DETERMINATION OF COMPOSITE PAVEMENT DISTRESSES IN NORTH CAROLINA

by

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ABSTRACT

THOMAS PAUL SANDS. DETERMINATION OF COMPOSITE PAVEMENT DISTRESSES IN NORTH CAROLINA. (UNDER THE DIRECTION OF DR. THOMAS NICHOLAS II)

Composite pavements have gained popularity in the last fifty years due to their smooth riding surface and heavy capacity substructure. A systematic method of determining the triggering distress is lacking. With a triggering distress found, the maintenance can be more specific to the failure. This study was conducted to address this issue. North Carolina construction and maintenance data was used as the database for this research. In addition to identifying the trigger points on the composite pavements in the North Carolina Department of Transportation (NCDOT) road system, the prescribed maintenance from the Pavement Management System (PMS) decision trees were determined. Once these prescribed maintenance decisions were determined, an associated unit cost estimate was established for each maintenance option.

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CHAPTER 1: INTRODUCTION

1.1 Background and significance

Highways are at the center of everyday life and influence how people and goods move. It is important that departments of transportation (DOT) have all the correct tools and techniques when it comes to pavement maintenance methods. The transportation industry classically has had two classes of pavements, flexible and rigid. A third hybrid pavement also exists, that includes both flexible and rigid pavements together, and is known as “Composite Pavements”. The typical composite pavement structure is constructed with a rigid base layer, typically of some sort of concrete with a flexible pavement layer on top, such as hot mix asphalt to provide a smooth surface for a more comfortable ride. The difference in the two materials’ properties allows for both a strong stiff base to support heavy wheel loads and a smooth comfortable driving surface [1]. There is currently not a separate maintenance system devoted specifically to composite pavements in North Carolina.

1.2 Problem Statement

The North Carolina Department of Transportation (NCDOT) does not have a pavement management system that is specific to composite pavements. Currently the NCDOT is using the flexible pavement management system to make maintenance decisions for distresses on composite pavement roadways. The purpose of this research is to use maintenance data provided by the NCDOT to determine the trigger points for maintenance on composite pavements. Once the trigger points are identified, a maintenance cost will be associated with the triggering distress that caused repair. This research will help NCDOT engineers determine if composite pavements are being maintained properly using the flexible pavement management system or whether the flexible pavement management system is skewing the maintenance to distresses that are not the true problems. If this is the case, there is a need for a separate maintenance system specific to composite pavements.

1.3 Purpose and Objectives

The purpose of this research was to evaluate maintenance data provided by the NCDOT and identify the distresses that are triggering maintenance on composite pavement roadways. The objective of this research was to determine the following:

- The triggering distresses in composite pavements
- The maintenance that the NCDOT should perform based on the triggering distress using the NCDOT pavement management system
- An associated unit cost for the performed maintenance used to correct the triggering distress on the composite pavement roadway

1.4 Scope and Limitations

In order to complete the objectives for this project, the current state of the data set requires the removal of satisfactorily performing road sections and outliers. These outliers included sections of roadways that have unreasonably low distress index values, less than ten. The triggering distress for failing road sections also needs to be determined and compared to the preferred maintenance. Lastly, define an associated cost for the performed maintenance as it relates to the triggering distress.

A limitation associated with this project was that the triggering distresses were determined using data collected for North Carolina roadways and the performance curve rating (PCR) values were calculated using North Carolina DOT's PCR equations. The cost data for each maintenance was also collected using North Carolina rates, and therefore the models and costs might not be applicable to be used in other states. The methodology, however, is flexible enough that other state DOTs can follow the same steps to make decisions that will work with their roadways.

CHAPTER 2: LITERATURE REVIEW

2.1 Background of Composite Pavements

Normally, an existing Portland Cement Concrete (PCC) pavement is overlaid with a hot mix asphalt (HMA) layer, or another PCC surface layer; both methods are considered composite pavements (Nunez, 2007). Past studies of pavement performance indicate that composite pavements possess potential advantages functionally, structurally, and economically compared to traditional methods of pavements (Nunez, 2007). Pavement structures, throughout their service life, tend to show development of different types of distresses which may be categorized as fracture, distortion or disintegration. Composite pavements are believed to resist most of these distresses when high quality hot mix asphalt (HMA) is used in the top flexible layer of the pavement.

2.2 History and the Use of Composite Pavements

Long life composite pavements have been used for decades all over the world due to their ability to handle heavy traffic loads while providing a smooth riding surface; this is due to the combination of the rigid subbase substructure with the flexible HMA layer (Nunez, 2008). Composite pavements became prevalent during the 1950s. Now, composite pavements are one of the most commonly used concrete pavement rehabilitation methods (Chen, 2015). The states of New Jersey, Washington, and Ohio have constructed composite pavements with a traditional cementitious base using HMA as the wearing surface. The rest of the United States has followed, using a similar style of composite pavement. Some states have also made pavements with HMA laid over a reinforced cement concrete (RCC) base (Nunez, 2008).

European countries like the United Kingdom, Germany, and Italy also use composite pavements. They use a low noise HMA surface layer and Jointed Concrete Pavement (JCP) or Continuously Reinforced Concrete (CRC) as the base layer. Long-term studies were conducted on the performance of composite pavements in the United States and Canada during the 1950s and the 1970s. These studies showed that HMA/PCC composite pavements needed the lowest amount of maintenance (Nunez, 2008). In 1999, the United Kingdom had 649 km of composite pavements installed between 1959 and 1987, and carrying 8 to 97 million single axle loads per year. Composite pavements from the U.K., the Netherlands, and Hungary performed satisfactorily in terms of cracking, rutting, and deflections. Compared to flexible pavements, the expected life of composite pavements was longer even under heavy traffic loads (Nunez, 2008). There is extensive use of composite pavements in Spain; however, instead of PCC they use various types of rigid bases that vary from each other in cement content, type of aggregate, and size of aggregate (Nunez, 2008).

2.3 Composite Pavement System Strength

The rigid layer of a composite pavement undergoes deformation due to distresses such as curling and warping because of the concrete slab’s expansion, which is caused by temperature changes and moisture gradient differences. The flexible asphalt layer acts as a moisture barrier and thermal insulator, which reduces the effect of vertical temperature and moisture gradients, helping prevent deformation of the rigid layer. The asphalt also acts as a wearing surface, which controls the wearing effect of the different wheel loads on the rigid surface layer (Caltrans, 2008).

During the placement of the HMA layer, the high temperature of the mix speeds up the evaporation of the moisture content on the surface of the rigid layer, which reduces relative humidity. Once placed, the HMA layer acts as an insulating material to the rigid layer after it cools, which reduces the development of warping stress (Tompkins, 2013). The mechanism by which curling stresses are reduced involves the HMA layer buffering the lower rigid layer from temperature fluctuations. This can have an effect of extending pavement life between total restorations, in some cases up to fourteen years (Chen, 2015).

2.4 Composite Pavement Behavior and Distresses

Common distresses in Composite pavements are fatigue cracking, rutting, top-down cracking, shrinkage cracking, reflective cracking, and thermal fatigue cracking (Hernando, 2013). Reflective cracking is defined as cracking that occurs because of pre-existing (prior to overlay) cracking on the base layer beneath. This distress is easily created in the asphalt overlay when it moves with the underlying cement layer as it expands and contracts due to change in temperature (Dave, 2010). The majority of the reflective cracks in composite pavements occur along the expansion joints in the cement base.

Top down cracking is a distress that, by contrast with reflective cracking, starts at the asphalt layer and propagates downward. North Carolina Department of Transportation (NCDOT) uses the term “longitudinal cracking” to refer to this top-down cracking behavior. This type of cracking typically appears around the wheel path and on the edges of a roadway. Rutting is a load related distress that occurs in composite pavements when pressure of the wheel load causes the flexible asphalt layer to be pushed outward and to the side, because the rigid base layer will not itself deform. Shrinkage cracking occurs mostly when an asphalt overlay is put directly on top of a newly constructed cement base. As the concrete base cures, shrinkage occurs that causes the asphalt layer to be put under stress and then cracking occurs. Thermal fatigue cracking occurs when stresses due to low temperatures act on the pavement structure under vehicular load. As the temperature of the pavement system drops, the material becomes more brittle, especially the top asphalt layer. Under these conditions, the material does not perform as well and can release stress in the form of thermal fatigue cracking (Wang, 2013).

2.5 Maintenance of Composite Pavements

Reflective cracking is the most common type of distress in composite pavements with HMA overlay. If reflective cracking is left untreated, it can cause excessive riding noise and premature failure (Rodezno, 2005). In 2015, (Chen, 2015) studied factors affecting reflective cracking in composite pavements. This study identified the following treatments for composite pavements:

- HMA overlay
- HMA mill and Fill
- Heater scarification (SCR)
- PCC rubblization

The effectiveness of HMA overlay treatment for composite pavements depends on the amount of reflective cracking present prior to overlay. Per the Federal Highway Administration (FHWA), surface recycling is an acceptable method to remove reflective cracks before laying an HMA overlay. Two other treatment methods, HMA mill and fill and heat scarification (SCR), are commonly used in the state of Iowa to remove existing cracks from pre-existing HMA overlays. In HMA mill and fill, new asphalt is mixed and used for repaving after milling. However, in the SCR treatment, recycling agents are used in addition to pulverized pavement materials for repaving. The main goal of the PCC rubblization process is to produce a sound base without any distresses and joints, which prevents reflective cracks. This is achieved by breaking the existing concrete pavement and overlaying it with HMA. In our study, a reflective cracking index (RCI) was used to quantify the severity of cracking and its corresponding threshold value was developed. Along with reflective cracking index, International Roughness Index and pavement condition index were used to indicate the condition of the pavement (Chen, 2015). Among the several distresses found in composite pavements, reflective cracking was the most common distress (Akkari, 2012;(Leng, 2006;Von Quintus et al., 2010; Lytton et al., 2010). Reflective cracking is developed when cracks extend all the way from the PCC base to the surface of the HMA overlay. Subsequent penetration of moisture and other environmental components cause the failure of the pavement. According to Bennert and Maher (Bennert, 2007), state highway authorities reported that composite pavements were subject to reflective cracking within the first four years and other state highway authorities found reflective cracking within the first two years.

In a study conducted by Michigan Department of Transportation (MDOT) in 2010 (Ram, 2014), the performance of preventive maintenance treatments was evaluated. MDOT has a capital maintenance program (CMP) through which preventive maintenance treatments are implemented to slow down the process of deterioration and to correct surface irregularities on asphalt surfaced pavements. These preventive maintenance treatments postpone major rehabilitation and construction activities, thus saving money. A Distress Index (DI) is used to quantify various distresses. A DI value of 50 is set as the threshold value by MDOT for rehabilitation activities and the value is set to 40 for preventive maintenance activities. It was found that the first preventive maintenance activities could extend a composite pavement's life by nine years.

Louisiana Department of Transportation and Development (LADOTD) conducted a study to develop pavement treatment performance models for overlay treatment of composite pavements (Khattak, 2014). In this study, pavements with HMA overlays in the state of Louisiana were analyzed and international roughness index models were developed. In this study, it was found that the following maintenance treatments have been used by LADOTD to maintain composite and flexible pavements:

- Replacement
- Structural (thick) overlay
- Non-structural (thin) overlay
- Crack sealing
- Chip deals
- Micro-surfacing
- Patching
- Full-depth concrete repair
- White Topping

In New York City, a study (Simpson, 2013) was conducted to identify the most cost effective and efficient method to mitigate reflective cracking in composite pavements. In order to evaluate the various treatment methods, performance of composite pavements with several treatment methods was compared with pavements without any treatment. Visual condition surveys, falling weight deflectometer surveys, forensic coring and material testing were used for the evaluation process. In this research, the following treatments used to mitigate reflective cracking by New York City Department of Design and Construction (NYCDDC) were studied:

- Saw and seal the HMA overlay
- NYCDDC standard, nonwoven polypropylene fabric
- NYCDDC alternative fabric at the HMA surface and HMA binder interface
- Heavy-duty membrane interlayer or membrane
- Stress-absorbing interlayer composite
- Fiberglass reinforcement layer of Type 1
- Fiberglass reinforcement layer of Type 2

The study concluded that the saw and seal method gave the best performance. It was also concluded that 15-foot joints perform better that 20-foot joints in controlling high severity cracking.

In 2006, the New Jersey Department of Transportation (NJDOT) conducted a survey to study the various practices and HMA designs used by state highway agencies in the United States to mitigate reflective cracking. The following mitigation methods were identified:

- Paving fabrics and geotextiles (PFGs)

- Geogrids (GEOs)
- Stress-absorbing membrane interlayers (SAMIs)
- Reflective crack relief interlayer mixes–Strata-type mixes (RCRIs)
- Crack arresting layers (CALs)
- Excessive overlay thickness (EOT)

In addition to the above mitigation methods, some treatments were applied on PCC even before HMA overlays were laid in order to extend the life of the HMA overlay. These treatments are:

- Repair Cracks
- Replace Joints & Slabs
- Underseal
- Void Fill
- Crack & Seat
- Rubblize
- Edge Drains

Transverse cracking can be caused by many factors. One of the factors is shrinkage, both plastic and drying, which causes transverse cracking early in the pavements life. Another common factor is surface cracks deteriorating over time and becoming transverse cracks due to heavy traffic loads or climatic variations in temperature and/or moisture conditions that cause expansion and contraction of the base layer. This movement in the base layer induces interface friction between the overlay and the base layer, which can lead to transverse cracking (Frabizzio, 1999). Crack sealing is the traditional method used to treat transverse cracking. There are several other treatments which can be used before overlay is laid. Some of these treatments include fiberglass–polyester paving mat, hot-mix patching, hot-mix patching combined with fiberglass–polyester paving mat, and crack sealing.

In 2013, the Federal Highway Administration (FHWA) conducted a study to identify methods to evaluate the Interstate highway system (Simpson, 2013). In this study, several metrics representing conditions of pavements were reviewed. One of the metrics used for evaluating composite pavements is pavement remaining service life (RSL).

To determine the RSL of composite pavements, the FHWA Pavement Health Track (PHL) was used. This tool was used to predict distress values including international roughness index, rutting, cracking and faulting at the end of the overall service life of composite pavements. The number of years remaining was calculated before the pavement reached the IRI and reflection cracking threshold values. In addition to these threshold values, a threshold age was also set for composite pavements in case the predicted distress did not reach threshold values. A threshold value for IRI was set as 170 in/mile and 100 ft/mi for reflection cracking. Overall RSL threshold values were set as follows:

- Good: RSL > 10 years,
- Fair: 1 < RSL ≤ 10 years,
- Poor: RSL ≤ 1 year.

2.6 Maintenance Cost

Pavement performance steadily declines as the traffic loads increase and the life of the pavement is extended (Yong, 2016). There comes a point in the pavements life that maintenance needs to be performed to keep the road functioning. This maintenance has cost associated with it: conception of maintenance and rehabilitation strategies, old material extraction, new material, construction equipment, and operations cost all add up to a total maintenance cost (Babashamsi, 2016). Not all sections of road need the same amount of maintenance, some need complete reconstruction and others simply need an overlay. Maintenance cost should be considered when choosing maintenance, especially due to rapidly rising maintenance cost (Babashamsi, 2016).

CHAPTER 3: DETERMINING TRIGGERING DISTRESSES AND ASSOCIATED MAINTENANCE COST

The PCR value is a metric that represents how a section of roadway is performing as a whole system that incorporates all different types of distresses. The PCR value of sixty is the threshold value that the NCDOT has assigned to indicate that a roadway needs maintenance or repair. This chapter is a summary of the methodologies used to determine the triggering distresses that cause the performance curve rating (PCR) value of a section of roadway to receive a curve rating of sixty or lower.

3.1 Roadway Families

The NCDOT has four established classifications for roadways: Interstates, United States Highways (US), North Carolina Highways (NC), and Secondary Roads (SR). These roadway families are further subdivided based on the roadway's Average Annual Daily Traffic (AADT); for this research, the families were divided as shown in Table 1.

Table 1: Roadway families

Family	**AADT**
Interstate	ALL
US	0 – 5,000
	5,000-15,000
	15,000 plus
NC	0 – 5,000
	5,000 plus

Only three of the four families were used in this study (Interstate, US, NC). The secondary road family did not have sufficient data for composite construction.

3.2 Effective Layers

The effective layer for a roadway is the top layer of pavement, more commonly referred to as the riding surface. Riding surfaces are overlaid with newer layers as a form of maintenance; when this occurs there is a new effective layer established for that particular section of pavement. This research looks at the effects and distresses on the first overlay surface. This overlay is when the pavement is converted from a traditional pavement class (flexible or rigid) to the composite pavement class.

For this research, “real_n” is that nomenclature that is used to communicate what effective layer a pavement is on. Table 2 below, shows the effective layers that correspond with the real_n values for both the construction and maintenance data.

Table 2: Real_n values and the corresponding layers

	Construction Data	**Maintenance Data**
Real_n	**Effective Layer**	**Effective Layer**
Real_n = 0	1	N/A
Real_n = 1	2	1
Real_n = 2	3	2
Real_n = 3	4	3
Real_Etc.	Etc.	Etc.

Real_n values of zero and one were used in this research because those values represent a roadway section becoming a composite pavement section. The construction data used a real_n value of zero to represent the first overlay while the maintenance data used the value of one to represent the first overlay; due to this both real_n values of zero and one were used.

The raw data for this research was separated into sections by the effective layer and family. The divisions of data are shown below in Table 3.

Table 3: Research Project Data Organization

Construction and Maintenance
Interstate
US Highways (0-5,000 AADT)
US Highways (5,000-15,000 AADT)
US Highways (15,000 + AADT)
NC Highway (0-5,000 AADT)
NC Highways (5,000 + AADT)

The effective layers and the families were determined to be the most logical and easiest way to break down the data.

3.3 PCR Values

Once the data was separated into its respective family, a PCR value for the roadway sections needed to be determined by using the equation that has the appropriate weights for the different distresses, according to the NCDOT. There are two PCR values for each section of road, load and non-load. NCDOT uses the following equations to determine their PCR values.

PCR (LDR) = Alligator * 0.531645+ Non-wheel path patch * 0.0886072+ Wheel path patch * 0.151903+ Rutting * 0.227845;

Where:

Alligator = The distress index value for alligator cracking
Non-wheel path patch = The distress index value for non-wheel path patching
Wheel path patch = The distress index value for wheel path patching
Rutting = The distress index value for rutting

PCR (NDR) = Transvers * 0.425002+ Longitudinal * 0.224998+ Longitudinal lane joint * 0.175+ Raveling * 0.175

Where:

Transvers = The distress index value for transvers cracking
Longitudinal = The distress index value for longitudinal cracking
Longitudinal lane joint = The distress index value for longitudinal lane cracking

Raveling = The distress index value for raveling

The weight of each distress is determined by local DOTs, the above weights are specific for North Carolina.

After all non-first effective layers except for the first effective layer and divided into their families all the sections of roadway that did not have a distress value below sixty were removed from the data set. This left only values that had a possibility of returning a PCR value below sixty once run though the PRC equations.

3.3.1 SAS ®

SAS is a linear and non-linear regression modeling software, and has the ability to use a batch process and allows several mathematical commands to be entered at once. SAS was chosen because of its ability to run multiple commands at once and eliminate nonessential data efficiently. SAS was used to remove the data that did not pertain to this research from the raw data set. This included data for sections of roadway that did not have any distress value that was below sixty.

3.3.2 Excel®

Once the data that did not have the possibility of producing a PCR value below sixty was removed, it was then imported to Microsoft Excel. Microsoft Excel was selected due to its ability to create and manipulate spreadsheets. Excel can perform complex analyses, and it summarizes data with previews of graphics, allowing for comparison of graphics and the selection of the one that best represents the data (Excel, 2017). Excel was used to format, tabulate, and store the project data.

Specifically, the data was cleaned in SAS and exported into Excel. Using the feature of Excel to create and calculate a custom formula the load and non-load PCR values were found. If a roadway section passed there is no maintenance needed, and therefore no triggering distress. All data points that passed were removed from the data, leaving only sections of roadway that needed maintenance.

Using the “if then” feature of Excel the trigger distress was determined by taking the two most heavily weighted values in the PCR equations and finding the lowest of the two distresses. This distress was considering the triggering distress. For load related failure the two distress that could trigger maintenance, according to the North Carolina equations, were alligator cracking and rutting. For non-load failure, the two distresses that can trigger maintenance were transverse cracking and raveling.

Once the triggering distress was identified the preferred method of maintenance was determined using the NCDOT’s maintenance decision tree for flexible pavements. The use of the flexible pavement decision tree was due to the lack of a composite pavement decision tree.

3.4 Summary of Work Flow

The data in this research was meticulously cleaned down to only necessary data points that represented roadway sections that were composite pavements and were on their first effective layer and needed maintenance because the PCR value for the section was determined to be sixty or below. The following steps summarize the work flow.

Phase 1 – Determine Triggering Distresses for Maintenance and Identify prescribed maintenance:

- Step 1: Separate all data points into their respective families.

For this research, the data was broken down into the following families: Interstate, US Highways (0-5,000 AADT), US Highways (5,000-15,000 AADT), US Highways (15,000 + AADT), NC Highway (0-5,000 AADT), and NC Highways (5,000 + AADT)

- Step 2: Remove all data that is not on the first effective layer (real_n = 0 for construction and real_ =1 for maintenance).

Each family was then separated based on the data set it originated from, so that there were two sets of each family, one for construction and maintenance.

- Step 3: Remove all data points that do not have any distress values lower than sixty using SAS. This leaves only data that has the possibility of returning a failing PCR value.

The table below shows an example of a data entry that would have been removed (top entry) and one that would have remained after step 3 (bottom entry). The values that are indicated are what would cause the data entry to remain because with one index value less than sixty there is a possibility for the PCR to return less than sixty as well.

Table 4: Data Elimination Example

Transverse Cracking Index	Alligator Cracking Index	Raveling Index	Longitudinal Cracking Index	Longitudinal Lane Cracking Index	Wheel Path Patching Index	Non-Wheel Path Patching Index	Rutting Index
92	87	73	66	100	93	75	61
83	43	39	53	100	100	100	99.51

- Step 4: Export all data that remains into Excel and calculate the load and non-load PCR values using the equations provided by the NCDOT.
- Step 5: Determine if the road section failed (PCR≤60).
- Step 6: Remove all sections that have a passing PCR value, leaving only roadway sections that need maintenance.
- Step 7: Using Excel determine the triggering distress through the weighted values assigned to the distress in the PCR equation.

By looking at the PCR value that caused the roadway section to fail the triggering distress can be determined. Using the load PCR equation for example:

PCR (Load Related) = **Alligator * 0.531645**+ Non-wheel path patch * 0.0886072+ Wheel path patch * 0.151903+ **Rutting * 0.227845**.

The only two distresses based on the weights that can possibly trigger maintenance are alligator cracking or rutting. Those two indexes values are compared to determine which values are lower, therefore triggering maintenance.

- Step 8: Using the NCDOT flexible pavement decision tree determine the preferred maintenance that the roadways section requires.

- Step 9: Combine both construction and maintenance data together to analysis the results.

Phase 2 – Assign Estimate Unit Cost for Prescribed Maintenance:

- Step 10: Separate the North Carolina maintenance data into two classifications (Interstate and Non-Interstate).
- Step 11: Isolate each type of prescribed maintenance (patching, mill and replace, full depth reconstruction, etc.).
- Step 12: Change the contract total price into a cost per lane mile.
- Step 13: Average the cost per lane mile for each awarded contract to determine an estimated unit cost per lane mile for each type of maintenance.

The cost data was provided by the NCDOT but was not complementary exclusively of the maintenance data provided. The cost per lane mile estimate reflects the entire state of North Carolina. Causing the estimate to not be an exact estimate for each region. In addition, the cost of the project includes any other cost that would occur for any addition work added to the project during maintenance.

Below is an example of the estimated unit cost calculation performed using the provided data from the NCDOT.

Table 5: Cost Example Calculation

Supercontract Cost	Cost/Lane Mile	Begin MP	To MP	Number of Lanes	Work Code
$3,925,757.02	$2,044,665.11	0.00	0.72	2.00	Mill+Resurface

Step 1: Divide the Super Contract Cost by the difference between the "To MP" and the "Begin MP."

$$\frac{Supercontract\ cost}{\text{To MP} - Begin\ MP} = Estimated\ Cost\ per\ Mile$$

Step 2: Divide estimated cost per mile by the number of lanes on the project.

$$\frac{Cost\ per\ Mile}{Number\ of\ Lanes} = Estimated\ Cost\ per\ Lane\ Mile$$

An example for each spreadsheet used for this research can be found in appendix A "spreadsheet examples." This includes the raw data for both the maintenance, the cleaned data used to identify triggering distresses, the raw maintenance cost data, and the cost data modified with the unit cost added.

This completed the work flow for determining the triggering distress for maintenance and the associated cost for that maintenance. Figure 1 below gives a visual representation of how the data was cleaned to obtain only germane roadway sections.

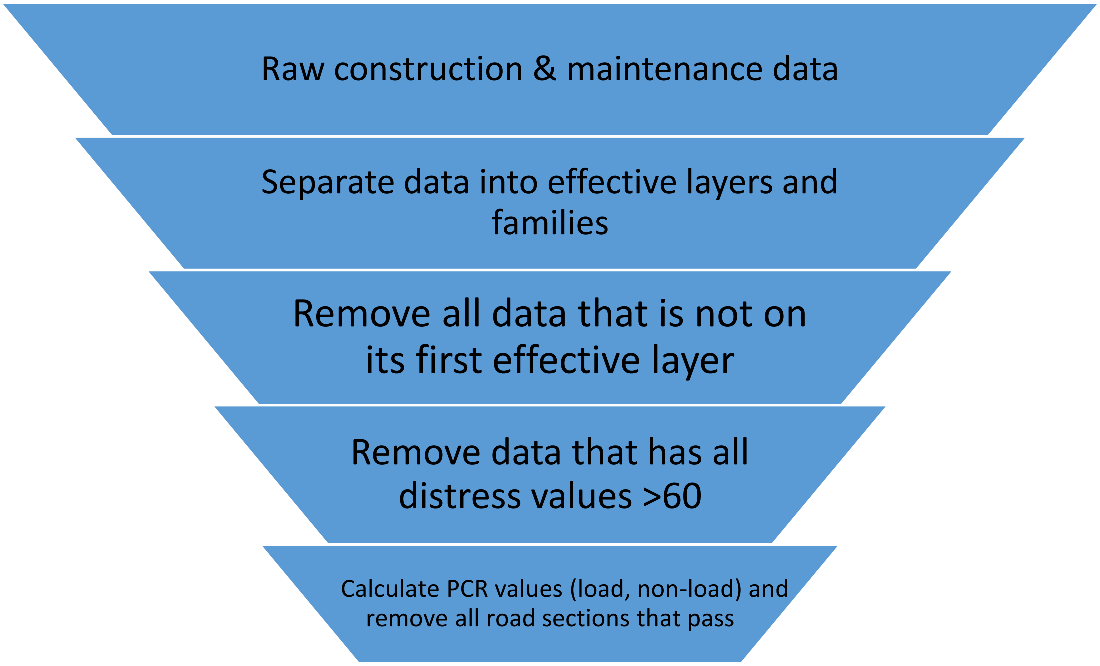

Figure 1: Data cleaning (visual representation)

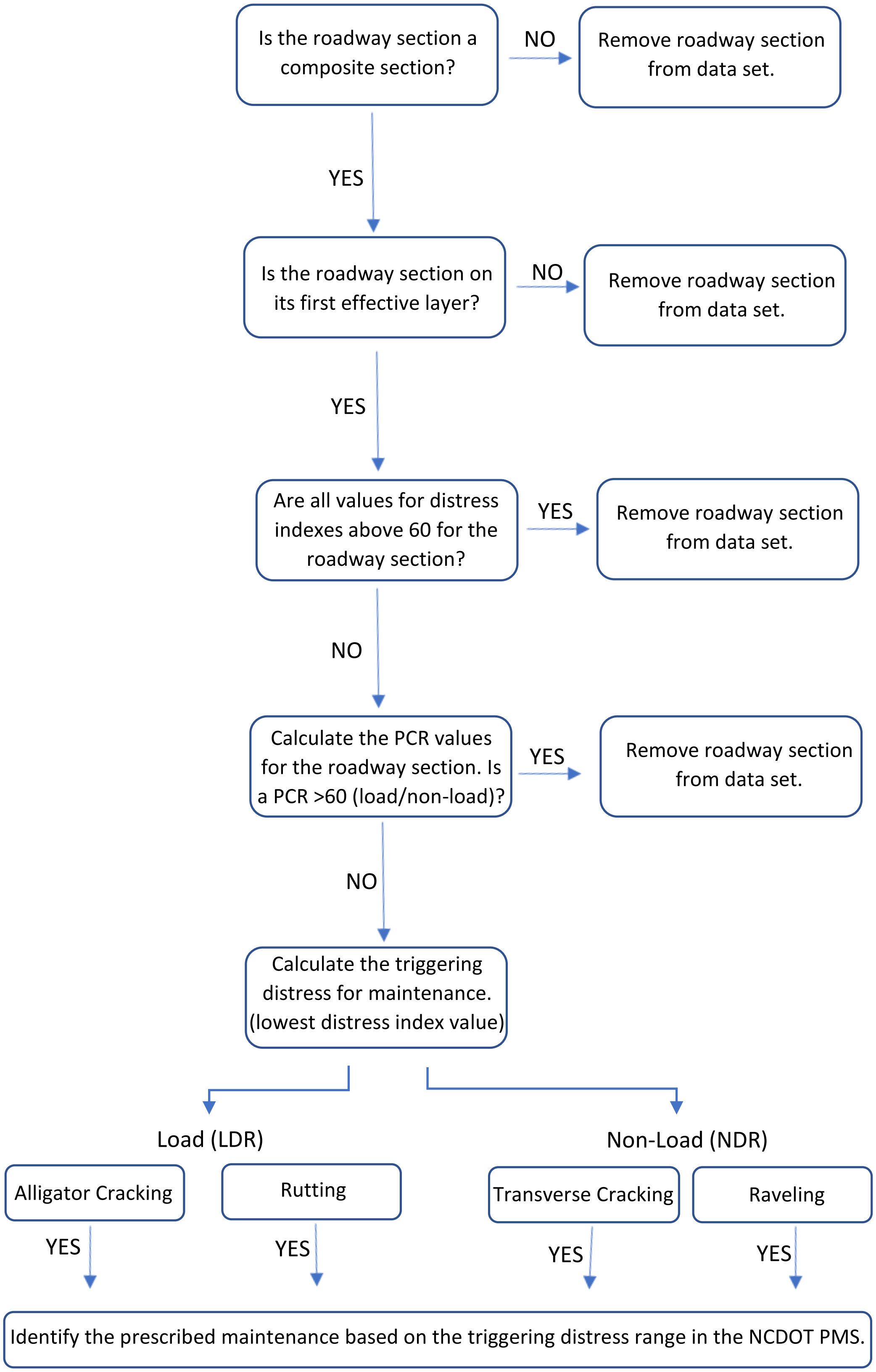

Figure 2: Data Qualification Flow Chart

CHAPTER 4: RESULTS

Four options for triggering distresses were identified based on the NCDOT PCR equations used:

- LDR (Load Related) = **Alligator * 0.531645**+ Non-wheel path patch * 0.0886072+ Wheel path patch * 0.151903+ **Rutting * 0.227845**;
- NDR (Non-Load Related) = **Transvers * 0.425002**+ Longitudinal * 0.224998+ Longitudinal lane joint * 0.175+ **Raveling * 0.175**

For LDR, the two distresses that could trigger maintenance were alligator cracking and rutting. Alligator cracking was identified as a triggering distress due to its 53% weight in the PCR equation. Rutting was also identified due to it accounting for 23% of the PCR value. These two distresses encompass 76% of the PCR value. Meaning that these two distresses have the most chance of causing maintenance to be triggered. The NDR value could fail based on two triggering distresses, transverse cracking, 43%, and raveling, 18%. Longitudinal cracking is weighted more heavily than raveling in the non-load equation, but longitudinal cracking does not have any prescribed maintenance in the NCDOT pavement management system. Raveling was identified as the next significant distress.

For the load PCR, the only distress that triggered any maintenance was alligator cracking. This is due to the significant weight of alligator cracking in the PCR equation. The climate in North Carolina does not induce rutting, causing it to not occur. The high value can be attributed to its high priority if it does occur. The maintenance choices for the load PCR failures differ based on the severity of the failure. The summary of all the combined maintenance and construction data is summarized in the tables below. The North Carolina routes, NC 0 – 5,000 AADT and NC 5,000 plus, results are comprised entirely of maintenance data. There was no available construction data for these two families.

The cost data shown below in the results data was calculated using a separate data set provided by the NCDOT. The data set included cost data ranging from 2005 to 2016. The cost that was included in the data set had the total cost of the contract which included any additional services that the NCDOT requested on the contract. Due to this the estimated unit cost of the prescribed maintenance could be affected. Also, an estimated unit cost for patching was not applicable because patching is not performed for a continuous mile.

4.1 Interstate Family

For the interstate family, load failures where the primary source of maintenance. Raveling was also an issue in the interstate family. Table 4 below summarizes the results for the interstate family.

Table 6: Summary of Interstate Failures

	Occurrences	**Distress**	**Occurrences**	**Overall Percentage of Failure**	**Relative Percentage**
Load Failures	527	Alligator	527	53%	100%
Non-Load Failures	578	Transverse	165	17%	29%
		Raveling	413	42%	71%
Both Load and Non-Load Failures	112				
Total	***1105***				

All load failures where triggered by alligator cracking accounting for 53% of the total failures for the interstate family. The non-load failures however, where split between transverse and raveling, with raveling being the primary triggering distress causing maintenance. Of the non-load failures, raveling accounted for 71% while transverse cracking accounted for 29%. The table above also shows the amount of overlap between non-load and load failures. When this occurs the load failure takes precedence over the non-load failure. This is because load failure can cause structural damage that will ensue if the load failure is not corrected.

The tables below show the number of times each type of maintenance that could be prescribed by the NCDOT pavement management system was to be used. The unit cost per lane mile is also shown for each of the maintenance choices.

Table 7: Interstate results for Alligator Cracking

Alligator Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	391	74.2%	$0
Interstate -Patching	16	3.0%	N/A
Interstate - 1.5 in. Overlay (D Level)	11	2.1%	$17,648,500
Interstate Full Depth Patching/1.5 in. Overlay (D Level)	13	2.5%	$4,982,100
Interstate - Mill 2.5 in. & Replace/1.5 in. Overlay (D Level)	2	0.4%	$6,855,100
Interstate - Mill 2.5 in. & Replace/3.0 in. Overlay (D Level)	14	2.7%	$9,424,500.00
AC Reconstruction - AADT >15000	80	15.2%	$139,585,900

The two most often used decisions used for the alligator cracking repairs for the interstate family were the “Do Nothing” decision and the “AC Reconstruction” decision. These two maintenance choices are the two most extreme choices. The more moderate choices of maintenance only accounted for 11% of all maintenance performed. The reconstruction decision that was utilized 15% of the time is the most expensive option of maintenance.

Table 8: Interstate Results for Transverse Cracking

Transverse Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	22	13.3%	$0
Interstate - Rout & Seal Cracks /1.5 in. Overlay (D Level)	131	79.4%	$96,500
Interstate - Mill 2.5 in. & Replace / 1.5 in. Overlay (D Level)	12	7.3%	$6,855,100

Transverse cracking had three maintenance decisions that were possible for the interstate family. The one that gets prescribed the most is the decision to rout & seal cracks /1.5 in. overlay (D level). Unlike the alligator cracking maintenance decisions, the transverse cracking maintenance decisions have moderate maintenance prescribed 79% of the time.

Table 9: Interstate Results for Raveling

Raveling Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	0	0.0%	$0
Interstate - 1.5 in. Overlay (D Level)	413	100.0%	$17,648,500

Raveling for the interstate family was the most occurring non-load triggering distress with 413 occurrences. These occurrences where prescribed the interstate - 1.5 in. overlay (D level) maintenance. The maintenance choice for the overlay has a high unit cost associated with it while the do nothing has no cost associated with it. Forcing any maintenance performed for rutting expensive.

4.2 US 0-5k Family

The US 0 – 5,000 AADT routes had more non-load failures with small amounts of load failures. Table 16 below shows the amount each type of distress that occurred in the family.

Table 10: Summary of US 0 – 5k Failures

	Occurrences	**Distress**	**Occurrences**	**Overall Percentage of Failure**	**Relative Percentage**
Load Failures	22	Alligator	22	21%	100%
Non-Load Failures	100	Transverse	50	47%	50%
		Raveling	50	47%	50%
Both Load and Non-Load Failures	16				
Total	***122***				

The non-load triggering distresses are divided evenly between transverse cracking and raveling for the US 0 – 5 k routes. Load failures occurred 21% of the time when a load failure was triggered alligator cracking was the triggering distress 100% of the time. Table 18 provides the amount each type of maintenance was prescribed and the unit cost associated with that type of maintenance.

Table 11: US 0 - 5k Results for Alligator Cracking

Alligator Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	0	0.0%	$0
Patching	0	0.0%	N/A
1.5 in. Overlay (C Level)	0	0.0%	$2,983,642
Full Depth Patching / 1.5 in. Overlay (C Level)	0	0.0%	$2,130,129
Mill 1.5 in. & Replace / 1.5 in Overlay (C Level)	0	0.0%	$2,891,217
Mill 2.5 in. & Replace / 3.0 in. Overlay (C Level)	2	9.1%	$2,325,521
AC Reconstruction - 5,000<= AADT < 15,000	20	90.9%	$4,365,165

Similar to the previous families the maintenance decisions for a triggering distress of alligator cracking are to the extreme amount of cost and effort with 91% of the prescribed maintenance being reconstruction.

Table 12: US 0 - 5k Results for Transverse Cracking

Transverse Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	12	24.0%	$0
Rout & Seal Cracks	14	28.0%	$96,500
Rout & Seal Cracks / 1.5 in Overlay (B Level)	24	48.0%	$6,855,100

Transverse cracking has more of a distribution then the alligator cracking for the US 0 – 5k family. Like the alligator cracking maintenance, the majority of the maintenance decisions are for the most extreme maintenance choice allowed by the NCDOT PMS, rout and seal cracks / 1.5 in overlay (B level). This is also the highest cost choice of maintenance. As seen in Table 19 the more intense the maintenance decision is the greater the associated cost.

Table 13: US 0 - 5k Results for Raveling

Raveling Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	50	100.0%	$0

Raveling was tied with transverse cracking for the non-load triggering distress but had the lowest associated unit cost for the prescribed maintenance due to “Do Nothing” is the only decision that is prescribed by the NCDOT pavement management system.

4.3 US 5-15k Family

The US 5,000 – 15,000 AADT routes had a more non-load failures with load failures being a close second. Table 12 below shows the amount each type of distress that occurred in the family.

Table 14: Summary of US 5 – 15k Failures

	Occurrences	**Distress**	**Occurrences**	**Overall Percentage of Failure**	**Relative Percentage**
Load Failures	53	Alligator	53	51%	100%
Non-Load Failures	72	Transverse	57	55%	79%
		Raveling	15	14%	21%
Both Load and Non-Load Failures	21				
Total	***125***				

The most occurring non-load triggering distress for US 5 – 15k family was transverse cracking at a 79% failure rate. The remaining non-load failure can be attributed to raveling at a 21% failure rate. The Tables 14-16 show the number of times a maintenance method was prescribed for each triggering distress.

Table 15: US 5 - 15k Results for Alligator Cracking

Alligator Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	0	0.0%	$0
Patching	0	0.0%	N/A
1.5 in. Overlay (C Level)	0	0.0%	$2,983,642
Full Depth Patching / 1.5 in. Overlay (C Level)	0	0.0%	$2,130,129
Mill 1.5 in. & Replace / 1.5 in Overlay (C Level)	0	0.0%	$2,891,217
Mill 2.5 in. & Replace / 3.0 in. Overlay (C Level)	0	0.0%	$2,325,521
AC Reconstruction - 5,000<= AADT < 15,000	53	100.0%	$4,365,165

The fifty-three load failures for the US 5 – 15k all had the same prescribed maintenance of complete reconstruction for the US 5 – 15k family. The unit cost for this maintenance is the highest unit cost for any of the potential prescribed maintenances. With the PMS forcing maintenance decisions to be the extreme cost skews the cost data as a whole for composite pavements to be much higher than is required.

Table 16: US 5 - 15k Results for Transverse Cracking

Transverse Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	5	8.8%	$0
Rout & Seal Cracks	22	38.6%	$96,500
Rout & Seal Cracks / 1.5 in Overlay (C Level)	30	52.6%	$6,855,100

Transverse cracking was the triggering distress with the most failures for the US 5- 15k family. The maintenance choices for transverse cracking are more evenly distributed then the alligator cracking maintenance decisions. The even dispersal of maintenance choices for transverse cracking allows for the cost to maintain composite pavements against transverse cracking to a more reasonable distribution and not be the most expensive option indefinitely.

Table 17: US 5 - 15k Results for Raveling

Raveling Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	15	100.0%	$0

Raveling was not the predominant non-load triggering distress but had the lowest associated unit cost for the prescribed maintenance due to “Do Nothing” is the only decision that is prescribed by the NCDOT pavement management system.

4.4 US 15,000 Plus Family

The US routes that have a AADT of 15,000 or over experienced non-load failures more than load failures with very little overlap. Table 8 summarizes the types of failures for the US 15k plus family.

Table 18: Summary of US 15k Plus Routes Failures

	Occurrences	**Distress**	**Occurrences**	**Overall Percentage of Failure**	**Relative Percentage**
Load Failures	44	Alligator	44	26%	100%
Non-Load Failures	142	Transverse	60	36%	42%
		Raveling	82	49%	58%
Both Load and Non-Load Failures	19				
Total	***186***				

All the load failures for the US 15k plus family where triggered by alligator cracking, like the interstate family. Raveling, similarly to the interstate family, occurred at a high level for the US 15,000 and over family. The number of total failures for the US 15k plus family is much lower than the interstate family, this can be attributed the substantial less amount of roadway that is constructed using composite pavements. The tables below show in detail the prescribed maintenance occurrences as well as their estimated cost per lane mile.

Table 19: US 15k Plus Results for Alligator Cracking

Alligator Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	0	0.0%	$0
Patching	0	0.0%	N/A
1.5 in. Overlay (C Level)	0	0.0%	$2,983,642
Full Depth Patching / 1.5 in. Overlay (C Level)	0	0.0%	$2,130,129
Mill 1.5 in. & Replace / 1.5 in Overlay (C Level)	1	2.3%	$2,891,217
Mill 2.5 in. & Replace / 3.0 in. Overlay (C Level)	4	9.1%	$2,325,521
AC Reconstruction - 5,000<= AADT < 15,000	39	88.6%	$4,365,165

Alligator cracking did not have the most occurrences for the US 15K plus family but the maintenance decision for 87% of the failures was reconstruction. Reconstruction for this type of roadway is not the most expensive choice but is the second most expensive. The maintenance choices for alligator cracking in this family also are skewed towards the most extreme and costly maintenance choice. With these results alligator cracking is shown to need to be the majority of the maintenance budget for composite pavements.

Table 20: US 15k Plus Results for Transverse Cracking

Transverse Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	10	16.7%	$0
Rout & Seal Cracks	32	53.3%	$96,500
Rout & Seal Cracks / 1.5 in Overlay (C Level)	18	30.0%	$6,855,100

Transverse cracking was the second most occurring triggering distress. Unlike the alligator cracking decisions, the transverse cracking decisions are more centered around the moderate maintenance choice. Rout and seal cracks is the middle maintenance choice for cost and extent of maintenance, and was utilized 53% of the time to repair the transverse cracking failures for the US 15k plus family.

Table 21: US 15k Plus Results for Raveling

Raveling Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	82	100.0%	$0

Raveling again was the largest amount of non-load failures but had the lowest amount of cost for the prescribed maintenance due to “Do Nothing” is the only decision that is prescribed by the NCDOT pavement management system.

4.5 NC 0-5k Family

The NC 5,000 plus AADT routes had no load failures with small amounts of non-load failures. Table 21 below shows the amount each type of distress that occurred in the family.

Table 22: Summary of NC 0 - 5k Failures

	Occurrences	**Distress**	**Occurrences**	**Overall Percentage of Failure**	**Relative Percentage**
Load Failures	11	Alligator	11	48%	100%
Non-Load Failures	13	Transverse	6	26%	46%
		Raveling	7	30%	54%
Both Load and Non-Load Failures	1				
Total	***24***				

There were only twenty-four failures for the NC 0 - 5k family. This is due to the lack of roadway miles that are comprised of composite pavement in this family. Of these failures, there was an even distribution between loan and non-load failures. The tables below show all of the prescribed maintenance occurrences and their associated unit cost.

Table 23: NC 0 - 5k Results for Alligator Cracking

Alligator Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	0	0%	$0
Patching	0	0%	N/A
1.5 in. Overlay (C Level)	0	0%	$2,983,642
Full Depth Patching / 1.5 in. Overlay (C Level)	0	0%	$2,130,129
Mill 1.5 in. & Replace / 1.5 in Overlay (C Level)	0	0%	$2,891,217
Mill 2.5 in. & Replace / 3.0 in. Overlay (C Level)	0	0%	$2,325,521
AC Reconstruction - 5,000<= AADT < 15,000	11	100%	$4,365,165

All the load failures for the NC 0 – 5k family were triggered by alligator cracking. Of the eleven failures, all of them were prescribed the maintenance decision of full reconstruction.

Table 24: NC 0 - 5k Results for Transverse Cracking

Transverse Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	0	0.0%	$0
Rout & Seal Cracks	5	83.3%	$96,500
Rout & Seal Cracks / 1.5 in Overlay (B Level)	1	16.7%	$6,855,100

Transverse cracking had more moderate maintenance choices prescribed. The majority, 83%, was prescribed the intermediate cost maintenance, “Rout & Seal Cracks.”

Table 25: NC 0 - 5k Results for Raveling

Raveling Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	7	100.0%	$0

Raveling had more failures then transverse cracking for the non-load triggering distresses but had the lowest associated unit cost for the prescribed maintenance due to “Do Nothing” is the only decision that is prescribed by the NCDOT pavement management system.

All of these results were tabulated using a combined data set of both construction and maintenance data. The result broken down into maintenance data and construction data are shown in appendix B “Results Separated into Maintenance and Construction Data.”

4.6 NC 5k plus Family

The NC 5,000 plus AADT routes had no load failures with small amounts of non-load failures. Table 21 below shows the amount each type of distress that occurred in the family.

Table 26: Summary of NC 5k plus Failures

	Occurrences	**Distress**	**Occurrences**	**Overall Percentage of Failure**	**Relative Percentage**
Load Failures	0	Alligator	0	0%	0%
Non-Load Failures	11	Transverse	6	26%	55%
		Raveling	5	22%	45%
Both Load and Non-Load Failures	0				
Total	***11***				

There were only eleven of failures for the NC 5k plus family. This is due to the lack of roadway miles that are comprised of composite pavement in this family. Of these failures, none were load failures. All the failures where triggered by transverse cracking or raveling.

Table 27: NC 5k Plus Results for Transverse Cracking

Transverse Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	3	50.0%	$0
Rout & Seal Cracks	3	50.0%	$96,500
Rout & Seal Cracks / 1.5 in Overlay (B Level)	0	0.0%	$6,855,100

Transverse cracking maintenance decisions for the NC 5k plus family were split between “Do Nothing” and “Rout & Seal Cracks.” None of the prescribed maintenances were the most extreme maintenance, rout and seal cracks / 1.5 in overlay (B level).

Table 28: NC 5k Plus for Raveling

Raveling Maintenance Decisions (per NCDOT)			
Decision	Occurrences	% of Occurrence	Cost / Lane Mile
Do Nothing	5	100.0%	$0

Raveling triggered some failures for the NC 5k plus family but had the lowest associated unit cost for the prescribed maintenance due to “Do Nothing” is the only decision that is prescribed by the NCDOT pavement management system and has an associated cost of $0.00.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The transportation industry in North Carolina has historically classified pavements as either flexible or rigid. Over the years, the NCDOT has both purposefully and unintentionally created a third, hybrid pavement defined as a Composite Pavement. The typical composite pavement structure is constructed with a rigid base layer, typically of some sort of concrete with a flexible pavement layer on top, such as hot mix asphalt to provide a smooth surface for a more comfortable ride. The research previously presented sought to define a systematic way to determine the triggering distress for maintenance decisions as they pertain to composite pavements. This methodology was developed utilizing the North Carolina flexible pavement PCR equations. The results were tabulated to determine the level of occurrence, the severity of the prescribed maintenance decision, and show the estimated unit cost of the repair.

5.1 Conclusions

The purpose of this research was to evaluate maintenance data provided by the NCDOT and identify the distresses that are triggering maintenance on composite pavement roadways. Based on the results from Chapter 4 of this document, the following conclusions can be drawn”

1. There were two triggering distresses identified for each of the load and non-load PRC equations. Alligator cracking and rutting for LDR and transverse cracking and raveling for NDR. This is due to the heavy weight

place on each distress in the equation. For our study, there were no failures that were triggered by rutting. All load failures where triggered by alligator cracking. This can be attributed to the climate of North Carolina not being able to induce rutting. For NDR the two identified triggering distresses were transverse cracking and raveling. Raveling occurred two times as more for the higher AADT roads while transverse cracking was the three times more predominate of a failure for roads with a smaller AADT.

2. The predominate maintenance choices where “Do Nothing” and “AC Reconstruction” for both load and non-load failures. This is because the North Carolina PMS coupled with the flexible decision tree allows for maintenance to possibly be delayed, based upon interpretation, until the pavement surface is beyond any repair and must be replace.

3. The cost to maintain an interstate is higher than the cost to maintain a non-interstate roadway as shown in Chapter 4. Chapter 4 using the provided NCDOT data shows that interstates as a whole have a higher estimated cost per lane mile than non-interstate roadways. There are also more options for non-load triggered maintenance in the NCDOT PMS for the interstate family. Allowing the interstate families to occur more cost than is possible for the non-interstate families.

5.2 Limitations of the Research

The limitations to the results of this study are:

1. Cost data are limited in their ability to accurately represent maintenance that is not intended to be performed for a mile. Patching for example is intended to be performed over short distances. If patching is done for a quarter of a mile and is extrapolated out into a mile, then the mobilization, specialty equipment, and any other onetime cost are encouraged four times for one mile.
2. The roadway families having smaller AADT have less data points to be observed. This can be related to the lack of composite pavement miles in these families.

5.3 Recommendations

Based on the results of this study. There are four recommendations for future work as follows:

1. It is recommended that there be an update of the pavement management system so that it incorporates a section for composite pavements. The triggering distresses and prescribed maintenances in this study were determined using the flexible pavement section of the management system. Triggering distresses that were determined with a composite pavement section of the management system would be more specific to composite pavements and have a better representation of the types of distresses that composite pavements experience.

2. It is recommended to determine the actual maintenance performed on a roadways section. The actual maintenance would then need to be compared to the prescribed maintenance to see if the actual maintenance would be a suitable repair for the triggering distress.

3. It is recommended to incorporate the amount of time a performed maintenance increases to the roadways effective life into the maintenance decision tree as well. With time incorporated into the decision tree better decisions can be made on the total cost of the repair. This would allow for more efficient decisions to be made.

4. It is recommended that the cost data for maintenance performed be broken down into individual line items. This would allow for increased insight into what is actually being performed on the roadways section. This would also allow for a better estimation of unit cost because the onetime cost could be counted only one time.

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APPENDIX A: SPREADSHEET EXAMPLES

Example of a Raw Data Sheet (1/2)

ROUTE1	EFF_YEAR	COUNTY	OFFSET_FROM	OFFSET_TO	real_layer	real_n	aadt	age	TRNSVRS_IDX_MAE	ALGTR_IDX_MAE
10000026	2013	11	18.75	18.85	1996	0	39000	17	79	98
10000026	2013	11	18.85	18.95	1996	0	39000	17	79	99
10000026	2013	11	18.95	19.05	1996	0	39000	17	92	54
10000026	2013	11	19.05	19.15	1996	0	39000	17	90	99
10000026	2013	11	19.15	19.25	1996	0	39000	17	89	53
10000026	2013	11	19.25	19.35	1996	0	39000	17	89	95
10000026	2013	11	19.35	19.45	1996	0	39000	17	87	93
10000026	2013	11	19.45	19.55	1996	0	39000	17	90	95
10000026	2013	11	19.55	19.65	1996	0	39000	17	88	74
10000026	2013	11	19.65	19.75	1996	0	39000	17	99	98
10000026	2013	11	19.75	19.85	1996	0	39000	17	90	98
10000026	2014	11	18.852	18.952	1996	0	39000	18	85	96
10000026	2014	11	18.952	19.052	1996	0	39000	18	87	92
10000026	2014	11	19.352	19.452	1996	0	39000	18	86	99
10000026	2014	11	19.452	19.552	1996	0	39000	18	86	99
10000026	2014	11	19.552	19.652	1996	0	39000	18	89	96
10000026	2014	11	19.752	19.852	1996	0	39000	18	97	92
10000026	2014	11	19.852	19.952	1996	0	39000	18	98	94
10000026	2014	11	20.152	20.252	1996	0	39000	18	100	99
10000026	2014	11	20.352	20.452	1996	0	39000	18	90	99
10000026	2014	11	21.152	21.252	1996	0	37500	18	100	99
10000026	2014	11	21.152	21.252	1996	0	37500	18	100	99
10000026	2014	11	21.652	21.752	1996	0	37500	18	100	94
10000026	2014	11	21.652	21.752	1996	0	37500	18	100	94
10000026	2014	11	21.752	21.852	1996	0	37500	18	100	97
10000026	2014	11	21.752	21.852	1996	0	37500	18	100	97
10000026	2014	11	23.552	23.652	1994	0	37500	20	98.62746175	96
10000026	2014	11	23.752	23.852	1994	0	37500	20	99	97
10000026	2014	11	23.852	23.952	1994	0	37500	20	99	99
10000026	2014	11	23.952	24.052	1994	0	37500	20	98.62746175	96
10000026	2014	11	24.052	24.152	1994	0	37500	20	99	100
10000026	2014	11	24.152	24.252	1994	0	37500	20	98.48853646	96
10000026	2014	11	24.252	24.352	1994	0	37500	20	98.62746175	98
10000026	2014	11	24.652	24.752	1994	0	37500	20	98	99
10000026	2015	11	18.849	18.949	1996	0	39000	19	91	99
10000026	2015	11	18.949	19.049	1996	0	39000	19	93	100
10000026	2015	11	19.049	19.149	1996	0	39000	19	92	99
10000026	2015	11	19.249	19.349	1996	0	39000	19	91	92

Example of a Raw Data Sheet (2/2)

RVL_IDX_MAE	LNGTDNL_IDX_MAE	LNGTDNL_LANE_JNT_IDX_MAE	WP_PTCH_IDX_MAE	NWP_PTCH_IDX_MAE	MAX_RUT_IDX_MAE	PCR_LDR	PCR_NDR
85	51	100	86	85	98.31	95.10	77.43
86	75	100	29	37	99	82.87	83.00
73	26	100	11	0	99.19	52.98	75.23
100	17	100	100	100	99.51	99.36	77.08
100	9	100	100	100	98.79	74.74	74.85
100	16	100	100	100	98.79	97.07	76.43
96	0	100	95	98	98.56	95.01	71.28
100	6	100	100	100	98.56	97.01	74.60
92	0	100	100	100	98.79	85.90	71.00
50	88	100	80	79	99.19	93.85	88.13
100	49	100	100	100	99.75	98.88	84.28
79	82	100	26	28	99	80.03	85.90
92	75	100	10	0	98.79	72.94	87.45
96	50	100	95	98	98.56	98.20	82.10
100	49	100	100	100	98.56	99.14	82.58
89	32	100	100	100	99	97.65	78.10
100	52	100	100	100	99.64	95.66	87.93
100	51	100	100	100	99.75	96.75	88.13
100	38	100	100	100	99.64	99.39	86.05
100	26	100	100	100	99.51	99.36	79.10
100	51	100	100	100	99.64	99.39	88.98
100	51	100	100	100	99.64	99.39	88.98
100	55	100	100	100	99.36	96.66	89.88
100	55	100	100	100	99.36	96.66	89.88
100	53	100	100	100	99.75	98.35	89.43
100	53	100	100	100	99.75	98.35	89.43
100	27	100	100	100	99.51	97.76	82.99
100	52	100	100	100	99.51	98.29	88.78
100	42	100	100	100	99.36	99.32	86.53
100	51	100	100	100	98.79	97.60	88.39
100	47	100	100	100	98.79	99.72	87.65
100	51	100	100	100	99.64	97.79	88.33
100	30	100	100	100	99.64	98.85	83.67
100	50	100	100	100	99.36	99.32	87.90
93	98	0	25	23	98.31	80.87	77.00
82	100	0	2	0	98.79	75.98	76.37
100	100	0	100	100	99.19	99.28	79.10

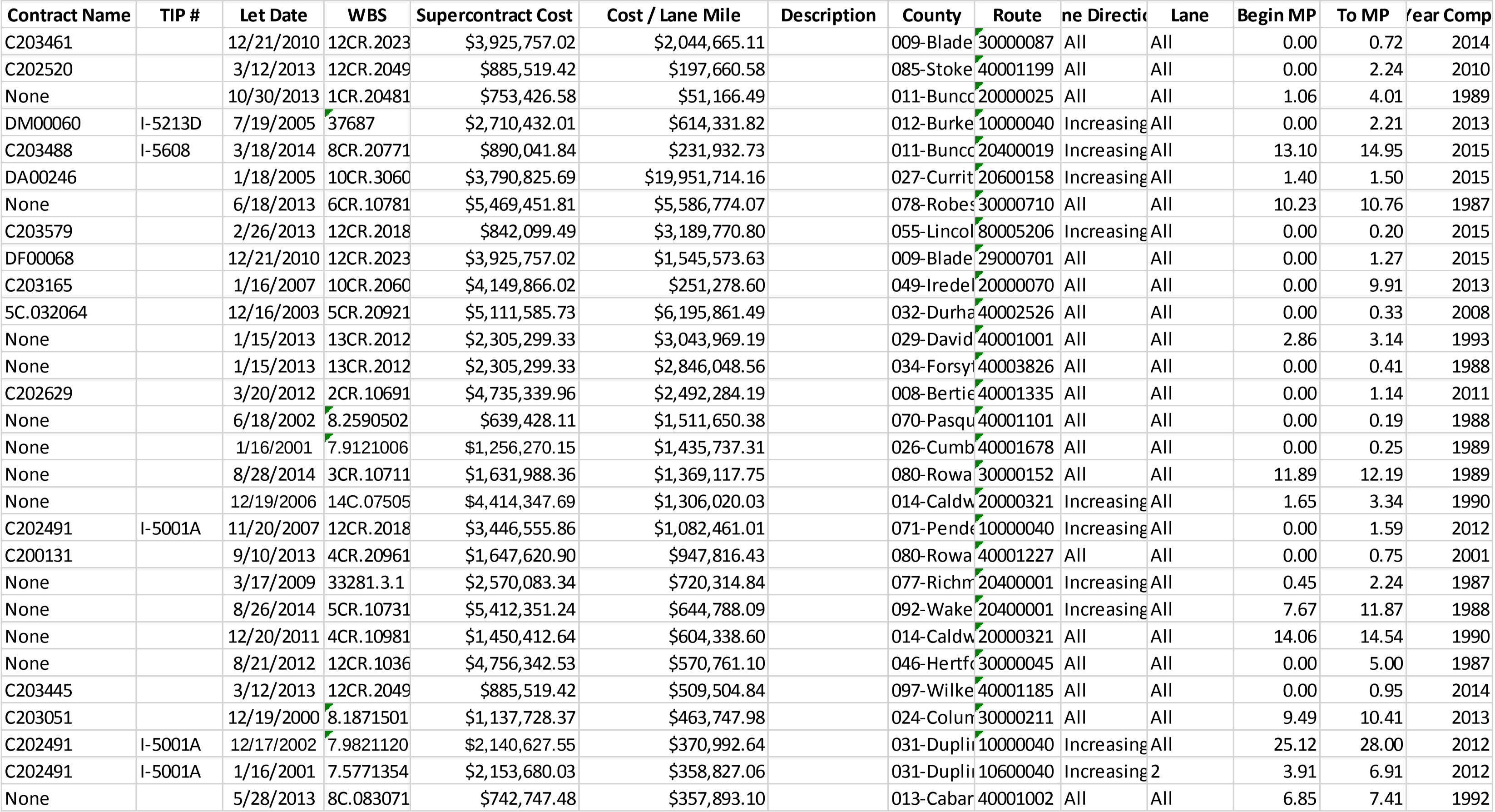
Example of Calculating Load or Non-Load Failure and Triggering Distress

PCR_LDR	PCR_NDR	Pass or Fail (PCN<60)		Load or Non-Load Failure		Load Distress that triggered	Non-Load Distress that triggered
52.98	75.23	Fail	1	Load failure		ALGTR	
46.72	71.53	Fail	1	Load failure		ALGTR	
97.46	43.15	Fail	1		Non-Load failure		TRNSVRS
46.72	65.15	Fail	1	Load failure		ALGTR	
98.66	58.45	Fail	1		Non-Load failure		RVL
46.72	72.43	Fail	1	Load failure		ALGTR	
56.88	73.48	Fail	1	Load failure		ALGTR	
96.83	44.78	Fail	1		Non-Load failure		TRNSVRS
96.83	44.78	Fail	1		Non-Load failure		TRNSVRS
44.46	43.35	Fail	1	Load failure	Non-Load failure	ALGTR	RVL
46.78	62.92	Fail	1	Load failure		ALGTR	
46.78	62.92	Fail	1	Load failure		ALGTR	
46.75	53.60	Fail	1	Load failure	Non-Load failure	ALGTR	TRNSVRS
46.75	53.60	Fail	1	Load failure	Non-Load failure	ALGTR	TRNSVRS
70.70	51.07	Fail	1		Non-Load failure		RVL
70.70	51.07	Fail	1		Non-Load failure		RVL
46.72	40.08	Fail	1	Load failure	Non-Load failure	ALGTR	RVL
46.72	40.08	Fail	1	Load failure	Non-Load failure	ALGTR	RVL
46.84	70.25	Fail	1	Load failure		ALGTR	
46.84	70.25	Fail	1	Load failure		ALGTR	
46.72	51.86	Fail	1	Load failure	Non-Load failure	ALGTR	TRNSVRS
46.72	51.86	Fail	1	Load failure	Non-Load failure	ALGTR	TRNSVRS
46.65	44.82	Fail	1	Load failure	Non-Load failure	ALGTR	RVL
46.65	44.82	Fail	1	Load failure	Non-Load failure	ALGTR	RVL
97.36	50.33	Fail	1		Non-Load failure		RVL
97.36	50.33	Fail	1		Non-Load failure		RVL
98.13	59.85	Fail	1		Non-Load failure		RVL
98.13	59.85	Fail	1		Non-Load failure		RVL
52.57	76.49	Fail	1	Load failure		ALGTR	
52.57	76.49	Fail	1	Load failure		ALGTR	
51.49	70.52	Fail	1	Load failure		ALGTR	
51.49	70.52	Fail	1	Load failure		ALGTR	
99.39	56.70	Fail	1		Non-Load failure		RVL
99.39	56.70	Fail	1		Non-Load failure		RVL
98.85	57.25	Fail	1		Non-Load failure		RVL
98.85	57.25	Fail	1		Non-Load failure		RVL
99.41	54.18	Fail	1		Non-Load failure		RVL

Example of Prescribed Maintenance Decision

Decision Tree Choice for ALGTR	Decision Tree Choice for TRNSVRS	Decision Tree Choice for RVL
AC Reconstruction - AADT >15000		
Do Nothing		
	Interstate - Mill 2.5 in. & Replace / 1.5 in. Overlay (D Level)	
Do Nothing		
		Interstate - 1.5 in. Overlay (D Level)
Do Nothing		
Do Nothing		
	Interstate - Rout & Seal Cracks /1.5 in. Overlay (D Level)	
	Interstate - Rout & Seal Cracks /1.5 in. Overlay (D Level)	
Interstate -Patching		Interstate - 1.5 in. Overlay (D Level)
Do Nothing		
Do Nothing		
Do Nothing	Interstate - Rout & Seal Cracks /1.5 in. Overlay (D Level)	
Do Nothing	Interstate - Rout & Seal Cracks /1.5 in. Overlay (D Level)	
		Interstate - 1.5 in. Overlay (D Level)
		Interstate - 1.5 in. Overlay (D Level)
Do Nothing		Interstate - 1.5 in. Overlay (D Level)
Do Nothing		Interstate - 1.5 in. Overlay (D Level)
Do Nothing		
Do Nothing		
Do Nothing	Interstate - Rout & Seal Cracks /1.5 in. Overlay (D Level)	
Do Nothing	Interstate - Rout & Seal Cracks /1.5 in. Overlay (D Level)	
Do Nothing		Interstate - 1.5 in. Overlay (D Level)
Do Nothing		Interstate - 1.5 in. Overlay (D Level)
		Interstate - 1.5 in. Overlay (D Level)
		Interstate - 1.5 in. Overlay (D Level)
		Interstate - 1.5 in. Overlay (D Level)
		Interstate - 1.5 in. Overlay (D Level)
Do Nothing		
Do Nothing		
Interstate Full Depth Patching/1.5 in. Overlay (D Level)		
Interstate Full Depth Patching/1.5 in. Overlay (D Level)		
		Interstate - 1.5 in. Overlay (D Level)
		Interstate - 1.5 in. Overlay (D Level)
		Interstate - 1.5 in. Overlay (D Level)
		Interstate - 1.5 in. Overlay (D Level)
		Interstate - 1.5 in. Overlay (D Level)

Example of Cost Data Spread Sheet (1/2)

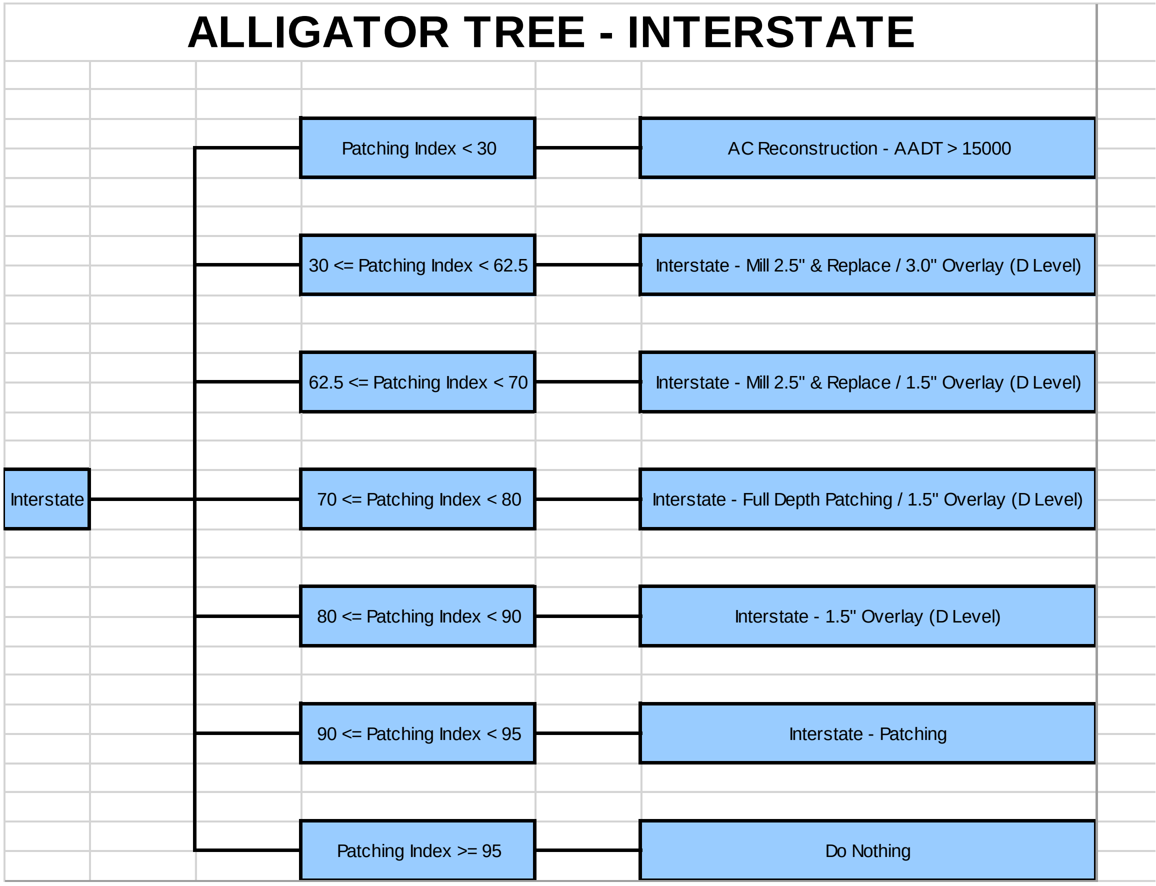


Contract Name	TIP #	Let Date	WBS	Supercontract Cost	Cost / Lane Mile	Description	County	Route	ne Directic	Lane	Begin MP	To MP	/ear Comp
C203461		12/21/2010	12CR.2023	$3,925,757.02	$2,044,665.11		009-Blade	30000087	All	All	0.00	0.72	2014
C202520		3/12/2013	12CR.2049	$885,519.42	$197,660.58		085-Stoke	40001199	All	All	0.00	2.24	2010
None		10/30/2013	1CR.20481	$753,426.58	$51,166.49		011-Buncc	20000025	All	All	1.06	4.01	1989
DM00060	I-5213D	7/19/2005	37687	$2,710,432.01	$614,331.82		012-Burke	10000040	Increasing	All	0.00	2.21	2013
C203488	I-5608	3/18/2014	8CR.20771	$890,041.84	$231,932.73		011-Buncc	20400019	Increasing	All	13.10	14.95	2015
DA00246		1/18/2005	10CR.3060	$3,790,825.69	$19,951,714.16		027-Currit	20600158	Increasing	All	1.40	1.50	2015
None		6/18/2013	6CR.10781	$5,469,451.81	$5,586,774.07		078-Robes	30000710	All	All	10.23	10.76	1987
C203579		2/26/2013	12CR.2018	$842,099.49	$3,189,770.80		055-Lincol	80005206	Increasing	All	0.00	0.20	2015
DF00068		12/21/2010	12CR.2023	$3,925,757.02	$1,545,573.63		009-Blade	29000701	All	All	0.00	1.27	2015
C203165		1/16/2007	10CR.2060	$4,149,866.02	$251,278.60		049-Iredel	20000070	All	All	0.00	9.91	2013
5C.032064		12/16/2003	5CR.20921	$5,111,585.73	$6,195,861.49		032-Durha	40002526	All	All	0.00	0.33	2008
None		1/15/2013	13CR.2012	$2,305,299.33	$3,043,969.19		029-David	40001001	All	All	2.86	3.14	1993
None		1/15/2013	13CR.2012	$2,305,299.33	$2,846,048.56		034-Forsyt	40003826	All	All	0.00	0.41	1988
C202629		3/20/2012	2CR.10691	$4,735,339.96	$2,492,284.19		008-Bertie	40001335	All	All	0.00	1.14	2011
None		6/18/2002	8.2590502	$639,428.11	$1,511,650.38		070-Pasqu	40001101	All	All	0.00	0.19	1988
None		1/16/2001	7.9121006	$1,256,270.15	$1,435,737.31		026-Cumb	40001678	All	All	0.00	0.25	1989
None		8/28/2014	3CR.10711	$1,631,988.36	$1,369,117.75		080-Rowa	30000152	All	All	11.89	12.19	1989
None		12/19/2006	14C.07505	$4,414,347.69	$1,306,020.03		014-Caldw	20000321	Increasing	All	1.65	3.34	1990
C202491	I-5001A	11/20/2007	12CR.2018	$3,446,555.86	$1,082,461.01		071-Pende	10000040	Increasing	All	0.00	1.59	2012
C200131		9/10/2013	4CR.20961	$1,647,620.90	$947,816.43		080-Rowa	40001227	All	All	0.00	0.75	2001
None		3/17/2009	33281.3.1	$2,570,083.34	$720,314.84		077-Richm	20400001	Increasing	All	0.45	2.24	1987
None		8/26/2014	5CR.10731	$5,412,351.24	$644,788.09		092-Wake	20400001	Increasing	All	7.67	11.87	1988
None		12/20/2011	4CR.10981	$1,450,412.64	$604,338.60		014-Caldw	20000321	All	All	14.06	14.54	1990
None		8/21/2012	12CR.1036	$4,756,342.53	$570,761.10		046-Hertfc	30000045	All	All	0.00	5.00	1987
C203445		3/12/2013	12CR.2049	$885,519.42	$509,504.84		097-Wilke	40001185	All	All	0.00	0.95	2014
C203051		12/19/2000	8.1871501	$1,137,728.37	$463,747.98		024-Colun	30000211	All	All	9.49	10.41	2013
C202491	I-5001A	12/17/2002	7.9821120	$2,140,627.55	$370,992.64		031-Duplii	10000040	Increasing	All	25.12	28.00	2012
C202491	I-5001A	1/16/2001	7.5771354	$2,153,680.03	$358,827.06		031-Duplii	10600040	Increasing	2	3.91	6.91	2012
None		5/28/2013	8C.083071	$742,747.48	$357,893.10		013-Cabar	40001002	All	All	6.85	7.41	1992

Example of Cost Data Spread Sheet (2/2)

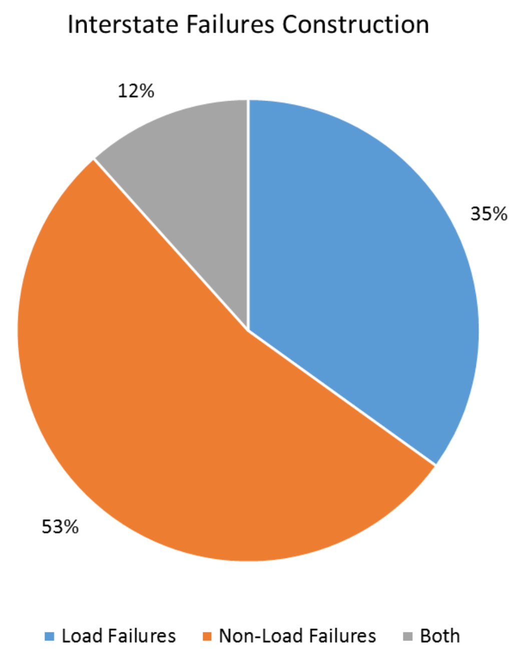
Card. Dir.	Travel Lane Width	nber Of La	Work Code	in Descript	End Description	Milling (in	Material 1	Thick 1	Material 2	Thick 2	Material 3	Thick 3
B	32.00	2.00	Mill+Resu	COLUMBU	SR 1736 + 0.13 MI	0.50	S9.5B	1.50				
B	24.00	2.00	Mill+Resu	NC 268	SR 1210	0.50	S9.5B	1.50				
B	60.00	4.00	Mill+Resu	NC 280	NC 146 + 1.04 MI	0.50	I-2	1.50				
E	24.00	2.00	Mill+Resu	MCDOWE	SR 1129 + 1.00 MI	0.63	UBWC	0.63				
S	25.00	2.00	Mill+Resu	NC 251	I-240 WEST	0.63	UBWC	0.63				
W	24.00	2.00	Mill+Resu	DARE CO	SR 1187	0.75	FC-2	0.75				
B	22.00	2.00	Mill+Resu	B77076	NC 711	0.75	I-2	1.50	H	0.75		
B	16.00	1.00	Mill+Resu	NC 27	US 321 SOUTH	0.75	S9.5C	1.50				
B	24.00	2.00	Mill+Resu	COLUMBU	COLUMBUS CO LINE + 1.27 MI	0.75	S9.5B	1.50				
B	20.00	2.00	Mill+Resu	CATAWBA	SR 1351 + 0.17 MI	0.75	S9.5B	1.50				
B	30.00	2.00	Mill+Resu	BEGIN MA	END MAINT	1.00	S9.5B	1.50				
B	32.00	2.00	Mill+Resu	NC 109	SR 2414	1.00	I-1	1.00				
B	24.00	2.00	Mill+Resu	NC 109	NC 109 + 0.40 MI	1.00	I-1	1.00				
B	20.00	2.00	Mill+Resu	BGN MAI	NC 45	1.00	SF9.5A	1.25				
B	27.00	2.00	Mill+Resu	NC 34	NC 34 + 0.19mi	1.00	I-2	1.50				
B	42.00	3.00	Mill+Resu	NC 210	SR 1775	1.00	I-2	1.00				
B	48.00	4.00	Mill+Resu	NC 152 W	US 29 + 0.50 MI	1.00	I-1	1.00				
N	24.00	2.00	Mill+Resu	BURKE CO	SR 1246 + 0.24 MI	1.00	BCSC	1.00	BCBIN	2.00	BCBIN	1.00
E	24.00	2.00	Mill+Resu	DUPLIN C	SR 1501 + 0.35 MI	1.00	FC-2	0.63	S12.5C	2.00		
B	28.00	2.00	Mill+Resu	NC 152	SR 2739	1.00	S9.5C	1.50				
S	24.00	2.00	Mill+Resu	MOORE C	MOORE CO LINE + 2.235 MI	1.00	BCSC	1.00				
S	24.00	2.00	Mill+Resu	B910305	SR 2041	1.00	I-2	1.00				
B	60.00		Mill+Resu	NC 18 + 0.	NC 18 + 0.58 MI	1.00	BCSC	1.00	BCBIN	1.00		
B	20.00	2.00	Mill+Resu	BERTIE CO	SR 1002 + 0.18 MI	1.00	I-2	1.00				
B	22.00	2.00	Mill+Resu	NC 268	US 421 BUS	1.00	S4.75A	1.00				
B	32.00	2.00	Mill+Resu	NC 214	NC 214 + 0.92 MI	1.00	S9.5B	1.50				
E	24.00	2.00	Mill+Resu	NC 11 + 0.	PENDER CO LINE	1.00	FC-2	0.63	S12.5C	2.00		
W	24.00	2.00	Mill+Resu	NC 11 + 0.	SR 1162 + 1.022 MI	1.00	FC-2	0.63	S12.5C	2.00		
B	44.00	5.00	Mill+Resu	NC 3 + 0.1	NC 73	1.00	I-1	1.00				

Example of Decision Tree Branch

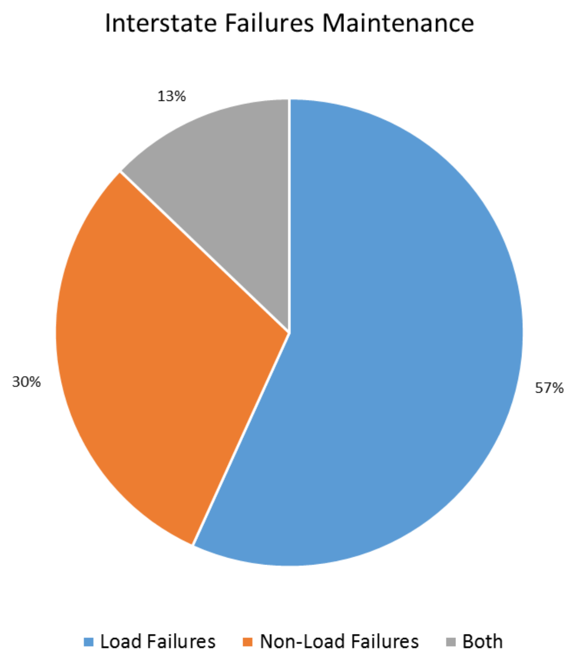


APPENDIX B: RESULTS SEPARATED INTO MAINTENANCE AND CONSTRUCTION DATA

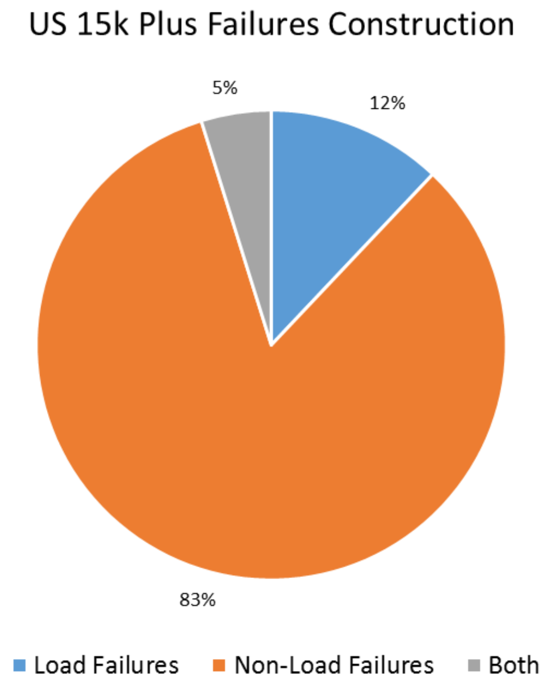
Interstate Construction Data Failures



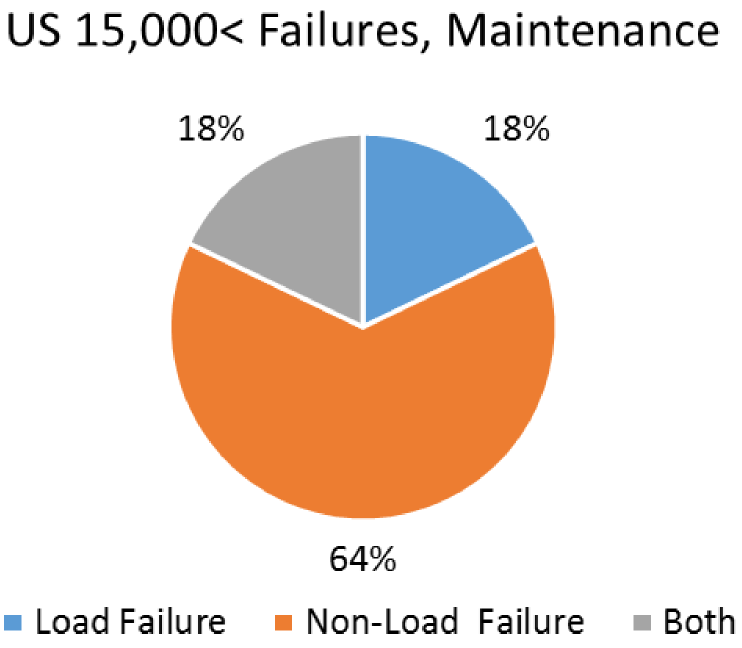
Interstate Maintenance Data Failures



US 15k Plus Construction Data Failures

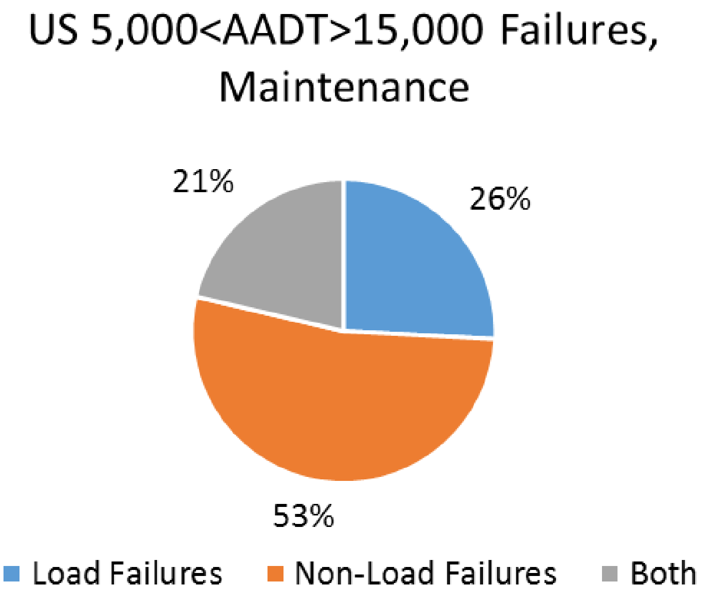


US 15k Plus Maintenance Data Failures



US 5 - 15k Construction Data Failures (<16 Failures)

US 5 - 15k Maintenance Data Failures



US 0 - 5k Construction Data Failures (<12 Failures)

US 5 - 15k Maintenance Data Failures