2017

Pavement Condition Index and Cost of Ownership Analysis on Preventative Maintenance Projects in Kentucky

Dominic J. Michels
University of Kentucky, dmichels57@hotmail.com
Digital Object Identifier: https://doi.org/10.13023/ETD.2017.084

Recommended Citation

Michels, Dominic J., "Pavement Condition Index and Cost of Ownership Analysis on Preventative Maintenance Projects in Kentucky" (2017). *Theses and Dissertations--Civil Engineering*. 53.
https://uknowledge.uky.edu/ce_etds/53

STUDENT AGREEMENT:

I represent that my thesis or dissertation and abstract are my original work. Proper attribution has been given to all outside sources. I understand that I am solely responsible for obtaining any needed copyright permissions. I have obtained needed written permission statement(s) from the owner(s) of each third-party copyrighted matter to be included in my work, allowing electronic distribution (if such use is not permitted by the fair use doctrine) which will be submitted to UKnowledge as Additional File.

I hereby grant to The University of Kentucky and its agents the irrevocable, non-exclusive, and royalty-free license to archive and make accessible my work in whole or in part in all forms of media, now or hereafter known. I agree that the document mentioned above may be made available immediately for worldwide access unless an embargo applies.

I retain all other ownership rights to the copyright of my work. I also retain the right to use in future works (such as articles or books) all or part of my work. I understand that I am free to register the copyright to my work.

REVIEW, APPROVAL AND ACCEPTANCE

The document mentioned above has been reviewed and accepted by the student's advisor, on behalf of the advisory committee, and by the Director of Graduate Studies (DGS), on behalf of the program; we verify that this is the final, approved version of the student's thesis including all changes required by the advisory committee. The undersigned agree to abide by the statements above.

Dominic J. Michels, Student

Dr. Gabe Dadi, Major Professor

Dr. Yi-Tin Wang, Director of Graduate Studies

PAVEMENT CONDITION INDEX AND COST OF OWNERSHIP ANALYSIS ON PREVENTATIVE MAINTENANCE PROJECTS IN KENTUCKY

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering in the College of Engineering at the University of Kentucky

By

Dominic Joseph Michels

Fort Mitchell, Kentucky

Director: Dr. Gabe Dadi, Professor of Civil Engineering

Lexington, Kentucky

2017

ABSTRACT OF THESIS

PAVEMENT CONDITION INDEX AND COST OF OWNERSHIP ANALYSIS ON PREVENTATIVE MAINTENANCE PROJECTS IN KENTUCKY

The Commonwealth of Kentucky has seen increasing use over time of preventative maintenance treatments on its asphalt pavements. Performance of two of the most prevalent treatments employed by the Kentucky Transportation Cabinet (KYTC) – Thin Asphalt Overlay (Thinlay) and Microsurfacing – had yet to be examined in-depth through condition surveys. This thesis describes the data collection process to find the Pavement Condition Index (PCI) of each preventative maintenance site in Kentucky from the last 10 years. With PCI from each site, deterioration curves were generated for each treatment – providing the estimated life extension benefit of each. The analysis then converted life extension to life cycle costs to ultimately determine which product was more cost effective. Cost effectiveness would be the definitive metric in determining which product should be used by KYTC. It is hoped that this thesis can begin to quantitatively and statistically answer the question of how to best approach asphalt maintenance projects in Kentucky.

KEYWORDS: Asphalt Pavement Maintenance, Kentucky Roadway Conditions, Pavement Condition Index, Asphalt Life Cycle Costs, Microsurfacing, Thin Asphalt Overlay

Dominic Michels

April 22nd, 2017

PAVEMENT CONDITION INDEX AND COST OF OWNERSHIP ANALYSIS ON PREVENTATIVE MAINTENANCE PROJECTS IN KENTUCKY

By

Dominic Joseph Michels

Dr. Gabe Dadi

Director of Thesis

Dr. Yi-Tin Wang

Director of Graduate Studies

April 22nd, 2017

This thesis is dedicated to the memory of Paul F. Michels and Vince J. Michels, who both constructed and supported quality pavements throughout their distinguished careers, and who continue to inspire my family in all of our works.

Acknowledgements

The data collection and analysis in this thesis would not have been possible without support from Brian Wood, Paul Del Rio, and Cherie Stivers at the Plantmix Asphalt Industry of Kentucky – who initially hired me to answer the question of asphalt maintenance in the Commonwealth. PAIKY heavily contributed to the development of this analysis and their guidance has helped steer my thinking and decision making throughout this process.

Acknowledgement is also extended to the paving contractors throughout the state who provided traffic control assistance during data collection. Their diligence and willingness to assist ensured that the data was collected in the safest manner possible.

Lastly, the advising abilities of Dr. Gabe Dadi have left a mark of improvement on the analysis and presentation of the thesis data. He never hesitated to review and critique my work and his advice has been invaluable.

Table of Contents

List of Tables

List of Figures

1. Introduction

In recent years, the Kentucky Transportation Cabinet (KYTC) has seen Microsurfacing, Thinlay, and other preventative maintenance treatments being increasingly applied due to factors with limited funding. FHWA defines preventative maintenance as “a planned strategy of cost effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity).” However, a detailed publication or study on the performance of these treatment methods in Kentucky has yet to be conducted that incorporates data from the specific projects where they are used. It was decided to further investigate the issue in order to answer a number of questions. Are the products being properly applied? When applied, how do they perform over time? If one product has a longer life than the other, which is ultimately more cost effective?

After some time of deliberation on how to move forward, the entire list of KYTC projects was compiled where preventative maintenance treatments were applied in the past 10 years. The projects span a large variety of traffic conditions, age, and pre-existing surface age. With the large variety of conditions represented, some general conclusions can be made about the different paving materials.

When preparing to begin the physical pavement evaluations, ASTM D6433 was chosen as the most favored method to provide the most credible data (ASTM 2007). Eventually, the PCI (Pavement Condition Index) values were all calculated in order to make conclusions about the expected service life of each material. The following pages will detail the background information in project evaluation methodology, an analysis of the raw data with respect to common distresses, a thorough statistical analysis, the development of the deterioration curve for each product, and finally the cost benefit analysis. The primary objective of this thesis is to evaluate the relationship between preventative maintenance efforts and pavement condition. The contributions of this work will inform and guide practitioners on issues relating to preventative maintenance treatments including evaluating pavement conditions and life cycle cost.

2. Product Descriptions

Although both products are used in preventative maintenance applications, they have very different properties and construction practices. These properties range from the gradation of the mix to the simple thickness of the mat. Figure 2.1 below illustrates some of these differences.

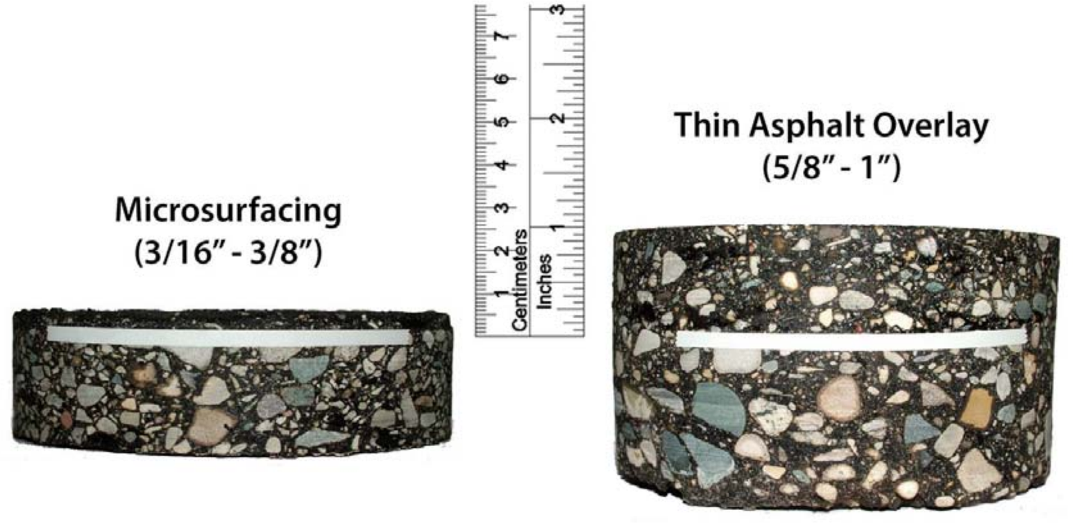


Figure 2.1: Microsurfacing/Thinlay Profiles (Plantmix Asphalt Industry of Kentucky)

Thinlay is typically applied between 5/8” to 1” of thickness, compared to Microsurfacing which is between 3/16” and 3/8” thick. During construction, Thinlay is applied in the same manner as any HMA overlay. There are no specialized materials or equipment required by the contractor. When applying Microsurfacing, a polymer modified emulsion is mixed on site with the aggregate at the paver. A nozzle on the paver sprays water onto to the surface ahead of the material in order to improve bonding. Often times in Kentucky, a road will be crack sealed before Microsurfacing is applied in order to retard cracking through the new surface.

Due to its lack of structure, Microsurfacing should be used on roadways without excess deformation or rutting, as it will only mirror the old surface. Contrasting this, Thinlay is useful in addressing minor rutting and can more effectively level the profile of a road, improving rideability.

3. Establishing an Evaluation Method

A number of different rating systems and evaluation methods exist for quantifying pavement conditions. Two prevalent methods were examined and compared. These are the PASER and PAVER systems, which utilize two very different procedures for collecting data and assigning a condition number to the pavement in question.

PASER is a more simplified method of surveying pavement condition. It involves examining pavement distresses from a general viewpoint as opposed to physically measuring cracks and deformations. There are rating categories for this system that range from 1 (failed pavement) to 10 (excellent pavement). The rating selected by the evaluator depends upon variables such as crack spacing, crack width, patching, crack spalling, and the density of fatigue cracking. The PASER manual provides pictures and descriptions of all the distress types and varying severity levels (Transportation Information Center 2002).

PAVER is a more involved system than PASER, with the evaluator obtaining detailed distress measurements as opposed to PASER. This system provides a PCI (Pavement Condition Index) that ranges from 0 (failed pavement) to 100 (excellent pavement). The use of this method was examined within ASTM D6433, Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. Using this standard, the evaluator selects a number of random sample units (typically 2500 ± 1000 square feet), and measures all of the distresses in those units. Through an iterative calculation, these measurements are used to determine the final PCI of the pavement.

After comparing these two systems, it was determined that ASTM D6433 would provide stronger, less biased data for this particular study. The need to accurately monitor pavement condition trends for industry research suggests that a more involved system than PASER is required. After reaching this conclusion, preparation began to undergo pavement evaluations according to the ASTM method.

4. ASTM D6433 Procedure

Required Equipment:

- Surveyor’s Wheel
- 6.5 Foot Level
- Folding Ruler
- PAVER Distress Identification Manual

Before formally beginning the evaluation, it was useful to drive the roadway and perform a general windshield survey. This practice helps to determine the consistency of the roadway and to check if there are any significant areas of unrepresentative distresses. When beginning to evaluate a pavement, random sample units must first be selected, which are then known to be consistent with the general roadway condition by performing the windshield observations. These units can range in area from 1500 to 3500 square feet. When in the field, a starting point is randomly selected, and the desired length of the unit is measured along with the width. Next, the evaluator can begin measuring distresses using the surveyor’s wheel. Some distresses are measured as linear feet, and others as square feet. Table 4.1 summarizes the distress types defined by PAVER.

Table 4.1: PAVER Distress Types

Distress Type	**Measurement Type**
Alligator Cracking	Area
Bleeding	Area
Block Cracking	Area
Bumps and Sag	Length
Corrugation	Area
Depression	Area
Edge Cracking	Length
Joint Reflection Cracking	Length
Lane/Shoulder Drop-off	Length
Longitudinal and Transverse Cracking	Length
Patching	Area
Polished Aggregate	Area
Potholes	Count
Railroad Crossing	Area
Rutting	Area
Shoving	Area
Slippage Cracking	Area
Swell	Area
Raveling	Area
Weathering	Area

Distress measurements are quantified by both the numerical component as well as the severity level, which can be Low, Medium, or High. For example, severity level in longitudinal and transverse cracking is determined by crack width, spalling, and crack sealing condition. After determining both components, the evaluator records the measurement on the data sheet for that sample unit.

Once the desired number of sample units is gathered, the field work for that pavement section is complete, and the PCI calculation is performed. First, the density for each distress type is calculated as a percentage by dividing the measurement by the sample unit area. Using the density and the severity level, a deduct value is determined for that distress by consulting the deduct value curves provided by ASTM. The following graph is an example of the deduct value curves for alligator cracking. An example of a data sheet is also provided.

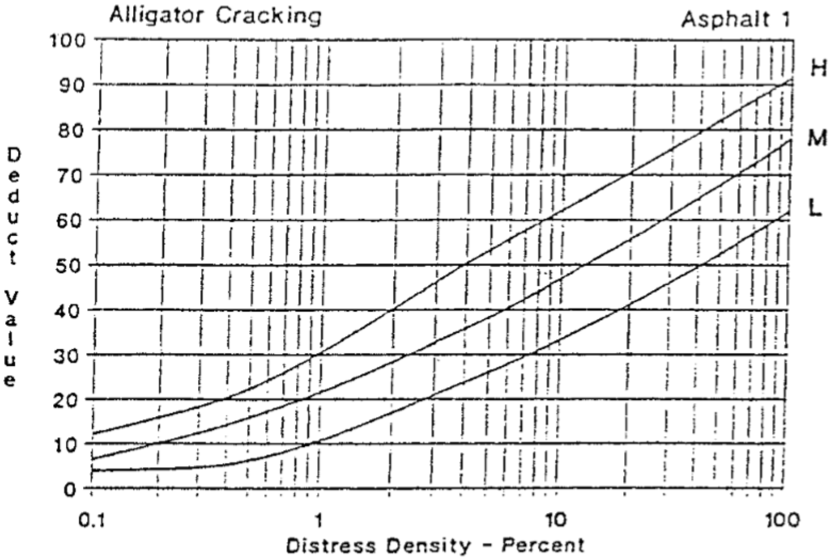
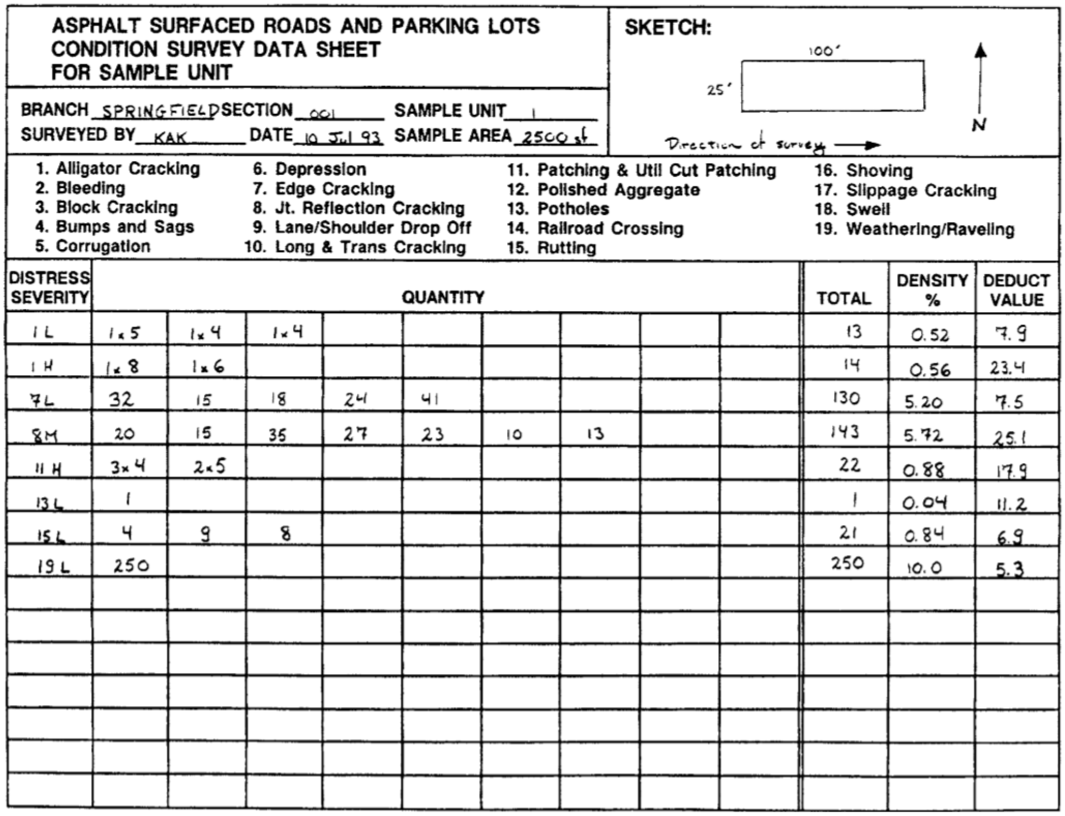


Figure 4.1: Alligator Cracking Deduct Curves (ASTM 2007)



ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH SPRINGFIELD SECTION 001 SAMPLE UNIT 1

SURVEYED BY KAK DATE 10 Jul 93 SAMPLE AREA 2500 sf

SKETCH:

1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Bumps and Sags
5. Corrugation
6. Depression
7. Edge Cracking
8. Jt. Reflection Cracking
9. Lane/Shoulder Drop Off
10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering/Raveling

DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE
1 L	1x5	1x4	1x4							13	0.52	7.9
1 H	1x8	1x6								14	0.56	23.4
7L	32	15	18	24	41					130	5.20	7.5
8M	20	15	35	27	23	10	13			143	5.72	25.1
11 H	3x4	2x5								22	0.88	17.9
13 L	1									1	0.04	11.2
15 L	4	9	8							21	0.84	6.9
19 L	250									250	10.0	5.3

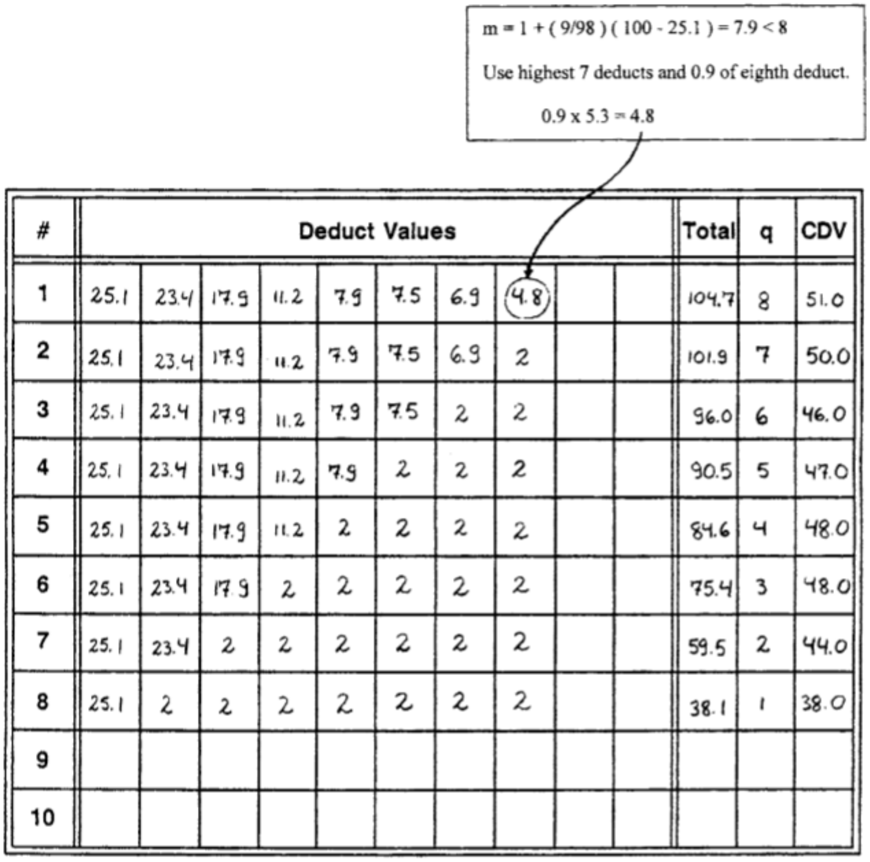
Figure 4.2: ASTM D6433 Samples Data Sheet (ASTM 2007)

After assigning each distress type a deduct value, an iterative process is used to calculate the maximum CDV (Corrected Deduct Value). This is described as follows:

- If either one or zero deduct values are greater than two, then the sum of the deduct values is used as the max CDV. Otherwise, the iterative process must be used.
- List the deduct values in descending order.
- Calculate m, the allowable number of deducts (do not round m to a whole number).

  $$m = 1 + \left(\frac{9}{98}\right)(100 - HDV) \leq 10$$

  HDV = highest individual deduct value
- Reduce the number of individual deduct values to the m largest deduct values, including the fraction. For example, if there are 8 deduct values, but m = 6.4, then only use the 6 highest deduct values along with 0.4 of the 7th. If the number of deduct values is less than m, use all of the deduct values.
- With the usable deduct values recorded depending on m, complete the iterative process of reducing the smallest value greater than 2.0 to 2.0 and summing the deduct values. This is visually represented in the table below.



$m = 1 + (9/98) (100 - 25.1) = 7.9 < 8$

Use highest 7 deducts and 0.9 of eighth deduct.

$0.9 \times 5.3 = 4.8$

#	Deduct Values										Total	q	CDV
1	25.1	23.4	17.9	11.2	7.9	7.5	6.9	4.8			104.7	8	51.0
2	25.1	23.4	17.9	11.2	7.9	7.5	6.9	2			101.9	7	50.0
3	25.1	23.4	17.9	11.2	7.9	7.5	2	2			96.0	6	46.0
4	25.1	23.4	17.9	11.2	7.9	2	2	2			90.5	5	47.0
5	25.1	23.4	17.9	11.2	2	2	2	2			84.6	4	48.0
6	25.1	23.4	17.9	2	2	2	2	2			75.4	3	48.0
7	25.1	23.4	2	2	2	2	2	2			59.5	2	44.0
8	25.1	2	2	2	2	2	2	2			38.1	1	38.0
9													
10													

Figure 4.3: Example Iterative Calculation (ASTM 2007)

- Record q as the number of deduct values with a value greater than 2.0.
- The correction curves, as shown below, are then used to find the CDV (corrected deduct value) using q and the total sum of DV’s as variables.

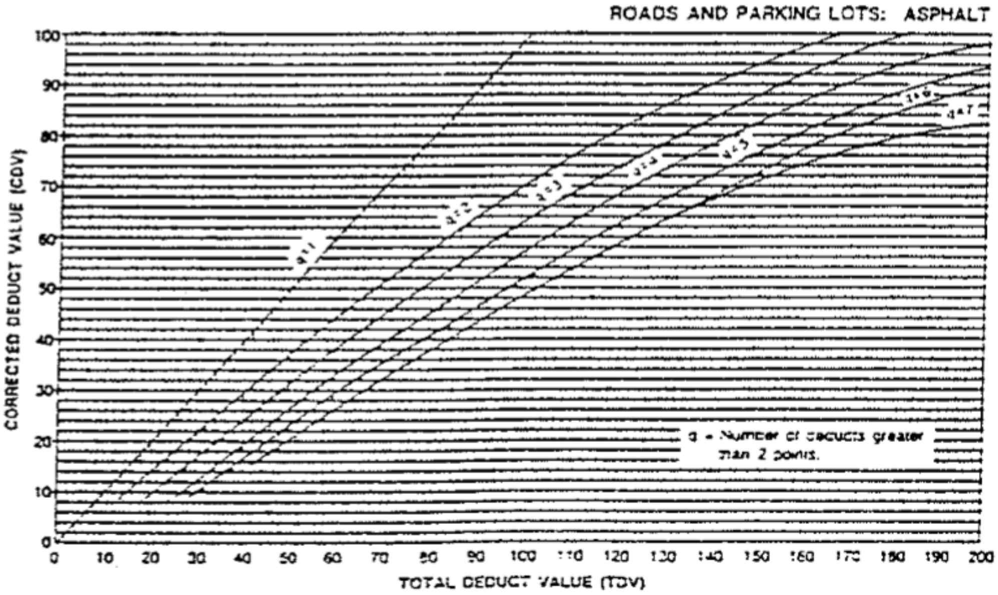


Figure 4.4: CDV Curves (ASTM 2007)

- Repeat this process until q=1.
- Take the largest of the CDV’s as the max CDV.
- PCI is then calculated as 100 – max CDV.

Once a PCI is calculated for each sample unit in the section, an area weighted average is calculated in order to determine the final PCI of the pavement. Figure 4.5 provides a rating scale based on the PCI value.

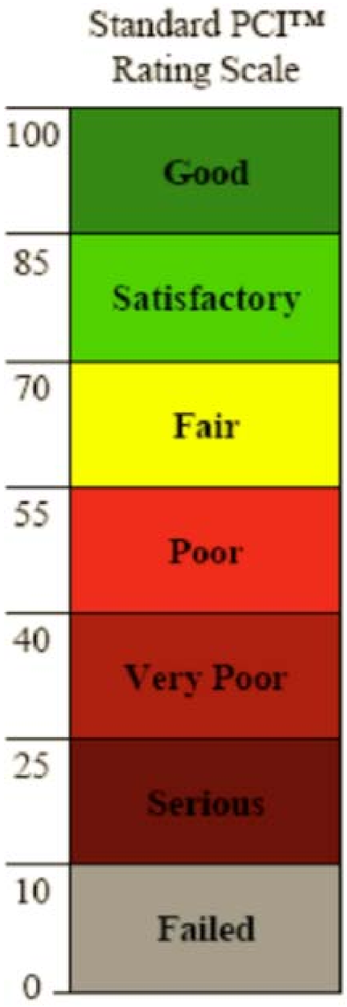
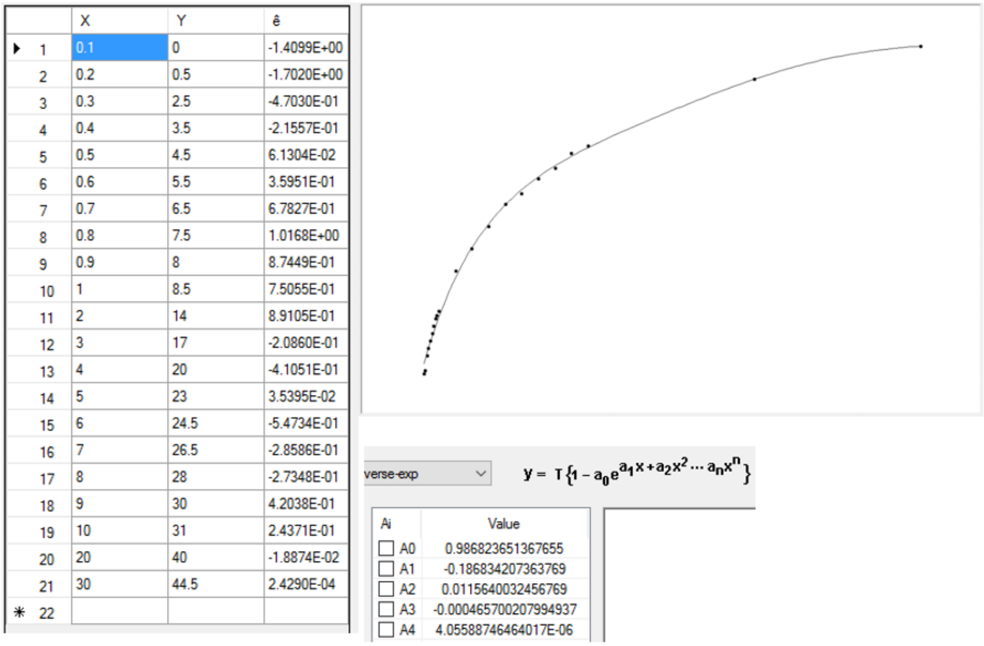


Figure 4.5: ASTM D6433 Rating Scale (ASTM 2007)

5. Software Development for PCI Calculation

The previously described method of PCI Calculation is one that can be somewhat time consuming. Therefore, with the large number of pavement sections included in this study, it was decided to house a more automated calculation process within an Excel spreadsheet. Purchasing expensive pavement condition software was not an ideal option, so the software would need to be developed in-house.

The first step was to determine the equations for the deduct value curves, as well as the corrected deduct value curves. As described in the ASTM D6433 document, the process of developing the curves was empirically based without any strict mathematical equations defining them. Therefore, the curves were manually replotted by estimating the coordinate values along them. The CADRE Regression software was used to input the data points and apply a line of best fit to each curve. An equation for the line would then be displayed within the software. Some sample screenshots from CADRE are shown below.



	X	Y	ê
▸ 1	0.1	0	-1.4099E+00
2	0.2	0.5	-1.7020E+00
3	0.3	2.5	-4.7030E-01
4	0.4	3.5	-2.1557E-01
5	0.5	4.5	6.1304E-02
6	0.6	5.5	3.5951E-01
7	0.7	6.5	6.7827E-01
8	0.8	7.5	1.0168E+00
9	0.9	8	8.7449E-01
10	1	8.5	7.5055E-01
11	2	14	8.9105E-01
12	3	17	-2.0860E-01
13	4	20	-4.1051E-01
14	5	23	3.5395E-02
15	6	24.5	-5.4734E-01
16	7	26.5	-2.8586E-01
17	8	28	-2.7348E-01
18	9	30	4.2038E-01
19	10	31	2.4371E-01
20	20	40	-1.8874E-02
21	30	44.5	2.4290E-04
* 22			

verse-exp

$$y = T\{1 - a_0 e^{a_1 x + a_2 x^2 \cdots a_n x^n}\}$$

Ai	Value
☐ A0	0.986823651367655
☐ A1	-0.186834207363769
☐ A2	0.0115640032456769
☐ A3	-0.000465700207994937
☐ A4	4.05588746464017E-06

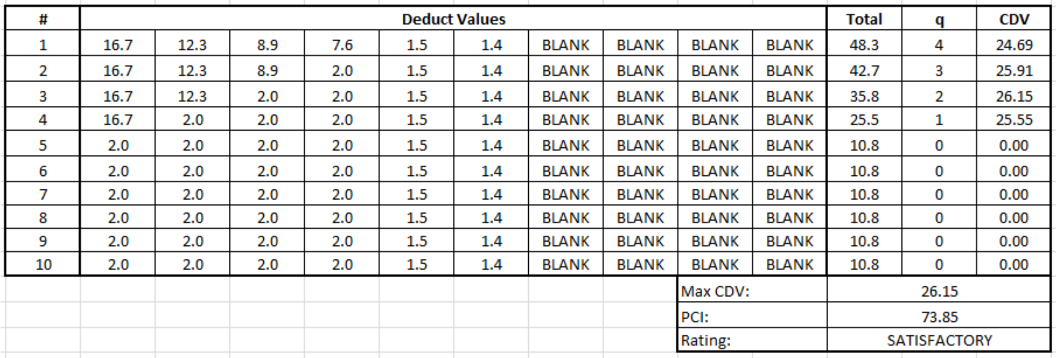
Figure 5.1: CADRE Regression Output

With the DV and CDV curve equations obtained, they were programmed into the Excel files as macro functions. For example, the function for alligator cracking was defined as AC(q,Sev), where “q” is the number of deduct values greater than 2, and “Sev” is the severity of the distress type.

The iterative process within the PCI calculation would also need to be programmed as a separate table within the spreadsheet. This was accomplished through a series of IF statements. An example of one of the cell’s coding is as follows:

```
=IF(1>ROUNDUP($B$34,0),"BLANK",(IF(COUNT($D$12:$D$31,$G$12:$G$31,$J$12:$J$31)<1,"BLANK",(IF(N12="BLANK",(IF(COUNT($D$12:$D$31,$G$12:$G$31,$J$12:$J$31)<$B$34,LARGE(($D$12:$D$31,$G$12:$G$31,$J$12:$J$31),1),(1-(1-$B$34))*LARGE(($D$12:$D$31,$G$12:$G$31,$J$12:$J$31),1))),LARGE(($D$12:$D$31,$G$12:$G$31,$J$12:$J$31),1))))))
```

The completed calculation table is shown below, based on deduct values obtained from the input area of the spreadsheet.

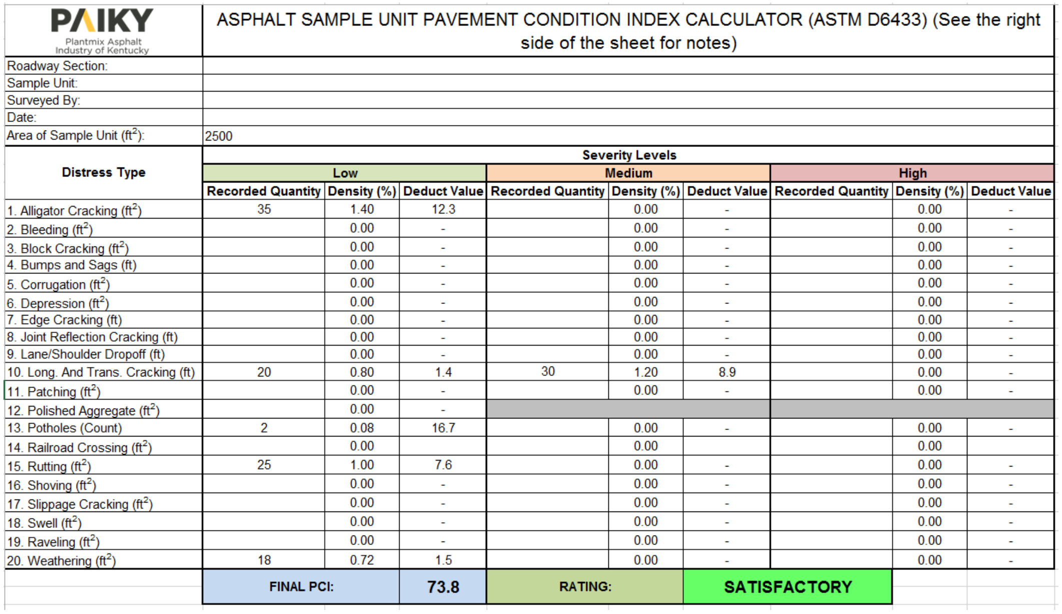


#	Deduct Values										Total	q	CDV
1	16.7	12.3	8.9	7.6	1.5	1.4	BLANK	BLANK	BLANK	BLANK	48.3	4	24.69
2	16.7	12.3	8.9	2.0	1.5	1.4	BLANK	BLANK	BLANK	BLANK	42.7	3	25.91
3	16.7	12.3	2.0	2.0	1.5	1.4	BLANK	BLANK	BLANK	BLANK	35.8	2	26.15
4	16.7	2.0	2.0	2.0	1.5	1.4	BLANK	BLANK	BLANK	BLANK	25.5	1	25.55
5	2.0	2.0	2.0	2.0	1.5	1.4	BLANK	BLANK	BLANK	BLANK	10.8	0	0.00
6	2.0	2.0	2.0	2.0	1.5	1.4	BLANK	BLANK	BLANK	BLANK	10.8	0	0.00
7	2.0	2.0	2.0	2.0	1.5	1.4	BLANK	BLANK	BLANK	BLANK	10.8	0	0.00
8	2.0	2.0	2.0	2.0	1.5	1.4	BLANK	BLANK	BLANK	BLANK	10.8	0	0.00
9	2.0	2.0	2.0	2.0	1.5	1.4	BLANK	BLANK	BLANK	BLANK	10.8	0	0.00
10	2.0	2.0	2.0	2.0	1.5	1.4	BLANK	BLANK	BLANK	BLANK	10.8	0	0.00
									Max CDV:		26.15		
									PCI:		73.85		
									Rating:		SATISFACTORY		

Figure 5.2: Excel Iterative Calculation for PCI

As shown above, the table completes the iterative process and then sums each of the rows to fill the “Total” column. Based on the derived CDV equations and the values for Total and q, a CDV value is obtained for each row. The max CDV and PCI are then calculated, and a rating based on the scale shown in Section 4 is displayed.

When a user opens the spreadsheet, they will be shown the following display:



PAIKY
Plantmix Asphalt Industry of Kentucky

ASPHALT SAMPLE UNIT PAVEMENT CONDITION INDEX CALCULATOR (ASTM D6433) (See the right side of the sheet for notes)

Roadway Section:	
Sample Unit:	
Surveyed By:	
Date:	
Area of Sample Unit (ft^2):	2500

Distress Type	Severity Levels								
	Low			Medium			High		
	Recorded Quantity	Density (%)	Deduct Value	Recorded Quantity	Density (%)	Deduct Value	Recorded Quantity	Density (%)	Deduct Value
1. Alligator Cracking (ft^2)	35	1.40	12.3		0.00	-		0.00	-
2. Bleeding (ft^2)		0.00	-		0.00	-		0.00	-
3. Block Cracking (ft^2)		0.00	-		0.00	-		0.00	-
4. Bumps and Sags (ft)		0.00	-		0.00	-		0.00	-
5. Corrugation (ft^2)		0.00	-		0.00	-		0.00	-
6. Depression (ft^2)		0.00	-		0.00	-		0.00	-
7. Edge Cracking (ft)		0.00	-		0.00	-		0.00	-
8. Joint Reflection Cracking (ft)		0.00	-		0.00	-		0.00	-
9. Lane/Shoulder Dropoff (ft)		0.00	-		0.00	-		0.00	-
10. Long. And Trans. Cracking (ft)	20	0.80	1.4	30	1.20	8.9		0.00	-
11. Patching (ft^2)		0.00	-		0.00	-		0.00	-
12. Polished Aggregate (ft^2)		0.00	-						
13. Potholes (Count)	2	0.08	16.7		0.00	-		0.00	-
14. Railroad Crossing (ft^2)		0.00			0.00			0.00	
15. Rutting (ft^2)	25	1.00	7.6		0.00	-		0.00	-
16. Shoving (ft^2)		0.00	-		0.00	-		0.00	-
17. Slippage Cracking (ft^2)		0.00	-		0.00	-		0.00	-
18. Swell (ft^2)		0.00	-		0.00	-		0.00	-
19. Raveling (ft^2)		0.00	-		0.00	-		0.00	-
20. Weathering (ft^2)	18	0.72	1.5		0.00	-		0.00	-
	FINAL PCI:		73.8	RATING:		SATISFACTORY			

Figure 5.3: Input Area for PCI Calculator

The user must simply input the sample unit area and the recorded distress quantities from their field collection, and all other values are calculated by the spreadsheet. The final PCI and rating category are displayed at the bottom of the spreadsheet.

Ultimately, this software provides a means of more efficiently obtaining PCI values for the preventative maintenance study. There is a certain degree of error due to the process of manually plotting the deduct value curves, though the margin seems to be negligible as long as the same curve equations are used on a consistent basis.

6. List of Pavement Sites

To properly draw any conclusions from the set of data, a sufficient number of both Microsurfacing and Thinlay sites would need to be evaluated. By examining state bidding information, the recent history of these products within the state provided a total of 42 different sites to evaluate, including 26 Microsurfacing, 15 Thinlay, and 1 Chip Seal. These sites represent a multitude of different ages, traffic conditions, and pre-surfacing conditions. The sites are summarized in Table 6.1.

Table 6.1: List of Projects (continued)

Date Visited	**County**	**Surface Age**	**Let Year**	**Route**	**Treatment**
6/17/2016	Edmonson	2014	2013	KY0259/101	Thinlay
7/19/2016	Perry	2013	2013	KY 15	Thinlay
7/19/2016	Letcher	2015	2015	US 119	Thinlay
6/17/2016	Hardin/Meade	2016	2015	KY 1500	Thinlay
7/2/2016	Pendleton	2016	2015	KY 9	Chip Seal (Pre-Condition)
6/16/2016	Christian	2013	2013	US0068	Thinlay
6/15/2016	Graves	2014	2014	KY121X	Thinlay
6/14/2016	Muhlenberg	2013	2012	US 62	Thinlay
7/20/2016	Laurel (South)	2015	2015	KY 363	Micro
6/8/2016	Mercer	2014	2014	US 127	Cape Seal
6/16/2016	Todd	2012	2012	KY0178	Thinlay
6/8/2016	Mercer	2014	2014	US 127	Double Micro
6/8/2016	Mercer	2014	2014	US 127	Thinlay
6/15/2016	Graves	2014	2014	KY0097	Thinlay
7/22/2016	Adair	2014	2013	KY 80	Thinlay
7/7/2016	Mason	2015	2015	KY 9	Thinlay
6/8/2016	Mercer	2014	2014	US 127	Micro
7/20/2016	Laurel (North)	2015	2015	KY 363	Micro
6/14/2016	Graves	2011	2011	KY0994	Micro
6/8/2016	Mercer	2014	2014	US 127	Crack Seal
7/7/2016	Fleming	2015	2015	KY 11	Micro
6/14/2016	McCracken	2011	2011	KY0994	Micro
6/8/2016	Mercer	2014	2014	US 127	Control
7/21/2016	Pulaski	2013	2012	KY 461	Thinlay
6/29/2016	Washington/Nelson	2015	2015	KY 555	Micro
6/16/2016	Todd	2016	2015	US 68	Micro (Pre-Condition)
6/16/2016	Warren	2016	2015	US 231	Micro (Pre-Condition)

7/21/2016	Rockcastle	2015	2015	US 25	Micro
7/20/2016	Bell	2011	2011	US 25E south	Micro
7/21/2016	Wayne	2011/2007	2007	KY 92	Thinlay
7/20/2016	Jackson	2016	2015	KY 290	Thinlay (Pre-Condition)
6/16/2016	Logan	2016	2015	US 68	Micro (Pre-Condition)
7/7/2016	Bath	2015	2015	KY 11	Micro
6/23/2016	Marion	2015	2015	US 68	Micro
6/24/2016	Fayette	2015	2015	KY 353	Micro
7/21/2016	Pulaski	2016	2015	KY 192	Thinlay (Pre-Condition)
6/29/2016	Nelson	2015	2015	US 31E	Micro
7/20/2016	Bell	2012	2012	US 25E north	Micro
6/15/2016	Fulton	2012	2012	JC9003	Micro
7/22/2016	Green	2007	2007	KY 218	Thinlay
7/6/2016	Rowan	2015	2015	KY 801	Micro
7/6/2016	Lewis	2013	2012	KY 9	Micro
7/6/2016	Greenup	2014	2013	KY 10	Micro
6/30/2016	Pike	2013	2012	US 23	Micro
7/19/2016	Harlan	2015	2015	KY 38	Micro
6/16/2016	Allen	2016	2015	US 231	Micro (Pre-Condition)
6/24/2016	Nicholas	2010	2010	US 68	Micro
6/23/2016	Boyle	2010	2010	KY 52	Micro
7/7/2016	Bath	2012	2012	KY 11	Micro
7/1/2016	Clark	2008	2008	KY 9000	Micro
8/10/2016	Warren	2016	2015	US 231	Micro
8/10/2016	Allen	2016	2015	US 231	Micro

7. Raw Data Collected

Using the previously described methods of analysis under ASTM D6433, the sites were systematically evaluated through the months of June, July, and August of 2016. There were a total of 145 sample units surveyed, which correlates to an average of about 3.5 per site, and totals 342,637 square feet. Over all 42 sites, approximately 1600 photos were taken and entered into a database. Using the PCI calculation software, each sample unit was assigned a value and all of the units in a site were averaged by area to find a final PCI. This information is summarized in Table 7.1 below.

Table 7.1: Summary of PCI Data (continued)

Date Visited	**County**	**Surface Age**	**Let Year**	**Route**	**Treatment**	**PCI**
6/17/2016	Edmonson	2014	2013	KY0259/101	Thinlay	98.0
7/19/2016	Perry	2013	2013	KY 15	Thinlay	97.9
7/19/2016	Letcher	2015	2015	US 119	Thinlay	95.3
6/17/2016	Hardin/Meade	2016	2015	KY 1500	Thinlay	93.9
7/2/2016	Pendleton	2016	2015	KY 9	Chip Seal (Pre-Condition)	92.2
6/16/2016	Christian	2013	2013	US0068	Thinlay	91.7
6/15/2016	Graves	2014	2014	KY121X	Thinlay	91.7
6/14/2016	Muhlenberg	2013	2012	US 62	Thinlay	91.5
7/20/2016	Laurel (South)	2015	2015	KY 363	Micro	91.4
6/8/2016	Mercer	2014	2014	US 127	Cape Seal	90.6
6/16/2016	Todd	2012	2012	KY0178	Thinlay	90.5
6/8/2016	Mercer	2014	2014	US 127	Double Micro	90.3
6/8/2016	Mercer	2014	2014	US 127	Thinlay	90.3
6/15/2016	Graves	2014	2014	KY0097	Thinlay	88.9
7/22/2016	Adair	2014	2013	KY 80	Thinlay	88.5
7/7/2016	Mason	2015	2015	KY 9	Thinlay	87.8
6/8/2016	Mercer	2014	2014	US 127	Micro	87.7
7/20/2016	Laurel (North)	2015	2015	KY 363	Micro	86.7
6/14/2016	Graves	2011	2011	KY0994	Micro	86.5
6/8/2016	Mercer	2014	2014	US 127	Crack Seal	74.3
7/7/2016	Fleming	2015	2015	KY 11	Micro	74.2
6/14/2016	McCracken	2011	2011	KY0994	Micro	74.1
6/8/2016	Mercer	2014	2014	US 127	Control	72.8
7/21/2016	Pulaski	2013	2012	KY 461	Thinlay	72.7
6/29/2016	Washington/Nelson	2015	2015	KY 555	Micro	71.3
6/16/2016	Todd	2016	2015	US 68	Micro (Pre-Condition)	69.6
6/16/2016	Warren	2016	2015	US 231	Micro (Pre-Condition)	67.1
7/21/2016	Rockcastle	2015	2015	US 25	Micro	64.3

7/20/2016	Bell	2011	2011	US 25E south	Micro	62.4
7/21/2016	Wayne	2011/2007	2007	KY 92	Thinlay	61.7
7/20/2016	Jackson	2016	2015	KY 290	Thinlay (Pre-Condition)	61.1
6/16/2016	Logan	2016	2015	US 68	Micro (Pre-Condition)	60.6
7/7/2016	Bath	2015	2015	KY 11	Micro	60.1
6/23/2016	Marion	2015	2015	US 68	Micro	59.4
6/24/2016	Fayette	2015	2015	KY 353	Micro	58.6
7/21/2016	Pulaski	2016	2015	KY 192	Thinlay (Pre-Condition)	56.9
6/29/2016	Nelson	2015	2015	US 31E	Micro	58.0
7/20/2016	Bell	2012	2012	US 25E north	Micro	56.7
6/15/2016	Fulton	2012	2012	JC9003	Micro	55.1
7/22/2016	Green	2007	2007	KY 218	Thinlay	55.1
7/6/2016	Rowan	2015	2015	KY 801	Micro	54.3
7/6/2016	Lewis	2013	2012	KY 9	Micro	54.2
7/6/2016	Greenup	2014	2013	KY 10	Micro	52.6
6/30/2016	Pike	2013	2012	US 23	Micro	52.4
7/19/2016	Harlan	2015	2015	KY 38	Micro	52.0
6/16/2016	Allen	2016	2015	US 231	Micro (Pre-Condition)	51.4
6/24/2016	Nicholas	2010	2010	US 68	Micro	39.1
6/23/2016	Boyle	2010	2010	KY 52	Micro	37.4
7/7/2016	Bath	2012	2012	KY 11	Micro	33.0
7/1/2016	Clark	2008	2008	KY 9000	Micro	24.8
8/10/2016	Warren	2016	2015	US 231	Micro	63.9
8/10/2016	Allen	2016	2015	US 231	Micro	68.4

When scanning the raw data, it becomes quickly apparent that the Microsurfacing PCIs trend to the bottom of the list, while the Thinlay numbers trend to the top. This can be explained by more closely examining the individual distresses found within the surface. There were common distresses associated with each product that contribute to the disparity between them.

Microsurfacing was found to be more susceptible to liquid asphalt bleeding than Thinlay. The bleeding would primarily originate from the presence of crack sealing material underneath the surface. While this distress did not contribute much numerically to the PCI difference, its commonality with Microsurfacing is worth noting. Some examples of this distress are shown below.

Figure 7.1: Fayette County, Bleeding Distress

Figure 7.2: Morgan County, Bleeding Distress, Brand New Surface

Edge Cracking as well as Longitudinal/Transverse Cracking were found to be the most common distresses between both products. Edge Cracking can be caused by either repeated traffic loading or a weakened base/subgrade under the edge of the pavement surface. Longitudinal and Transverse Cracking can be caused by traffic loading or environmental conditions, such as oxidation and hardening of the surface combined with multiple freeze-thaw cycles. In the case of surface treatments, it is very characteristic for cracks in the old surface to reflect through to the new surface. It is apparent that Microsurfacing is more susceptible to this reflection cracking due to its thinness. Therefore, Microsurfacing is more susceptible to Longitudinal and Transverse Cracking at an earlier age, which could partly explain the PCI disparity between the two products. It was found that Edge Cracking is at more of an even level between Microsurfacing and Thinlay, most likely due to the factors affecting that distress outside of the surface treatment properties. Some examples of these distresses are shown below.

Figure 7.3: Green County, Longitudinal/Transverse Cracking, Thinlay

Figure 7.4: Greenup County, Reflective Crack/Edge Cracking, Microsurfacing

Figure 7.5: Pulaski County, Edge Cracking, Thinlay

Figure 7.6: Laurel County, Transverse Cracking, Microsurfacing

Alligator Cracking was a common distress encountered during the pavement evaluations. This distress is caused by repeated traffic loading that eventually causes the pavement to crack and break apart in a pattern similar to chicken wire or alligator skin. It is a symptom that there is structural damage occurring in the pavement, and that the cracks are forming from the bottom to the top. Alligator Cracking appeared to be more common amongst Microsurfacing sites than Thinlay. There are a number of factors that may have contributed to this observation, including the thin layer thickness of Microsurfacing, or the possibility that the pre-existing pavement already had structural damage. If Microsurfacing or a Thinlay is applied to a surface with such structural damage, sub-par performance is expected of either product. Within the ASTM deduct value curves, alligator cracking is a very sensitive parameter, and can significantly reduce the PCI with a relatively small density. Therefore, the presence of more alligator cracking in Microsurfacing significantly contributed to its low PCI values. Some visual examples of this distress are shown below. These images, as well as the vast majority of recorded alligator distress, represent low severity, before the cracking patterns into alligator skin.

Figure 7.7: Wayne County, Alligator Cracking, Thinlay

Figure 7.8: Greenup County, Alligator Cracking, Microsurfacing

The distress within the ASTM method that most significantly contributed to PCI loss was rutting, which is longitudinal deformation caused by wheel loading. It was found that Microsurfacing recorded significantly more cases of rutting than Thinlay. All rutting recorded was found to be low severity, which means that the maximum depth was between ¼” and ½”. It could be that Microsurfacing is too thin to properly correct for even minor rutting, or that physical wearing in the wheel path is creating the rut. Some examples are shown below.

Figure 7.9: Harlan County, Rutting, Microsurfacing

Figure 7.10: Warren County, Rutting, Microsurfacing

Figure 7.11: Nelson County, Rutting, Microsurfacing

In certain Microsurfacing sites, it was found that the material was visibly wearing away and the underlying pavement layer was visible. While this severe wearing was not common to every site, it is worth noting as a distress unique to Microsurfacing, and was never seen on a Thinlay product. The notable occurrences were at the Fayette County and Boyle County Sites, as shown below.

Figure 7.12: Boyle County, Surface Wearing, Microsurfacing

Figure 7.13: Fayette County, Surface Wearing, Microsurfacing

By providing the more detailed analysis of each common distress type, there is more insight into why the Microsurfacing generally yields a lower PCI than Thinlay. In addition to PCI, some additional data was collected for supplemental purposes. The most-up-to date IRI data available from the KYTC website was obtained for each site. Some values correspond to the newest surface treatment, whereas others were taken on the old pavement surface. This data will become more useful as it is updated by KYTC and can be tracked over a period of time to observe the change in IRI.

In addition to PCI data collected on Microsurfacing and Thinlay, some pre-condition data was recorded for sites soon to be treated. These included those in the counties of Warren, Allen, Todd, Logan, Jackson, and Pulaski.

The sites in Allen, Logan, and Jackson Counties contained alligator cracking, indicating structural issues. These observations would appear to suggest that they are not ideal preventative maintenance candidates, since significant damage to the pavement cross section has already occurred. Warren, Logan, Pulaski, and Allen counties contained rutting along the wheel paths. While it was all low severity rutting under ½” maximum depth, it further counts against these sites as viable candidates.

Very shortly after Microsurfacing was applied to the Warren and Allen County precondition sites, the opportunity was taken to observe how Microsurfacing was performing early in its life. Since Warren County exhibited rutting and Allen County exhibited rutting/alligator cracking before treatment, the observations yielded results about how distresses reflect through Microsurfacing. Both the Warren and Allen County sites showed that the rutting had immediately reflected through after construction, providing concrete evidence that Microsurfacing struggles to fill ruts when applied. The alligator cracking encountered at Allen County in the pre-condition state had not reflected through that early in the treatment's life. Some images of rutting taken from these sites are shown below. Moving forward with the pavement evaluations in the future, it will be important to observe how these sites perform, knowing that they contained significant distress beforehand.

Figure 7.14: Warren-Allen County, Rutting, Fresh Microsurfacing

Figure 7.15: Warren-Allen County, Rutting, Fresh Microsurfacing

Tracking all of the raw data variables over time will be useful in further analyzing the performance of Thinlay versus Microsurfacing. However, the rest of this report will focus on the current year data for PCI in determining age/cost predictions for each product.

7.1 Mercer County Experimental Section

In addition to the various sites located throughout the state, the experimental section on US 127 in Mercer County was examined, which was applied in 2014. The section is composed of various treatments applied to both North and Southbound, where each is ¼ mile long. The treatments include a single layer Microsurfacing, a double layer Microsurfacing, a Cape Seal (Microsurfacing on top of Chip Seal), Thinlay, Crack Sealing, and an untreated control section. Note that all sections other than the control received crack sealing treatment before applying the surface treatment.

The same ASTM methodology used on other sites was applied to US 127. Two sample units were analyzed for each treatment section, totaling 12 sample units. The Cape Seal, double layer Microsurfacing, and Thinlay all had the highest PCI and were nearly identical with PCIs of 90.6, 90.3, and 90.3 respectively. The next highest was the single layer Microsurfacing with a PCI of 87.7. The Crack Sealing and Control Sections were the lowest with PCIs of 74.3 and 72.8, respectively. The results are consistent with what was expected from the section. The Cape Seal, double layer Microsurfacing, and Thinlay provide more structure than other preventative maintenance treatments and would be expected to better correct surface deformation and retard cracking. On the other hand, Microsurfacing and Crack Sealing provide little to no structure and are deficient in properly correcting certain types of surface distress.

At two years of age, the test section on US 127 is still very young on the scale of pavements. Tracking the distresses there over time will reveal more compelling conclusions about comparing a wide range of preventative maintenance treatments.

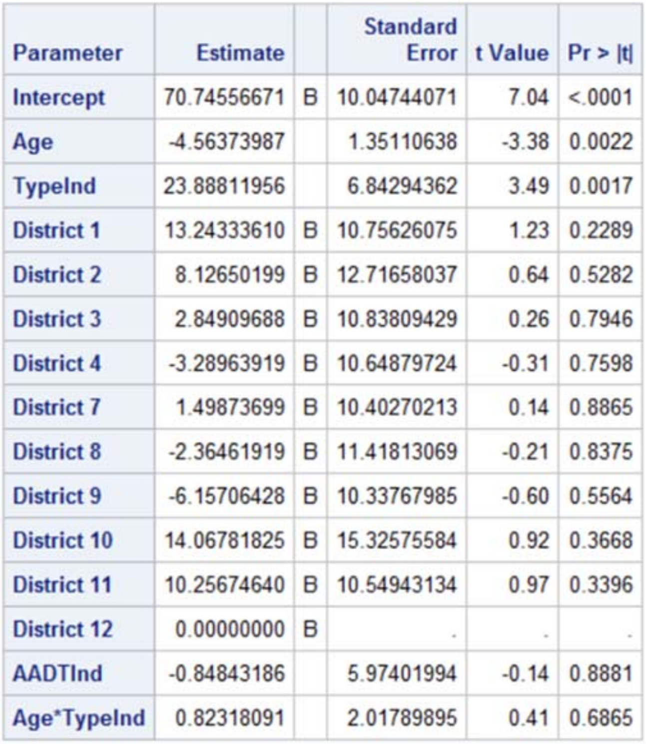
8. Statistical Analysis of Raw Data

The raw data of PCI for each pavement product must be analyzed statistically in order to justify any valid conclusions on life cycle and cost of ownership. SAS version 9.4 was the chosen software, and the coding used is attached in Appendix 1. The sample sizes were 26 Microsurfacing sites and 15 Thinlay sites. In addition, an alpha of 0.05 was chosen a priori for significance tests and confidence intervals. The first step in the analysis is to define the factors to be included in the multiple linear regression model for predicting PCI. These factors are as follows, with their variable names from SAS in bold:

- Age (years): **Age**
- District (1 – 8) as a categorical variable: **District**
- Treatment Type (0 for Microsurfacing, 1 for Thinlay) as an indicator variable: **TypeInd**
- Traffic Level (0 for <10,000 AADT, 1 for >10,000 AADT) as an indicator variable: **AADTInd**
- Interaction variable between Treatment Type and Age: **TypeInd_Age**

Including these factors in the first regression yields the following results in SAS:

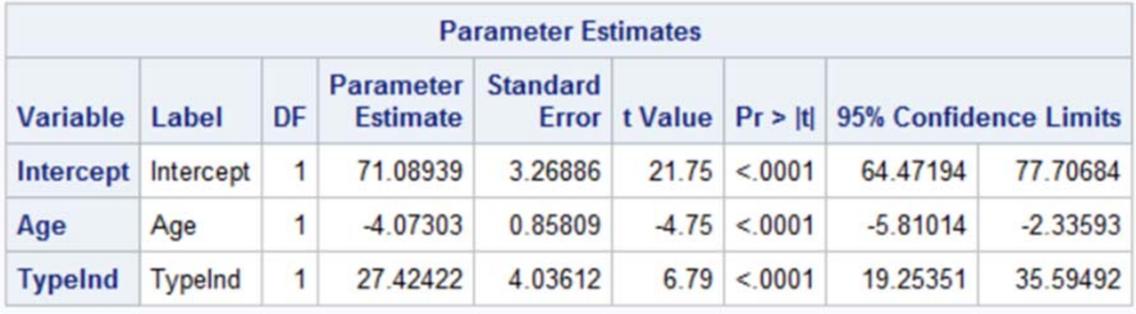
Table 8.1: Multiple Linear Regression Variable Selection



Parameter	Estimate		Standard Error	t Value	Pr > |t|
Intercept	70.74556671	B	10.04744071	7.04	<.0001
Age	-4.56373987		1.35110638	-3.38	0.0022
TypeInd	23.88811956		6.84294362	3.49	0.0017
District 1	13.24333610	B	10.75626075	1.23	0.2289
District 2	8.12650199	B	12.71658037	0.64	0.5282
District 3	2.84909688	B	10.83809429	0.26	0.7946
District 4	-3.28963919	B	10.64879724	-0.31	0.7598
District 7	1.49873699	B	10.40270213	0.14	0.8865
District 8	-2.36461919	B	11.41813069	-0.21	0.8375
District 9	-6.15706428	B	10.33767985	-0.60	0.5564
District 10	14.06781825	B	15.32575584	0.92	0.3668
District 11	10.25674640	B	10.54943134	0.97	0.3396
District 12	0.00000000	B	.	.	.
AADTInd	-0.84843186		5.97401994	-0.14	0.8881
Age*TypeInd	0.82318091		2.01789895	0.41	0.6865

With the District variable being insignificant (p value greater than alpha of 0.05) at every category, it is removed from the model. The remaining variables were selected using backward selection, where the most insignificant variable is removed until every remaining variable is significant. This ultimately yielded the following results:

Table 8.2: Optimized PCI Prediction Model



Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits	
Intercept	Intercept	1	71.08939	3.26886	21.75	<.0001	64.47194	77.70684
Age	Age	1	-4.07303	0.85809	-4.75	<.0001	-5.81014	-2.33593
TypeInd	TypeInd	1	27.42422	4.03612	6.79	<.0001	19.25351	35.59492

As seen in Table 8.2, the only variables that remained significant in predicting PCI were Age and the Treatment Type, with p values less than 0.0001. As Age increases by 1 year, PCI decreases on average by 4.07 when holding the Treatment Type constant. Thinlay sites (TypeInd of 1) increase the PCI by 27.42 when holding Age constant. Generally speaking, these results indicate that the slope of PCI vs. Age does not change between Thinlay and Microsurfacing. However, the intercept changes by 27.42 PCI. This could be indicating that Microsurfacing generally starts its life at a much lower PCI than Thinlay and then deteriorates at the same rate afterwards.

The final model for predicting PCI based on Age and Treatment Type is as follows:

$$PCI = 71.09 - 4.07 * Age + 27.42 * TypeInd$$

The R Squared value for this model is 0.6248, meaning that it is accounting for the majority of the variance in PCI (62.48%) and should be considered an acceptable value.

To complete the analysis and check the validity of this model, the residual assumptions for linear regression should be checked. These assumptions are as follows:

1. The residual errors have a mean value of zero
2. The residual errors are independent
3. The residual errors have a constant variance
4. The residual errors have a normal distribution

The residual error plots used to verify these assumptions are shown below in Figure 8.1.

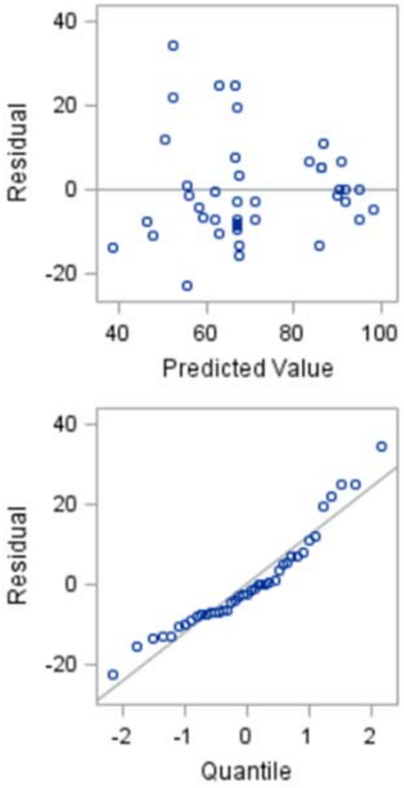


Figure 8.1: Residual and Quantile Plots

The Residual vs. Predicted Value plot shows that the residual errors have an approximate mean of zero, and there does not appear to be a pattern – suggesting they are independent. There is a possible left funnel in the plot which could be indicating a violation of constant variance. The Quantile Plot, used to verify normality, suggests that the data has heavy tails, but this should not be considered a major violation of normality. Overall, the regression assumptions are largely met and the multiple linear regression model should be considered valid but approached with a degree of caution.

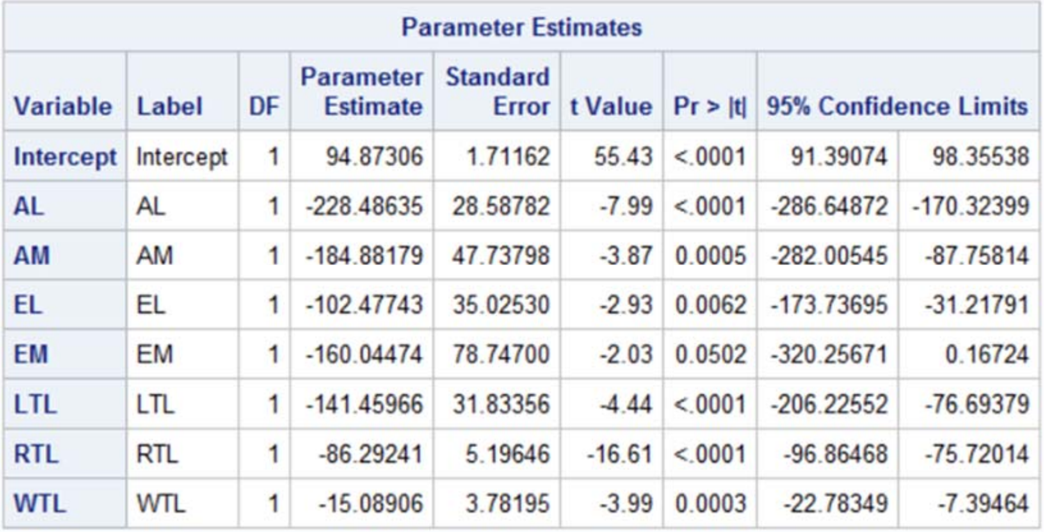
In addition to the regression model based on Age and Treatment Type, another model based on distress types can be analyzed to determine which distresses are the most significant predictors. The variable selection was performed using the same strategy of backwards selection as the model in Table 8.2. Each distress that was ever encountered during data collection was included as a variable and then the most insignificant variable was removed until only significant distress variables were left in the model. The following list of distress types were found to be significant predictors of PCI on Kentucky's preventive maintenance projects, with the variable name from SAS in bold:

- Low Severity Alligator Cracking: **AL**
- Medium Severity Alligator Cracking: **AM**

- Low Severity Edge Cracking: **EL**
- Medium Severity Edge Cracking: **EM**
- Low Severity Longitudinal/Transverse Cracking: **LTL**
- Low Severity Rutting: **RTL**
- Low Severity Weathering: **WTL**

The results yielded from SAS are shown in Table 8.3.

Table 8.3: Optimized Distress Model



Parameter Estimates

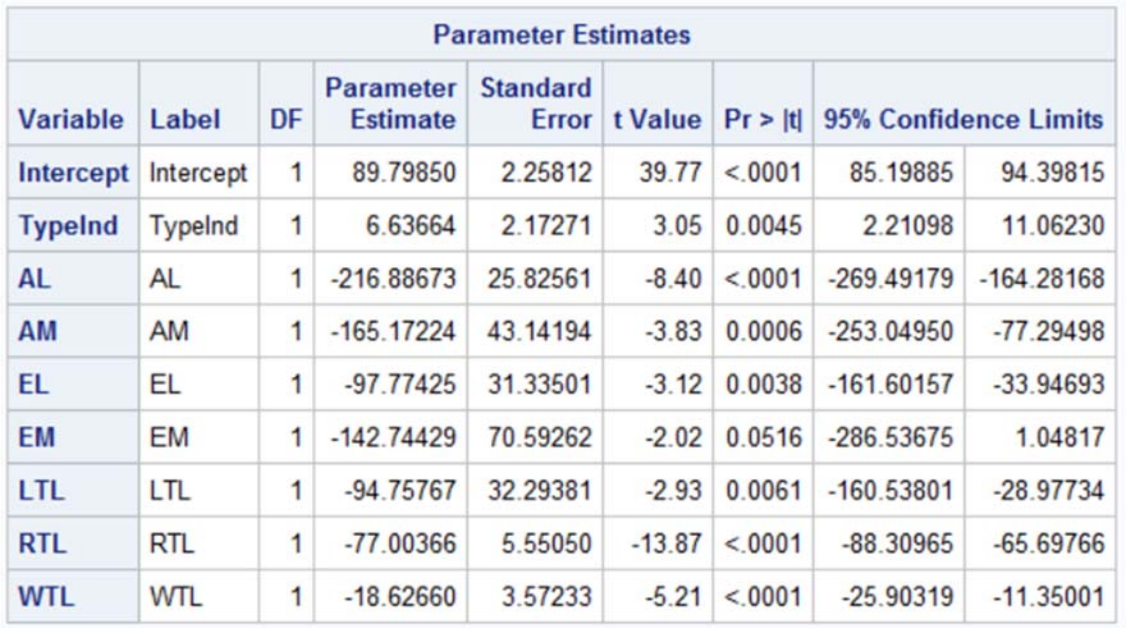
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits	
Intercept	Intercept	1	94.87306	1.71162	55.43	<.0001	91.39074	98.35538
AL	AL	1	-228.48635	28.58782	-7.99	<.0001	-286.64872	-170.32399
AM	AM	1	-184.88179	47.73798	-3.87	0.0005	-282.00545	-87.75814
EL	EL	1	-102.47743	35.02530	-2.93	0.0062	-173.73695	-31.21791
EM	EM	1	-160.04474	78.74700	-2.03	0.0502	-320.25671	0.16724
LTL	LTL	1	-141.45966	31.83356	-4.44	<.0001	-206.22552	-76.69379
RTL	RTL	1	-86.29241	5.19646	-16.61	<.0001	-96.86468	-75.72014
WTL	WTL	1	-15.08906	3.78195	-3.99	0.0003	-22.78349	-7.39464

As seen in the table of parameter estimates, the distress types shown have p values of 0.05 or less. The most significant distress types in predicting PCI were shown to be Low Severity Alligator Cracking, Low Severity Longitudinal/Transverse Cracking, and Low Severity Rutting – all with p values less than 0.0001. The R Squared value for the final distress model was 0.9479, indicating that very little variation is being unaccounted for. This is a sensible result since distresses are directly used in the PCI calculation. It is very important to note when observing this data that these distress predictors are only applicable to PCIs for the preventive maintenance projects in Kentucky as of the summer of 2016. For example, High Severity Rutting would obviously very significantly reduce PCI in a pavement. However, that distress was never encountered in this study so it is not shown in the model.

Generally, it appears that rutting and alligator cracking are the most detrimental distresses to PCI. This is due to the fact that they most often represent serious structural damage to the pavement that cannot be corrected by simple surface treatments.

To further analyze the distress model, it is valuable to include the Treatment Type as a variable in order to accurately quantify error in the data collection. Theoretically, if all distresses are held constant between two pavements, then the PCI found during the survey should be exactly the same. With Treatment Type added as a variable to the model of significant distresses, SAS yields the following results:

Table 8.4: Optimized Distress Model with Treatment Type Error



Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits	
Intercept	Intercept	1	89.79850	2.25812	39.77	<.0001	85.19885	94.39815
TypeInd	TypeInd	1	6.63664	2.17271	3.05	0.0045	2.21098	11.06230
AL	AL	1	-216.88673	25.82561	-8.40	<.0001	-269.49179	-164.28168
AM	AM	1	-165.17224	43.14194	-3.83	0.0006	-253.04950	-77.29498
EL	EL	1	-97.77425	31.33501	-3.12	0.0038	-161.60157	-33.94693
EM	EM	1	-142.74429	70.59262	-2.02	0.0516	-286.53675	1.04817
LTL	LTL	1	-94.75767	32.29381	-2.93	0.0061	-160.53801	-28.97734
RTL	RTL	1	-77.00366	5.55050	-13.87	<.0001	-88.30965	-65.69766
WTL	WTL	1	-18.62660	3.57233	-5.21	<.0001	-25.90319	-11.35001

TypeInd is shown to be a significant variable when holding the distresses constant, with a p value of 0.0045. The statistical analysis is essentially stating that PCI increases by 6.64 for Thinlay when distresses are held constant. Obviously, this is not a true statement and the PCI value of 6.64 represents error in the data collection in favor of Thinlay. In Chapter 9, this error will be accounted for when determining the life cycle of each treatment type.

9. Graphical Representation of PCI Data

After compiling the raw PCI data from each site, it was decided that graphing PCI vs. surface Age would most likely be the most effective method to graphically represent the data. The statistical model found in Chapter 8 confirms this suspicion. Figure 9.1 below simply shows each data point, before applying a trendline.

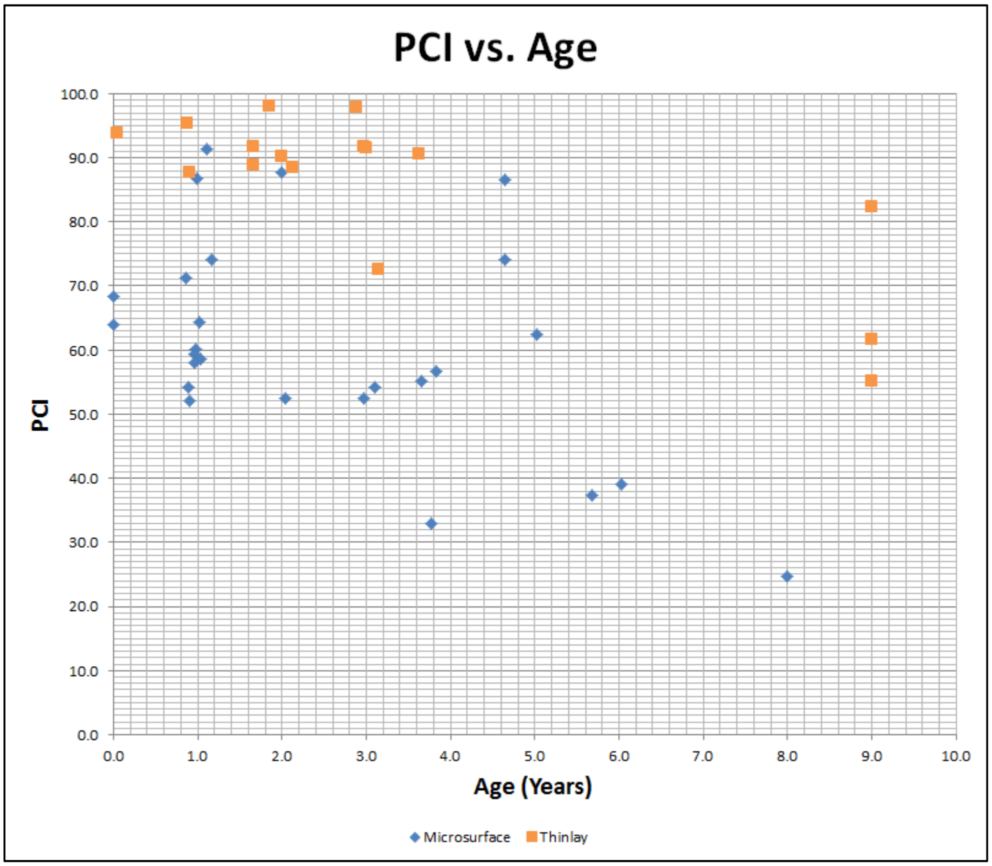


Figure 9.1: PCI vs. Age without Trendlines

The model used from Chapter 8 to plot the lines for each treatment is as follows:

$$PCI = 71.09 - 4.07 * Age + 27.42 * TypeInd$$

For Microsurfacing with "TypeInd" equal to 0:

$$PCI = 71.09 - 4.07 * Age$$

For Thinlay with "TypeInd" equal to 1:

$$PCI = 98.51 - 4.07 * Age$$

These lines are then plotted on the graph of raw data to visually represent the deterioration of each product.

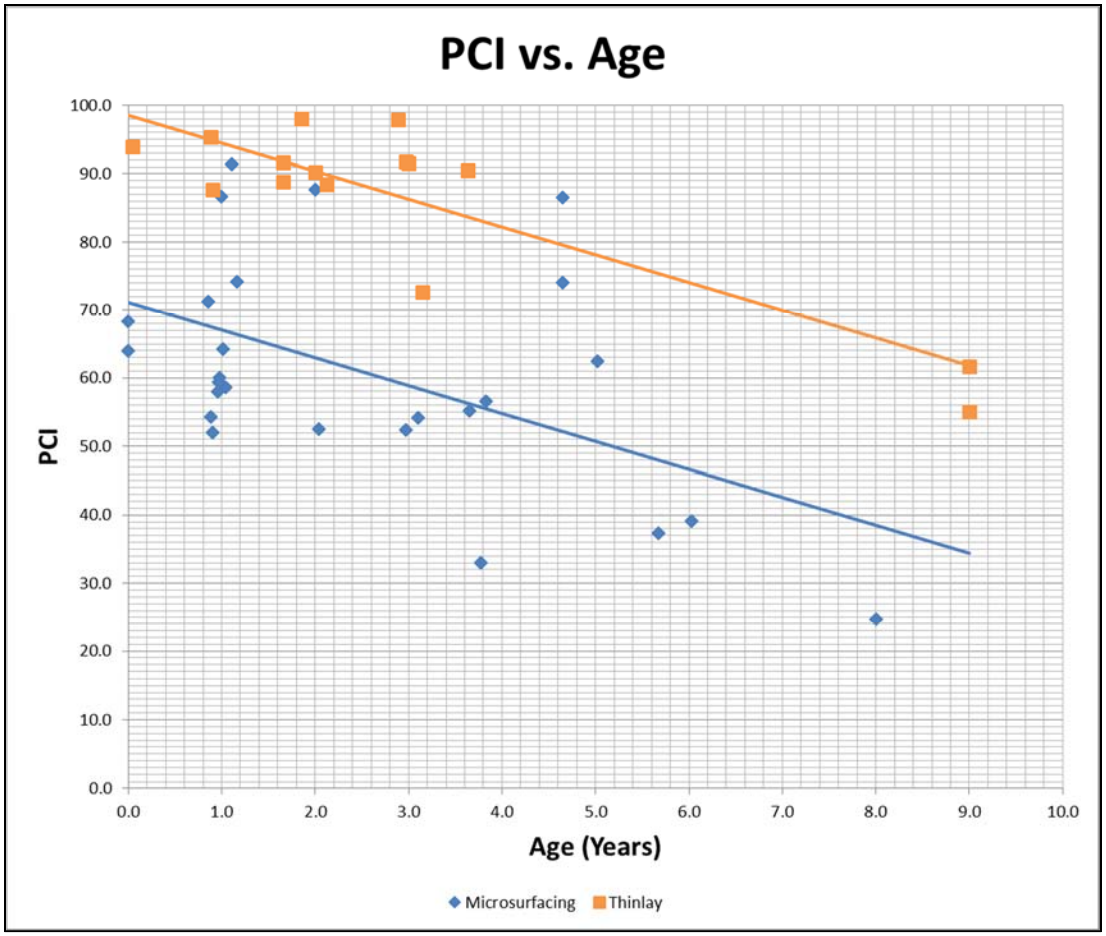


Figure 9.2: PCI vs. Age with Prediction Model

Again, the treatments are both deteriorating at the same rate. However, Microsurfacing is possibly starting its life cycle at a much lower PCI. This is most likely due to Microsurfacing's susceptibility to reflecting previous distresses. These plots are subsequently used to quantify the life extending benefit of each product. A common discussion in the pavement industry is how to define the threshold of when preventative maintenance should be used or not. If the maintenance is applied too late, its benefit is greatly reduced due to the presence of structural damage or severe cracking. These thin treatments would tend to simply reflect distress in that case. Building upon the methodology of ASTM D6433, the rating scale from that publication will be used (See Chapter 4). Two possible candidates for the threshold are a PCI of 70 (Satisfactory/Fair border) and a PCI of 55 (Fair/Poor border). However, if the PCI of 70 is chosen, the data in this study would indicate that Microsurfacing provides almost zero years of life extension. This would be an unrealistic statement, so the PCI threshold of 55 is chosen.

With the PCI threshold chosen, the model equation is used to calculate Microsurfacing's life extension:

$$PCI = 71.09 - 4.07 * Age$$

$$55 = 71.09 - 4.07 * Micro\ Life\ Extension$$

$$\boldsymbol{Micro\ Life\ Extension = 4.0\ years}$$

When considering the life extension of Thinlay, recall that the statistical analysis in Chapter 8 discovered some error in the distress model related to treatment type. When Thinlay was the type, the PCI would increase in the model by 6.64 when holding all distresses constant. Therefore, to account for this error in the life extension calculation, 6.64 will be added to the PCI threshold of 55 – resulting in a Thinlay PCI threshold of 61.64. The life extension calculation is then as follows:

$$PCI = 98.51 - 4.07 * Age$$

$$61.64 = 98.51 - 4.07 * Thinlay\ Life\ Extension$$

$$\boldsymbol{Thinlay\ Life\ Extension = 9.1\ years}$$

Ultimately, Thinlay is showing to provide more than double the life extension than that of Microsurfacing. It is important to note once more that this data is only applicable to the maintenance projects in Kentucky at the time of data collection. These numbers should not be extrapolated to use of these treatments in other states or regions.

10. Cost of Ownership Comparison

Though Thinlay has been shown to provide more life extension than Microsurfacing, the question arises of which one provides more cost benefit? The first step is to determine the unit price of each product. This was accomplished by compiling prices and quantities from the bid tab for each project. Microsurfacing was simpler due to the fact that it is bid as dollars per square yard. Table 10.1 below summarizes the Microsurfacing cost data acquired from the bid tabs.

Table 10.1: Microsurfacing Unit Cost Determination (continued)

TYPE	**COUNTY**	**LENGTH**	**Letting**	**Alt Bid**	**Contract Amount**	**Quantity (SY)**	**Micro $/SY**
Micro	Nicholas	6.033	Jan-10	No	$ 379,685.82	89,934.00	$ 1.69
Micro	Clark	6.602	Jun-08	No	$ 449,047.68	100,703.00	$ 1.58
Micro	Bell	3.336	Apr-11	No	$ 295,002.81	50,885.00	$ 2.19
Micro	Graves	4.328	Jun-11	No	$ 389,703.50	76,282.00	$ 3.15
Micro	Bath	3.278	Apr-12	No	$ 320,600.00	52,075.00	$ 2.70
Micro	Bell	3.336	Apr-12	No	$ 285,800.00	50,885.00	$ 2.30
Micro	Boyle	0.200	Jun-10	No	$ 36,839.65	1204.00	$ 17.50*
Micro	Fulton	1.781	Jul-12	No	$ 423,939.40	54,500.00	$ 2.18
Micro	Pike	2.222	Dec-12	Yes	$ 474,500.00	120,000.00	$ 2.50
Micro	Lewis	5.85	Dec-12	Yes	$ 249,800.00	98,071.00	$ 1.90
Micro	Greenup	8.29	Oct-13	Yes	$ 495,000.00	160,839.00	$ 2.42
Micro	Rowan	8.441	Feb-15	No	$ 618,735.82	135,962.00	$ 2.11
Micro	Fleming	10.216	Feb-15	Yes	$ 404,902.65	182,795.00	$ 1.71
Micro	Nelson	1.596	Feb-15	Yes	$ 188,024.40	63,250.00	$ 2.14
Micro	Bath	7.549	Feb-15	Yes	$ 498,878.59	127,970.00	$ 1.78
Micro	Rockcastle	0.869	Feb-15	Yes	$ 74,611.46	19,149.00	$ 2.83
Micro	Marion	4.126	Feb-15	Yes	$ 218,343.46	78,606.00	$ 2.15
Micro	Laurel	1.447	Feb-15	Yes	$ 104,083.00	23,250.00	$ 2.46
Micro	Laurel	3.270	Feb-15	Yes	$ 134,742.80	45,850.00	$ 2.22
Micro	Harlan	8.233	Feb-15	Yes	$ 442,281.30	139,574.00	$ 2.30
Micro	Fayette	4.367	Feb-15	Yes	$ 150,692.98	58,778.00	$ 2.06
Micro	Nelson	1.243	Feb-15	Yes	$ 102,492.20	35,220.00	$ 2.26
Micro	Morgan	2.66	15-Nov	No	$ 330,059.00	57,292.00	$ 2.60
Micro	Morgan	4.1	15-Nov	Yes	$ 243,046.20	73,228.00	$ 2.40
Micro	Clark	0.49	15-Nov	No	$ 161,221.70	22,970.00	$ 2.65
Micro	Warren/Todd/Logan/Allen	24.73	15-Nov	Yes	$ 2,108,462.62	848,644.00	$ 2.06
Thinlay	Todd	3.123	Jul-12	Yes	$ 144,852.18	36,650.00	$ 2.35
Thinlay	Pulaski	3.794	Dec-12	Yes	$ 164,937.25	55,645.00	$ 2.60
Thinlay	Muhlenberg	1.938	Dec-12	Yes	$ 111,738.40	35,606.00	$ 2.60
Thinlay	Perry	1.470	Jan-13	Yes	$ 118,010.71	32,241.00	$ 3.40
Thinlay	Christian	2.653	Jan-13	Yes	$ 313,584.66	97,666.00	$ 2.55

Thinlay	Adair	9.776	Oct-13	Yes	$ 511,962.50	138,235.00	$ 2.79
Thinlay	Edmonson	1.380	Oct-13	Yes	$ 214,854.83	65,064.00	$ 2.72
Thinlay	Graves	3.600	Jul-14	No	$ 372,578.20	80,352.00	$ 2.99
Thinlay	Mason	7.147	Feb-15	Yes	$ 295,721.28	128,740.00	$ 1.80
Thinlay	Letcher	1.143	Feb-15	Yes	$ 69,578.50	17,434.00	$ 3.27
Thinlay	Pulaski	9.44	15-Nov	Yes	$ 404,518.40	138,498.00	$ 2.43
Thinlay	Jackson	3.59	15-Nov	Yes	$ 149,800.53	51,481.00	$ 2.46
Thinlay	Hardin/Meade	3.32	15-Nov	Yes	$ 135,254.00	47,982.00	$ 2.80

The Microsurfacing unit cost from the Boyle County job, as seen in Table 10.1, was listed as $17.50 per SY. It was decided that this cost should be treated as an extreme outlier compared to the rest of the data. The unit cost at this site was larger most likely due to how small the job was in terms of total square yards. In order to avoid putting Microsurfacing at a disadvantage because of a single site's unit cost, this point was ultimately thrown out of the unit cost calculation.

Averaging this data provides a unit price of **$2.40 per square yard** for Microsurfacing in Kentucky.

Calculating the unit price for Thinlay involved some extra steps, since it is bid as dollars per ton. In alternate bid jobs, it was a simple step of multiplying the quantity in tons by the cost per ton to find total dollars. The total dollars was then divided by the quantity in square yards to find dollars per square yard. On non-alternate bid jobs where square yardage is not given, a common conversion factor of 110 pounds per SY-Inch was used to convert from the tonnage quantity to square yards. First, the tonnage was divided by the conversion factor to find SY-Inch, which was then divided by the pavement thickness (5/8") to find the square yards. Table 10.2 below summarizes the cost data for Thinlay.

Table 10.2: Thinlay Unit Cost Determination

TYPE	COUNTY	Letting	Alt Bid	Contract Amount	Quantity (SY)	Quantity (tons)	Unit Price (tons)	Thinlay $/SY
Thinlay	Wayne	Jun-07	No	$ 139,905.21	46,400.00	1,595.00	$ 59.75	$ 3.02
Thinlay	Green	Jul-07	No	$ 161,566.43	48,727.27	1,675.00	$ 69.25	$ 3.32
Thinlay	Todd	Jul-12	Yes	$ 144,852.18	36,650.00	1,260.00	$ 84.65	$ 2.91
Thinlay	Pulaski	Dec-12	Yes	$ 164,937.25	55,645.00	1,913.00	$ 70.00	$ 2.41
Thinlay	Muhlenberg	Dec-12	Yes	$ 111,738.40	35,606.00	1,230.00	$ 79.65	$ 2.75
Thinlay	Perry	Jan-13	Yes	$ 118,010.71	32,241.00	1,110.00	$ 78.62	$ 2.71
Thinlay	Christian	Jan-13	Yes	$ 313,584.66	97,666.00	3,360.00	$ 74.58	$ 2.57
Thinlay	Adair	Oct-13	Yes	$ 511,962.50	138,235.00	4,800.00	$ 76.00	$ 2.64
Thinlay	Edmonson	Oct-13	Yes	$ 214,854.83	65,064.00	2,466.00	$ 73.90	$ 2.80
Thinlay	Graves	Jul-14	No	$ 372,578.20	80,352.00	2,780.00	$ 80.00	$ 2.77
Thinlay	Mason	Feb-15	Yes	$ 295,721.28	128,740.00	4,430.00	$ 55.30	$ 1.90
Thinlay	Letcher	Feb-15	Yes	$ 69,578.50	17,434.00	600.00	$ 85.00	$ 2.93
Thinlay	Pulaski	15-Nov	Yes	$ 404,518.40	138,498.00	4,761.00	$ 64.25	$ 2.21
Thinlay	Jackson	15-Nov	Yes	$ 149,800.53	51,481.00	1,770.00	$ 64.65	$ 2.22
Thinlay	Hardin/Meade	15-Nov	Yes	$ 135,254.00	47,982.00	1,675.00	$ 59.90	$ 2.09
Micro	Pike	Dec-12	Yes	$ 474,500.00	120,000.00	3,850.00	$ 84.20	$ 2.70
Micro	Lewis	Dec-12	Yes	$ 249,800.00	98,071.00	3,715.00	$ 68.50	$ 2.59
Micro	Greenup	Oct-13	Yes	$ 495,000.00	160,839.00	5,530.00	$ 79.70	$ 2.74
Micro	Fleming	Feb-15	Yes	$ 404,902.65	182,795.00	6,284.00	$ 57.30	$ 1.97
Micro	Nelson	Feb-15	Yes	$ 188,024.40	63,250.00	2,175.00	$ 79.50	$ 2.73
Micro	Bath	Feb-15	Yes	$ 498,878.59	127,970.00	4,400.00	$ 84.00	$ 2.89
Micro	Rockcastle	Feb-15	Yes	$ 74,611.46	19,149.00	660.00	$ 90.00	$ 3.10
Micro	Marion	Feb-15	Yes	$ 218,343.46	78,606.00	2,705.00	$ 78.95	$ 2.72
Micro	Laurel	Feb-15	Yes	$ 104,083.00	23,250.00	800.00	$ 84.00	$ 2.89
Micro	Laurel	Feb-15	Yes	$ 134,742.80	45,850.00	1,580.00	$ 82.00	$ 2.83
Micro	Harlan	Feb-15	Yes	$ 442,281.30	139,574.00	4,800.00	$ 80.76	$ 2.78
Micro	Fayette	Feb-15	Yes	$ 150,692.98	58,778.00	2,025.00	$ 77.25	$ 2.66
Micro	Nelson	Feb-15	Yes	$ 102,492.20	35,220.00	1,215.00	$ 79.45	$ 2.74
Micro	Morgan	15-Nov	Yes	$ 243,046.20	73,228.00	2,530.00	$ 81.00	$ 2.80
Micro	Warren/Todd/Logan/Allen	15-Nov	Yes	$ 2,108,462.62	848,644.00	29,637.00	$ 63.55	$ 2.22

By averaging the unit prices, we find that Thinlay has an average cost of **$2.63 per square yard** in Kentucky.

Next, the dollars per square yard value was annualized for each product at the chosen PCI threshold of 55 by dividing the average unit cost by the age associated with the threshold. The annualized unit cost was then converted to annualized dollars per lane mile assuming 12’ wide lanes. The annualized costs are shown below in Table 10.3.

Table 10.3: Annualized Costs at PCI = 55

Treatment Type	Extended Life	Annualized Cost/SY	Annualized Cost/Ln. Mile
Microsurfacing	4.0	$ 0.60	$ 4,224.00
Thinlay	9.1	$ 0.29	$ 2,041.60

Based on this simple analysis, it is apparent that Thinlay is more cost effective than Microsurfacing, despite having a higher up-front cost. Thinlay begins at being $0.23/SY more expensive than Microsurfacing, though becomes less than half the cost of Microsurfacing over the life extension of each product. As the threshold point lowers, the difference in cost for the products begins to slightly narrow. However, delaying the treatment to a point where the pavement begins to fail is contradictory to the primary purpose of preventative maintenance itself.

10.1 Life Cycle Cost Analysis

In addition to determining annualized costs for each product based on unit cost and life extension, a more complex life cycle cost analysis (LCCA) can be determined. Providing both types of cost values is beneficial depending on the audience. The LCCA software, courtesy of the APA (Asphalt Pavement Alliance), was used to determine the cost values.

Within the software, an analysis period of 40 years was assumed. The project length was entered as 1 mile in order to provide a per unit life cycle cost. The number of lanes was one in each direction, which was the most common roadway orientation within the preventative maintenance sites. LCCA includes the capability to calculate the work zone user costs. However, based upon the scope of this study and the standard practice used by KYTC in determining life cycle costs, it was decided to exclude these user costs from the analysis.

First, a control alternative was entered into the software. It is based off of KYTC's standard for life cycle costs in asphalt pavements, from Appendix E of the KYTC Pavement Design Manual. This alternative utilizes no preventative maintenance treatments, and instead assumes overlays are applied every 15 years. Year 0 begins with the original construction. At Year 15, there is 1.5" of milling and a new 1.5" overlay. Finally, at Year 30, there is again 1.5" of milling. However, to stay consistent with KYTC LCC standards, the year 30 overlay is assumed to be 3.5" thick (KYTC 2009). Unit costs in this analysis were calculated as $/SY. Based upon an average HMA price in the project bid tabs of $73.91/ton, the cost of a 3.5" overlay is $14.23/SY, and a 1.5" overlay is $6.10/SY (KYTC 2015). Based upon the KYTC 2015 average of $17.09/ton for milling, the $/SY value is $1.41 (KYTC 2015).

Table 10.4: Control Schedule

Control Schedule	
Application	**Year**
1.5" Mill and Overlay	15
1.5" Mill and 3.5" Overlay	30

Next, the life cycle for the Microsurfacing alternative was entered. The unit cost in this alternative was the same as the annualized cost analysis, which is $2.40/SY. It was assumed that the Microsurfacing would be applied at Year 10 of the original pavement's life. After four years of life extension (note that LCCA requires integers for year inputs), another Microsurfacing treatment would be used to provide further life extension for a total comparable to that of a Thinlay. Another Overlay would be applied after both Microsurfacing treatments.

Table 10.5: Microsurfacing Treatment Schedule

Microsurfacing Treatment Schedule	
Application	**Year**
Microsurfacing	10
Microsurfacing	14
1.5" Mill and Overlay	18
Microsurfacing	28
Microsurfacing	32
1.5" Mill and Overlay	36

Finally, the Thinlay data was created in the software. The Thinlay unit cost of $2.63/SY was applied. As with the previous alternative, ten years pass on the original pavement or overlay before the surface treatment is applied. The Thinlay then provides nine years of life extension.

Table 10.6: Thinlay Treatment Schedule

Thinlay Treatment Schedule	
Application	**Year**
Thinlay	10
1.5" Mill and Overlay	19
Thinlay	29
1.5" Mill and Overlay	38

It is important to note that each alternative starts with an existing asphalt pavement for which the construction cost is the same in each. Therefore, the assumption was made to remove the initial construction costs from the analysis in order to more accurately compare the differences in future costs based on varying preventative maintenance strategies.

After inputting each alternative into the software, the simulation yielded the following results:

Table 10.7: Life Cycle Cost Analysis Results for PCI = 55

	PCI = 55 (Overlay @ Year 10, Double Micro Application)	
Treatment	**Life Extension**	**Net Present Value**
Thinlay	9	$ 93,281.00 per Lane Mile
Microsurfacing	4	$ 127,992.00 per Lane Mile
Control		$ 111,319.00 per Lane Mile
Micro - Thinlay		$ 34,711.00 per Lane Mile
4.35 mile section		$ 150,993.00

The NPV column represents the Net Present Value in dollars of each alternative. The "Microsurfacing – Thinlay" value is simply the difference between those two alternatives in NPV. This difference was then multiplied by the average project length of 4.35 miles, which represents the average life cycle cost difference between Microsurfacing and Thinlay on an average KY project, using a PCI threshold of 55.

11. Summary and Conclusions

With the ever increasing use of Preventative Maintenance in Kentucky, it is significantly important to further study this issue to understand the value to the taxpayers of Kentucky. ASTM D6433 was selected as the method of evaluation due to its unbiased and statistical approach. After a period of approximately two months, PCI data for all the projects was obtained and compiled into a spreadsheet database. From the first glances at the completed data, it became apparent that Thinlay was outperforming the Microsurfacing sites from an engineering point of view. The data was graphed and trendlines were applied based off of the multiple linear regression model in Chapter 8. After deciding to use PCI vs. Age as the primary graphing method, Figure 11.1 was used as the basis for the age/cost analysis:

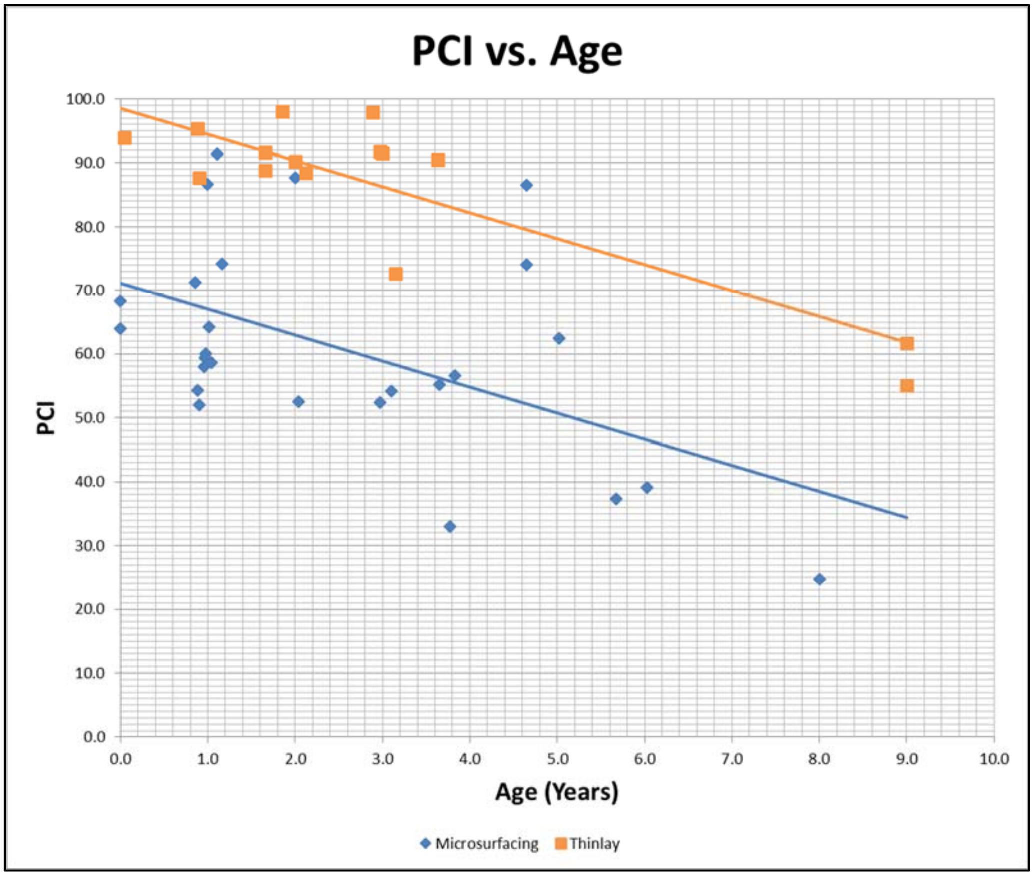


Figure 11.1: PCI vs. Age with Prediction Model

The statistical results from Chapter 8 showed that there is a significant difference in PCI performance between Microsurfacing and Thinlay. However, the difference is not in the slope of PCI vs. Age but in the PCI towards the start of each product's life. It can be suspected that Microsurfacing begins at a lower PCI depending on the condition of the pavement it is applied to. This concept was demonstrated when comparing the per-condition distresses at Warren and Allen County to the distresses after Microsurfacing was applied. The rutting encountered in those sites immediately reflected through the treatment – indicating that Microsurfacing does not provide the structure necessary to fill ruts. The alligator cracking encountered at Allen County did not reflect through immediately. However, it should be noted that preventive maintenance should not be used to correct structural damage – such as alligator cracking – in pavements. Overall, the assessment of the pre-condition sites indicates that KYTC may be misusing preventive maintenance by applying to sites that require more extensive rehabilitation or even reconstruction.

It was also shown in the statistical data that there are a number of distresses that are more significant in predicting PCI on Kentucky's preventive maintenance sites. These included edge cracking, longitudinal/transverse cracking, rutting, alligator cracking, and weathering. Rutting, alligator cracking, and longitudinal cracking were especially significant with very low p values. This supports the conclusion that these treatments are significantly affected by distresses that indicate structural damage.

Furthermore, a cost analysis was needed to finalize the results. By averaging bid tab data from KYTC, the unit costs of $2.40 and $2.63 per square yard for Microsurfacing and Thinlay, respectively, were calculated. Next, the trendline equations were used to calculate PCI based on age for each product in order to find annualized cost values. These values are summarized in Table 11.1 below.

Table 11.1: Annualized Costs at PCI = 55

Treatment Type	**Extended Life**	**Annualized Cost/SY**	**Annualized Cost/Ln. Mile**
Microsurfacing	4.0	$ 0.60	$ 4,224.00
Thinlay	9.1	$ 0.29	$ 2,041.60

A Life Cycle Cost Analysis was also performed. This analysis examined the PCI threshold point of 55, with the same life extension as the annualized cost results. The following table summarizes the life cycle costs for those assumptions:

Table 11.2: Life Cycle Cost Analysis Results for PCI = 55

	PCI = 55 (Overlay @ Year 10, Double Micro Application)	
Treatment	**Life Extension**	**Net Present Value**
Thinlay	9	$ 93,281.00 per Lane Mile
Microsurfacing	4	$ 127,992.00 per Lane Mile
Control		$ 111,319.00 per Lane Mile
Micro - Thinlay		$ 34,711.00 per Lane Mile
4.35 mile section		$ 150,993.00

The Mercer County experimental data suggests that Thinlay, Cape Seal, and Double Microsurfacing are all very comparable in terms of performance, though Cape Seal and Double Microsurfacing would have a higher up-front cost than Thinlay. Microsurfacing at this site showed higher performance over only the Crack Sealing and Control sections. However, no final conclusions can be drawn from US 127 at this time. The surface is only two years of age and further data will be needed to determine treatment performance several years into the future.

The graph of PCI vs. Age suggests that Thinlay is outperforming Microsurfacing in terms of the life extending benefit of the product. At a PCI threshold of 55, Thinlay provides a 9.1 year life extension, and Microsurfacing provides a 4.0 year life extension. Again, this is most likely due to Thinlay's relative ability to resist rutting and reflective/fatigue cracking. Microsurfacing has very little structure at 3/8" thickness, and is susceptible to multiple distresses at an early point in its design life.

Translating the performance advantages of Thinlay into the cost analysis shows that over the life extension of each product, Thinlay becomes more cost effective despite being $0.23/SY more expensive during construction. To be more exact, Thinlay becomes $0.29/SY/Year and Microsurfacing becomes $0.60/SY/Year over the life extension of each.

Examining the LCCA results also reveals Thinlay to be more cost effective. When comparing trendline to trendline, Thinlay's NPV is approximately $34,711 lower per project mile.

Ultimately, it appears that Thinlay provides a number of advantages over Microsurfacing in distress resistance and cost effectiveness. As these sites are further analyzed in the future years, the deterioration curves can be further assessed, especially at the pre-condition sites. However, the current data seems to yield a statistically viable sample and should be useful in improving the preventative maintenance program in Kentucky.

11.1 Contribution to Practitioners and Agencies

For practitioners in the pavement maintenance industry, this thesis presents several main takeaways. Concerning the distress analysis, it was confirmed that Microsurfacing provides little resistance to certain distress types – namely rutting and alligator/fatigue cracking. The comparison of pre-condition to post-treatment distresses at the Microsurfacing site in Warren/Allen County showed that Microsurfacing reflects even minor rutting in the previous surface. Practitioners should consider this observation when selecting roadway candidates for pavement maintenance. When rutting and other structural distresses are present, this thesis provides evidence that further rehabilitation beyond preventive maintenance is required to fully address the problem. For state highway agencies, it is recommended that pavement maintenance programs pay special attention to the presence of structural distresses and apply the best treatment to maximize cost efficiency and life cycle improvement.

To more specifically address practitioners in Kentucky, as well as KYTC, this thesis shows that Thinlay is performing to a higher standard than Microsurfacing under the current conditions in the state. This is hypothesized to be due to two major reasons – Thinlay's reduced susceptibility to rutting and reflective cracking (thicker material), and poorly chosen maintenance candidates. It is possible that Microsurfacing would perform closer to Thinlay if proper roads were being selected. However, information at the Warren/Allen County site shows that poor candidates have been selected in the past. KYTC should examine their selection system and make sure that preventive maintenance is being applied in the right situations. If this improvement occurs, the performance difference between Microsurfacing and Thinlay in general can be more accurately determined. However, this thesis presents the actual performance of these treatments in Kentucky thus far – and the life cycle costs calculated for each will remain accurate as long as KYTC retains its current selection policy.

11.2 Limitations of the Research

While this thesis provided a number of valid and interesting conclusions, there were some limitations and imperfections in the methodology. The major limitation was that pre-condition data could not be found for the roadway before the treatment was applied – with the exception of Warren and Allen County. The PCI of the previous surface is a major factor in predicting how the PCI will progress in the new surface. Therefore, the life cycle extensions for each treatment in this data set should not be applied to regions other than Kentucky. As previously mentioned, the data represents how preventive maintenance is likely performing under the current conditions in the state.

As pavement practitioners are aware, pavements do not deteriorate linearly over their lifespan. As the roadway ages, PCI deterioration typically accelerates until the pavement reaches the “failed” status. However, this thesis presented the PCI prediction model using multiple linear regression. Since multiple pavement sites were used to construct the PCI vs. Age graphs, the statistical spread was higher than what would be seen in data collected on a single pavement site over time. Therefore, a precise non-linear model was difficult to fit to this thesis' data in terms of statistical quality. Multiple linear regression provided a means of extracting useful results from the data analysis.

Lastly, the data collected does not account for construction quality – which can drastically affect the PCI at the start of a pavement's life cycle. A number of different contractors worked on the sites examined in this study. Paving methodology and quality control could certainly vary between them. Ideally, testing and QA/QC data would be added as a factor in the multiple linear regression model. However, this data was never obtained or made available.

11.3 Future Research

For those who wish to continue examining preventive maintenance in Kentucky or in general, there are some potential next steps. Each site examined in this study could be surveyed again in future years in order to construct a deterioration curve for each site. After several years of data collection, it could be confirmed whether or not Microsurfacing and Thinlay deteriorate at different rates. For maintenance treatments that are scheduled by KYTC but yet to be applied, pre-condition surveys should be completed since the initial PCI is a very important factor in analyzing deterioration. Combining pre-condition data with several years of surveying from each site, practitioners could very accurately predict Microsurfacing and Thinlay PCI as functions of initial PCI, pre-condition PCI, and age. Life cycle costs could then be compared when holding pre-condition PCI constant, removing any bias that could arise from two sites having very different histories.

Appendix 1: SAS Code

```
/*import data - all*/
proc import
      OUT= WORK.PAVEMENT
      datafile="\\Client\C$\Users\Dominic\Desktop\STA 671\PCI Database
2017 Update.xlsx"
      dbms=xlsx
      replace;
sheet="SAS Table All";
getnames=yes;
run;
proc print data=PAVEMENT;
run;
/*All Data vs. Age*/
PROC REG DATA=PAVEMENT;
MODEL PCI=AGE/CLB;
RUN;
/*Thinlay PCI vs. Age*/
PROC REG DATA=PAVEMENT(WHERE=(TypeInd=1));
MODEL PCI=AGE/CLB;
RUN;
/*Micro PCI vs. Age*/
PROC REG DATA=PAVEMENT(WHERE=(TypeInd=0));
MODEL PCI=AGE/CLB;
RUN;
/*Thinlay PCI vs. Age and AADT*/
PROC REG DATA=PAVEMENT(WHERE=(TypeInd=1));
MODEL PCI=AGE AADTInd/CLB;
RUN;
/*Micro PCI vs. Age and AADT*/
PROC REG DATA=PAVEMENT(WHERE=(TypeInd=0));
MODEL PCI=AGE AADTInd/CLB;
RUN;
/*Thinlay PCI vs. Age and District*/
PROC REG DATA=PAVEMENT(WHERE=(TypeInd=1));
MODEL PCI=AGE District/CLB;
RUN;
/*Micro PCI vs. Age and District*/
PROC REG DATA=PAVEMENT(WHERE=(TypeInd=0));
MODEL PCI=AGE District/CLB;
RUN;
/*CREATE INTERACTION VARIABLES*/
DATA PAVEMENT2;
SET PAVEMENT;
TypeInd_Age=TypeInd*Age;
AADTInd_TypeInd=AADTInd*TypeInd;
AADTInd_Age=AADTInd*Age;
TypeInd_AL=TypeInd*AL;
TypeInd_AM=TypeInd*AM;
TypeInd_BlL=TypeInd*BlL;
TypeInd_EL=TypeInd*EL;
TypeInd_EM=TypeInd*EM;
TypeInd_LTL=TypeInd*LTL;
TypeInd_LTM=TypeInd*LTM;
```

```
TypeInd_LTH=TypeInd*LTH;
TypeInd_RTL=TypeInd*RTL;
TypeInd_SPL=TypeInd*SPL;
TypeInd_WTL=TypeInd*WTL;
RUN;
PROC GLM plots=diagnostics;
class District;
model PCI=Age TypeInd District AADTInd TypeInd*Age / solution;
RUN;
PROC REG DATA=PAVEMENT2;
MODEL PCI=AGE TypeInd District AADTInd TypeInd_Age/CLB;
RUN;
PROC REG DATA=PAVEMENT2;
MODEL PCI=AGE TypeInd District TypeInd_Age/CLB;
RUN;
PROC REG DATA=PAVEMENT2;
MODEL PCI=AGE TypeInd District/CLB;
RUN;
PROC REG DATA=PAVEMENT2;
MODEL PCI=AGE TypeInd/CLB;
RUN;
PROC REG DATA=PAVEMENT2;
MODEL PCI=AGE TypeInd/CLB;
RUN;
/*Distress Analysis - Best Model*/
PROC REG DATA=PAVEMENT2;
MODEL PCI= AL AM EL EM LTL RTL WTL/CLB;
RUN;
/*Distress Analysis with TypeInd Error*/
PROC REG DATA=PAVEMENT2;
MODEL PCI= TypeInd AL AM EL EM LTL RTL WTL/CLB;
RUN;
```

References

ASTM. (2007). “Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys.” *D6433*, ASTM International, West Conshohocken, PA, 2007.

KYTC. (2009). “Pavement Design Guidance, Appendix E.” Kentucky Transportation Cabinet, Frankfort, KY.

KYTC. (2015). “Average Unit Bid Prices, 2015.” Kentucky Transportation Cabinet, Frankfort, KY.

KYTC. (2017). “Unit Bid Tabulations.”, http://transportation.ky.gov/Construction-Procurement/Pages/Unit-Bid-Tabulations.aspx (May 2016).

KYTC. (2017). “Photolog.”, http://maps.kytc.ky.gov/photolog/ (May 2016).

Transportation Information Center. (2002). PASER Asphalt Roads Manual. Wisconsin Transportation Information Center, Madison, WI.

Vita

1. Educational institutions attended and degrees already awarded:
    a. University of Kentucky – Bachelors of Science in Civil Engineering (May 2016)
2. Professional Positions held:
    a. Asphalt Technology Intern – Marathon Petroleum Corporation (May – August 2015)
    b. Pavement Evaluator and Intern – Plantmix Asphalt Industry of Kentucky (May – August 2016)
    c. Construction Laborer and Pipe Layer – Michels Construction (May – August in 2012, 2013, and 2014)
    d. Graduate Research Assistant – University of Kentucky (August 2016 – May 2017)
3. Scholastic and professional honors
    a. Two time recipient of ASCE Student Chapter scholarship (2015 and 2016) awarded by ASCE Kentucky Section