INFRAME

INFRASTRUCTURE MANAGEMENT AND ENGINEERING

EFFECTIVENESS OF CRACK SEALING ON PAVEMENT SERVICEABILITY AND LIFE

FINAL REPORT

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16. Abstract:

This report presents the details of a study to evaluate effectiveness of Ohio Department of Transportation's prevailing crack sealing program. Evaluation was performed through field monitoring a large number of crack sealed and control sections. Field monitoring included collection of performance data for over five year period after crack sealing. The data collected was used to address the following specific issues:

- Do existing crack sealing practices within ODOT enhance pavement performance?
- What is the optimum timing of the treatment?
- Does crack sealing extend pavement life?
- Is crack sealing a cost effective treatment?

The analysis revel that crack sealed pavements, in general, performed better than the control sections on a 5-year cycle. Regardless of pavement type, aggregate type used in the surface layer, and the prior pavement condition crack sealing always results in performance gain. Maximum performance gain can be achieved by treating pavements with Pavement Condition Rating ranging from 66 to 80. The performance prediction models indicate crack sealing treatment can extend the service life of pavements by up to 3.6 years. The cost analysis using a common metric such as the Net Present Value illustrates that crack sealing, as a maintenance strategy, is economically viable for pavements in the prior PCR range of 66-70. From a practical point of view, it is hereby recommended that ODOT develops a policy to allow crack sealing as a strategy for pavement preventive maintenance for all pavements in the prior PCR range of 66 to 80.

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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 type and severity of cracks sealed, the extent of crack sealing on a given pavement and 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, and availability of operating funds. Figure 1 shows crack sealing operation while Figures 2 through 4 show typical crack sealed pavements to illustrate various types of cracks and the extent of cracks sealed.

Cleaning cracks with compressed air | Placing hot sealant with a squeeze (wand) | Finished Seal

Figure 1. Crack Sealing Operation

A successful crack sealing job can result in many benefits including substantial life cycle cost savings, improved customer service, and better system-wide performance. However, crack sealing may also have adverse effects on the pavement in many ways such as, tracking of sealing material by tire action, reduced skid resistance, and a rougher pavement. Crack sealing is deemed beneficial if pavement life is increased while maintaining safety and serviceability.

Figure 2. Extensive Crack Sealing in Flexible Pavements

Figure 3. Sealing High Severity Cracks

Figure 4. Sealing Reflection Cracks in Composite Pavements

In March 2000, ODOT developed a project in association with the University of Cincinnati (UC) to 'design a project to statistically verify the effectiveness of ODOT's current crack sealing program on pavement condition and life'. The primary intent of the study was 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. During the period 2000 through 2002, the UC researchers worked with ODOT engineers, district highway managers and county managers to initiate this project. The study led to setting up of over 700 test sections (each 1000' long), conducting preliminary pavement condition evaluations, and establishment of guidelines for further monitoring. A report for Phase 1 study [1] was submitted to ODOT describing the details of the work performed and guidelines for future monitoring.

Following the Phase 1 study, ODOT continued to monitor the performance of the experimental sections for an additional eight years. In the meantime, in 2008, ODOT initiated Phase 2 study. The purpose of Phase 2 study was to review the data being collected and to develop a methodology to comprehensively process and analyze the long-term performance monitoring data. The present report describes the details of the efforts performed during the Phase 2 study and includes a description of the data collection procedures, analysis procedure, results derived, performance and cost benefits of ODOT's prevailing crack sealing program, conclusions, recommendations, and guidelines for implementation of specification changes. In order to provide continuity from Phase 1, this report includes excerpts from Phase-1 report such as, a brief description of the experimental plan, testing and evaluation. The Phase-1 report presents a review of literature and the same is not repeated in this report.

2. OBJECTIVES AND SCOPE

The primary focus of this research is to evaluate the effectiveness of crack sealing procedures currently practiced in Ohio. The study does not concentrate on crack sealant material type and application methods, but rather on the effectiveness of sealing in general on overall pavement performance. This research included setting up test and control sections, and conducting pavement condition evaluations for the long term monitoring of these sections. The data collected was used to address the following specific issues:

- Do existing crack sealing practices within ODOT enhance pavement performance?
- If so, what is the optimum timing for treatment?
- Does crack sealing extend pavement life?
- Does crack sealing provide cost benefit? If so, to what extent?

3. REVIEW OF EXISTING CRACK SEALING PRACTICES IN OHIO

The study began with a survey of ODOT's county managers and district officials. A 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 cracks sealed, time of sealing, and their willingness to participate in a study to evaluate the effectiveness of crack sealing program. Forty six county managers responded to the survey. By summarizing the survey forms, the following observations were made:

- The counties perform crack sealing during the Fall, Winter and Spring months;
- Compressed air is commonly used for crack preparation;
- The pavement temperature when the seal is applied normally varies from 40^0F to 100^0F;
- The counties 'mostly clean' the pavement surface and keep the surface 'dry' before placing

the crack seal;

- The counties treat cracks of all severity (low, moderate and high). However, a greater number of counties treat only 'moderate' cracks;
- The types of cracks sealed include alligator, edge, block, longitudinal, reflection, and transverse cracks;
- A range of materials are used for crack sealing. MC-3000 stands out as the most widely used material;
- Routing is not done prior to crack sealing;
- The finished sealant is predominantly 'level with surface' or 'overband';
- The counties perform crack sealing using their own forces. The counties rarely outsource this work to contractors;
- The county managers who responded to the survey were willing to participate in this study to systematically evaluate the effectiveness of crack sealing practice.

This information was used to develop a 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, and the availability of sections.

4. DESIGN OF EXPERIMENT

Following the review of crack sealing practices in Ohio, discussions were held with the technical evaluation team. Several tasks, as mentioned below, to assist in the design and development of the experiment were finalized:

- Identification of experimental variables,
- Compiling a list of crack seal projects,

- Setting up layout of test sections,
- Crack treatment of test sections,
- Conducting field evaluations,
- Determining sample size required,
- Defining a measure of effectiveness,
- Determining type and frequency of data to be collected,
- Developing a database,
- Developing guidelines for monitoring.

4.1 Identification of Experimental Variables

Based on a review of variables that are known to affect the pavement performance in general, and the field variables that may have historically influenced the performance of Ohio's crack sealed pavements in particular, the following three variables, designated as primary factors, were included in the field experiment:

- Pavement type (flexible and composite),
- Type of aggregate in the surface layer (gravel and limestone), and
- Pavement Condition Rating, PCR (<75, 75-85, >85)

A schematic of the experimental variables is presented in Figure 5. The primary variables are the factors which exercise considerable influence on the outcome; they are actually selected for study in the experiment. A matrix of design factors used in the experiment is shown in Table 1. A group number was assigned to each set of factors as illustrated in the table.

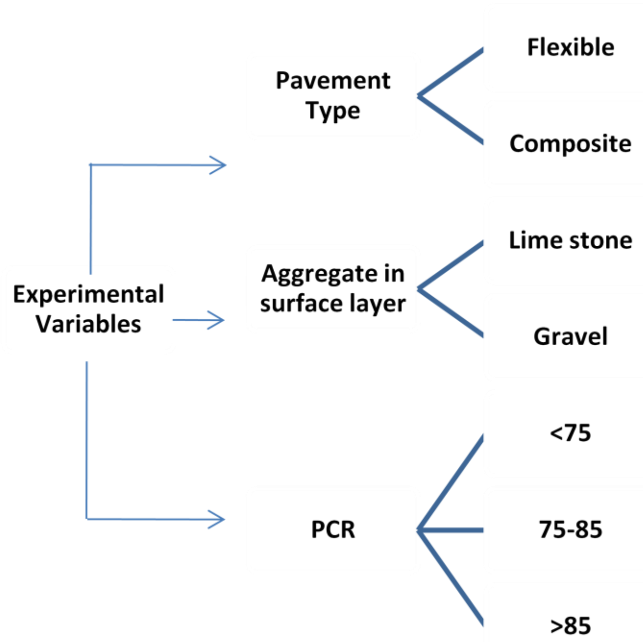


Figure 5. Experimental Variables

Table 1. Matrix of Test Sections

Pavement type	**Flexible**						**Composite**					
Aggregate in surface layer	Lime Stone			Gravel			Lime Stone			Gravel		
PCR of existing pavement	<75	75-85	>85	<75	75-85	>85	<75	75-85	>85	<75	75-85	>85
Group number	1	2	3	4	5	6	7	8	9	10	11	12

4.2 Compiling a list of Crack Seal Projects

In late 2000, the researchers, along with ODOT's Pavement Engineering personnel, met with several district and county managers at their premises. These meetings were convened to provide the officials 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. The districts were asked to provide details of pavement sections included in their crack sealing program, as noted in Table 2.

Table 2. Data Requested from ODOT Districts

List of pavement sections included in the annual crack seal program for Fiscal Year 2000 and 2001							
County	Route	Begin Log	End Log	Year of next resurfacing	Composite /Flexible	Aggregate in surface layer	Pavement Condition Rating

A comprehensive list of pavement sections intended for crack sealing in the year 2000 and 2001was prepared using the information provided by participating district offices and counties.

4.3 Preliminary Selection of Test Sections

The researchers, often accompanied by ODOT personnel, visited the pavement sections, the details of which was obtained from the districts, and drove over the entire length of each crack sealing project. From these projects, one mile long candidate test sections were selected for the field experiment using the following criteria:

- Pavement type: Should be either flexible or composite
- Pavement structure: The thickness and the layer configuration should be similar
- Pavement Condition: The pavement section should be fairly homogeneous, in terms of surface condition, 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.

Additional information for each section namely, current PCR, aggregate type in the surface course, 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 number 1 through 12 as defined in Table 1. This completed the preliminary selection of the test sections. The sections were well scattered over the state comprising of 57 counties.

4.4Setting up Layout of Test Sections

A typical layout of a test section is shown in Figure 6. As can be seen, each test section is 1-mile long. Each test section was divided into five subsections. In the first year, only subsection-1 received a crack seal treatment. Then, subsections 2, 3 and 4 received same crack seal treatments in years 2, 3, and 4 respectively. Subsection 5 was left unsealed and served as control (do-nothing) subsection. This procedure was adopted so as to study the effect of deferring crack sealing on pavement condition and life, and at the same time to generate information regarding the optimum timing of crack seal treatment.

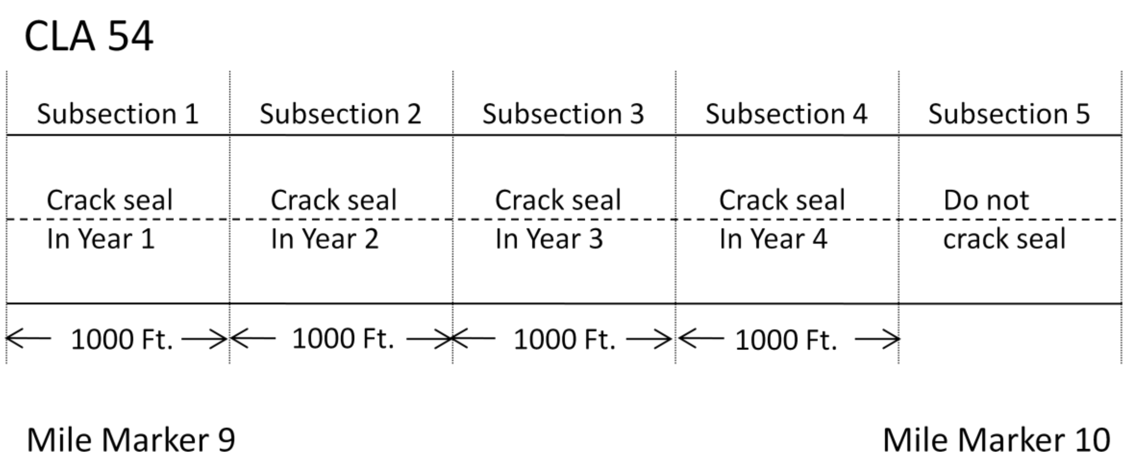


Figure 6. Layout of Test Sections

After selecting the test sections, the researchers made paint markings on the pavement to designate subsections and sequence of crack sealing. Letters were sent to respective counties with an attachment which showed the exact location of the test sections, and provided details about the field experiment. The counties were asked to crack seal only one subsection each year.

Often, on each route, two sections with similar conditions were selected. On 2-lane highways the gap between the two sections was 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 7 shows the general location of test sections on 2 and 4 lane highways.

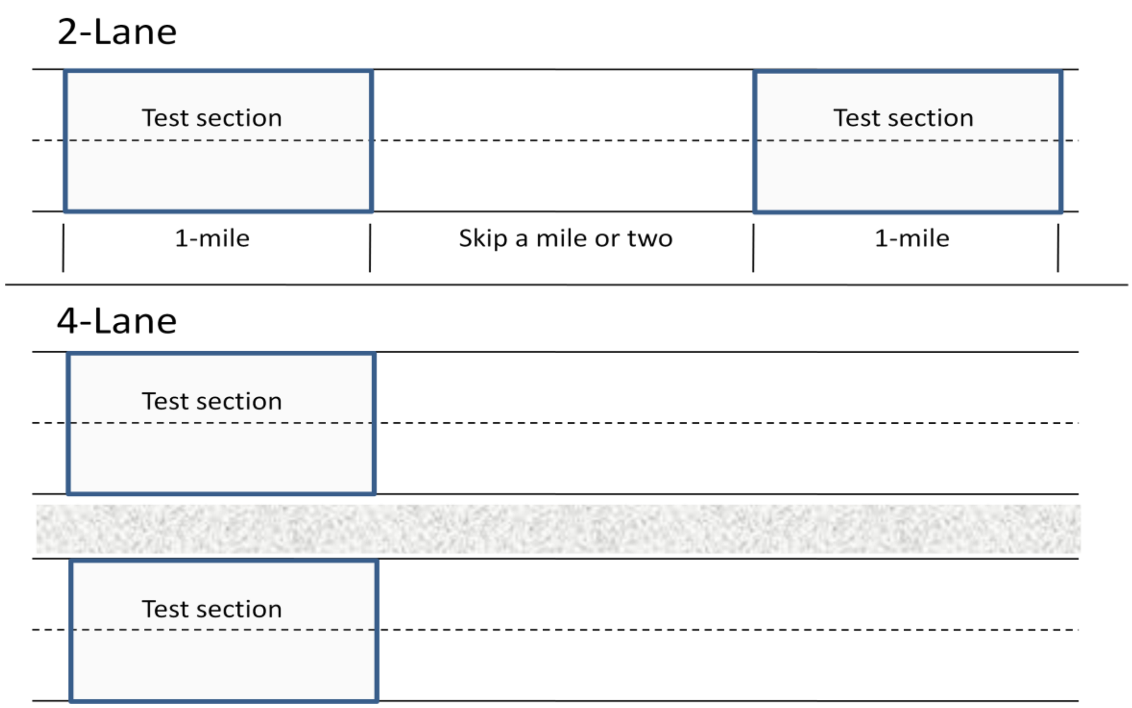


Figure 7. Location of Test Sections on 2-Lane and 4-Lane Highways

4.5 Crack Treatment of Test Sections

Since this research focused on evaluating the effectiveness of existing crack sealing 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. The counties were 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.

4.6 Conducting Field Evaluations

Field investigation included collecting PCR data for each subsection. 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 dedicated one technician for this project. This technician collected PCR data on all the test sections selected for this study. Using one rater for the entire period of research eliminated any errors that may arise due to differences in the observations made by different raters.

PCR data was collected on all test sections prior to crack sealing. In each subsection, photographs of typical cracks at three locations were taken for visual comparison of pavement condition.

During meetings with county managers, it was learned in most cases that, after crack sealing a pavement section, the counties do not perform any maintenance or rehabilitation activities during the following five years. Because of this practice, this study proposed the performance of the crack treated subsections be monitored for up to five years, after sealing. Hence the data collection effort continued for a period of five years after sealing the cracks in the last subsection. Since subsection-4 was treated in year 4, field monitoring was made for a total of nine years.

4.7 Interactive Database

An interactive database was developed to assist 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. Figure 8 shows an overview of ODOT-ECS. The software offered friendly screens to enter data and to generate reports. Input to the system included three basic modules namely (i) section description, (ii) crack seal data, and (iii) PCR data. Figures 9, 10 and 11 show the screen layout for each of these modules.

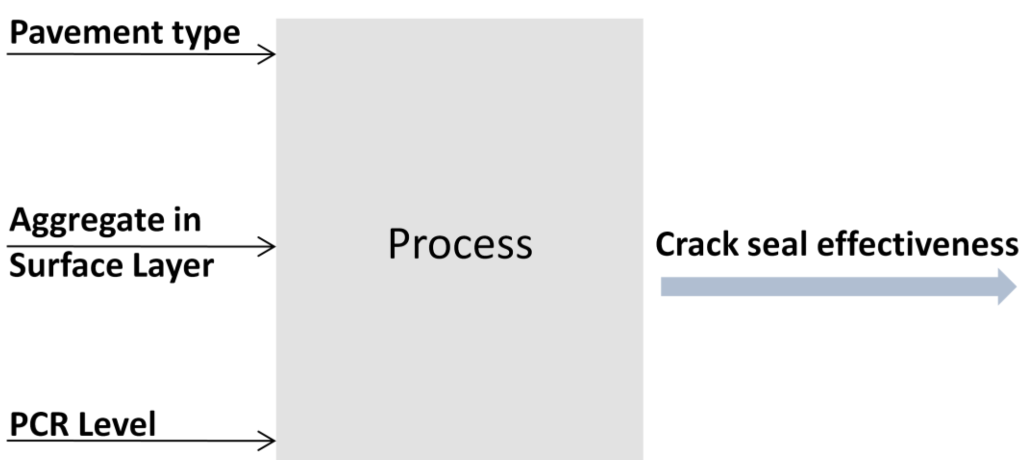


Figure 8. Schematic Illustration of Process Model

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 were used to generate a unique section ID. 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 was entered in the crack seal data module. This screen also displayed the PCR for each year. PCR data entered for each year, for each test section, was stored in the database.

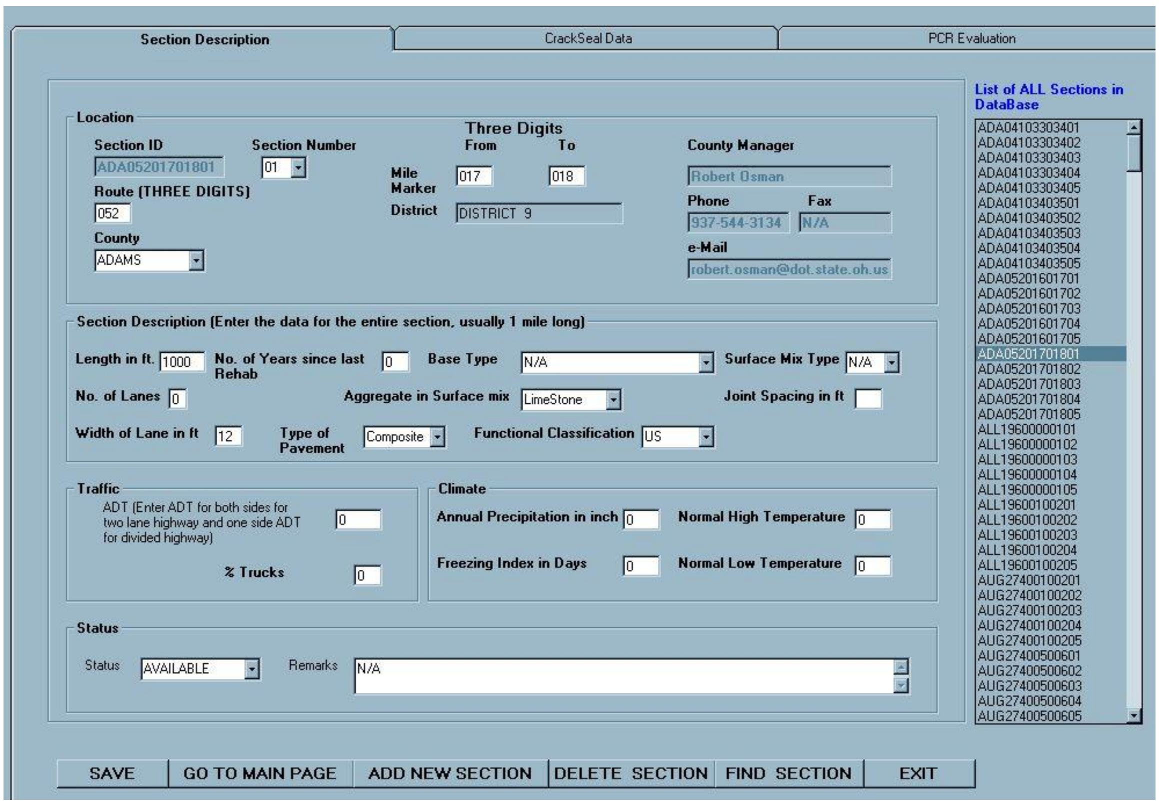


Figure 9. Section Description Module

Based on ODOT's requirements, many reports were generated to do the following:

- Query reports with respect to a field variable,
- Generate matrix of test sections, and
- Generate helpful reports to track:
    - Progress
    - Problems
    - Delays in crack treatment and/or sending information sheet
    - Counties to contact

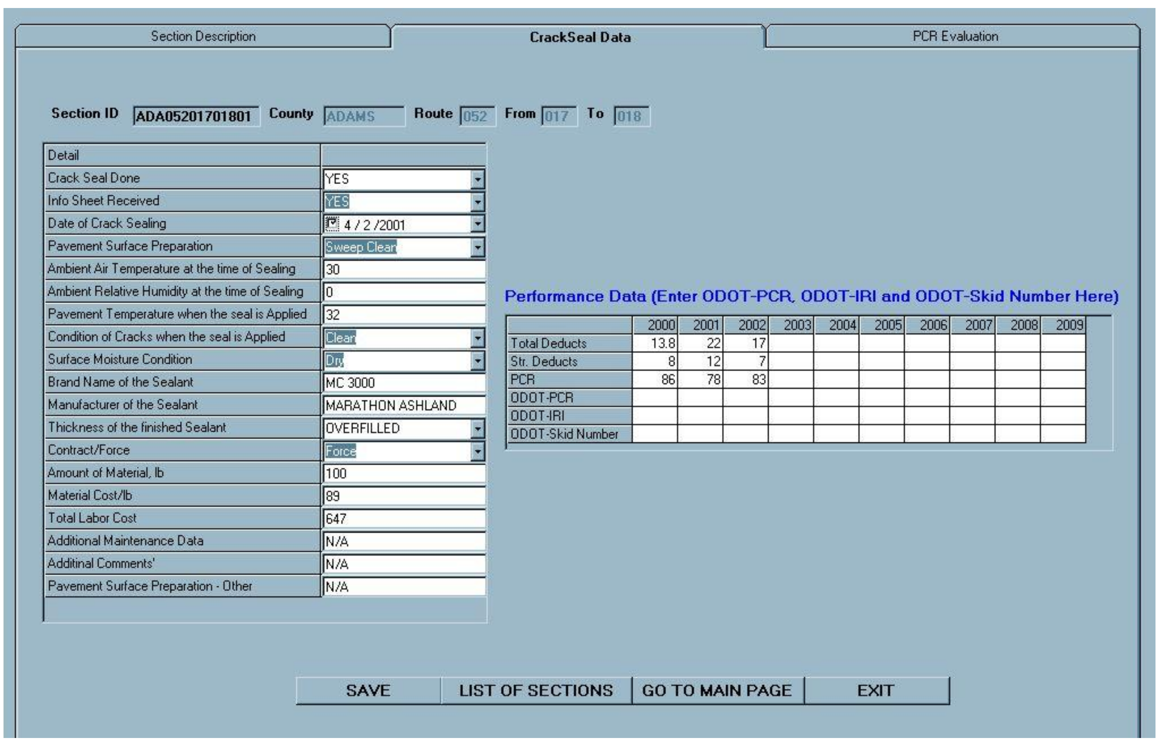
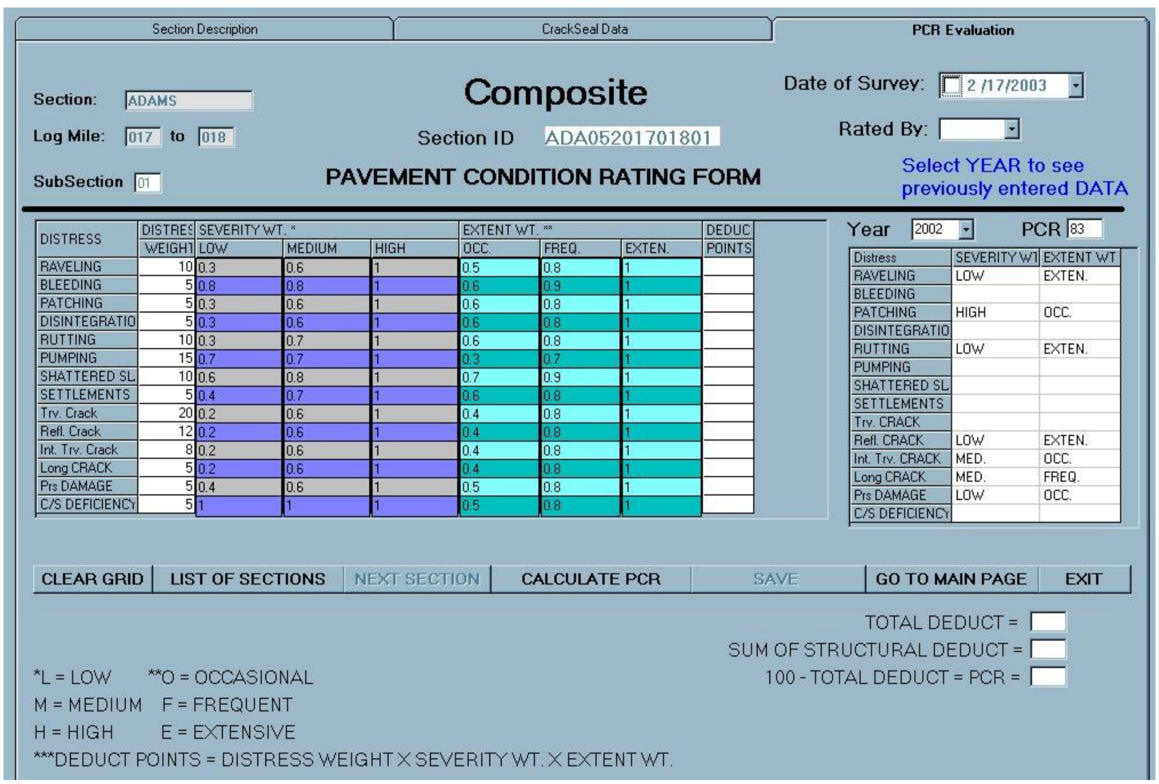


Figure 10. Crack Seal Data Entry Module

The reports were 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 had a critical role to play in this research. They were instructed to crack seal only the appropriate 1000 foot long section each year. Communication and coordination between the counties and the research team was extremely important to the success of this project. Despite this, there were occasions where some county forces unknowingly crack sealed the entire test section or more than one subsection in a given year. The reports generated by the software helped ODOT document such cases, keep track of progress and potential problems, and assist in organizing the research.



DISTRESS	DISTRESS WEIGHT	SEVERITY WT. * LOW	MEDIUM	HIGH	EXTENT WT. ** OCC.	FREQ.	EXTEN.	DEDUCT POINTS
RAVELING	10	0.3	0.6	1	0.5	0.8	1	
BLEEDING	5	0.8	0.8	1	0.6	0.9	1	
PATCHING	5	0.3	0.6	1	0.6	0.8	1	
DISINTEGRATIO	5	0.3	0.6	1	0.6	0.8	1	
RUTTING	10	0.3	0.7	1	0.6	0.8	1	
PUMPING	15	0.7	0.7	1	0.3	0.7	1	
SHATTERED SL	10	0.6	0.8	1	0.7	0.9	1	
SETTLEMENTS	5	0.4	0.7	1	0.6	0.8	1	
Trv. Crack	20	0.2	0.6	1	0.4	0.8	1	
Refl. Crack	12	0.2	0.6	1	0.4	0.8	1	
Int. Trv. Crack	8	0.2	0.6	1	0.4	0.8	1	
Long CRACK	5	0.2	0.6	1	0.4	0.8	1	
Prs DAMAGE	5	0.4	0.6	1	0.5	0.8	1	
C/S DEFICIENCY	5	1	1	1	0.5	0.8	1	

Distress	SEVERITY WT	EXTENT WT
RAVELING	LOW	EXTEN.
BLEEDING		
PATCHING	HIGH	OCC.
DISINTEGRATIO		
RUTTING	LOW	EXTEN.
PUMPING		
SHATTERED SL		
SETTLEMENTS		
Trv. CRACK		
Refl. CRACK	LOW	EXTEN.
Int. Trv. CRACK	MED.	OCC.
Long CRACK	MED.	FREQ.
Prs DAMAGE	LOW	OCC.
C/S DEFICIENCY		

Figure 11. PCR Data Entry Module

5. OVERVIEW OF ANALYSIS APPROACH

Crack sealing is a pavement preventive maintenance treatment. Investigation of effectiveness of crack sealing on pavement performance is a classic example of determining the effectiveness of pavement maintenance treatments on future performance of pavements. When used appropriately, this treatment may have the ability to improve the pavement performance, prolong the remaining service life and result in cost-effective pavement maintenance and management procedure. While investigating if crack sealing is an effective preventive maintenance treatment, the two important questions which need to be addressed are: ***where*** and ***when***. ***Where*** refers to a set of physical conditions and ***when*** relates to a time at which crack seal treatment should be performed. In the present study, ***where*** is defined by the two experimental variables namely, pavement type and type of aggregate used in the surface layer, while ***when*** is described by the PCR value of the pavement at the time of treatment. The analysis focused on identifying the set of conditions and optimal timing of treatment that would maximize the performance of pavements.

6. MEASURE OF EFFECTIVENESS

An important step in the evaluation of the effectiveness of crack sealing is to define the 'measure of effectiveness', a score describing the performance of pavements. In the present study, the following two measures of effectiveness were used:

- Average performance gain, and
- Service life extension.

6.1 Average Performance Gain

Figure 12 illustrates the method adopted for deriving average performance gain. A test section in Fairfield County on state route 22 between mile markers 19 and 20 has been used for this illustration. The figure shows two performance curves – one for a crack sealed subsection and the other for the control section. The crack seal treatment was placed when the PCR of the in-service pavement was 88. As a result of the treatment, the PCR of the pavement increased to 91. The PCR values of the treated pavement were higher than that of control section during the subsequent years. The performance gain for each year was calculated as the difference in PCR between the treated and control subsections, see Table 3.

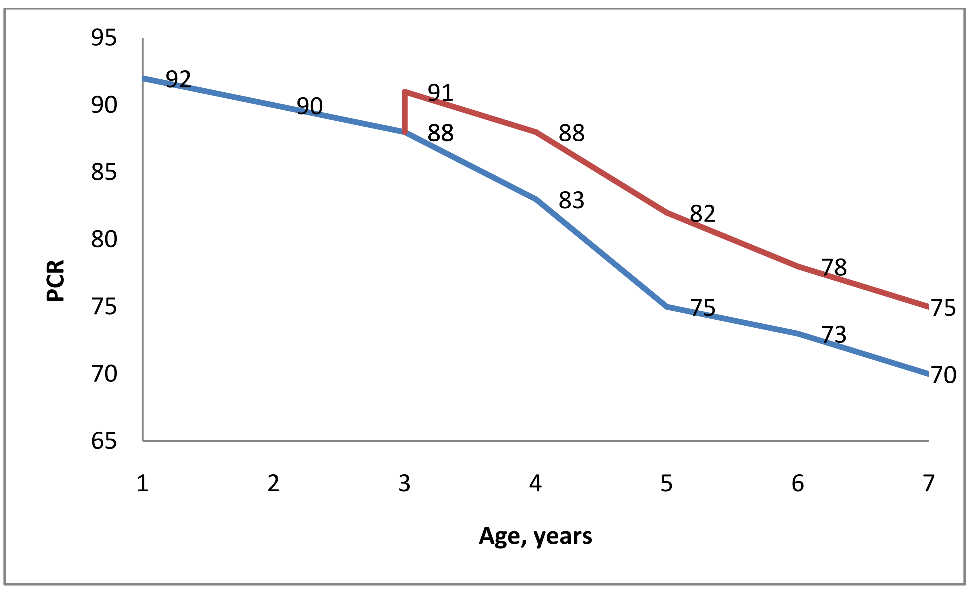


Figure 12. Deriving Average Performance Gain

Table 3. Calculating Average Performance Gain

Age, years	PCR of treated pavement	PCR of control section	PCR difference
1	91	88	3
2	88	83	5
3	82	75	7
4	78	73	5
5	75	70	5
		Average performance gain:	5

As can be seen in the figure and table, the performance gain varied with time. Average performance gain was calculated as the average of PCR difference for five years.

6.2 Service Life Extension

The data from this study was used to verify whether crack sealing extends the service life. In order to do this, performance curves were developed for crack sealed and control pavements. As a precursor to the analysis, the subsections were placed into several groups based on prior PCR such as 45-50, 51-55, 56-60, and so on. These PCR values indicate the condition of the subsections just before the crack seal treatment. Performance prediction models were developed for each group of treated subsections with PCR as a function of age. The linear models provided the best fit in most cases. Based on the discussions with ODOT engineers, service life calculations were made for threshold PCR values corresponding to 60 and 65. The number of years required to reach a threshold PCR value of 60 and 65 was read from the graph and was reported as the life of the treated pavements.

Figure 13 shows a sample of the performance prediction model and service life extension calculation for prior PCR group 66-70.

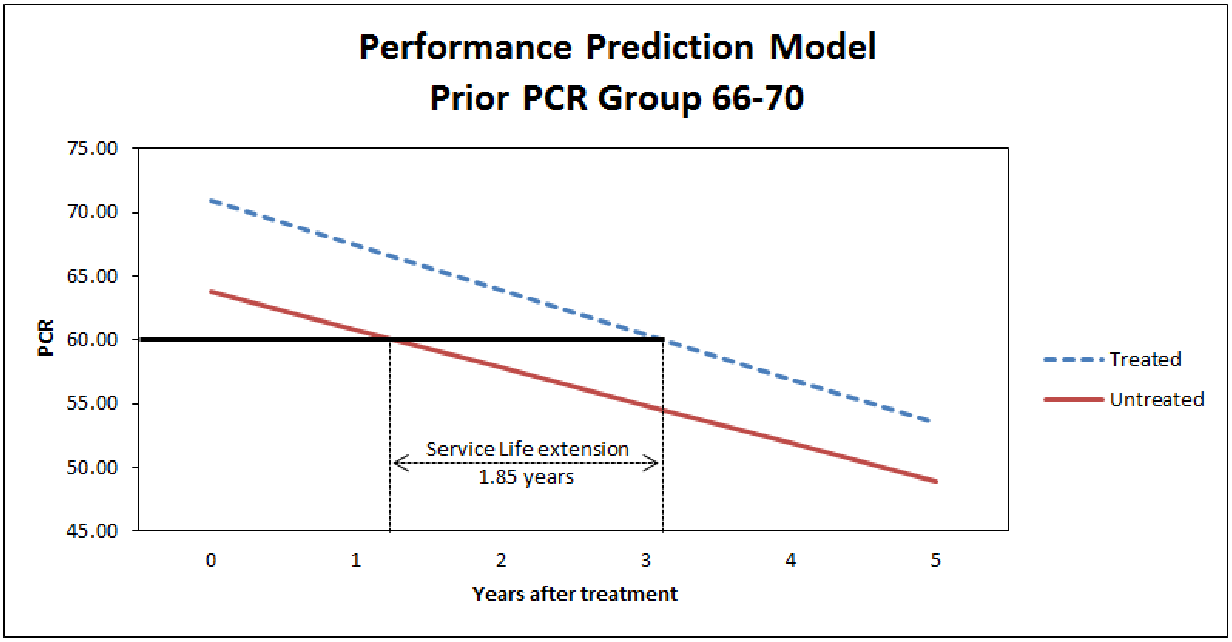


Figure 13. Performance Prediction Model Showing Service Life Extension Calculation

7. DATA ORGANIZATION

For each of the mile long test section selected for field monitoring, the following information was collected:

- Location: county, route, mile markers
- Geometrics and pavement data: number of lanes, width of lane, joint spacing (in case of composite pavement), pavement type, type of aggregate in surface layer
- Traffic: ADT, % truck, functional classification (IR, US, SR)

Following this, each test section was divided into five subsections and an 11-digit identification number was assigned to each subsection as shown in Figure 14.

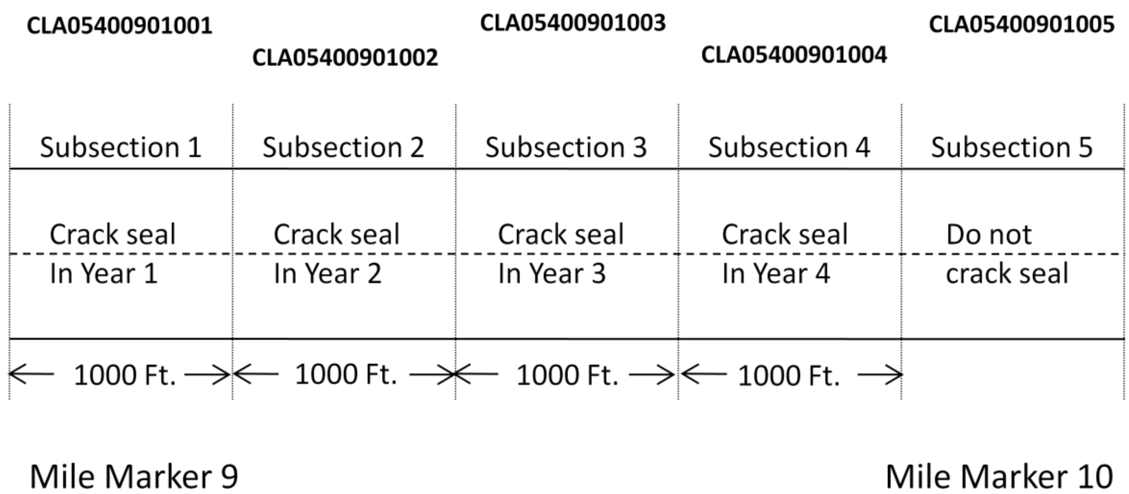


Figure 14. Identification Numbers for Subsections

The ID comprised of name of the county (3 digits), route number (3 digits), begin mile marker (3 digits), end mile marker (3 digits), and subsection number (2 digits).PCR data was collected for all subsections, prior to crack sealing and designated as 'prior PCR'. The PCR of each subsection within a mile was identical with little variation. This PCR data, along with the individual distress data that make up PCR was entered and stored in ODOT ECS. Crack seal treatment was performed on subsection-1 in 2001. PCR data was collected again on all subsections in 2001 and stored in the database. This step was continued until subsection-4 was treated. After this period, PCR data collection was continued on all subsections for 5-years. Table 4 shows an example of PCR data stored for the FAI 22 section.

Table 4. Typical PCR Data for a Test Section

PCR Data collection for each test subsection on FAI 22						
Year	Date of crack seal	FAI02201902001	FAI02201902002	FAI02201902003	FAI02201902004	FAI02201902005
2000	12/30/2000	88	88	85	86	87
2001	8/23/2001	91	82	84	82	83
2002	5/24/2002	88	87	80	80	82
2003	6/5/2003	82	82	81	74	75
2004	5/27/2004	78	78	79	75	73
2005	3/21/2005	75	74	72	70	70
2006	5/30/2006	74	71	71	68	68
2007	6/22/2007	74	67	69	65	66
2008						
Highlighted values indicate PCR after crack sealing						

Crack seal deficiency is one of the distresses surveyed and it carries a 5 point weight. A crack sealed pavement would gain 5 points according to the survey procedure employed by ODOT. The first PCR survey after crack sealing was designated as PCR after crack seal. The first survey was conducted within a few weeks to several months after crack seal operation. Subsection 1 in the table above shows 3-PCR point gain due to crack treatment while subsection 2 shows 5 point gain. Subsections 3 and 4 indicate only one PCR point gain. This can be attributed to the time period between crack seal and the survey.

For data processing, a master database was created including all subsections, their performance data and primary variables. An extract of the database is shown in Figure 15.

Additionally, the individual distress data and other data such as geometrics, traffic was stored in other tables.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	SectionId	Year	Date of Data Collection	PCR	Date of Crack Seal	1	Date of Crack Seal for SS1	Age	2	Date of Crack Seal for SS2	Age	3	Date of Crack Seal for SS3	Age	4	Date of Crack Seal for SS4	Age	5	Date of Crack Seal for SS5	Age	Pavement Type	Aggregate Mix type
2	ADA04103303401	2000	8/1/2000	90	12/12/2000	90	12/12/2000	133													Flexible	LimeStone
3	ADA04103303401	2001	5/22/2001	78	12/12/2000	78	12/12/2000														Flexible	LimeStone
4	ADA04103303401	2002	4/16/2002	75	12/12/2000	75	12/12/2000														Flexible	LimeStone
5	ADA04103303401	2003	2/27/2003	63	12/12/2000	63	12/12/2000														Flexible	LimeStone
6	ADA04103303401	2004	3/26/2004	64	12/12/2000	64	12/12/2000														Flexible	LimeStone
7	ADA04103303401	2005	4/19/2005	63	12/12/2000	63	12/12/2000														Flexible	LimeStone
8	ADA04103303401	2006	4/20/2006	60	12/12/2000	60	12/12/2000														Flexible	LimeStone
9	ADA04103303401	2007	3/8/2007	59	12/12/2000	59	12/12/2000														Flexible	LimeStone
10	ADA04103303401	2008	7/31/2008	59	12/12/2000	59	12/12/2000														Flexible	LimeStone
11	ADA04103303402	2000	8/1/2000	90	4/4/2002				90	4/4/2002	611										Flexible	LimeStone
12	ADA04103303402	2001	5/22/2001	75	4/4/2002				75	4/4/2002	317										Flexible	LimeStone
13	ADA04103303402	2002	4/16/2002	81	4/4/2002				81	4/4/2002											Flexible	LimeStone
14	ADA04103303402	2003	2/27/2003	77	4/4/2002				77	4/4/2002											Flexible	LimeStone
15	ADA04103303402	2004	3/26/2004	73	4/4/2002				73	4/4/2002											Flexible	LimeStone
16	ADA04103303402	2005	4/19/2005	67	4/4/2002				67	4/4/2002											Flexible	LimeStone
17	ADA04103303402	2006	4/20/2006	64	4/4/2002				64	4/4/2002											Flexible	LimeStone
18	ADA04103303402	2007	3/8/2007	62	4/4/2002				62	4/4/2002											Flexible	LimeStone
19	ADA04103303402	2008	7/31/2008	59	4/4/2002				59	4/4/2002											Flexible	LimeStone
20	ADA04103303403	2000	8/1/2000	94	11/21/2002							94	11/21/2002	842							Flexible	LimeStone
21	ADA04103303403	2001	5/22/2001	78	11/21/2002							78	11/21/2002	548							Flexible	LimeStone
22	ADA04103303403	2002	4/16/2002	74	11/21/2002							74	11/21/2002	219							Flexible	LimeStone
23	ADA04103303403	2003	2/27/2003	73	11/21/2002							73	11/21/2002								Flexible	LimeStone
24	ADA04103303403	2004	3/26/2004	71	11/21/2002							71	11/21/2002								Flexible	LimeStone
25	ADA04103303403	2005	4/19/2005	63	11/21/2002							63	11/21/2002								Flexible	LimeStone
26	ADA04103303403	2006	4/20/2006	63	11/21/2002							63	11/21/2002								Flexible	LimeStone
27	ADA04103303403	2007	3/8/2007	60	11/21/2002							60	11/21/2002								Flexible	LimeStone
28	ADA04103303403	2008	7/31/2008	60	11/21/2002							60	11/21/2002								Flexible	LimeStone
29	ADA04103303404	2000	8/1/2000	94	3/17/2004										94	3/17/2004	1324				Flexible	LimeStone
30	ADA04103303404	2001	5/22/2001	77	3/17/2004										77	3/17/2004	1030				Flexible	LimeStone
31	ADA04103303404	2002	4/16/2002	73	3/17/2004										73	3/17/2004	701				Flexible	LimeStone
32	ADA04103303404	2003	2/27/2003	69	3/17/2004										69	3/17/2004	384				Flexible	LimeStone
33	ADA04103303404	2004	3/26/2004	75	3/17/2004										75	3/17/2004					Flexible	LimeStone
34	ADA04103303404	2005	4/19/2005	67	3/17/2004										67	3/17/2004					Flexible	LimeStone
35	ADA04103303404	2006	4/20/2006	64	3/17/2004										64	3/17/2004					Flexible	LimeStone
36	ADA04103303404	2007	3/8/2007	61	3/17/2004										61	3/17/2004					Flexible	LimeStone
37	ADA04103303404	2008	7/31/2008	59	3/17/2004										59	3/17/2004					Flexible	LimeStone
38	ADA04103303405	2000	8/1/2000	94	#N/A													94	#N/A		Flexible	LimeStone
39	ADA04103303405	2001	5/22/2001	79	#N/A													79	#N/A		Flexible	LimeStone
40	ADA04103303405	2002	4/16/2002	76	#N/A													76	#N/A		Flexible	LimeStone
41	ADA04103303405	2003	2/27/2003	71	#N/A													71	#N/A		Flexible	LimeStone
42	ADA04103303405	2004	3/26/2004	69	#N/A													69	#N/A		Flexible	LimeStone
43	ADA04103303405	2005	4/19/2005	65	#N/A													65	#N/A		Flexible	LimeStone
44	ADA04103303405	2006	4/20/2006	64	#N/A													64	#N/A		Flexible	LimeStone
45	ADA04103303405	2007	3/8/2007	60	#N/A													60	#N/A		Flexible	LimeStone
46	ADA04103303405	2008	7/31/2008	59	#N/A													59	#N/A		Flexible	LimeStone
47	ADA04103403501	2000	8/1/2000	92	4/19/2001	92	4/19/2001	261													Flexible	LimeStone

Figure 15. Data Organization

8. VERIFICATION OF DATA INTEGRITY, COMPLETENESS AND VALIDATION OF CRACK SEAL DATABASE

Before proceeding with data processing, it was decided to do the following:

1. Thoroughly review the ODOT-ECS database
2. Identify missing data
3. Identify sources for locating missing data
4. Collect missing data and update the database
5. Visit 20% of test sections
6. Validate the ODOT-ECS database

The database organized all the data in several tables as below:

- Location details
- County
- Crack conditions
- Performance Data for each year from 2000 through 2008

A review of the database at the beginning of this study revealed that a significant number of records did not contain the date of crack seal. Also some errors were identified in the distress data for a few records. When a distress data is entered, the user has to record both severity and extent values. If either of them is missing, it can result in incorrect PCR value.

An additional computer program was written to scan every record in each table. The purpose of this software was to conduct a thorough review of the database so as to (i) ensure all required entries have been made, and (ii) verify correctness of the entries. The program was designed to systematically access each table and scan the entries. Primary focus was on:

- Date of crack seal
- Distress data

The date of crack seal is extremely important to: (i) ensure crack seal has been performed as requested by the research team, (ii) confirm an appropriate value has been entered in the database and, (iii) track and compare the performance of test sections. The distress data entered for each subsection for each survey period was meticulously checked with respect to the type of distresses, their severity and extent. The database was also reviewed to ensure that the other essential fields such as pavement type, type of aggregate in the surface, functional classification and traffic were entered.

The computer program checked each record for missing and/or invalid entries. Where such discrepancies were found, the entries were corrected and validated by consulting project liaison.

In 2008, the researchers visited 53 in-service test sections. The primary objective of the visit was to validate the condition data with respect to the field condition.

8.1 Validation of the Database

Validation of the database was done by performing a range of tests, or by manually reconciling suspect values. Data validation consisted of two steps: data screening and data verification. Data screening used a series of validation routines to screen all the data for suspect (questionable and erroneous) values. This task was accomplished by the computer program. Data verification was done on a case-by-case decision on what to do with the suspect values - retain them as valid, reject as invalid, or replace them with redundant valid values (if available). This part is where judgment by a qualified person is needed. All the records were restored and no data was left out as invalid. Table 5 shows the number of subsections available in the database.

Table 5. Data Available for Analysis

Number of subsections available for analysis				
Year	Flexible/Lime Stone	Flexible/Gravel	Composite/Lime Stone	Composite/Gravel
2000	340	130	110	105
2001	300	165	114	95
2002	289	160	140	93
2003	291	173	140	100
2004	280	175	140	100
2005	250	175	129	100
2006	204	169	95	100
2007	175	155	67	99
2008	175	155	67	99

It is interesting to see how the number of subsections has changed with time. New sections were added up to 2004, while at the same time some sections were lost due to either resurfacing and/or rehabilitation of test sites. Resurfacing and/or rehabilitation were prompted when the test sites deteriorated to a point warranting such an action. In about 5% of the cases, the test sites were dropped when all subsections were wrongly crack sealed. The ODOT-ECS database contains all the data, regardless of whether the test sites are *available* or *dropped*, and includes the remarks column describing the reasons for dropping a test site.

9. ANALYSIS OF DATA

Analysis was performed in four parts as below:

1. Comparing performance of all treated and control subsection sections, regardless of variables such as pavement type, type of aggregate in the surface layer and prior PCR of treated subsections as shown in Figure 16,
2. Comparing performance of treated and control subsection sections based on the pavement type, Figure 17, (regardless of aggregate type in surface layer and prior PCR),
3. Comparing performance of treated and control sections based on pavement type and aggregate in surface layer, Figure 18, (regardless of prior PCR),
4. Comparing performance of treated and untreated pavements based on prior PCR (Figure 19).

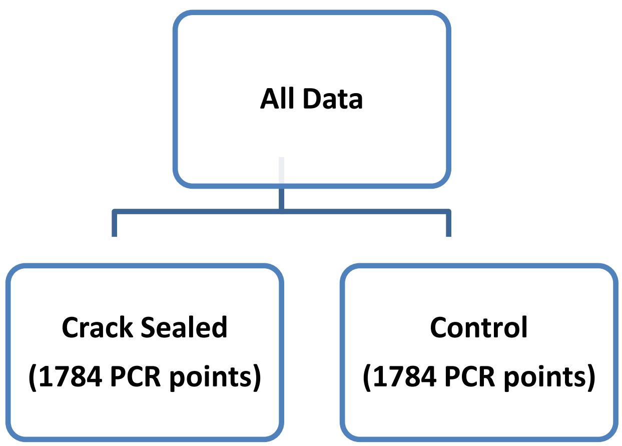


Figure 16. Comparing Performance of all Data Regardless of Experimental Variables

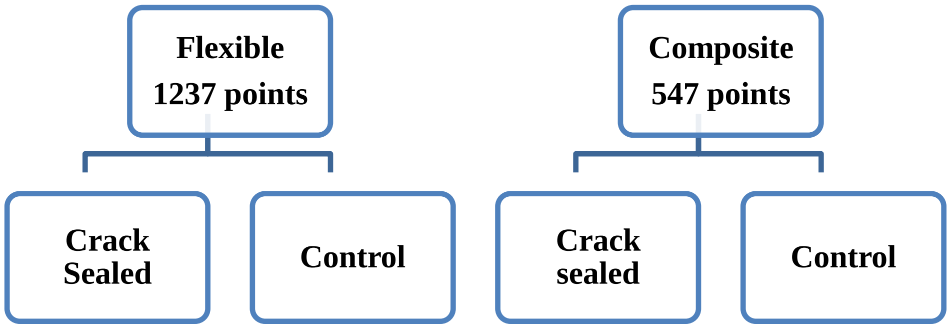


Figure 17. Comparing Performance Based on Pavement Type

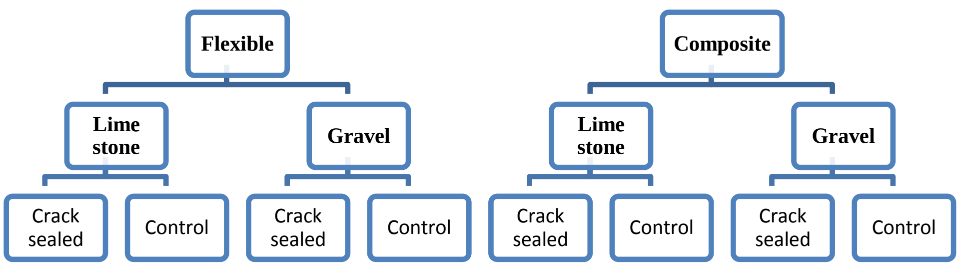


Figure 18. Comparing Performance Based on Pavement and Aggregate Type

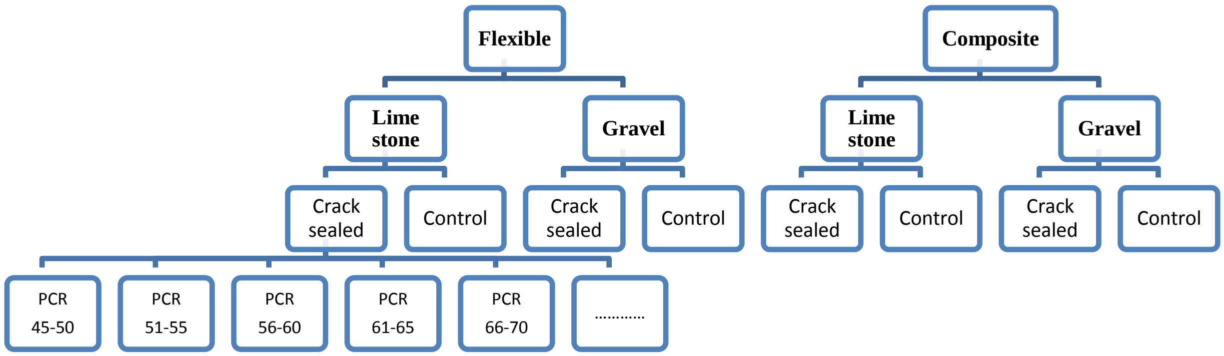


Figure 19. Comparing Performance Based on Pavement Type, Aggregate Type and Prior PCR

One of the analysis procedures adopted is testing for differences in average performance gain. If one desires 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 average performance gain of the treated sections and the untreated (control) sections. The two alternative decisions that can be made are:

- The average performance gain of a crack sealed section is greater than that of the control section,
- There is no evidence to believe that the average performance gain 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 subsections in group 1 that are crack sealed in year 2000 and the corresponding control subsections have the same average performance gain, on the average, after five years. The performance gains of the crack sealed and the control sections 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 ‘is the observed difference significant?’. This will depend on several factors: the amount of variability within each group; the number of sections in each group; and the confidence in the accuracy of the conclusion. Using the data stored in the ODOT-ECS database, in conjunction with a statistical package, a comparative analysis was made. For statistical inference, hypothesis testing (also called significance testing) was used in comparing two formulations. Hypothesis testing allows an objective comparison of the two formulations to be made on objective terms, with knowledge of the risks associated with reaching the wrong conclusions.

9.1 Average Performance Gain

The Average Performance Gain values were calculated for each pair of treated and control subsection. The Average Performance Gain for all data was found to be 3.9. This indicates that, crack sealed pavements, on a whole, result in improved performance on a 5-year cycle. The difference was found to be statistically significant at 95% confidence interval. Figure 20 demonstrates the Average Performance Gain for the different pavement and aggregate types.

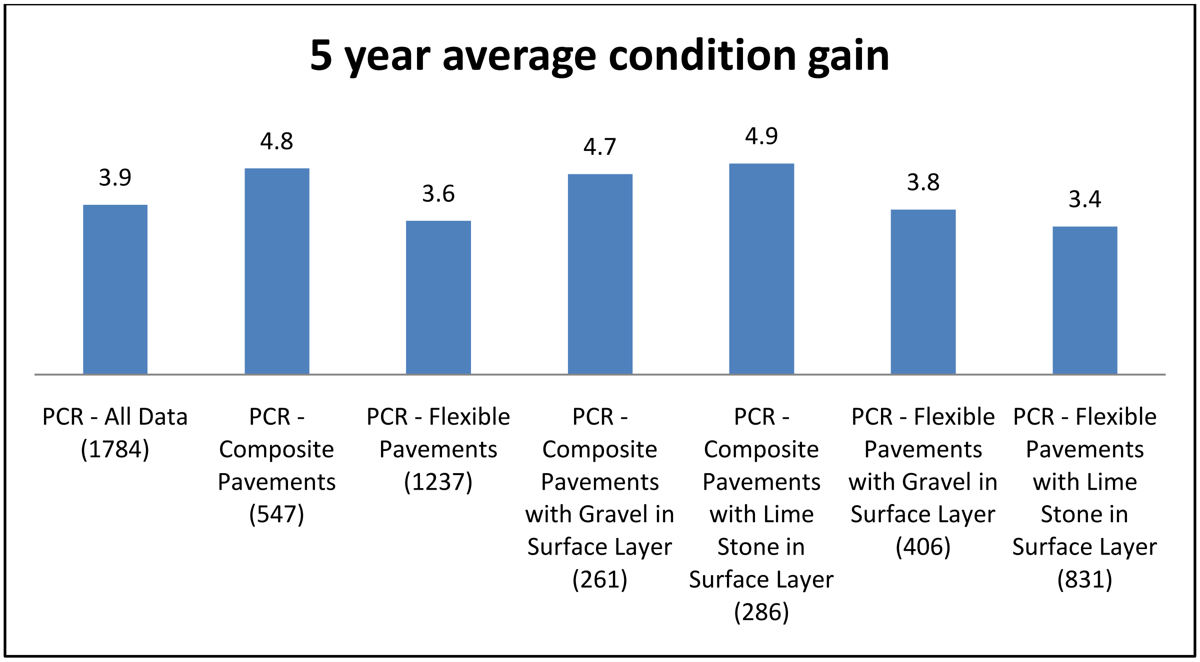


Figure 20. Average Performance Gain

The figure shows Average Performance Gain for various sets of data along with the number of PCR points (shown in parenthesis) that were used to establish the gain. All of these values were found to be statistically significant at 95% confidence interval.

The analysis was continued to include prior PCR groups as a variable. A consolidated table showing summary of results is presented in Table 6.

Table 6. Summary of Average Performance Gain Calculations

Prior PCR group	Variable						
	All data	Composite	Composite Gravel	Composite limestone	Flexible	Flexible Gravel	Flexible Limestone
56-60	3.20				3.20		3.54
61-65	3.54				3.54		3.60
66-70	**4.34**	**7.52**			3.81	2.77	**4.53**
71-75	**3.84**	**4.54**	**4.20**	**4.89**	3.27	**4.68**	2.85
76-80	**4.56**	**5.38**	**6.19**	**4.86**	3.60	**4.45**	2.98
81-85	3.61	3.94	3.89		3.49	3.64	3.30
86-90	3.70	3.18	3.06		3.94	5.38	1.34
91-95	2.83				2.80		3.31

Note: Blank cells indicate not enough data

The Average Performance Gain for each data set is shown in the table. The significance of the above table is, it highlights the importance and the extent to which the primary variables such as, pavement type, aggregate type in surface layer, and PCR of pavement prior to crack sealing affect the performance of crack sealed pavements. In certain cases, the Average Performance Gain was higher than 3.9, particularly when the prior PCR range was 66 to 80. From this table it may be inferred that maximum performance gain is realized for all pavement and aggregate types when crack sealing is performed while the PCR of the existing pavement is in the range of 66 to 80. The significance of this observation is that this analysis provides optimal timing of treatment (***when***) to maximize the performance. A careful look at the results also indicates that the average performance gain for composite pavements in the aforementioned range is relatively higher than that of flexible pavements – 5.81 vs. 3.56. Furthermore, it appears that pavements with gravel in the surface layer display relatively higher performance gain.

9.2 Service Life Extension

Figure 21 shows two performance models – one for the treated subsections and the other for control subsections. These models were used to determine the service life extension, the results of which are shown in Table 7.

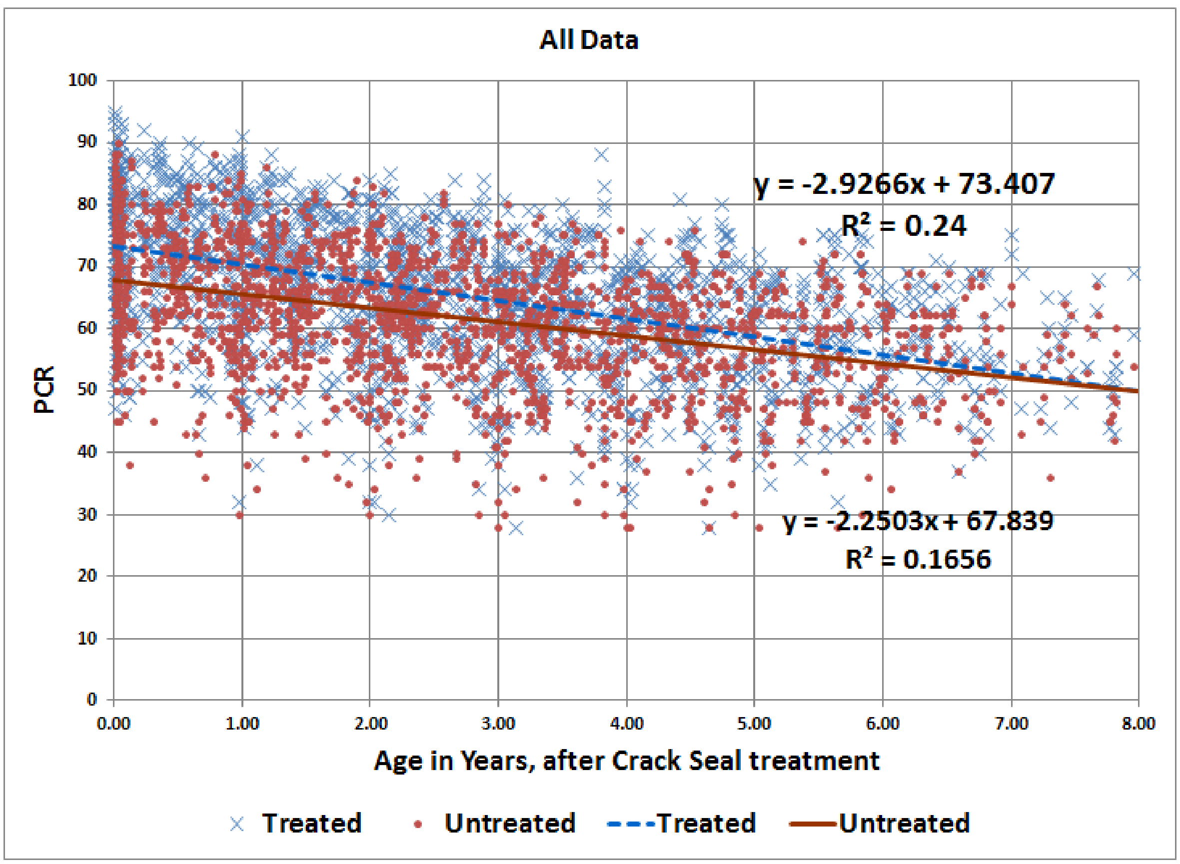


Figure 21. Performance Prediction Models for All Data

Table 7. Service Life Extension

Threshold PCR	Life of Crack sealed Subsections	Life of Control Subsections	Additional Life, years
60	4.6	3.5	1.1
65	2.9	1.3	1.6

The figure demonstrates a wide scatter of points. This is because all the variables are included in the analysis which makes the data heterogeneous. As a result, the R^2 is low and not significant. However, the results show a logical trend.

Similar trends are seen in the performance prediction models when the data was grouped according to pavement types and aggregate type. These models are presented in Figures 22 through 27.

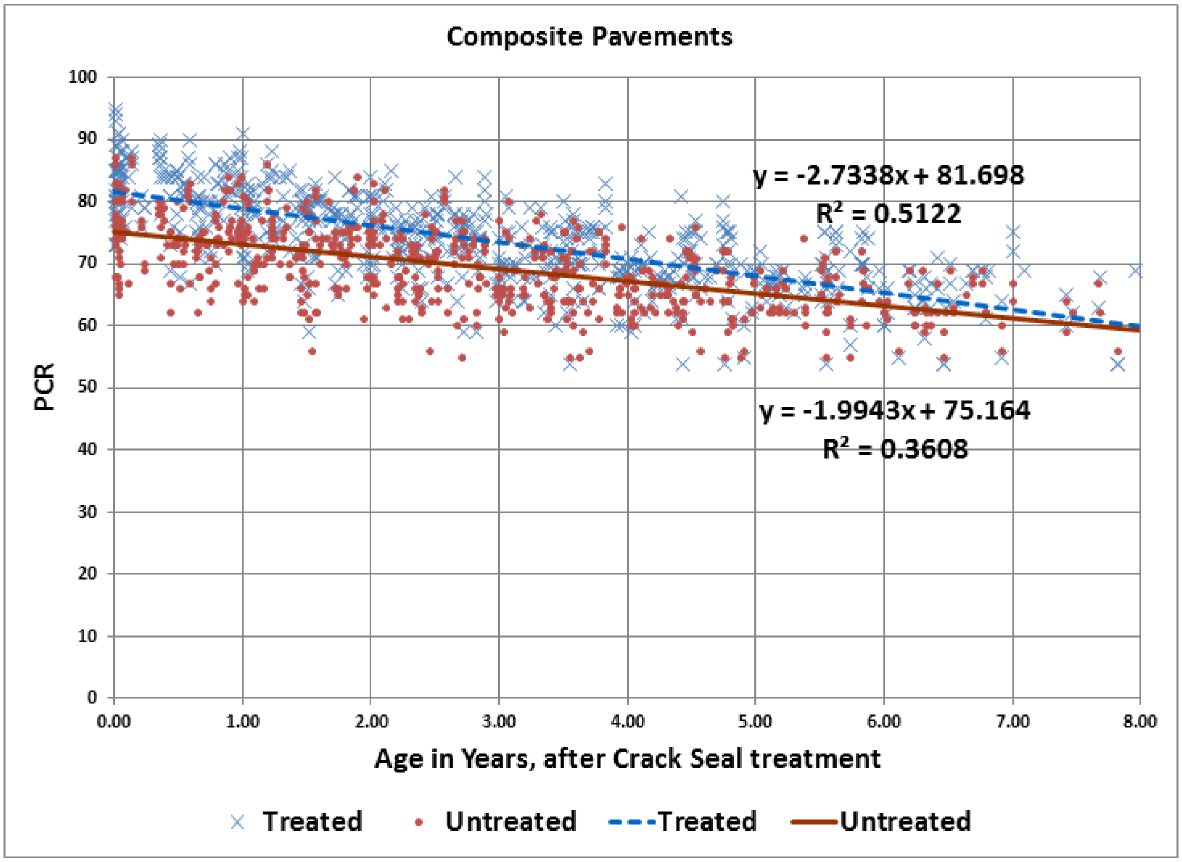


Figure 22. Performance Prediction Models for Composite Pavements

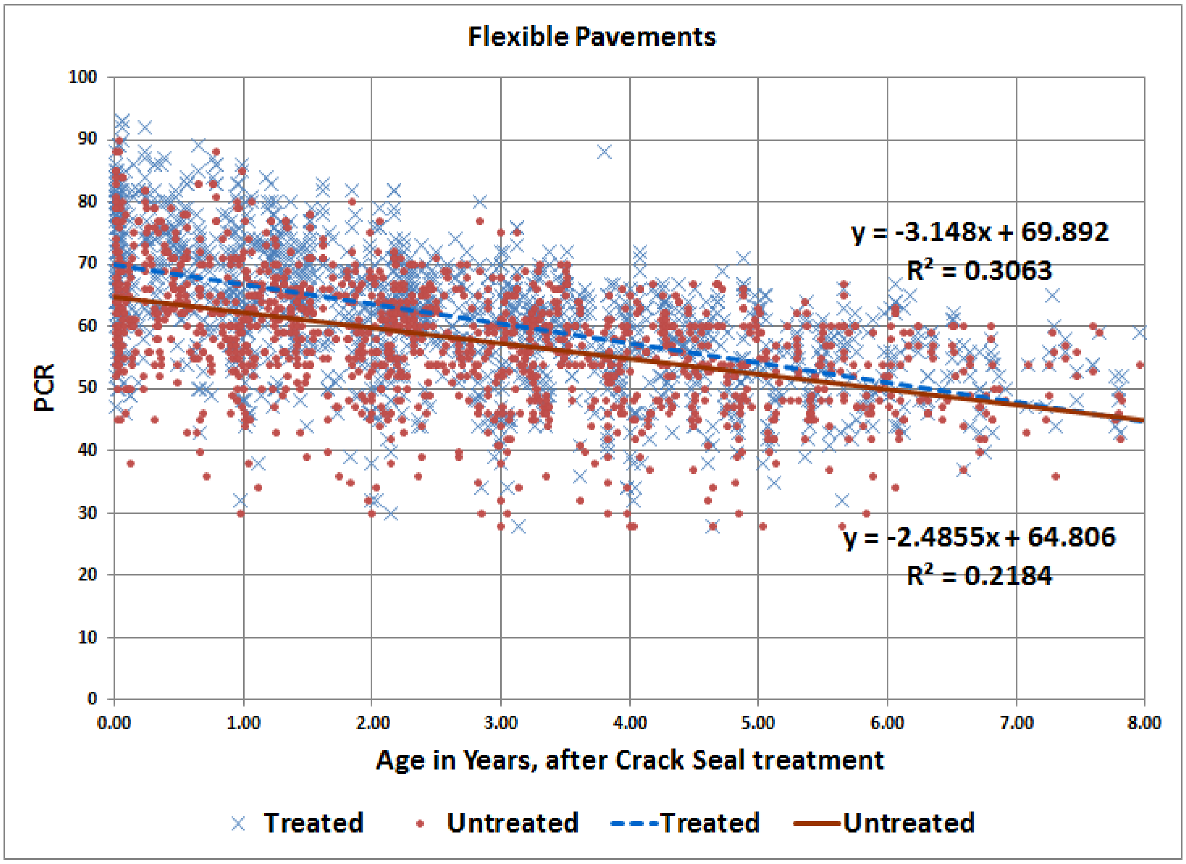


Figure 23. Performance Prediction Models for Flexible Pavements

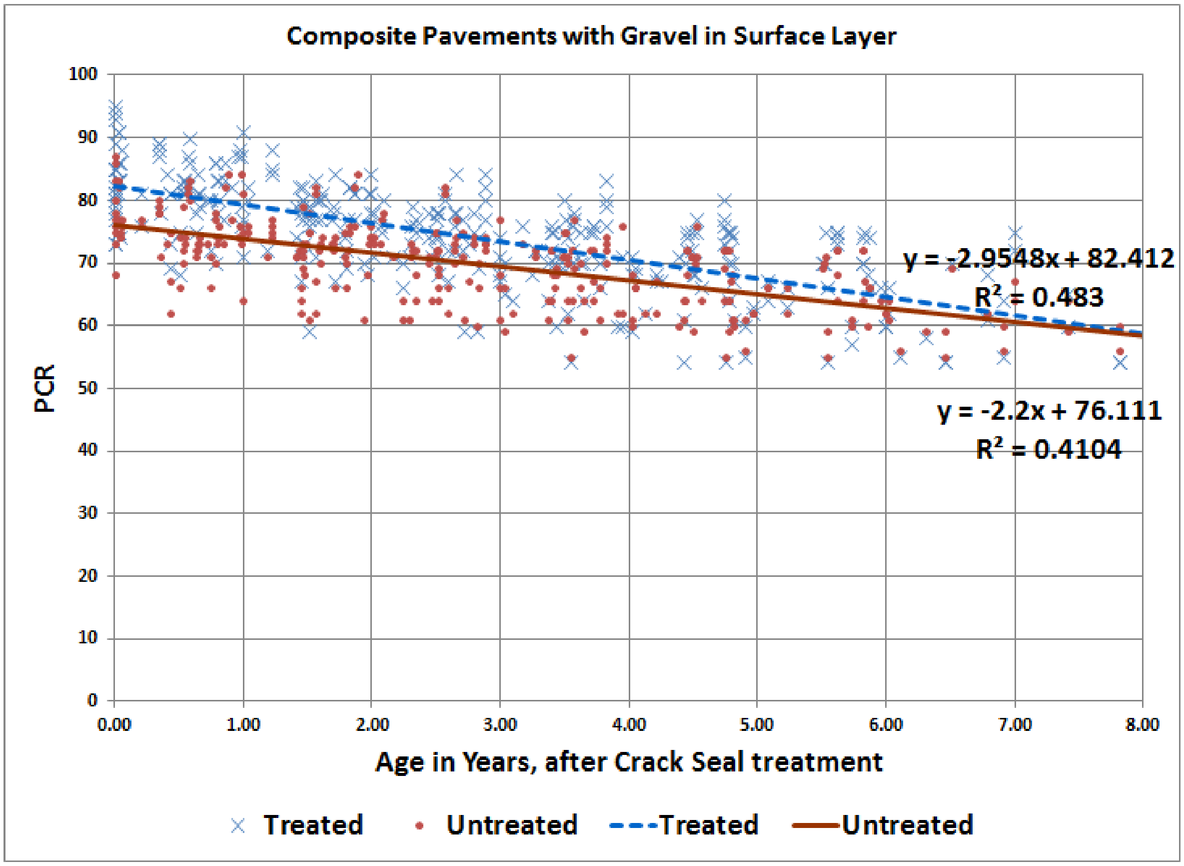


Figure 24. Performance Prediction Models for Composite Pavements with Gravel in Surface Layer

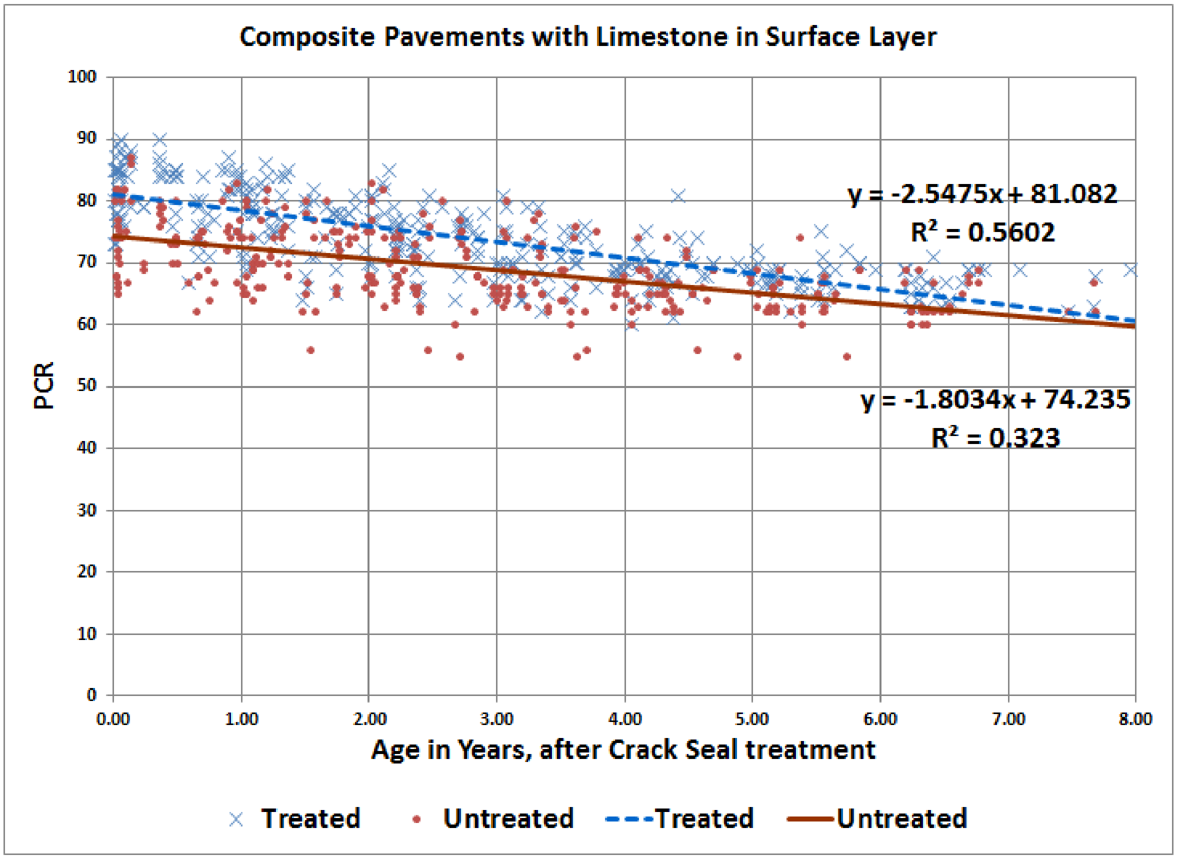


Figure 25. Performance Prediction Models for Composite Pavements with Limestone in Surface Layer

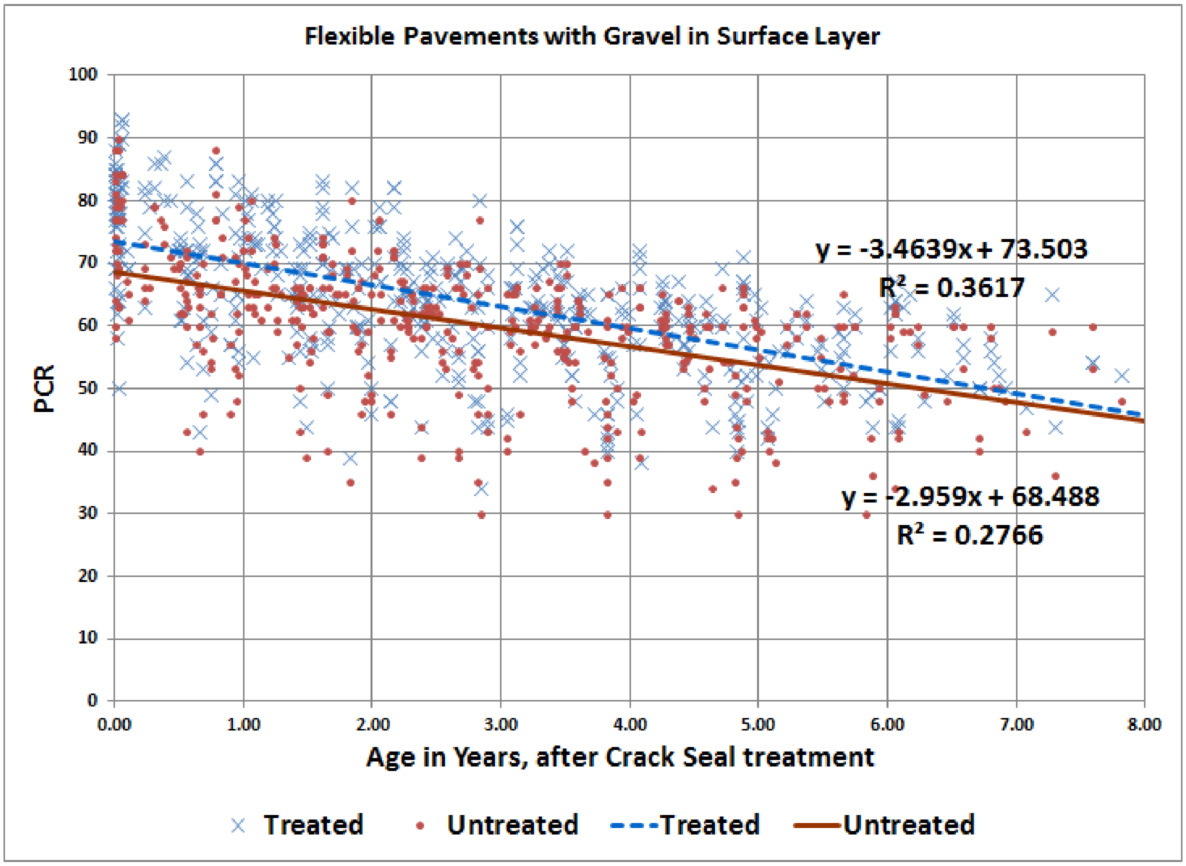


Figure 26. Performance Prediction Models for Flexible Pavements with Gravel in Surface Layer

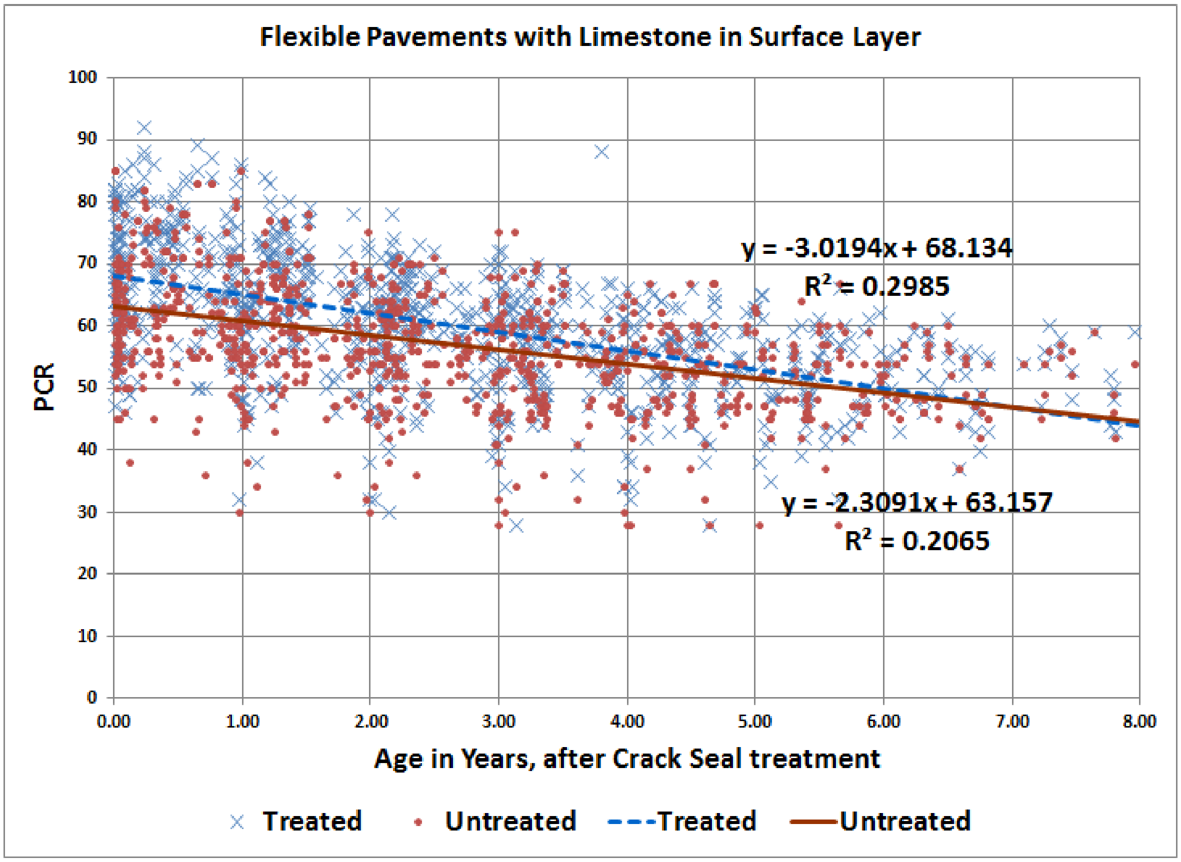


Figure 27. Performance Prediction Models for Flexible Pavements with Limestone in Surface Layer

Service life extensions for these models were calculated after parsing the data into Prior PCR Groups. Service life extension was calculated corresponding to two threshold PCRs, namely PCR=60 and PCR=65. These results are presented in tables 8 and 9 respectively.

Table 8. Summary of Service Life Extension (in years) Calculations corresponding to Threshold PCR = 60

Prior PCR group	Variable						
	All data	Composite	Composite Gravel	Composite limestone	Flexible	Flexible Gravel	Flexible Limestone
66-70	1.85	2.71			1.83	1.47	2.01
71-75	0.55		0.08	0.00	0.43		0.62
76-80	0.63	0.44	2.75		0.52	0.74	0.39
81-85	0.83	0.67			1.18	1.23	1.05
86-90	0.14						
91-95							
96-100	0.14				0.14		0.26

Note: Shaded area indicates not enough data to develop performance prediction model

Table 9. Summary of Service Life Extension (in years) Calculations corresponding to Threshold PCR = 65

Prior PCR group	Variable						
	All data	Composite	Composite Gravel	Composite limestone	Flexible	Flexible Gravel	Flexible Limestone
66-70	2.11	3.66			2.01	1.28	2.48
71-75	1.04	0.79	1.00	0.68	0.98	0.86	1.04
76-80	1.27	1.35	2.98	0.61	0.99	0.94	1.05
81-85	1.02	0.86			1.29	1.42	1.08
86-90	0.32					0.28	
91-95							0.39
96-100	0.16				0.16		0.33

Note: Shaded area indicates not enough data to develop performance prediction model

The analysis of performance based on the average performance gain, as shown in Table 6, revealed that maximum performance can be achieved by treating pavements when their PCR is in the range of 66-80. A careful study of service life extensions estimated as in Tables 8 and 9 shows that maximum service life extension can be obtained for a narrow PCR range of 66-70 instead of

66-80. The R^2 value for both types of pavement in the prior PCR group of 66-80 was found to be 0.33 (for treated) and 0.24 (for untreated). The performance models developed for the sections treated in the prior PCR group of 66-70 show a better fit with R^2 value equal to 0.49 (for treated) and 0.44 (for untreated).

9.3 Results in Summary

In summary, the analysis of data lead to objective evaluation of effectiveness of crack seal practices and included the following:

- Evaluation of the effect of crack sealing on pavement serviceability,
- Development of deterioration curves,
- Estimation of the effect of crack sealing on remaining service life, and
- Identification of optimal timing of treatment

10. ADDITIONAL PERFORMANCE INDICATORS TO EVALUATE THE EFFECTIVENESS OF CRACK SEALING

Ohio's PCR is a composite index derived as a function of several individual distresses. Individual distresses, listed according to pavement type, are rated based on their severity and extent. Distress weights and deduct values are used to generate PCR on a 0 to 100 scale. Figures 28 and 29 depict the list of distresses and the method of obtaining PCR for flexible and composite pavements.

Section: ________________ Log mile: ______ to________ Sta: __________ to_________

FLEXIBLE

Date: __________________ Rated by: _______________

PAVEMENT CONDITION RATING FORM

DISTRESS	DISTRESS WEIGHT	SEVERITY WT.*			EXTENT WT.**			DEDUCT POINTS***
		L	M	H	O	F	E	
RAVELING	10	.3	.6	1	.5	.8	1	
BLEEDING	5	.8	.8	1	.6	.9	1	
PATCHING	5	.3	.6	1	.6	.8	1	
POTHOLES/DEBONDING	10	.4	.7	1	.5	.8	1 ✓	
CRACK SEALING DEFICIENCY	5	1	1	1	.5	.8	1	
RUTTING	10	.3	.7	1	.6	.8	1 ✓	
SETTLEMENT	10	.5	.7	1	.5	.8	1	
CORRUGATIONS	5	.4	.8	1	.5	.8	1	
WHEEL TRACK CRACKING	15	.4	.7	1	.5	.7	1 ✓	
BLOCK AND TRANSVERSE CRACKING	10	.4	.7	1	.5	.7	1 ✓	
LONGITUDINAL JOINT CRACKING	5	.4	.7	1	.5	.7	1	
EDGE CRACKING	5	.4	.7	1	.5	.7	1	
RANDOM CRACKING	5	.4	.7	1	.5	.7	1 ✓	

*L = LOW **O = OCCASIONAL TOTAL DEDUCT =

M = MEDIUM F = FREQUENT SUM OF STRUCTURAL DEDUCT (✓) =

H = HIGH E = EXTENSIVE **100 - TOTAL DEDUCT = PCR =**

*** DEDUCT POINTS = DISTRESS WEIGHT X SEVERITY WT. X EXTENT WT.

REMARKS:

Figure 28. ODOT's Pavement Condition Rating Form for Flexible Pavements

Section: ________________ Log mile: ______ to________ Sta: __________ to_________

COMPOSITE

Date: __________________ Rated by: _______________

PAVEMENT CONDITION RATING FORM

DISTRESS	DISTRESS WEIGHT	SEVERITY WT.*			EXTENT WT.**			DEDUCT POINTS***
		L	M	H	O	F	E	
RAVELING	10	.3	.6	1	.5	.8	1	
BLEEDING	5	.8	.8	1	.6	.9	1	
PATCHING	5	.3	.6	1	.6	.8	1	
SURFACE DISINTEGRATION or DEBONDING	5	.3	.6	1	.6	.8	1	
RUTTING	10	.3	.7	1	.6	.8	1	
PUMPING	15	.7	.7	1	.3	.7	1 ✓	
SHATTERED SLAB	10	.6	.8	1	.7	.9	1 ✓	
SETTLEMENTS	5	.4	.7	1	.6	.8	1	
TRANSVERSE CRACKS, UNJOINTED BASE	20	.2	.6	1	.4	.8	1 ✓	
JOINT REFLECTION CRACKS, JOINTED BASE	12	.2	.6	1	.4	.8	1 ✓	
INTERMEDIATE TRANSVERSE CRACKS, JOINTED BASE	8	.2	.6	1	.4	.8	1 ✓	
LONGITUDINAL CRACKING	5	.2	.6	1	.4	.8	1 ✓	
PRESSURE DAMAGE/UPHEAVAL	5	.4	.6	1	.5	.8	1	
CRACK SEALING DEFICIENCY	5	1	1	1	.5	.8	1	

*L = LOW **O = OCCASIONAL TOTAL DEDUCT =

M = MEDIUM F = FREQUENT SUM OF STRUCTURAL DEDUCT (✓) =

H = HIGH E = EXTENSIVE **100 - TOTAL DEDUCT = PCR =**

*** DEDUCT POINTS = DISTRESS WEIGHT X SEVERITY WT. X EXTENT WT.

REMARKS:

Figure 29. ODOT's Pavement Condition Rating Form for Composite Pavements

Although the intent of the present study was to determine the effect of crack sealing on overall pavement condition, it can be argued that crack sealing is a local treatment at the crack locations and this treatment may not have influence on distresses such as rutting, bleeding, settlements, pumping and patching to name a few. Hence it was thought that analyzing the data with respect to distresses related to cracking of pavements may isolate the distresses and provide better representation of the effect of crack sealing. The review panel suggested development of additional performance indicators such as:

1. PCR excluding C/S Deficiency (PCR – CS)
2. Cracking Distress Value (CDV)
3. Cracking Distress excluding Random cracking (CDV - random cracking)
4. Cracking Distress including Raveling (CDV + raveling)
5. Potholes + Patching

Crack seal deficiency distress carries a distress weight equal to five points. (PCR – CS) is obtained by excluding this distress. In doing so, the maximum points a pavement can achieve is 95.

Cracking Deduct Value (CDV) considers only the crack related distresses for both flexible and composite pavements. Tables 10 and 11 list the distresses considered for developing CDV.

Table 10. List of Cracking Distresses in Flexible Pavements

Distress name	**Distress weight**	**Severity Weight**			**Extent Weight**		
		Low	**Medium**	**High**	**Occasional**	**Frequent**	**Extensive**
C/S Deficiency	5	1	1	1	0.5	0.8	1
Whl-Trk Crack	15	0.4	0.7	1	0.5	0.7	1
Blk&Trv Crack	10	0.4	0.7	1	0.5	0.7	1
Long. Jt. Crack	5	0.4	0.7	1	0.5	0.7	1
Edge Crack	5	0.4	0.7	1	0.5	0.7	1
Random Crack	5	0.4	0.7	1	0.5	0.7	1

Table 11. List of Cracking Distresses in Composite Pavements

Distress name	**Distress weight**	**Severity Weight**			**Extent Weight**		
		Low	**Medium**	**High**	**Occasional**	**Frequent**	**Extensive**
Trv. Crack (Unjointed base)	20	0.2	0.6	1	0.4	0.8	1
Refl. Crack (Jointed base)	12	0.2	0.6	1	0.4	0.8	1
Int. Trv. Crack (Jointed base)	8	0.2	0.6	1	0.4	0.8	1
Long Crack	5	0.2	0.6	1	0.4	0.8	1
C/S Deficiency	5	1	1	1	0.5	0.8	1

CDV is calculated as:

$$\text{CDV} = \frac{Maximum\ Crack\ Deduct\ Points - Total\ Crack\ Deduct\ Points}{Maximum\ Crack\ Deduct\ Points}\, x\ 100$$

The maximum deduct points are 45 and 30 for flexible and composite pavements respectively. Note that the composite pavement has distresses related to both jointed base and unjointed base types. Appropriate distress weights were considered during calculations based on the type of composite pavement. Similar to CDV, other indicators were calculated by using the respective distress weights. Table 12 shows the maximum deduct points for each indicator.

Table 12. Maximum deduct points for each indicator

Indicator	**Maximum Deduct Points**		**Normalized Maximum Deduct Points**	
	Composite	**Flexible**	**Composite**	**Flexible**
PCR	100	100	100	100
PCR-C/S DEF.	95	95	100	100
CDV	50	45	100	100
CDV - Random	NA	40	100	100
CDV + Raveling	40	55	100	100
Potholes + Patching	5	15	100	100

Unlike PCR which operates on 0 to 100 scale, the additional indicators have a different scale. For a realistic comparison among them, these values were normalized to 100. The results thus obtained are presented in Figures 30 through 34. Non-normalized values are also indicated in these figures.

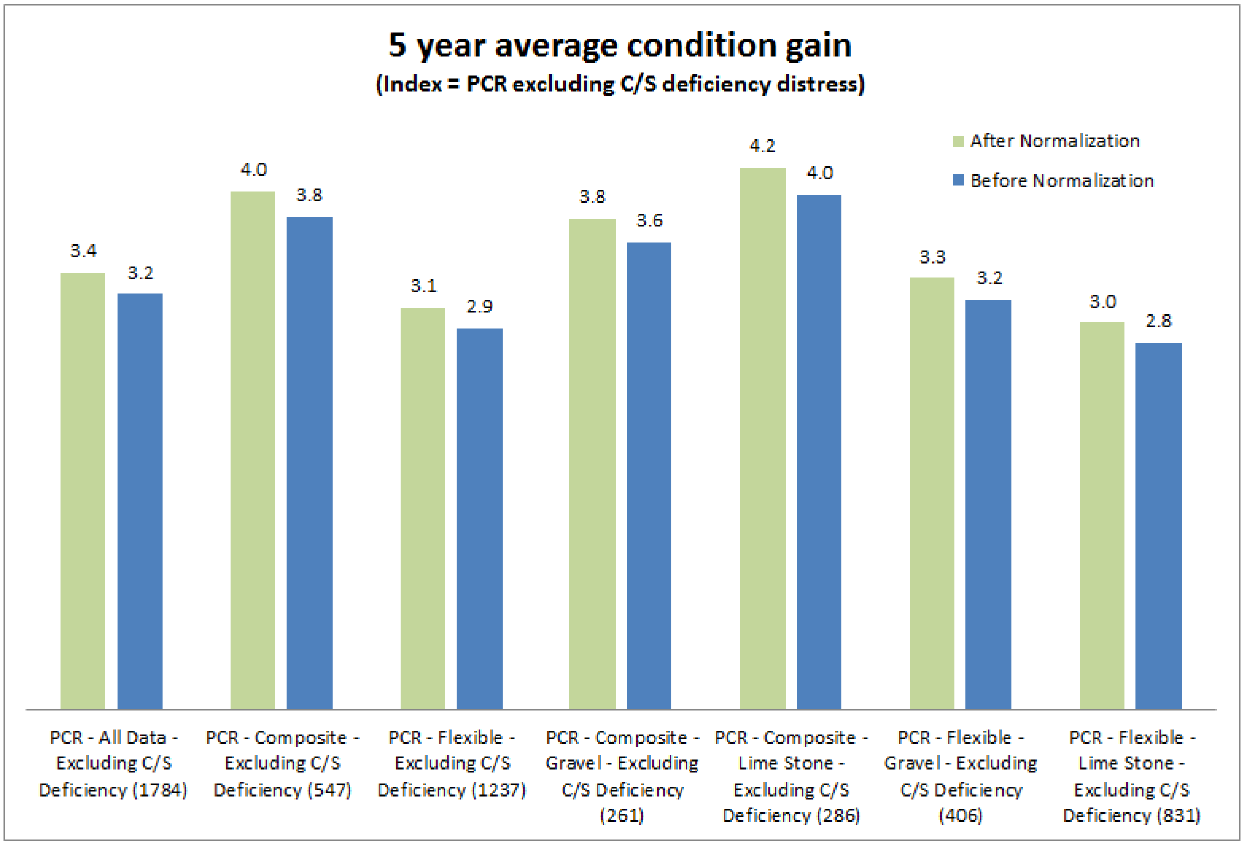


Figure 30. Effectiveness Based on (PCR – CS Deficiency)

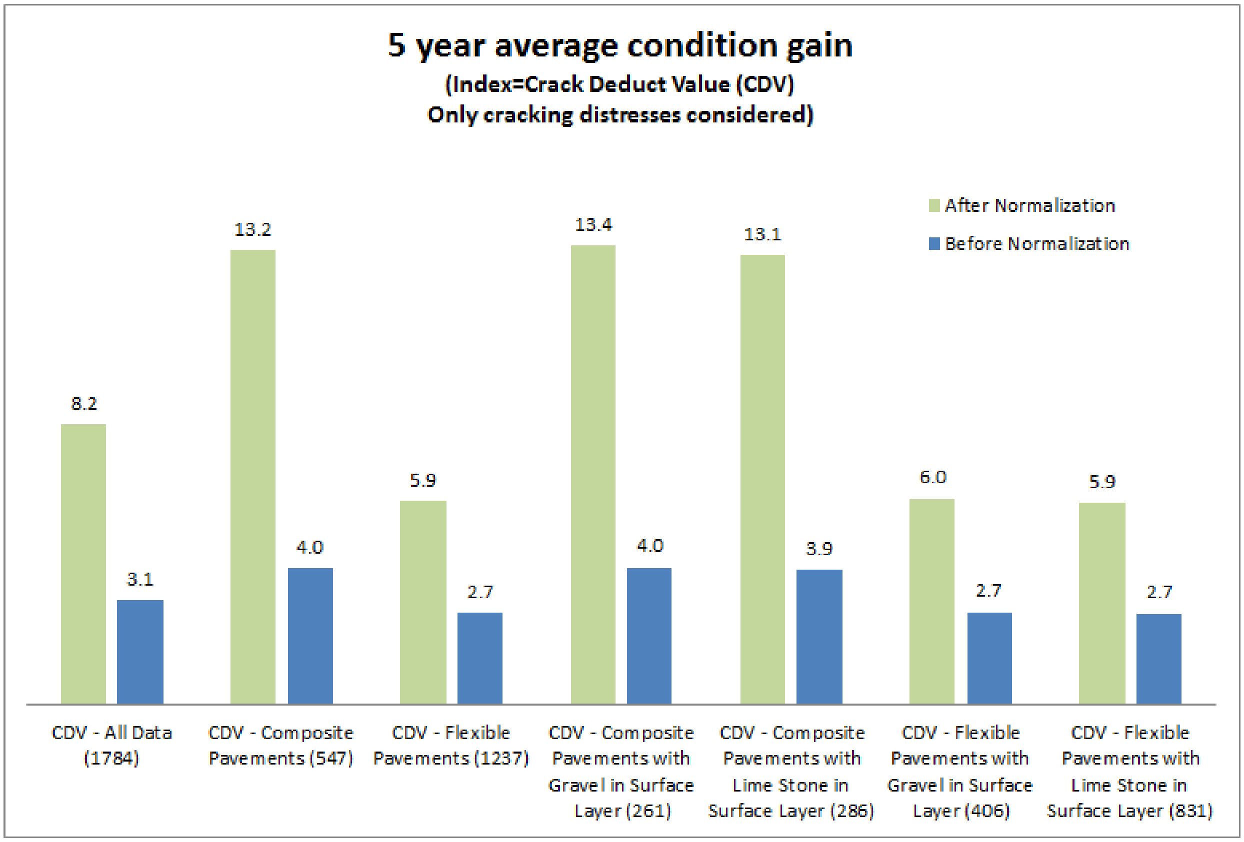


Figure 31. Effectiveness Based on CDV

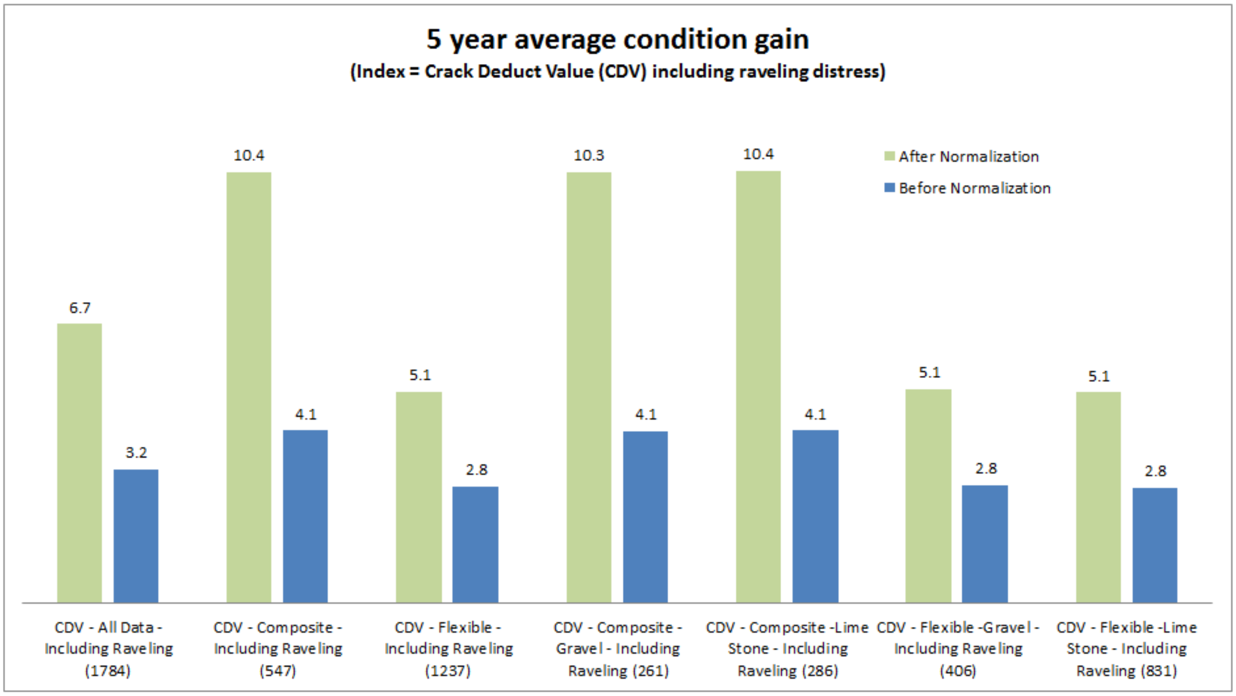
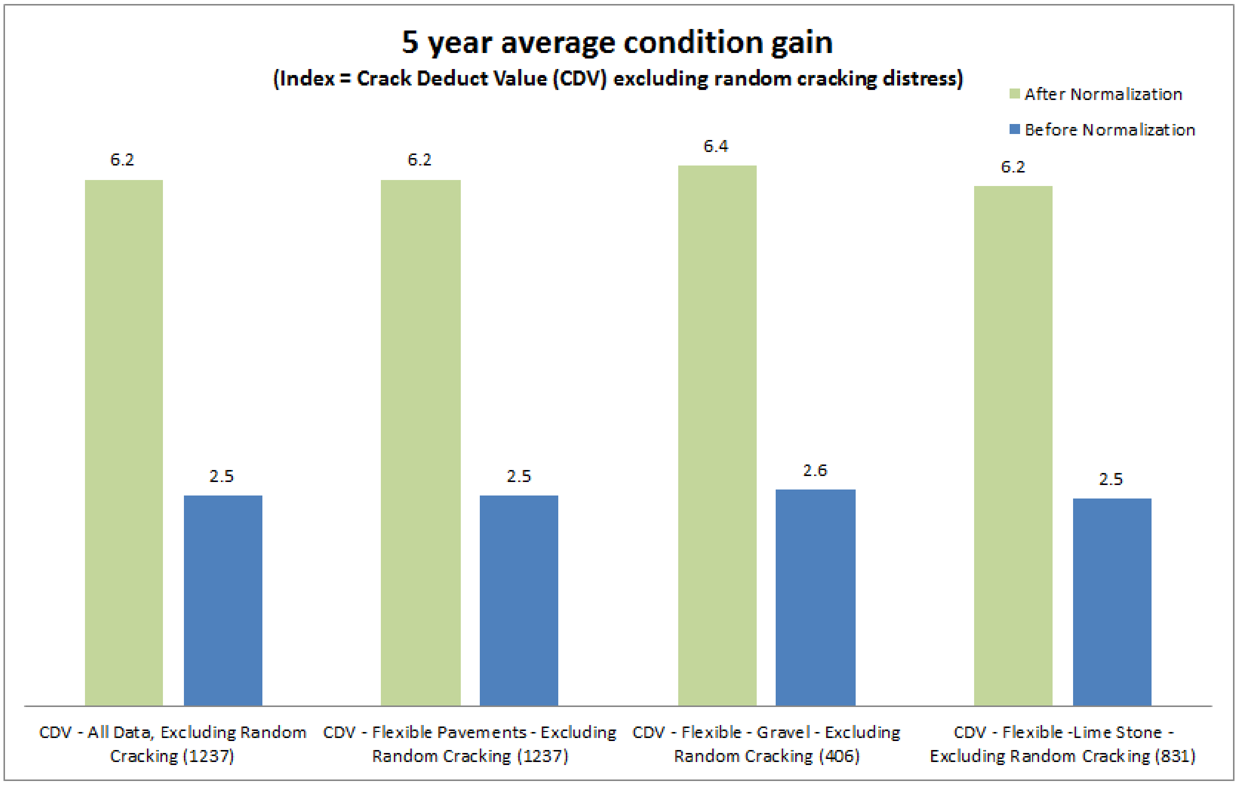


Figure 32. Effectiveness Based on CDV + Raveling



Note: Only flexible pavements are presented in above graph as random cracking distress is not associated with composite pavements.

Figure 33. Effectiveness Based on (CDV – Random) Cracking

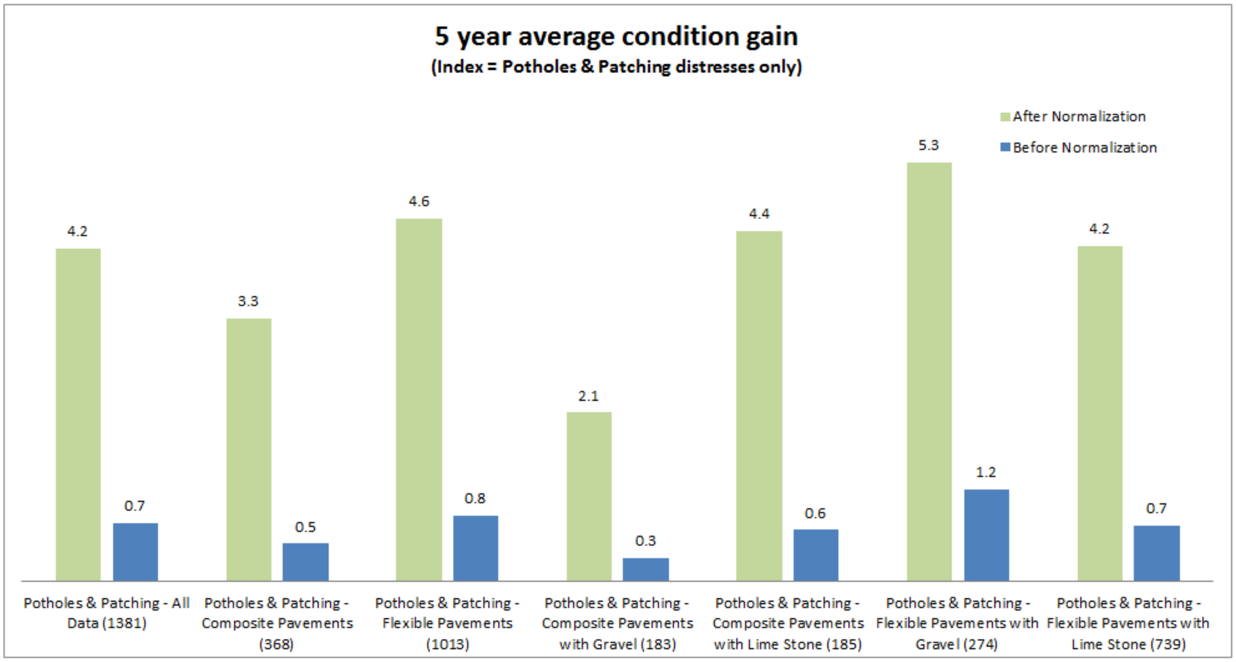


Figure 34. Effectiveness Based on Potholes and Patching

These figures indicate that crack sealing is an effective pavement preventive maintenance treatment. All the different indicators show a similar pattern of variation in effectiveness of crack sealing.

11. COST-EFFECTIVENESS OF CRACK SEALING

The benefits of crack sealing in this study, observed in terms of increase in average performance gain and extension of pavement service life, has been well-documented in the previous sections. The average performance gain of pavements in the PCR range 66-80 based on pavement type (from Table 6) is 4.2, 5.8, and 3.6 years for all pavement types, composite pavements, and flexible pavements respectively. And the service life of pavements based on pavement type in the same PCR range calculated at two different PCR threshold points namely, PCR=60 and PCR=65 is presented in Table 13.

Table 13. Service Life of Pavements in PCR Range 66-80

	Threshold PCR=60			Threshold PCR=65		
	All Pavements	**Composite Pavements**	**Flexible Pavements**	**All Pavements**	**Composite Pavements**	**Flexible Pavements**
Life of Crack sealed Subsections	4.87	7.70	3.14	3.25	5.82	1.81
Life of Control Subsections	3.79	7.46	2.09	1.56	4.55	0.29
Extension of Service Life, years	1.08	0.23	1.06	1.69	1.27	1.52

Consequentially, the question therefore is how do decision-makers use these observations to decide if application of crack seal as a strategy, in concert with time, is cost-effective? Therefore, a comparative cost analysis, using a common metric such as the Net Present Value (NPV) is performed. Net Present Value is the economic indicator of choice. The formula used to calculate NPV is:

$$NPV = \sum_{t=0}^{N} \left[\frac{C_t}{(1+r)^t} \right]$$

Where:

t – time at which cash is spent, N – total time under consideration, r – discount rate (4%), C_t – amount spent at time t

The two scenarios considered are namely, a) crack seal now and apply chip seal after a certain period of time and b) Do nothing now but apply chip seal after a given number of years. From ODOT's 2009 and 2010 construction records, the cost per lane mile for crack seal and chip seal is known to be \$2,504 and \$10,565 respectively. The results of the cost analysis are presented in Figures 35 through 40.

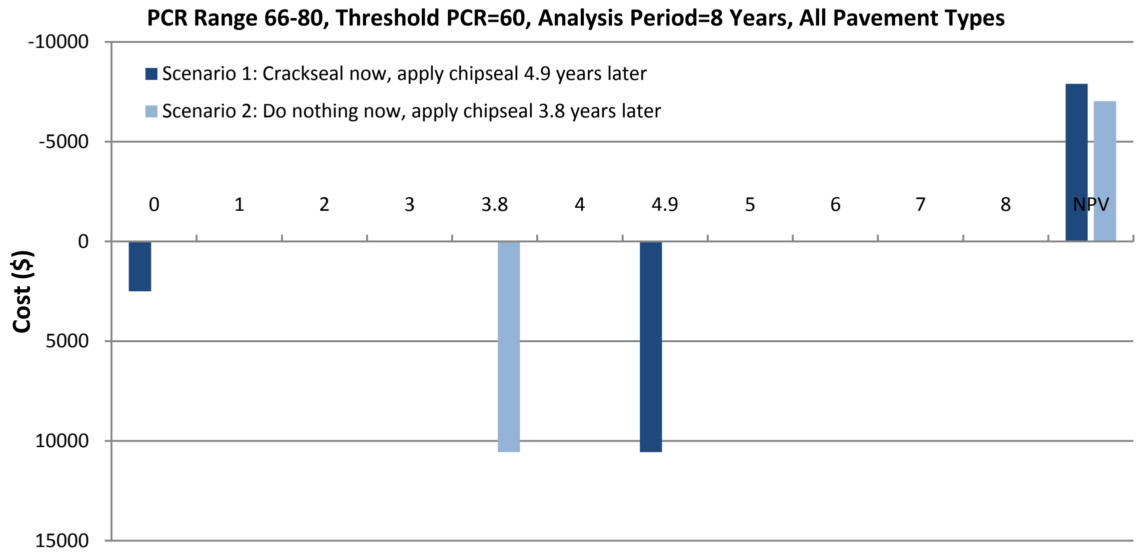


Figure 35. Cost-effectiveness of Two Alternate Treatments Based on Service Life for All Pavement Types

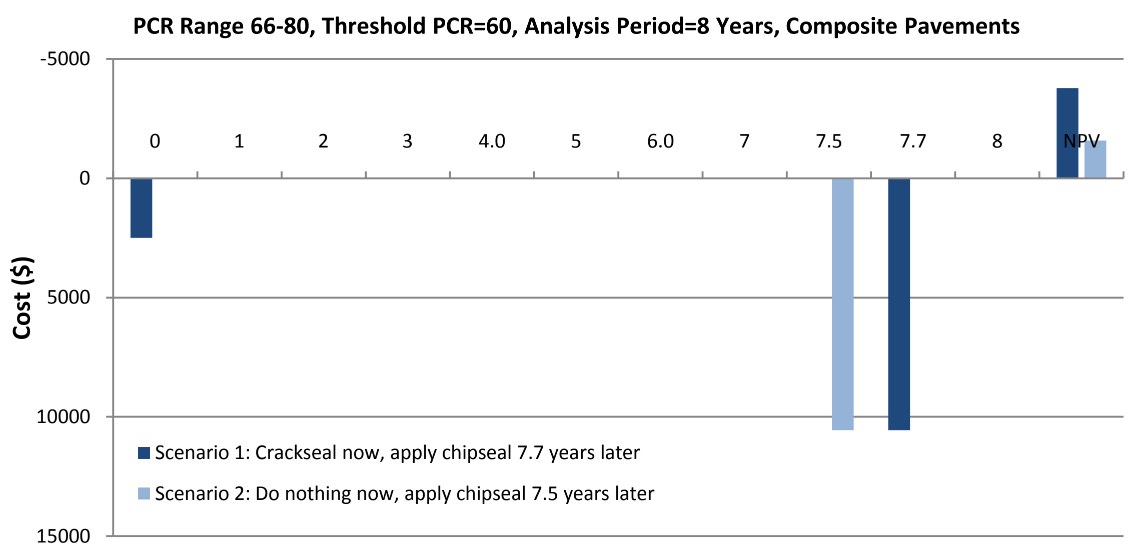


Figure 36. Cost-effectiveness of Two Alternate Treatments Based on Service Life for Composite Pavements

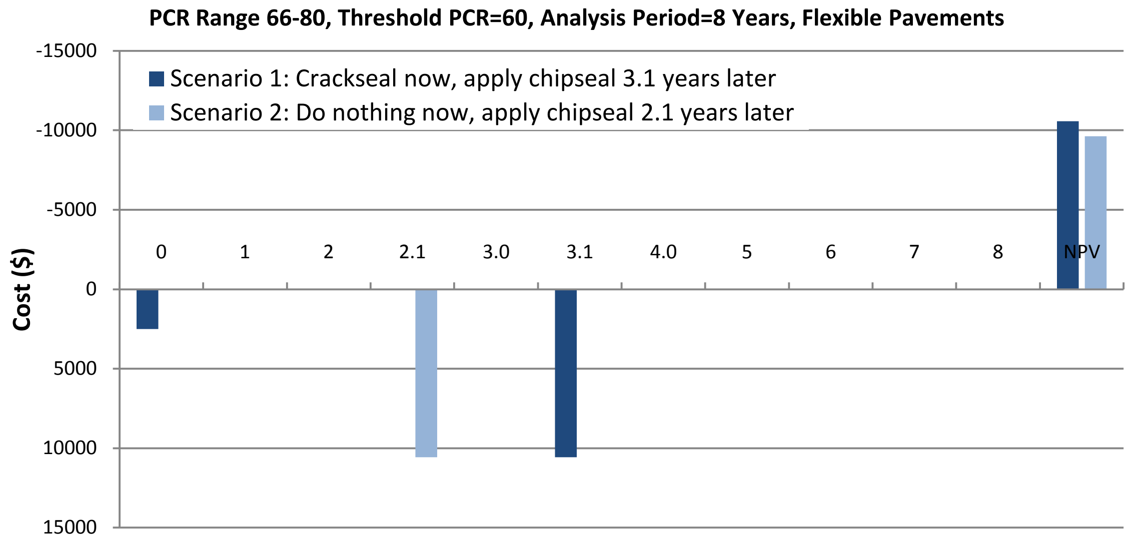


Figure 37. Cost-effectiveness of Two Alternate Treatments Based on Service Life for Flexible Pavements

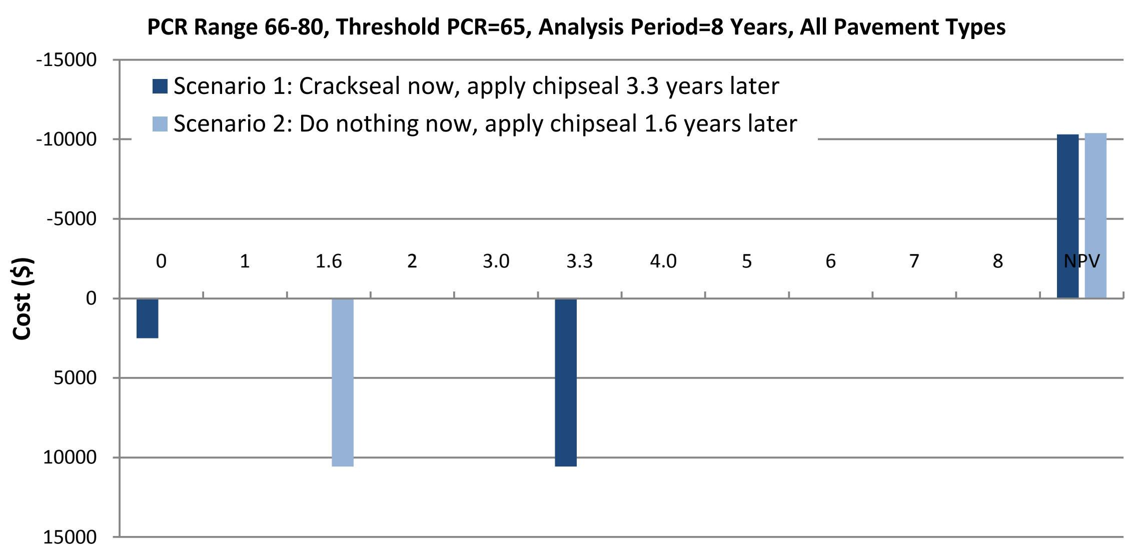


Figure 38. Cost-effectiveness of Two Alternate Treatments Based on Service Life for All Pavement Types

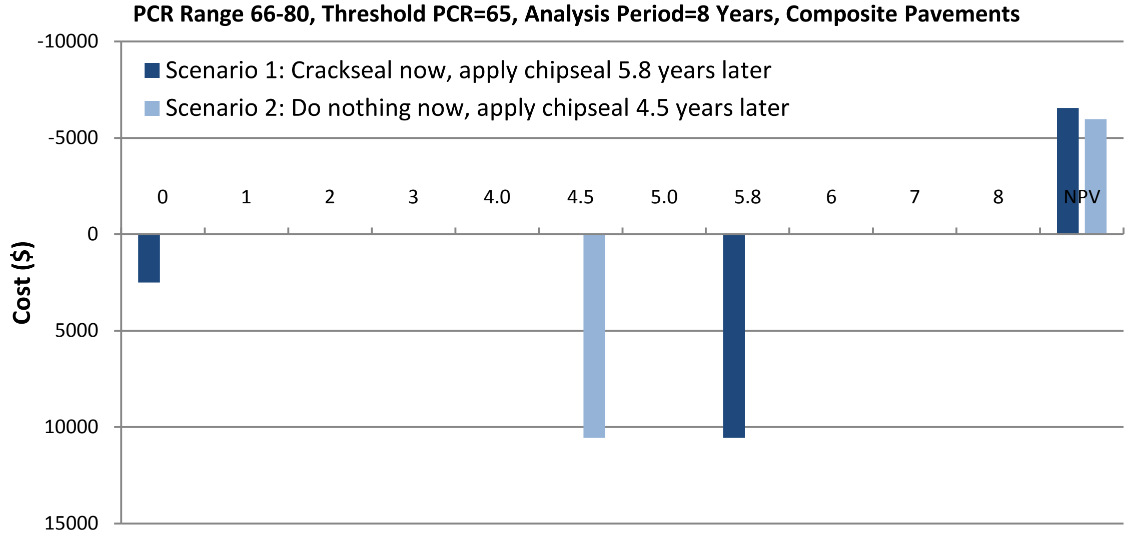


Figure 39. Cost-effectiveness of Two Alternate Treatments Based on Service Life for Composite Pavements

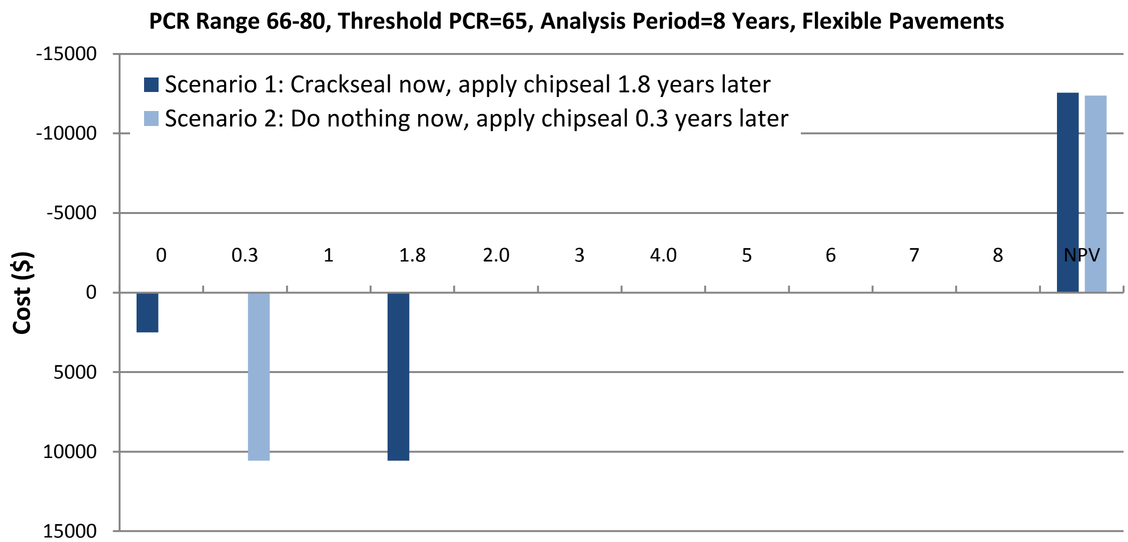


Figure 40. Cost-effectiveness of Two Alternate Treatments Based on Service Life for Flexible Pavements

As can be seen from the above figures, crack sealing turns out to be relatively ineffective in the PCR range of 66-80 for service life estimates calculated at threshold PCR of 60 and 65 for all conditions except one – illustrated in Figure 38 – where there is a marginal gain in using crack seal treatment.

In summary, as mentioned earlier, there is average performance gain (in terms of Pavement Condition Rating) because of crack seal treatment for all pavement types in the PCR range of 66-80. However, a comparative analysis of two different treatment scenarios, based on NPV estimates, calculated using the service life of treated and untreated pavement data belonging to the PCR range of 66-80, by and large does not indicate crack seal to be a cost-effective strategy.

To understand this contradiction, the researchers narrowed the PCR range to 66-70 in order to evaluate the cost-effectiveness of crack seal based on NPV estimates determined using the service life of treated and untreated pavements.

The service life estimates of treated and untreated pavements based on pavement type in the PCR range of 66-70 for two PCR thresholds namely, PCR=60 and PCR=65 is presented in Table 14. The shaded boxes in the table is intended to indicate that the service life of control subsections could not be determined using the available data. Thus, the cost-effectiveness of crack sealing is evaluated for service life estimates calculated at a threshold PCR of 60 for all pavement types and a threshold PCR of 65 for composite pavements.

Table 14. Service Life of Pavements in PCR Range 66-70

	Threshold PCR=60			Threshold PCR=65		
	All Pavements	**Composite Pavements**	**Flexible Pavements**	**All Pavements**	**Composite Pavements**	**Flexible Pavements**
Life of Crack sealed Subsections	3.12	7.44	2.74	1.69	5.07	1.25
Life of Control Subsections	1.27	4.75	0.91		1.42	
Additional Life, years	1.85	2.69	1.83		3.65	

The two treatment scenarios considered previously are used to estimate the NPV for different pavement types in the prior PCR range of 66-70. The results of the cost analysis are presented in Figures 41 through 44.

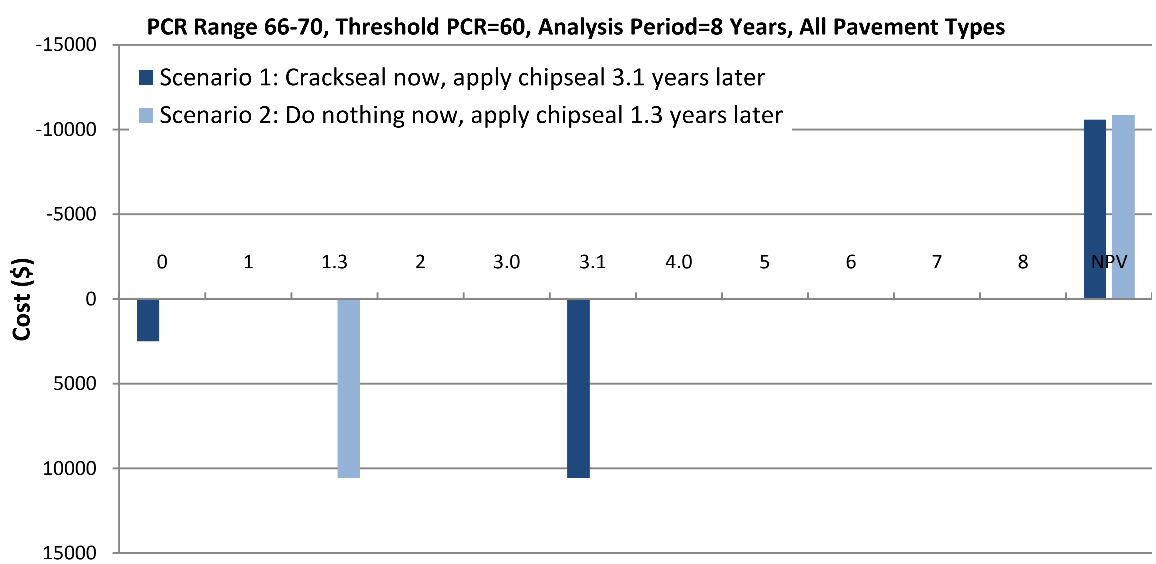


Figure 41. Cost-effectiveness of Two Alternate Treatments Based on Service Life for All Pavement Types

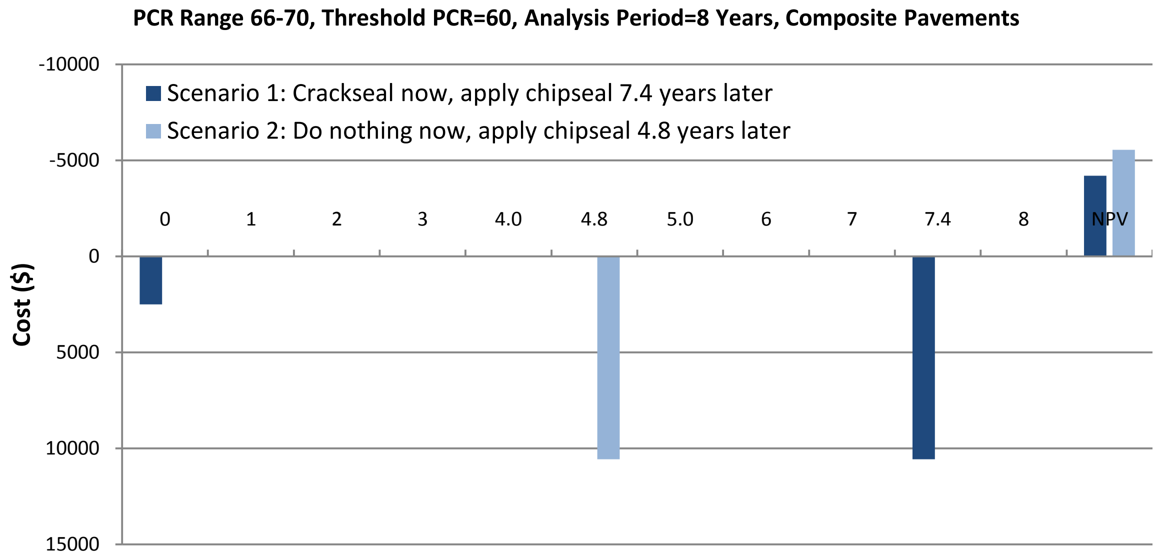


Figure 42. Cost-effectiveness of Two Alternate Treatments Based on Service Life for Composite Pavements

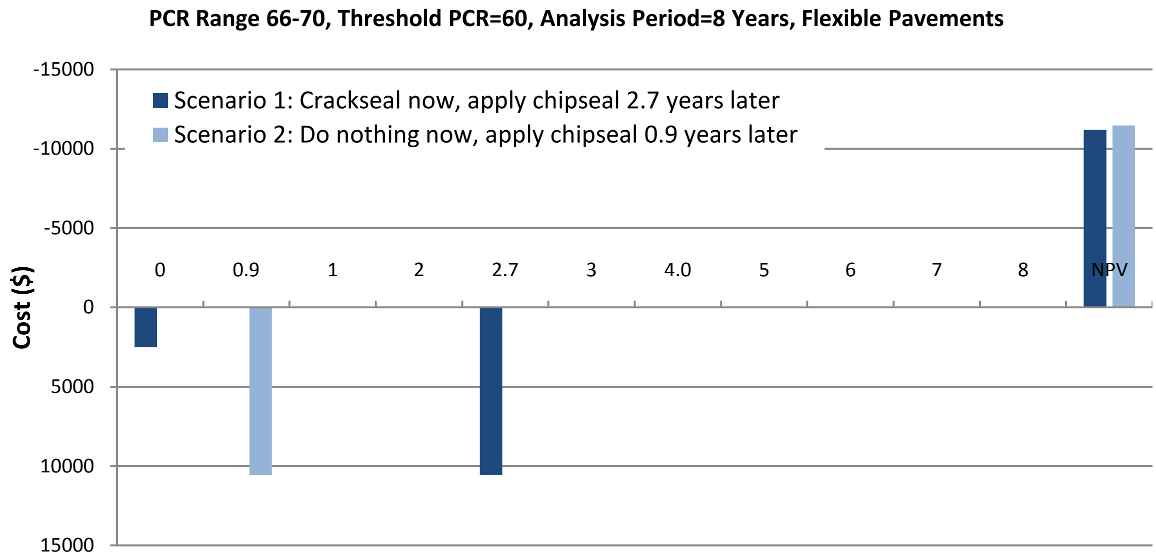


Figure 43. Cost-effectiveness of Two Alternate Treatments Based on Service Life for Flexible Pavements

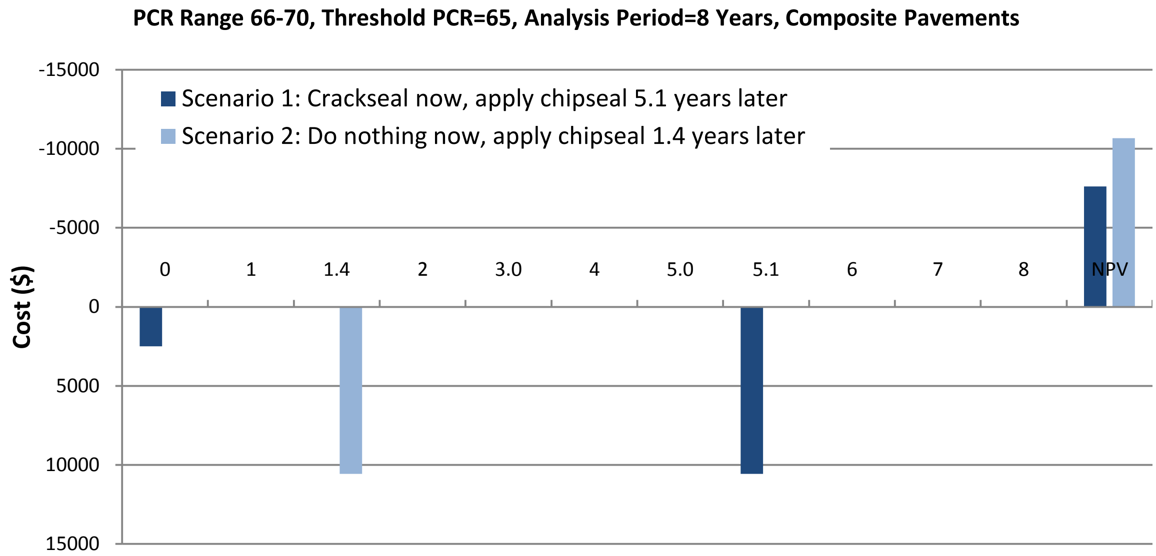


Figure 44. Cost-effectiveness of Two Alternate Treatments Based on Service Life for Composite Pavements

It is clear from the above figures that crack sealing turns out to be relatively effective in the PCR range of 66-70 for service life estimates calculated in Table 14. This result is in congruence with the average performance gain observed for the same PCR range (presented in Table 6), which also indicates that crack sealing enhances pavement performance. The results of the cost-analysis are summarized in Table 15. As can be seen from the table, the benefits of performance gain and service life gets translated to economic benefits when crack seal is applied for pavements in the PCR range of 66-70. Furthermore, it can be seen from Figures 42 and 44 that application of crack seal treatment to composite pavements in the prior PCR range of 66-70 is more cost-effective compared to flexible pavements.

Table 15. Cost-effectiveness of Crack Seal Based for Different Pavement Condition (Analysis Period=8 Years)

PCR Range	Threshold PCR	Pavement Type	Treatment Scenarios Compared	NPV	Is Crack Sealing Cost-effective?
66-80	60	All Pavements	Scenario 1: Crack seal now, apply chip seal 4.9 years later	$7,907	No
			Scenario 2: Do nothing now, apply chip seal 3.8 years later	$7,043	
		Composite	Scenario 1: Crack seal now, apply chip seal 7.7 years later	$3,779	No
			Scenario 2: Do nothing now, apply chip seal 7.5 years later	$1,576	
		Flexible	Scenario 1: Crack seal now, apply chip seal 3.1 years later	$10,581	No
			Scenario 2: Do nothing now, apply chip seal 2.1 years later	$9,620	
	65	All Pavements	Scenario 1: Crack seal now, apply chip seal 3.3 years later	$10,313	No
			Scenario 2: Do nothing now, apply chip seal 1.6 years later	$10,397	
		Composite	Scenario 1: Crack seal now, apply chip seal 5.8 years later	$6,554	No
			Scenario 2: Do nothing now, apply chip seal 4.5 years later	$5,971	
		Flexible	Scenario 1: Crack seal now, apply chip seal 1.8 years later	$12,575	No
			Scenario 2: Do nothing now, apply chip seal 0.3 years later	$12,394	
66-70	60	All Pavements	Scenario 1: Crack seal now, apply chip seal 3.1 years later	$10,590	**Yes**
			Scenario 2: Do nothing now, apply chip seal 1.3 years later	$10,856	
		Composite	Scenario 1: Crack seal now, apply chip seal 7.4 years later	$4,201	**Yes**
			Scenario 2: Do nothing now, apply chip seal 4.8 years later	$5,557	
		Flexible	Scenario 1: Crack seal now, apply chip seal 2.7 years later	$11,191	**Yes**
			Scenario 2: Do nothing now, apply chip seal 0.9 years later	$11,458	
	65	Composite	Scenario 1: Crack seal now, apply chip seal 5.1 years later	$7,608	**Yes**
			Scenario 2: Do nothing now, apply chip seal 1.4 years later	$10,681	

12. SUMMARY AND CONCLUSIONS

Sealing of cracks in asphalt surfaced pavements has long been one of the widely practiced pavement maintenance strategies by the highway agencies. Crack sealing is performed with intent to reduce water infiltration, prevent pumping and avoid the need for premature base and pavement repair. A successful crack sealing project can result in numerous benefits such as - improved pavement condition, increased safety, extended service life, reduced maintenance and rehabilitation needs and overall, lower life cycle costs. A host of factors namely: sealing materials, placement techniques, equipment, pavement types and condition, type and severity of crack sealed, regional environmental and traffic conditions, evaluation procedures and so on are known to directly influence the level of success that can be attained in a crack sealing project. These variables often act individually or collectively to affect the outcome of a crack seal project. Despite the intended benefits, crack sealing may also affect the pavement in many ways like, 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***.

A systematic evaluation will help to assess the effectiveness of an agency's current crack sealing practices and will provide necessary data to fine tune the prevailing practice by identifying specific areas that need improvement. The perceived benefits of such investigation include better utilization of public funds and greater return on the investment.

Realizing the importance of such an investigation, in 2000, the Ohio Department of Transportation initiated a 10-year study to 'statistically verify the effectiveness of its current force account crack sealing program on pavement condition and life'. The primary objective of the study was to develop a field experiment that would enable ODOT to collect long-term performance data. By analyzing this long term performance data, it was desired that the study will resolve the following key issues:

- Do existing crack sealing practices within ODOT enhance pavement performance?
- If so, what is the optimum timing for treatment?
- Does crack sealing extend pavement life?
- Does crack sealing provide cost benefit? If so, to what extent?

Previous studies carried out by several federal and state agencies have attempted to address similar concerns. However, no consensus appears to exist about the effectiveness of crack sealing practices. In comparison, a cursory look at ODOT's existing crack sealing practices revealed the following information:

- A range of materials and methods are in use for crack sealing.
- 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 need for crack sealing is not an issue; instead, 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.

During the period 2000 through 2002, ODOT set up over 700 test sections, each 1000 feet long, in asphalt surfaced pavements. The test sections were treated by crack sealing materials at various time periods reflecting varied pavement conditions. Control sections were set up in adjacent areas which served as ‘do-nothing’ treatments. The county managers were provided with guidelines describing the pavement limits, crack sealing schedule, required documentation and reporting. All these tasks were well coordinated by the Office of Pavement Engineering and ODOT’s district and county offices.

At the beginning of the study, a survey was conducted to summarize the prevailing crack sealing practices in Ohio. The district and county managers provided responses to a series of questions that assisted in summarizing the current crack sealing practices. The survey revealed there is a wide variation in the pavement condition prior to crack sealing. Additionally, many officials, based on their observation of historical performance of crack sealed pavements, recognized pavement type and the type of aggregate used in the surface layer as key factors affecting the performance of treated pavements. The field experiment was carefully designed to establish test sections that included the variables namely:

- Pavement type (flexible and composite),
- Type of aggregate in the surface layer (lime stone and gravel), and
- Pavement condition prior to crack sealing.

The test sections were surveyed annually to record their pavement condition ratings from the time prior to crack sealing and for a period of five to nine years after sealing, depending on the longevity of the test sections. Pavement condition survey was conducted in accordance with ODOT’s guidelines for pavement condition rating, by visually observing surface distresses and recording their severity and extent. One technician conducted condition survey of all the sections throughout the life of the study, thus eliminating differences in judgment between raters.

An interactive database was developed for (i) data gathering, (ii) data storing, (iii) data processing, and (iv) data analysis. A vast amount of data was acquired that included:

- PCR data for each year, for each of the 1000 ft long section, including individual distress data,
- Crack seal information: date of treatment, type, amount and cost of material, application procedure, pavement surface preparation procedure, environmental condition during crack treatment, and
- Section description: pavement type, type of aggregate in surface layer, functional classification, number of lanes.

In 2008, when the data collection process was completed, a total of 387 treated sections and corresponding control sections became available for the analysis of effectiveness of crack sealing. A sum of 1784 PCR points were available for the performance analysis of the treated and control sections.

As a first step in the analysis, all the PCR points were plotted relative to their corresponding age. This task resulted in the development of two performance curves – one for the treated and one for the control sections. The curves were used to derive two performance indicators namely:

- Average performance gain due to crack sealing, and
- Service life comparison of treated and control sections.

The difference in PCR values of the treated and control section for each test section was calculated for each year, up to five years. The average of these differences was denoted as 'average performance gain'. The average performance gain of all the crack sealed pavements, regardless of pavement type and prior pavement condition, ranged from 2 to 7 PCR points with an overall average of 3.9.

This meant that, the crack sealed pavements have, in general, performed better than the untreated sections on a 5-year life cycle. The difference was found to be statistically significant at 95% confidence interval.

Next, the performance models were used to determine the service life of the pavements. The treated pavements were found to have an additional service life of 1.1 years when compared using a threshold PCR of 60.

With a view to find the effect of experimental variables on the performance of treated pavements, the database was sorted out according to variables namely, pavement type (flexible and composite), aggregate type (lime stone and gravel), and the pavement condition in terms of prior PCR groups. Seven PCR groups were created on a 5-point range starting from 55 to 60 till 85 to 90.

The analysis – in terms of average performance gain – showed conclusive evidence that crack sealing is an effective preventive maintenance technique. The performance can be maximized by treating flexible as well as composite pavements whose PCR is in the range of 66 to 80. It is also interesting to see that performance gain is relatively higher in the case of composite pavements.

ODOT's PCR is a composite index of surface distresses that include cracking and non-cracking distresses such as raveling, rutting, patching, bleeding and many distresses. Crack sealing is an activity performed only at the cracks. This maintenance activity will have little to no effect on the progression of non-cracking distresses. A question arises here about the efficacy of using PCR to evaluate the effectiveness of crack sealing. To address this question, it was decided to isolate cracking distresses and further evaluate the effectiveness of crack sealing on pavement performance. Based on the suggestion from ODOT engineers, the following five additional performance indicators were created:

1. PCR excluding C/S Deficiency
2. Cracking Distress
3. Cracking Distress excluding Random cracking
4. Cracking Distress including Raveling
5. Potholes + Patching

Interestingly, each analysis indicated a similar trend and reaffirmed the effectiveness of crack sealing of composite pavements with a PCR of 66 to 80.

In summary, the results presented in this study and conclusions made thereof are based on a large amount of data. The 10-year field experiment provided a unique opportunity to investigate the long-term performance of nearly 700 test sections. The field experiment was extensive, well designed, coordinated and documented. The data was analyzed to develop statistically conclusive evidence about the effectiveness of crack sealing on pavement performance and the influence of experimental variables.

As mentioned above, it has been observed in this study that the benefits of crack sealing have resulted in increase in average performance gain and extension of pavement service life. However, the question is how do decision-makers decide – from these two observations – if application of crack seal as a strategy, in concert with time, is cost-effective? The cost analysis of two pavement maintenance treatment alternatives, using a common metric such as the Net Present Value, presented in Section 11, illustrates that crack sealing, as a maintenance strategy, is economically viable for pavements in the prior PCR range of 66-70.

In conclusion, the results of the study highlighted that crack sealing is an effective treatment in general. Regardless of pavement type, aggregate type used in the surface layer, and the prior pavement condition, crack sealing always results in performance gain. However, the maximum performance gain can be attained when the prior PCR is in the range of 66-80, and the cost-effectiveness is achieved when the prior PCR is in the range of 66-70. From the decision-maker's perspective, it becomes difficult to implement the crack sealing program for such a narrow range. On the contrary, while the crack sealing program for the prior PCR range of 66-80 is not entirely cost-effective, it is practically easier to implement the program which also results in performance gain.

13. RECOMMENDATIONS

From a practical point of view, it is hereby recommended that ODOT develops a policy to allow crack sealing as a strategy for pavement preventive maintenance for all pavements in the prior PCR range of 66 to 80.

REFERENCES

1. Rajagopal A.S. and Minkarah, I. A, “Effectiveness of Crack Sealing on Pavement Serviceability and Life”, Report No. FHWA/OH-2003/009, Ohio Department of Transportation, June 2003.