obtained from the table of cumulative probability values for the standard normal distribution.

The Pavement Management Section of ODOT collects PCR data on all sections every year. The researchers used 1998 data, which was the most recent data available at the beginning of the research. Overall the standard deviation of the PCR was computed from 9599 records as equal to 5. This value can be considered the standard deviation of the population. There is no established
procedure to specify a value for the required precision $d$. Based on the general spread of the PCR data and experience from previous investigations, the researchers assumed it to be equal to 2.5. The above equation was used to determine the sample size $n$ required to estimate the mean PCR with a precision of ±2.5 and a reliability of 90%, as follows:

$$
\sigma = 5
$$

$$
d = 2.5
$$

$$
\alpha = 10\% \text{ or } 0.1, \alpha/2 = 0.05
$$

$$
z_{\alpha/2} = 1.65 \text{ (from the tables) [3]}
$$

$$
n = \frac{(1.65^2 \times 5^2)}{2.5^2} \approx 11 \text{ observations.}
$$

In other words, for a two-sided alternative hypothesis with a probability of 90%, the sample size required for each combination (set) of factors, to detect a change in pavement condition rating based on the observed standard deviation is 11. However, in the present study, the minimum sample size required was specified as equal to 12.

If the available sample size is less than 12, the resulting reliability will be reduced. Table 3 shows the level of reliability for sample sizes 12 and less.

**Table 3. Sample Size vs. Reliability**

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Reliability</th>
<th>Sample Size</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>92%</td>
<td>7</td>
<td>81%</td>
</tr>
<tr>
<td>11</td>
<td>90%</td>
<td>6</td>
<td>78%</td>
</tr>
<tr>
<td>10</td>
<td>88%</td>
<td>5</td>
<td>73%</td>
</tr>
<tr>
<td>9</td>
<td>86%</td>
<td>4</td>
<td>68%</td>
</tr>
<tr>
<td>8</td>
<td>84%</td>
<td>3</td>
<td>62%</td>
</tr>
</tbody>
</table>
4.5 Performing the Experiment

The field experiment included the following tasks:

- Developing criteria to establish test sections,
- Coordinating with the District, County and Central offices,
- Compiling a list of crack seal projects by contacting ODOT districts,
- Setting up test sections,
- Treating the test sections,
- Conducting field evaluations, and
- Developing a database.

In late 2000, the researchers, along with Pavement Engineering personnel, met with several district officials and county managers at their premises. These meetings were convened to provide the officials with information regarding the scope of the research and the type and extent of cooperation required from them. It was generally agreed to consider only flexible and composite pavements that the counties have included in their annual crack sealing program, and not to develop specific test sections for the study. The districts were asked to provide details of pavement sections included in their crack sealing program for the year 2000, as noted in Table 4.

**Table 4. Data Requested from ODOT Districts**

<table>
<thead>
<tr>
<th>County</th>
<th>Route</th>
<th>Begin Log</th>
<th>End Log</th>
<th>Year of Next Resurfacing</th>
<th>Composite/Flexible</th>
<th>PCR</th>
<th>Aggregate in Surface Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


4.5.1 Preliminary Selection of Test Sections

Using the information provided by participating district offices and counties, the researchers, often accompanied by ODOT personnel, visited the pavement sections and drove over the entire length of each project. Candidate test sections were selected using the following criteria:

- Pavement type: Should be either flexible or composite
- Pavement Condition: The pavement section should be fairly homogeneous between two mile markers, and
- Year of next resurfacing: The pavement section under consideration should not be included in the resurfacing program for at least five more years.

A comprehensive list of pavement sections intended for crack sealing in the year 2000, and satisfying the above criteria was prepared.

The pavement sections were divided into one mile long segments. Additional information for each section namely, current PCR, aggregate type, functional classification, geometric details, and climate was collected from the available records. The group number which each pavement section belongs to was identified, and was assigned a group number 1 through 12 as defined in Table 2. This completed the preliminary selection of the test sections. The sections were well scattered over the state as shown in Figure 3.
Figure 3  Crack Seal Effectiveness Study Locations

- Test Sections
- Dropped Sections
- resurfaced
- chip sealed
- all sections sealed
4.5.2 Layout of Test Sections

Initially, the researchers prepared a layout to set up one mile long test sections at each location with one half of the section receiving a crack seal treatment and the other half left untreated to serve as a control section. However, the ODOT pavement engineer suggested a different layout. According to this, one mile long sections would be divided into five subsections. In the first year, only subsection 1 would receive a crack seal treatment. Then, subsections 2, 3 and 4 would receive similar crack seal treatments in years 2, 3, and 4. Subsection 5 would be left unsealed. This procedure was suggested so as to study the effect of deferring crack sealing on pavement condition and life and to provide information on an estimate for the optimum time to seal cracks in pavements. This layout was approved by the technical evaluation team.

A typical layout of a test section is shown in Figure 4. After selecting the test sections, the researchers made paint markings on the pavement. Letters were sent to the respective counties with an attachment, Figure 5, which showed the exact location of the test sections, and provided guidelines as to how the counties should do the crack sealing. The counties were asked to crack seal only one subsection each year.

Often, on each route, two sections with similar attributes (each one mile long) were selected. On 2-lane highways, as illustrated in Figure 6, the gap between the two sections is varied from zero to five miles depending on site specific conditions. On 4-lane highways, the two sections are either on parallel lanes or in the same direction as on 2-lane highways.
Figure 4. Layout of Test Sections

Section ID: CLA 54

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crack Seal in Year 1</td>
<td>Crack Seal in Year 2</td>
<td>Crack Seal in Year 3</td>
<td>Crack Seal in Year 4</td>
<td>Do Not Crack Seal</td>
</tr>
<tr>
<td></td>
<td>1000 Ft.</td>
<td>1000 Ft.</td>
<td>1000 Ft.</td>
<td>1000 Ft.</td>
<td></td>
</tr>
</tbody>
</table>

Mile Marker 9                       Mile Marker 10
Figure 5. Guidelines to Counties

1. The following road section in your county has been selected as a test section to evaluate the effectiveness of crack sealing practices in Ohio.
2. The test section is approximately one mile long and is divided into 1000 ft. subsections.
3. We have marked begin and end of section on the road.
4. Please proceed with crack sealing the first 1000 ft. (between markers 0 and 1) in Year 2001 and leave the remaining length of the mile unsealed. You do not have to make any changes in the materials and application methods.
5. In the Year 2002, crack seal the 1000 ft. long section between markers 1 and 2.
7. The sign shop is preparing signs which we will install with your help to mark the sections.
8. We are only considering roads that will not be resurfaced till the Year 2006. So please let us know if there is a need for any additional maintenance and/or rehabilitation that may become necessary before 2006 on the section selected.
9. For additional details that you may need please contact Dr. Raj Arudi (513-556-2128) or Dr. Sam Minkarah (513-556-3691) at the University of Cincinnati or Aric Morse at 614-995-5994.

Section ID:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Crack Seal in Year 1</td>
<td>Crack Seal in Year 2</td>
<td>Crack Seal in Year 3</td>
<td>Crack Seal in Year 4</td>
<td>Do Not Crack Seal</td>
</tr>
<tr>
<td>1000 Ft</td>
<td>1000 Ft</td>
<td>1000 Ft</td>
<td>1000 Ft</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mile Marker

Mile Marker
Figure 6. Layout of Sections on 2-Lane and 4-lane Highways

2-Lane

Test Section

One Mile

Skip a mile or two

One Mile

Test Section

4-Lane

Test Section

Test Section
4.5.3 Crack Treatment of Test Sections

As noted in Section 3 and Appendix B, the crack sealing practices among counties varied considerably within ODOT. Since this research focused on evaluating the effectiveness of the existing practices, the researchers asked the county managers to use their usual practice to seal the cracks in the test sections with respect to timing of the treatment, types of cracks sealed, materials used, and placement procedures. However, the counties were also asked to keep proper documentation of the issues relating to construction, materials used, placement techniques, environmental conditions at the time of crack sealing, time required for each operation, type and quantity of material used, and cost of the operation. Figure 7 shows the type of crack seal treatment data provided by the counties for each test section.

4.5.4 Conducting Field Evaluations

Field investigation included collecting PCR data for each subsection in accordance with the ODOT’s Pavement Condition Rating Manual [7]. Because of the subjectivity in PCR data collection, the researchers met with the Pavement Management personnel and calibrated their data collection procedure. In the first year, the researchers collected PCR data on most of the sections. However, for future data collection, ODOT has dedicated one technician for this project. This technician will be collecting PCR data on all the test sections selected for this study in the state. This is a very important and critical decision made by ODOT because, using one rater for the entire period of research will eliminate any variation that may arise due to differences in the observations made by other raters.
<table>
<thead>
<tr>
<th>County: __________</th>
<th>Route: ________</th>
<th>Mile Marker From: _____</th>
<th>To: ______</th>
</tr>
</thead>
</table>

1. Date of crack sealing: __________

2. Pavement surface preparation
   - □ None
   - □ Sweep clean
   - □ Cold mill
   - □ Shot blast
   - □ Hot Air Lance
   - □ Others (specify) ________________________________

3. Temperature at time seal coat is applied
   - Air temperature: _____°F
   - Relative humidity, %: ______
   - Pavement temperature: _____°F

4. Condition of cracks before sealing:
   - □ Clean
   - □ Mostly clean
   - □ Somewhat dirty
   - □ Dirty

5. Surface moisture condition:
   - □ Dry
   - □ Mostly dry
   - □ Somewhat damp
   - □ Wet

6. Type of material used to seal cracks:
   - Brand Name: __________
   - Manufacturer’s Name: __________________________

7. Thickness of finished sealant
   - □ Crack overfilled
   - □ Recessed
   - □ Level with surface
   - □ Overband

8. □ Force Account
   - □ Contract

9. Cost Data:
   - Amount of material, pounds: _____
   - Material Cost: _____
   - Labor Cost: _____

---

**Figure 7. Crack Seal Data Provided by Counties**
PCR data have been collected on all test sections prior to crack sealing. In addition, roughness data, in terms of the International Roughness Index (IRI) have been compiled using the data available in ODOT’s inventory. Skid data are not available on all test sections. Hence, limited data have been collected on a few test sections. In each subsection, photographs of typical cracks at three locations have been taken for visual comparison of pavement condition. A typical photograph is presented in Figure 8. It is recommended that photographs are taken at these locations again after five years. These photographs may be used as an additional information to better understand the changes in conditions of cracks during a five year period. Digital images of these photographs are being stored in the database for immediate retrieval. Proper identification marks have been made on the pavement to enable ODOT engineers to locate the test sections in the future. Each photograph is stored in a separate file in JPG format. For easy identification, the photographs have been assigned file names which indicate county name (using three letter code), route number (three digits), mile marker from (three digits), mile marker to (three digits), year when photograph was taken (four digits), subsection number (1, 2, 3, 4, or 5), and crack location (A or B or C - A is the first representative crack from the beginning of subsection, B is the second and C is the third crack photographed in the subsection). The same information is imprinted on each photograph. The text on the photograph in Figure 8 provides the following information: Portage County, Route Number 305, mile marker from 5 to 6, year of photograph 2000, subsection 1, location A. The figure also indicates that the crack (1A) is at a distance of 257 feet from the beginning of the subsection.
Figure 8. Typical Crack Location
4.5.5 Finalizing the Experimental Plan

In summary, the two-year effort was instrumental in finalizing the statistical design of the experiment described above and resulted in the following:

1. Selection of test variables,
2. Selection of response variables,
3. Determination of the sample size (test sections) required for a given confidence level,
4. Developing layout of test section, and
5. Study period and work to be performed by ODOT to accomplish the desired objectives.

The test variables and their levels are listed in Table 1. This resulted in 12 distinct groups as listed in Table 2. The response variables are PCR, IRI and SN. The minimum sample size specified is 12 for a confidence level of 92%. If an adequate sample is not available, the confidence level will vary as shown in Table 3. The layout of the test sections is presented in Figure 4.

4.5.5.1 Proposed Duration of the Study

It was anticipated that, during the first year of study (2000 - 2001), the required number of test sections would be selected and will be treated, and during the second year (2001 - 2002), the researchers would monitor the condition of the test sections and develop a database. ODOT would then continue data collection efforts for up to five years after crack sealing and continuously update the database. Thus, by the end of 2006, all the data required for the analysis would be available. However, the layout of the test sections adopted in this study and the number of test sections that were available for crack sealing in 2000 - 2001 necessitated a change in the study period.
During the meetings with county managers, it was learned that in most cases, after crack sealing a pavement section, the counties do not perform any maintenance or rehabilitation activities in the coming five years. Because of this practice, this study proposed that the performance of the crack treated subsections be monitored for up to five years, after sealing. Figure 9 shows the proposed monitoring program. Since the control section will not receive any treatment, it will end up by being monitored for nine years. Therefore, adequate data will be available at the end of nine years (year 2009). The data collected can also lead to the development of deterioration curves as illustrated in Figure 9. Thus the data collection effort will continue for a period of five years after sealing the cracks in last subsection.

4.5.5.2 Availability of Test Sections

The test sections were selected from a list of pavement sections included by the ODOT districts in their crack seal program. In year 2000, pavement sections from ODOT districts 1, 2, 3, 4, 6, 7, 9, and 11 were available for inclusion in the research program. Districts 5 and 8 had many sections included in their plan for year 2001. The original plan was to set up all the test sections in the same year (year 2000) and to perform condition evaluation during the remaining period of research. However, a review of the total number of sections that were available in 2000 revealed that the research program needs additional sections to satisfy the statistical requirements. Hence, more test sections were included in 2001. This will extend the total study period to the year 2010. It should be realized that, if new sections are again added, the study period will be extended further.
<table>
<thead>
<tr>
<th>1000 ft</th>
<th>1000 ft</th>
<th>1000 ft</th>
<th>1000 ft</th>
<th>1280 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crack Seal in Year 1</td>
<td>Crack Seal in Year 2</td>
<td>Crack Seal in Year 3</td>
<td>Crack Seal in Year 4</td>
<td>Control Section</td>
</tr>
</tbody>
</table>

Each section monitored for five years after crack seal treatment to develop deterioration rate curves as shown below.

![Graph showing crack treated and control sections monitored years 1 through 9.]

Total monitoring period = 9 years

Figure 9. Total Study Period
5. CURRENT STATUS

In accordance with the objectives and scope of this research, the researchers have identified and set up test sections to statistically analyze the effectiveness of ODOT’s current crack sealing practices. The counties have sealed more than 90% of the test sections that were due to receive crack treatment. Field monitoring which includes collecting PCR data once a year is in progress. Additional data like IRI and Skid Number, wherever available, has been compiled. Table 5 provides a summary of the number of test sections available in each group.

Each selected section is approximately one mile long. Each section has five subsections and each subsection is one sample. After selecting the pavement sections, each subsection is assigned a group number 1 through 12 depending on the pavement type (flexible or composite), aggregate in the surface layer (limestone or gravel), and PCR level (<75, 75 to 85, >85). Often subsections within a mile belonged to the same group. It appears that, at present, a large sample size is available in certain groups (group number 1, 2, 4, 5, 8, 11). It should be recognized that during the course of this research, many sections are likely to be dropped for one reason or another. Over a period of one year, this study lost about 30 sections for various reasons like:

1. road deteriorated; county decided to rehabilitate;
2. road deteriorated to the point where the county does not intend to apply further crack sealing material;
3. more than one or complete section sealed by mistake.
Table 5. Matrix of Test Sections

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>FLEXIBLE</th>
<th></th>
<th></th>
<th></th>
<th>COMPOSITE</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LIME STONE</td>
<td>GRAVEL</td>
<td>LIME STONE</td>
<td>GRAVEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate in Surface Layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCR of Existing Pavement</td>
<td>&lt;75</td>
<td>75-85</td>
<td>&gt;85</td>
<td>&lt;75</td>
<td>75-85</td>
<td>&gt;85</td>
<td>&lt;75</td>
<td>75-85</td>
</tr>
<tr>
<td>Group Number</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Number of Available Test Sections</td>
<td>190</td>
<td>94</td>
<td>11</td>
<td>53</td>
<td>83</td>
<td>34</td>
<td>28</td>
<td>71</td>
</tr>
</tbody>
</table>
The purpose of having a large sample size (where available) is two fold: (i) To ensure an adequate sample size in the event of losing sections in the following years for one of the reasons mentioned above (particularly those with PCR < 75), and (ii) To make more data available for detailed investigation of certain nuisance factors. It is important that Table 5 be updated every year to reflect the changes in the number of sections available in each group. It is hereby suggested that ODOT makes every effort to retain the test sections selected as of now, and not to drop a section unless there is a compelling reason to do so. If the sample size is reduced, Table 3 can be used to estimate the confidence level for the obtained results. ODOT should carefully consider the need to replace the lost sections so as to maintain an adequate sample size, but such a procedure will extend the study period as discussed in Section 4.5.5.1.

6. INTERACTIVE DATABASE

This study will result in a large quantity of data that will be collected over several years. Hence software becomes necessary for handling the data. Accordingly, an interactive database has been developed to assist the ODOT in (i) data gathering, (ii) data storing, (iii) data processing, and (iv) data analysis. This database termed ODOT-ECS (Ohio Department of Transportation - Database to Evaluate Crack Sealing Practices in Ohio) is a comprehensive MS Windows based software developed in MS Visual Basic and MS Access. An overview of ODOT-ECS is given in Figure 10.
The software offers user friendly screens to enter data and to generate reports. Input to the system includes three basic modules namely (i) section description, (ii) crack seal data, and (iii) PCR data. Figures 11, 12 and 13 show the screen layout for each of these modules.

The location of the test section, geometric data, traffic count, pavement composition and climate are all entered in the section description module. County name, route, mile marker from and to, and subsection numbers are used to generated a unique section ID. A list box displays the list of test sections that are already in the database. Crack seal information like the date of crack seal, temperature at the time of placing the seal, type of material used, quantity of material and cost is entered in the crack seal data module. This screen also displays the PCR, IRI and SN for each year. PCR evaluation is made following ODOT’s procedure. PCR data entered for each year, for each test section, is stored in the database. It should be recognized that all entries made by the user, including severity and extent of individual distress, are stored in the database in addition to computed values of structural deduct and PCR. This is a very important requirement since such data can be used by ODOT at a later date to investigate the adequacy of PCR as an indicator and to initiate the development of a new index, if necessary. An important feature of the PCR evaluation module is the data entered for the previous years can be readily seen. The small panel on the right (Figure 13) shows the PCR value for section ADA05201701801 (Adams County, Route 52, Mile marker from 17 to 18, Subsection 1) for year 2002 as the data for the same section in year 2003 is being entered. It has been found this information is extremely helpful to the rater in correctly identifying the distresses and their severity and extent.
Figure 10. Overview of ODOT-ECS
Figure 11. Section Description Module
Figure 12. Crack Seal Data Entry Module
Figure 13. PCR Data Entry Module
Based on ODOT’s requirements, many reports are generated to do the following:

- Query reports with respect to a field variable,
- Generate matrix of test sections,
- Run ODOT’s GQL Query, and
- Generate helpful reports to track:
  - progress
  - problems
  - delays in crack treatment and/or sending information sheet
  - counties to contact

The pavement engineering division of ODOT has developed a training manual [10] to provide guidelines to the districts and counties and assist in the pavement preventive maintenance program. This manual outlines the logic for the selection of candidate sections for various preventive maintenance programs, including crack sealing. By using the General Query Language (GQL), the districts and counties can access the pavement management database and obtain a first cut list of candidate projects for all pavement maintenance treatments. The logic that has been used to construct the query is based on the experience of many engineers. The data collected in the present study can be used to objectively formulate the query and validate the process of selecting candidate projects. The ODOT-ECS system incorporates a feature to verify if the sections selected for this research meet the criteria developed when using GQL query. If the GQL logic changes in the future, those changes can be appropriately incorporated in this database software.
The reports are designed to help ODOT stay organized throughout the research period and to ensure the timely and proper collection of the required data. The participating counties have a critical role to play in this research. Communication and coordination between the counties and the research team is key to the success of this project. In the past there have been cases where some county forces have unknowingly crack sealed the entire test section or more than one subsection in a given year. The reports will help ODOT keep track of progress and potential problems and assist in organizing the research scheme.

When developing this database, the researchers consulted the pavement engineering personnel at every stage. The contents and performance of the database have been tested and validated by the ODOT personnel and all the data that have been collected in this research have already been entered into the database. In order to accomplish the objectives of this research, data collection efforts will continue till the year 2010. The ODOT-ECS database has been carefully designed to include all the data elements that will be required by ODOT to analyze the performance and cost effectiveness of its crack sealing practices.

Although 2010 is the time when all the data required will be collected, a considerable amount of data will be available by 2005 and every year since then. It is recommended that ODOT initiates analysis of data in 2005 so as to finalize a data analysis procedure and develop interim results. The data from future years can be used to refine the analysis and to develop proper guidelines for the establishment of crack sealing procedure as a preventive maintenance technique in the State of Ohio.
7. PROPOSED ANALYSIS OF DATA

This study has developed a procedure to systematically collect data to evaluate the effectiveness of crack sealing practices in Ohio. The data collected will be organized in twelve groups as shown in Table 2. The database, ODOT-ECS, will store all the data including the monitored data (before and after crack sealing), crack seal materials used and placement procedures. Control sections have been established to compare the performance of crack sealing with the do-nothing option. The purpose of this section of the report is to provide an overview of the analytical and statistical procedures that can be adopted by ODOT to analyze the extensive data that will become available in this study.

During a project review session it was agreed that, ODOT will continue to collect PCR data at each section, every year, during the remaining period of the project. However, IRI data may be collected every other year and skid data may be available only on a limited basis. Hence, the discussion below uses PCR as the performance indicator. If adequate amount of IRI and SN become available (or if ODOT develops a new indicator), a similar analysis procedure can be employed.

The intent of this report is only to discuss the data analysis procedures and not to perform an actual analysis of the data.

7.1 Treated sections vs. Control Sections - A Comparative Analysis

One of the most important uses of statistics is in testing for differences. If one wishes to know whether a crack treatment applied to a group X affects its performance, a statistical test is applied to the experimental results to see whether one is justified in concluding that there is a
difference between the PCR of the treated sections and the untreated (control) sections. The two alternative decisions that can be made are:

- The average PCR of a crack sealed section is greater than that of the control section
- There is no evidence to believe that the average PCR of a crack sealed section is greater than that of the control section

The decision procedure is a very logical one. Suppose, one wishes to test whether the test sections in group 1 that are crack sealed in year 2000 and the corresponding control sections have the same PCR, on the average, after five years. The PCRs of the crack sealed and the control sections in year 2005 are tabulated and compared to test the significance of the difference between them. The question that arises is ‘how large must this difference be in order to conclude that the two types differ, or that the observed difference is significant’?. This will depend on several factors: the amount of variability within each group; the number of sections in each group; and the risk that one is willing to take by stating that a difference exists when there is really none. Using the data stored in the ODOT-ECS database, in conjunction with a statistical package, a comparative analysis of each of the 12 groups can be made. A technique of statistical inference called **hypothesis testing** (also called **significance testing**) can be used to assist the experimenter in comparing two formulations. Hypothesis testing allows an objective comparison of the two formulations to be made on objective terms, with a knowledge of the risks associated with reaching the wrong conclusions. Hypothesis testing is a method of inferential statistics. An experimenter starts with a hypothesis about a population parameter called the null hypothesis. Data are then collected and the viability of the null hypothesis is determined in light of the data. If the data are
very different from what would be expected under the assumption that the null hypothesis is true, then the null hypothesis is rejected. If the data are not greatly at variance with what would be expected under the assumption that the null hypothesis is true, then the null hypothesis is not rejected. Failure to reject the null hypothesis is not the same thing as accepting the null hypothesis.

7.2 Comparing Groups

The comparative analysis procedure can be extended to compare average PCR values of any two groups to ascertain if they differ in their average performance. By successively comparing groups, it is possible to investigate the effect of design factors included in the study. For example, one may wish to know if the type of aggregate in the surface layer induces an effect on the PCR value. By comparing group 1 with group 4 and group 7 with group 10 (please see Figure 14), it is possible to investigate the effect of type of aggregate in flexible and composite pavements.

Figure 14. Tree Diagram of Design Factors and Groups
By carefully following this procedure, it is possible to compare each successive group shown in the tree diagram (Figure 14) to systematically estimate the effect of the following factors:

- Pavement type
- Type of aggregate in the surface layer
- PCR of pavement prior to crack seal.

A similar analysis can also be performed to evaluate the effect of the following variables on the performance effectiveness of crack sealing:

- Materials and placement procedures
- Climate
- Traffic, and
- Functional classification of pavement

Please note that, although three groups of PCR has been considered as shown in Figure 14, the database will allow the analyst the flexibility to select any number of groups with varied incremental PCR value for the analysis. In other words, the PCR groups can be selected such that it will not hamper the ability to determine the optimum PCR at which to crack seal.

7.3 Performance Effectiveness

Several studies carried out in the past show many benefits that accrue from crack sealing namely, (i) improved serviceability, (ii) deferred major and/or minor rehabilitation or reconstruction program, (iii) lower life cycle cost, and (iv) a reduction in user delays and inconveniences [13, 14, 15, 16, 17]. There are also studies which suggest no benefits from crack
Some of the common methods of computing performance effectiveness employed in these studies are discussed below.

Pavement performance curves can be used to describe how pavement conditions change with time and/or traffic. Performance has been expressed by many as the area under the performance curve (Figure 15). Performance effectiveness can be described as the difference in the area under the performance curve for a crack treated pavement and that of a control section.

Effectiveness has also been expressed as the ratio (or percentage) of PCR of crack sealed and control sections, as illustrated below:

\[
\text{Effectiveness} = \frac{\text{PCR of crack sealed section}}{\text{PCR of control section}}
\]

It is possible that the effectiveness ratio for a pavement changes every year, indicating that effectiveness is maximum at some time during the analysis period. The performance effectiveness may also be expressed as the PCR gain, as shown below:

\[
\text{Performance Effectiveness} \text{(at time t)} = \frac{\text{PCR at time t after crack seal} - \text{PCR before crack seal}}{\text{PCR before crack seal}}
\]
Figure 15. Quantifying Pavement Performance
The extension of the remaining service life of pavements can also be used as an indicator of performance effectiveness of crack sealing. The data from this study can be adequately used to verify whether crack sealing extends the service life. In order to do this, the first step is to develop deterioration curves, also called performance curves, for crack sealed pavements and compare them with those of control sections, as illustrated in Figure 16. The deterioration curves can be developed using field data collected on pavement sections for a period of five years or more. These curves will need to be extrapolated to determine the time when they reach a threshold value. If the difference in this time period for the two pavements is significant, then crack sealing is said to be effective. Figure 16 describes this concept.

Developing deterioration curves is an important step in the study of performance effectiveness of ODOT’s crack sealing practices. Using the data collected over several years, ODOT can develop a family of curves for each group of pavements considered in this study. An illustration of this concept is presented in Figure 17. Considerable effort is needed to develop the curves shown in this figure. To begin with, the pavements are divided into three families depending on PCR before crack sealing namely, PCR < 75, PCR 75 to 85, PCR > 85. Each family contains four groups of pavements and corresponding control sections. It should be recognized that each group may have its own control section. However, for the sake of illustration, only one control section for four groups of pavements is shown in Figure 17. Using regression techniques, PCR data can be statistically analyzed to develop deterioration curves. Performance effectiveness can then be measured using one of the procedures discussed above. The curves can also be extrapolated to a threshold PCR to predict the remaining service life. In this illustration, it is assumed crack sealing results in an increase of PCR and the pavements that are treated generally
perform better than control section. However, physical data is required to verify this assumption.

In summary, a study of performance effectiveness can help to:

• Evaluate the effect of crack sealing on pavement serviceability,
• Estimate the effect of crack sealing on remaining service life,
• Develop deterioration curves,
• Identify optimal timing of treatment, and
• Objectively evaluate performance effectiveness

7.4 Cost Effectiveness

A number of economic analysis methods are applicable to the evaluation of crack sealing practices. They can be categorized as follows:

• Equivalent uniform annual cost method often termed the “annual cost method”
• Present worth method for
  \( S \) costs, or
  \( S \) benefits, or
  \( S \) benefits minus costs, usually termed the “net present value method”
• Rate-of return method
• Benefit-cost-ratio method
• Cost-effectiveness method
Y1 = Remaining life of control section
Y2 = Remaining life of crack sealed pavement
Y2 – Y1 = Extension of life due to crack sealing

Figure 16. Quantifying Pavement Performance
Figure 17. Deterioration Rate Curves for individual groups

- Control Section: PCR > 85
  - Group 1: Flexible/Lime Stone
  - Group 4: Flexible/Gravel
  - Group 7: Composite/Lime Stone
  - Group 10: Composite/Gravel

- Control Section: PCR 75-85
  - Group 2: Flexible/Lime Stone
  - Group 5: Flexible/Gravel
  - Group 8: Composite/Lime Stone
  - Group 11: Composite/Gravel

- Control Section: PCR < 75
  - Group 3: Flexible/Lime Stone
  - Group 6: Flexible/Gravel
  - Group 9: Composite/Lime Stone
  - Group 12: Composite/Gravel
An excellent review of these methods can be found in References 19 and 20. There are several basic considerations in selecting the most appropriate method. When the benefit/cost approach is used, benefit is typically estimated as the extension of life due to a particular treatment. The cost of the treatment, in terms of initial cost or life cycle cost, is used to determine the benefit/cost ratio. The recommended treatment is then identified as the treatment that provides the highest ratio. The benefits imparted to the pavement as a result of the treatment have to be evaluated to determine if they are cost-effective compared to the do nothing option (the control sections).

Many agencies use the cost effectiveness method to compare alternative strategies. This method requires the agencies to calculate some form of performance effectiveness, mentioned in Section 7.3, to evaluate one treatment over another. Cost effectiveness calculations are made as a simple ratio of effectiveness divided by cost. Typical costs included in such calculations are cost of actual work and user delays.

The discounted cash-flow analysis methods are the most common: present worth, annualized, and rate-of-return. Life-cycle cost analysis is a specialized method that is particularly applicable, because different maintenance treatments exhibit different life spans. The purpose of life-cycle costing is to find the maintenance and rehabilitation option with the lowest net cost. The implementation of life-cycle cost analyses of pavements requires an approach referred to as "demand-responsive", in that maintenance, rehabilitation, or reconstruction are viewed as responses to the demand for repair or renewal of the facility. With these models the highway agencies would be in a position to compare the costs of competing options.
The equivalent uniform annual cost (EUAC) method was used in the analysis by many agencies [19, 20, 21, 22], which indicated that preventive maintenance treatments applied to pavements in good condition were the most cost-effective.

7.5 Comments on Proposed Analysis Procedures

The primary focus of this research is to evaluate the effectiveness of ODOT’s existing crack sealing practices. Effectiveness means doing the right thing efficiently. To evaluate effectiveness, measures of effectiveness are needed. The above sections outlined several methods commonly used by various highway agencies for the performance and cost evaluation of pavement maintenance and rehabilitation alternatives. The choice of a particular method, however, depends on several factors including what method best suits the requirements of a particular agency. It should be recognized that the measures of effectiveness have no physical meaning in general. Instead, they provide a relative comparison of various treatments on a common scale. In most cases, the measure of effectiveness selected would indicate relative performance of two treatments. For example, crack sealing in flexible pavements may result in an extension of the remaining life by two years. In other words, the untreated sections may warrant some action two years earlier than the treated sections. In this case, additional life is the measure of effectiveness. But the question is ‘how significant is this difference?’ or ‘is this treatment considered effective?’. From the practical or engineering standpoint, it is necessary for ODOT to establish an appropriate measure of effectiveness and an acceptable value that can be considered significant.
8. ADEQUACY OF PCR TO MEASURE CHANGES DUE TO CRACK SEALING

The role of a performance measure is to objectively measure the efficiency and effectiveness of the system under investigation. The desirable qualities of a performance measure are:

- easy-to-measure,
- easy to use, and
- comprehensive.

ODOT’s PCR provides an index reflecting the composite effects of varying distress types, severity, and extent upon the overall condition of the pavement [7]. The list of distresses measured to arrive at the PCR are shown in Table 6.

Table 6. Distresses Used to Generate ODOT’s PCR

<table>
<thead>
<tr>
<th>Flexible Pavements</th>
<th>Composite Pavements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raveling</td>
<td>Raveling</td>
</tr>
<tr>
<td>Settlements</td>
<td>Settlements</td>
</tr>
<tr>
<td>Bleeding</td>
<td>Bleeding</td>
</tr>
<tr>
<td>Corrugations</td>
<td>Transverse Cracks, Unjointed Base</td>
</tr>
<tr>
<td>Patching</td>
<td>Patching</td>
</tr>
<tr>
<td>Wheel Track Cracking</td>
<td>Joint Reflection Cracks, Jointed Base</td>
</tr>
<tr>
<td>Potholes/Debonding</td>
<td>Surface Disintegration/Debonding</td>
</tr>
<tr>
<td>Block and Transverse Cracking</td>
<td>Intermediate Transverse Cracks, Jointed Base</td>
</tr>
<tr>
<td>Crack Sealing Deficiency</td>
<td>Longitudinal Cracking</td>
</tr>
<tr>
<td>Longitudinal Joint Cracking</td>
<td>Rutting</td>
</tr>
<tr>
<td>Rutting</td>
<td>Pumping</td>
</tr>
<tr>
<td>Edge Cracking</td>
<td>Pressure Damage/Upheaval</td>
</tr>
<tr>
<td>Random Cracking</td>
<td>Shattered Slab</td>
</tr>
<tr>
<td></td>
<td>Crack Sealing Deficiency</td>
</tr>
</tbody>
</table>
The PCR is computed as equal to 100 minus the deduct point for each observed distress. Deduct points are a function of distress type, severity and extent.

A cursory look at the distresses in Table 6 would indicate that not all of these distresses relate to cracks. In other words, crack sealing will not bring about changes in non-crack associated distresses. To illustrate this, consider the example shown in Table 7.

This example shows a pavement condition survey on a flexible pavement section, rated in accordance with ODOT’s Pavement Condition Rating Manual [7]. Two sets of data are shown - one set before crack sealing and the other a few months after crack sealing. For each of the observed distresses, the severity and extent of the distresses are recorded. Deduct points for each observed distress are also shown.

The PCR for the section before crack sealing is 67. After crack sealing, the sections gain five points because the ‘crack sealing deficiency’ does not exist any more. If all other distresses remain at the same extent and severity level, the PCR should be equal to 72. However, the severity and extent of raveling and rutting increased, resulting in a net loss of 6-PCR points. Hence, the PCR of the section is 66.

This value suggests that, crack sealing did not improve the condition of the pavement; instead, the PCR decreased by one point. It should be recognized that, crack sealing in general helps to hold the existing cracking distresses at the same level but would not reduce the severity or the extent.

Let us consider deduct points associated only with cracking distresses. The total deduct points before crack sealing is 24, while it is 19 after crack sealing. Thus if we develop an index that considers only cracking distresses, perhaps, it would allow the analyst to evaluate the
effectiveness of crack sealing on a rational basis. Hence, it is important to verify the adequacy of the PCR as an index to evaluate the effectiveness of crack sealing and to develop a new index that comprises of cracking distresses only. The database will store individual distress data along with the severity and extent values. This allows the researchers the flexibility to consider relevant distresses including base related and moisture related distresses, in addition to cracking distresses, in the development of new cracking index.

**Table 7. Illustration of PCR Data**

(Note: For the distress weights and other details, please see Reference 7)

<table>
<thead>
<tr>
<th></th>
<th>Flexible Pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Crack Seal</td>
</tr>
<tr>
<td></td>
<td>Severity</td>
</tr>
<tr>
<td>Raveling</td>
<td>M</td>
</tr>
<tr>
<td>Bleeding</td>
<td></td>
</tr>
<tr>
<td>Patching</td>
<td></td>
</tr>
<tr>
<td>Potholes/Debonding</td>
<td></td>
</tr>
<tr>
<td>Crack Sealing Deficiency</td>
<td>L</td>
</tr>
<tr>
<td>Rutting</td>
<td>L</td>
</tr>
<tr>
<td>Settlements</td>
<td></td>
</tr>
<tr>
<td>Corrugations</td>
<td></td>
</tr>
<tr>
<td>Wheel Track Cracking</td>
<td>M</td>
</tr>
<tr>
<td>Block and Transverse Cracking</td>
<td>M</td>
</tr>
<tr>
<td>Longitudinal Joint Cracking</td>
<td>M</td>
</tr>
<tr>
<td>Edge Cracking</td>
<td>L</td>
</tr>
<tr>
<td>Random Cracking</td>
<td>L</td>
</tr>
<tr>
<td>PCR</td>
<td></td>
</tr>
<tr>
<td></td>
<td>67</td>
</tr>
</tbody>
</table>
9. SUMMARY

The primary objective of this study was to design and develop a project to statistically evaluate the cost-effectiveness of ODOT’s current crack sealing program. The UC researchers have worked closely with the ODOT engineers for two years and have established a field experiment. This experiment is designed to help ODOT collect data so as to objectively investigate the effectiveness of its crack sealing practices. The experimental plan has been carefully designed to obtain statistically valid conclusions. The design of experiment included several tasks namely, identification of experimental variables, determining sample size required, defining a measure of effectiveness, selection of test sections, conducting field studies, determining type and frequency of data to be collected, and developing a database. The researchers have also established the duration of the study during which data collection will be made. The project will now be handed over to ODOT. ODOT will continue collecting data which can be used to address the following specific issues:

- Do existing crack sealing practices within ODOT enhance pavement performance?
- Are crack sealing practices cost beneficial?
- What is the optimum timing for treatment?

The test sections selected for this study are scattered all over the state. Each section is a mile long. Each one of these sections is divided into five subsections. The counties have been requested to crack seal one subsection each year and to leave the fifth subsection unsealed, to be used as a control section. This procedure puts a tremendous responsibility on the county managers. They have to maintain the test sections according to the guidelines given to them by the research
team, make sure they crack seal one subsection every year and, communicate with the Office of Pavement Engineering on a regular basis throughout the research period. Based on the interactions with district and county officials in the last two years, the researchers conclude that these officials have displayed a high level of interest and involvement in this research. Their active participation and continued cooperation are key to the success of this research.

A question that frequently came up during the project review sessions was - ‘should we add new sections to the program?’ A review of a number of available sections shows that, at present, there is a sufficient number of test sections in each group to generate statistically valid conclusions. However, this scenario may change with time if some sections are dropped as discussed in Section 5. The consequences of adding new sections are that the study period will be extended further. It is strongly recommended to focus all efforts on retaining the existing test sections. It is also extremely important to develop a specific data analysis program using the data already collected so as to ensure appropriateness, reliability and validity of the data.

An important issue that deserves immediate attention is the development of an appropriate indicator for the evaluation of effectiveness of crack sealing. Sufficient data has been collected in order to initiate and complete this task. A detailed analysis of data using mathematical and statistical techniques that will involve parametric analysis is needed to develop an indicator. The best approach is to develop an indicator using the data already collected and validate the same using future data. This indicator will be used by the ODOT ultimately to evaluate the performance and cost effectiveness of its crack sealing practices.
10. REFERENCES


5. Supplemental Specification 925, Hot Applied Crack Sealant Material, State of Ohio, Deptment of Transportation, September 1999


APPENDIX A

Questionnaire to Review Existing Crack Sealing Practices in Ohio

County: _______________________

Person completing form: _______________________

Person’s Phone No.: _______________________
Fax No.: _______________________

Person’s e-mail address: _______________________

(Please check one or more of boxes or enter information on each line as applicable)

1. Time of the year when crack sealing is routinely performed

   From __________ to __________

   From __________ to __________

   Comments: ______________________

2. Pavement surface preparation

   G None       G Sweep clean       G None G Cold mill       G Shot blast

   G Others (specify) ______________________

   Comments: ______________________

3. Ambient conditions at time seal cost is applied

   Air temperature       Low _____°F       High _____°F

   Relative humidity, % Low _____°F       High _____°F

   Comments: ______________________
4. **Pavement condition when seal is applied**

Pavement temperature  Low   ____°F  High   ____°F

Surface condition before sealing:

G Clean   G Mostly clean   G Somewhat dirty   G Dirty

Surface moisture condition:

G Dry   G Mostly dry   G Somewhat damp   G Wet

Comments: __________________________________________

5. **Average severity of cracks sealed**

G Low   G Moderate   G High   G All

Comments: __________________________________________

6. **Type of cracks sealed**

G Alligator   G Edge   G Block   G Longitudinal

G Reflection   G Transverse   G All

Comments: __________________________________________

7. **Type of material used to seal cracks**

a. __________________________________________

b. __________________________________________

c. __________________________________________

d. __________________________________________

Comments: __________________________________________

8. **Information on routing**

G Transverse cracks routed   G Diagonal cracks routed
GLongitudinal cracks routed  GNot done

Comments: ____________________________________________________________

9. **Dimensions of crack or routed reservoir** (if applicable)
   
   Width (inches): Minimum _____  Maximum _____  Mean _____
   Depth (inches): Minimum _____  Maximum _____  Mean _____

   Comments: ____________________________________________________________

10. **Condition of crack just prior to sealing**
    
    GClean    GDry    GHot air lance used
    GAsphalt around crack charred after heating

    Comments: ____________________________________________________________

11. **Thickness of finished sealant**
    
    GCrack overfilled  GRecessed  GLevel with surface  GOverband

    Comments: ____________________________________________________________

12. **If you use more than one method or material for sealing cracks, please indicate your preference:**

    ________________________________________________________________

13. **Does your county seal cracks with your own forces**
    
    GYes    GNo    GSometimes

    Comments: ____________________________________________________________
14. Does your county use contract crack sealing
   G Yes   G No   G Sometimes

   Comments: ____________________________________________________________

15. Approximately how many lane miles were crack sealed last year in your county
   _______ Lane miles

16. Approximately how many lane miles do you expect to be crack sealed in calendar year 1999?
   _______ Lane miles

17. Would you be willing to participate in this study?
   G Yes   G No   G May be

   Comments: ____________________________________________________________

   (Participation in this study would require the county to set aside certain lengths (control sections, approximately 500 feet) of pavement within a crack sealing project which would not receive any crack sealing. A commitment to preserving these sections by not crack sealing is essential)

18. Name of contact: ______________________   Telephone: ________________

   E-mail address: ______________________
1) **TIME OF YEAR WHEN CRACK SEALING IS ROUTINELY PERFORMED**

![Bar Chart](image)

**TIME OF YEAR WHEN CRACK SEALING IS ROUTINELY PERFORMED**

<table>
<thead>
<tr>
<th>MONTHS</th>
<th>NO. OF COUNTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>21</td>
</tr>
<tr>
<td>Feb</td>
<td>20</td>
</tr>
<tr>
<td>Mar</td>
<td>26</td>
</tr>
<tr>
<td>Apr</td>
<td>31</td>
</tr>
<tr>
<td>May</td>
<td>21</td>
</tr>
<tr>
<td>Jun</td>
<td>12</td>
</tr>
<tr>
<td>Jul</td>
<td>5</td>
</tr>
<tr>
<td>Aug</td>
<td>6</td>
</tr>
<tr>
<td>Sep</td>
<td>25</td>
</tr>
<tr>
<td>Oct</td>
<td>28</td>
</tr>
<tr>
<td>Nov</td>
<td>32</td>
</tr>
<tr>
<td>Dec</td>
<td>24</td>
</tr>
</tbody>
</table>
2) PAVEMENT SURFACE PREPARATION

![Bar Chart showing the number of counties using different surface preparation methods:]

- **None**: 16 counties
- **Sweep Clean**: 10 counties
- **Shot Blast**: 4 counties
- **Heat Lance**: 6 counties
- **Air Compressor**: 26 counties
3) AMBIENT CONDITIONS AT THE TIME WHEN COAT IS APPLIED

![Ambient Conditions Diagram]
4) **PAVEMENT CONDITION WHEN SEAL IS APPLIED**

![Pavement Temperature Chart]

- **NO. OF COUNTIES**
- **TEMPERATURE**
4) PAVEMENT CONDITION WHEN SEAL IS APPLIED

**Surface Condition Before Sealing**

<table>
<thead>
<tr>
<th>Condition</th>
<th>No. of Counties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean</td>
<td>12</td>
</tr>
<tr>
<td>Mostly Clean</td>
<td>33</td>
</tr>
<tr>
<td>Somewhat Dirty</td>
<td>2</td>
</tr>
</tbody>
</table>

**Surface Moisture Condition**

<table>
<thead>
<tr>
<th>Condition</th>
<th>No. of Counties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>30</td>
</tr>
<tr>
<td>Mostly Dry</td>
<td>19</td>
</tr>
<tr>
<td>Somewhat Damp</td>
<td>2</td>
</tr>
</tbody>
</table>
5) AVERAGE SEVERITY OF CRACKS SEALED

![Bar Chart]

- **Low**: 4
- **Moderate**: 24
- **High**: 9
- **All**: 15

**AVERAGE SEVERITY OF CRACKS**

**NO. OF COUNTIES**

**TYPE**

Low | Moderate | High | All
6) TYPES OF CRACKS SEALED

![Bar chart showing the number of counties sealed for different types of cracks.](Image)

- **Alligator**: 4
- **Edge**: 17
- **Block**: 6
- **Longitudinal**: 22

![Bar chart showing the number of counties sealed for different types of cracks.](Image)

- **Reflection**: 12
- **Transverse**: 21
- **All**: 22
7) TYPE OF MATERIAL USED TO SEAL CRACKS

![Bar Chart: Type of Material Used to Seal Crack]

- Material: [List of materials and their corresponding counts]
8) INFORMATION ON ROUTING

![Bar Chart: Information on Routing]

- Longitudinal Cracks: 2
- Transverse Cracks: 1
- Not Done: 37

**No. of Counties**

**Type**
9) **DIMENSIONS OF CRACK OR ROUTED RESERVOIR (IF APPLICABLE)**

**DIMENSIONS OF CRACK (WIDTH - MIN)**

<table>
<thead>
<tr>
<th>INCHES</th>
<th>NO. OF COUNTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8&quot;</td>
<td>6</td>
</tr>
<tr>
<td>1/4&quot;</td>
<td>11</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>2</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>1</td>
</tr>
</tbody>
</table>

**DIMENSIONS OF CRACK (WIDTH - MAX)**

<table>
<thead>
<tr>
<th>INCHES</th>
<th>NO. OF COUNTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4&quot;</td>
<td>6</td>
</tr>
<tr>
<td>1&quot;</td>
<td>5</td>
</tr>
<tr>
<td>1.5&quot;</td>
<td>4</td>
</tr>
<tr>
<td>2&quot;</td>
<td>4</td>
</tr>
<tr>
<td>2.5&quot;</td>
<td>1</td>
</tr>
</tbody>
</table>
9) **DIMENSIONS OF CRACK OR ROUTED RESERVOIR (IF APPLICABLE)**

**DIMENSIONS OF CRACK (DEPTH - MIN)**

- No. of Counties
- INCHES:
  - 1/8" 2
  - 3/16" 1
  - 1/4" 2
  - 1/2" 4
  - 3/4" 1
  - 1" 7
  - 1.5" 1

**DIMENSIONS OF CRACK (DEPTH - MAX)**

- No. of Counties
- INCHES:
  - 1" 2
  - 1.5" 2
  - 2" 6
  - 3" 5
  - 4-6" 1
10) CONDITION OF CRACK PRIOR TO SEALING

![Bar Chart]

**CONDITION OF CRACK PRIOR TO SEALING**

- **Clean**: 31
- **Dry**: 38
- **Hot Air Lance**: 11

**METHOD**

---

79
11) THICKNESS OF FINISHED SEALANT

![Bar chart showing thickness of finished sealant types.]
13) **DOES YOUR COUNTY SEAL CRACKS WITH YOUR OWN FORCES**

![Bar Chart](chart.png)

- **Yes**: 39
- **No**: 1
- **Sometimes**: 5

**Method**

**No. of Counties**
14) **DOES YOUR COUNTY USE CONTRACT CRACK SEALING**

![Bar chart showing the number of counties using contract crack sealing methods: 7 counties use it, 29 counties do not use it, and 8 counties use it sometimes.](image-url)
17) **WOULD YOU BE WILLING TO PARTICIPATE IN THIS STUDY**

![Bar chart showing the replies to the question: Yes 23, No 12, Sometimes 8.

Number of Counties: 30

Responses:
- Yes: 23
- No: 12
- Sometimes: 8

Replies: Yes, No, Sometimes.
18) IF YOU WERE ASKED TO INCLUDE METHODS AND MATERIALS FROM ANOTHER COUNTY AS A PART OF A TEST SECTION WOULD YOU BE WILLING TO DO SO

IF YOU WERE ASKED TO INCLUDE METHODS AND MATERIALS FROM ANOTHER COUNTY AS A PART OF A TEST SECTION WOULD YOU BE WILLING TO DO SO

<table>
<thead>
<tr>
<th>replies</th>
<th>No</th>
<th>Maybe</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
<td>22</td>
<td>13</td>
</tr>
<tr>
<td>no</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

NO. OF COUNTIES