RESEARCH & DEVELOPMENT

Development and Validation of Pavement Deterioration Models and Analysis Weight Factors for the NCDOT Pavement Management System (Phase I: Windshield Survey Data)

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Development and Validation of Pavement Deterioration Models and Analysis Weight Factors for the NCDOT Pavement Management System
Phase I: Windshield Survey Data

Final Report

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16. Abstract

Accurate pavement deterioration models, as well as appropriate system weight factors used in the Cost Benefit Analysis (CBA) process, are critical to enabling state highway agencies to conduct effective performance and funding analyses and make informative investment decisions. This study was conducted to develop more accurate deterioration models and weight factors for the North Carolina Department of Transportation (NCDOT) Pavement Management System (PMS), which has been used by the Pavement Management Unit (PMU) to maintain 79,000 miles of roadways across the state of North Carolina. In this study, manually collected windshield pavement condition data were cleaned, pavement ages were reset, categorical and non-linear regression analyses were performed to develop pavement deterioration models. In addition, weight factors were determined by conducting sensitivity analysis of CBA simulation results of all 14 divisions. The performance and distress models and new weight factors developed in this research project have been implemented in the NCDOT PMS by the engineers in the PMU. An entirely separate decision tree has been created using the update performance models.

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EXECUTIVE SUMMARY

The North Carolina Department of Transportation (NCDOT) has utilized its Pavement Management System (PMS) to conduct performance and funding analyses for its highway system since 1995. Every two years, pavement condition data are collected through windshield surveys at the network level. The data are then analyzed to develop a series of deterioration models by the type of route, i.e., Interstate, Primary (United States roads and NC roads), and Secondary, and by Annual Average Daily Traffic (AADT).

The NCDOT decided to develop and validate pavement deterioration models and Cost-Benefit Analysis (CBA) analysis weight factors for its PMS for two reasons: 1) the NCDOT's existing deterioration models were implemented in its PMS in 2008. Since then a large amount of pavement condition data have been collected. Therefore, there is a need to develop and valid new deterioration models; and 2) the estimated benefit of a proposed maintenance activity is largely determined by the roadway's weight factor (currently the NCDOT uses 2.0 for Interstate highways, 1.66 for US routes, 1.33 for NC routes, and 1.0 for Secondary routes). Once the new deterioration models are developed and implemented, a new set of CBA weight factors should be developed in order to avoid underestimating or overestimating the maintenance benefit.

This research project was conducted to fulfill these needs. In this study, manually collected windshield pavement condition data were cleaned, pavement ages were reset, categorical and non-linear regression analyses were performed to develop pavement deterioration models. In addition, weight factors were determined by conducting sensitivity analysis of CBA simulation results of all 14 divisions. The performance and distress models and new weight factors developed in this research project have been implemented in the NCDOT PMS by the engineers in the PMU. An entirely separate decision tree has been created using the update performance models.

Primary findings of this study include:

- A data cleansing method was developed and successfully used to prepare the raw pavement condition data for developing performance and distress models. There were two types of abnormalities in the raw data: bogus data points due to human raters' subjectivity, and pavement age not being reset after treatments. The data cleansing method developed in this study was able to identify these abnormalities by comparing all three consecutive PCR ratings, remove the bogus data and reset pavement age.
- The sigmoidal model form is more appropriate than other forms accepted by the NCDOT PMS in predicting pavement performance and alligator cracking. The NCDOT PMS accepts 7 model forms, and all these forms were used to fit the performance data and the alligator cracking data. The sigmoidal model form described the deterioration trends much better.
- An approach to building piecewise linear distress models was successfully developed to process ordinal categorical distress ratings with more than two severity levels. An extensive literature review indicated that this approach was the first attempt to address

this type of distress data. The approach considers the categorical nature of the distress data, uses ordinal logistic regression analysis to derive individual distress probabilities, and calculates ordinates of breakpoints for piecewise linear models.

- Large amounts of data are needed in order to develop reasonable deterioration models. In the NCDOT PMS, distress ratings and pavement age are stored in two separate databases. The data merging and cleansing process removed bogus ratings and observations of roadway sections that are very short in length, resulting in the final data set having a smaller sample size. This smaller sample size still fulfilled the strict sample size requirements of nonlinear regression analysis (sigmoidal models) and ordinal logistic analysis (piecewise linear models) because the NCDOT PMU's databases contain large amounts of historic condition data collected since 1985.

- Reasonable analysis length, cost and target constraints for CBA are crucial for determining appropriate weight factors. North Carolina has 14 Divisions. Because types and lengths of roadways managed by each Division are different, annual budget allocated to each Division varies. It appears that the same CBA assumptions should not be used for all divisions.

The following recommendations are proposed for future research:

- To improve data quality for increased PMS performance, it is recommended that 1) raters should record maintenance activities when observed. This allows pavement age to be accurately reset instead of judging from the magnitudes of PCR jumps; and 2) a centralized database should be developed that contains both pavement performance ratings and pavement construction history. This database eliminates the need to merge multiple databases, and more importantly preserves pavement sections presenting valuable pavement performance information that otherwise are purged during the database merging process.

- For asphalt SR routes, a comparison of pavement performance between minor rehabilitation and major rehabilitation/construction/reconstruction is recommended. This comparison can add a new decision tree variable to the NCDOT PMS, which can enable a more accurate funding analysis.

- This research project focused on asphalt and JCP pavements, and composite pavements are considered as a part of asphalt pavements, even though they perform differently. It is recommended that deterioration models for composite pavements be developed in future efforts.

- Even though some SR routes carry significant amount of traffic, their performance was evaluated with other low volume SR routes. It is recommended that future deterioration models be developed based on roadway systems (e.g., AADT), and not classifications (Interstate, US, NC, and SR).

- It is recommended to subdivide the current 18 roadway families into three regions. The reason is that for example, Interstate 0-50k routes in the Mountains region perform

differently than the ones in the Piedmont region, and similarly roadways belong to other families perform differently in different regions. Therefore, additional models (e.g., Interstate 0-50k_Mountains, Interstate 0-50k_Piedmont, and Interstate 0-50k_Coastal) should be developed, if possible, to enhance functionality of the NCDOT PMS.

- It is recommended that additional weight factors should be developed that consider highway use categories such as Statewide (National Highway System), Regional and Subregional (local) roads.

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CHAPTER 1 INTRODUCTION AND OBJECTIVES

1.1 Background

The North Carolina Department of Transportation (NCDOT) has utilized its Pavement Management System (PMS) to conduct performance and funding analyses for its highway system since 1995. Every two years, pavement condition data are collected through windshield surveys at the network level. The data are then analyzed to develop a series of deterioration models by the type of routes, i.e., Interstate, Primary (United States roads and NC roads), and Secondary, and by Annual Average Daily Traffic (AADT).

The NCDOT PMS uses deterministic pavement deterioration models derived from regression analysis. Composite Pavement Condition Rating (PCR) scores and individual pavement distresses are modeled, referring to as performance models (PCR vs. pavement age) and distress models (distress index vs. pavement age).

Distress models have been used by the Department to select appropriate maintenance treatments. Once a distress curve declines to a threshold, the decision tree in the NCDOT PMS is triggered, and a maintenance treatment is recommended. The associated costs are then calculated for funding analyses.

Performance models have been used by the Department to optimize funding through Cost-Benefit Analysis (CBA). In a CBA, the area under the performance curve is the Baseline Benefit. The estimated benefit of a proposed roadway maintenance activity is calculated by multiplying its Baseline Benefit by lane-miles and a weight factor. Finally, the estimated benefits are used to develop a ranked list of projects for the funding allocation purpose.

1.2 Research Needs and Significance

The NCDOT decided to develop and validate pavement deterioration models and CBA analysis weight factors for its PMS for the following reasons:

- Accuracy and suitability of deterioration models are essential for effective application of pavement maintenance and rehabilitation strategies. The NCDOT's existing deterioration models were implemented in its PMS in 2008. Since then a large amount of pavement condition data have been collected. Therefore, there is a need to develop and validate new deterioration models.

- The estimated benefit of a proposed maintenance activity is largely determined by the roadway's weight factor (currently the NCDOT uses 2.0 for Interstate highways, 1.66 for US routes, 1.33 for NC routes, and 1.0 for Secondary routes). Once the new deterioration models are developed and implemented, a new set of CBA weight factors should be developed in order to avoid underestimating or overestimating the maintenance benefit.

This research project was conducted to address these needs, and the following outcomes were generated that will be beneficial to the NCDOT:

- Reliable predictions of pavement performance that allow the NCDOT to make appropriate maintenance decisions; and
- Accurate CBA results that enable the NCDOT to evaluate alternate resource allocation scenarios.

1.3 Research Objectives

The objectives of this research project are twofold: (a) to develop and validate new deterioration models; and (b) to select appropriate values of weight factors and to review trigger points on treatment selection decision trees.

1.4 Report Organization

An introduction to the research project, research needs and objectives are presented in Chapter 1. A comprehensive literature review is provided in Chapter 2. Research methodology is discussed in Chapter 3. Chapter 4 focuses on the pavement condition data and its cleaning process. Chapter 5 presents development of pavement performance models. Chapter 6 presents development of pavement distress models. Chapter 7 addresses the determination procedure of weight factors for cost benefit analysis. Evaluation of decision trees is included in Chapter 8. Development of update guidelines is presented in Chapter 9. Chapter 10 provides conclusions drawn from this research and recommendations for future research.

Appendix A includes asphalt pavement performance curves. Appendices B through G present distress curves of alligator cracking, transverse cracking, oxidation, bleeding, patching, and rutting, respectively. Appendix H presents ride model curves. Appendix I includes JCP performance model curves. Appendices J and K presents CBA results.

CHAPTER 2 LITERATURE REVIEW

An extensive literature review was conducted to synthesize past and ongoing research related to the following prominent research components of this research project. Practical applications of these components in state DOTs are also provided.

2.1 Pavement Management System (PMS)

In 1993, AASHTO defined a Pavement Management System (PMS) as "a set of tools or methods that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time" [1]. The initial use of systematic processes to manage pavements, however, can be traced back to the mid-1960s in the United States [2, 3] and in Canada [4].

A PMS includes a centralized database, analysis tools, cost-benefit analysis models, and optimization models [5], and is generally used at both the network level and the project level [6]. The early PMSs were project level systems which provided support at the analysis and design levels, and were used mainly by technical personnel. In 1980, the first network-level PMS, the Arizona PMS, was developed based on a linear optimization model with the objective of minimizing agency costs [7]. The implementation of Arizona PMS has resulted in significant cost savings [8]; since then, many of the states have implemented PMSs. To facilitate state DOTs in establishing a framework for a PMS, in 2001 AASHTO published the Pavement Management Guide [6] which advises "technologies and processes pertaining to selection, collection, reporting, management, and analysis of data used in pavement management."

The NCDOT has utilized its PMS in decision making at network, division, and local levels. This PMS has been integrated with the existing Maintenance Management System (MMS), and can be accessed from county maintenance offices to the central office [9].

2.2 Condition Assessment Data

Without pavement condition databases, a PMS will not function. NCHRP Synthesis of Highway Practice 76, Collection and Use of Pavement Condition Data, published in 1981 [10], categorized the types of data that should be collected for PMSs: roughness (ride), surface distress, structural evaluation (deflection), and skid resistance. The 1986 NCHRP Synthesis of Highway Practice 126, Equipment for Obtaining Pavement Condition and Traffic Loading Data, summarized equipment used to collect pavement condition data [11]. In 1993, The Strategic Highway Research Program (SHRP) developed a distress identification manual [12] to assist agencies in obtaining accurate, consistent, and repeatable distress identification and evaluation. Beginning in 1994, the Highway Performance Monitoring System (HPMS) requires that states provide pavement condition information to support the functions and responsibilities of the FHWA [13]. Beginning in 2010, the Highway Performance Monitoring System Field Manual requires that section-by-section pavement condition parameters should be reported periodically [14]. NCHRP Synthesis of Highway Practice 203: Current Practices in Determining Pavement Condition, published in 1994, presented location reference methods and data management techniques [15].

The NCDOT has collected pavement condition data since 1982. Every two years, 100% of its flexible pavements and a 20% sample of each rigid pavement are surveyed [16]. Local personnel are trained using the latest NCDOT Asphalt/Concrete Pavement Survey Manual and then collect the following condition data through windshield surveys:

- Flexible pavements: alligator cracking, transverse cracking, rutting, raveling, oxidation, bleeding, ride quality, and patching.
- Rigid pavements: longitudinal cracking, transverse cracking, corner breaks, joint seal damage, faulting, spalling, surface wearing, pumping, ride quality, and patching.

Beginning in 2014, NCDOT began using a consultant to collect pavement condition for the secondary system on an annual basis.

2.3 Pavement Deterioration Models

A PMS must have pavement deterioration models that manipulate the pertinent condition data to produce useful information and recommendations for managers. The advantages and limitations of using two categories of pavement performance models, deterministic models and probabilistic models, were introduced in studies conducted by Sundin [17] and Broten [18]. Deterministic models estimate the average value of the dependent variable (e.g., PCR or the remaining life of a pavement). Most deterministic models used in PMSs are based on regression analysis. Probabilistic models, on the other hand, estimate a range of values of the dependent variable. Most state DOTs use deterministic models because it is easier to explain these models to users and usually it is easier to incorporate these models into their PMSs [19].

Markov chains, one of the most popular probabilistic modeling approaches, has its limitations [20]: it needs a large number of samples to obtain meaningful statistical analysis; it cannot predict performance of individual pavements. Abaze [21] investigated the suitability of deterministic performance prediction model for rehabilitation and management of flexible pavement. The results stated that the presented deterministic model provided an effective and convenient means for pavement engineers to address pavement design and rehabilitation issues. Previous research [22] was conducted to study the existing models used by the Arizona DOT, and proposed the application of site-specific models and default prediction models. The enhanced PMS showed a great deal of flexibility, and provided detailed and deterministic information for statewide needs. The Washington State Department of Transportation (WSDOT) PMS used regression equations to predict PCR, and the equations fit the data well [23]. Abu-Lebdeh et al. [24] developed auto-regression models for the Michigan Department of Transportation (MDOT) and the models fit well for non-freeway routes.

Performance models can be developed for groups of pavements, known as "family models", or for individual pavement sections, known as "section models". A section model is developed from historical data collected from a particular section of pavement; it requires a minimum of three data points to define a reasonable deterioration trend. The Minnesota DOT, for example, requires at least three data points to build a section model. Condition data of an individual pavement section can also be grouped with data from other pavement sections that have similar performance characteristics to develop a family model. A "family" of pavements has the same

surface type, functional classification (Interstate/U.S./state highways, and local roads), and traffic levels; these pavements are expected to perform following a similar deterioration pattern.

The family modeling technique is used by many state DOTs because it entails a smaller number of equations and it is easier to incorporate into a PMS than section models [19].The Colorado Department of Transportation uses both individual and family models. The Louisiana Department of Transportation and Development (LADOTD) utilizes pavement families based on the pavement type (composite, asphalt, jointed concrete and continuously reinforced concrete) and the functional classification system (interstate highway system (IHS), national highway system (NHS), State highway system (SHS) and regional highway system (RHS)) [25]. The Maryland State Highway Administration (MDSHA) also uses family models based on traffic levels (low, medium, and high), pavement types (flexible, rigid, and composite), and four last major treatment levels grouped by life expectancy (15 years, 12 years, 8 years, and 5 years). These family models can be used to predict the life expectancy if a treatment is applied to a pavement section, and to estimate pavement performance over time [26].

The family modeling technique was developed by the U.S. Army Construction Engineering Research Laboratory (USACERL) [27, 28]. The technique consists of five steps:

1. Define the pavement family;
2. Filter the data;
3. Conduct data outlier analysis;
4. Develop the family model; and
5. Predict the pavement section condition.

If the pavement age is the only independent variable used in the family models, pavement performance of an individual pavement can be predicted using one of the following two curves that passes through the known pavement condition-age point:

- An adjusted family curve [29];
- A curve that is parallel to the family curve [30].

Sadek et al. [31] indicated that the results of using these two methods were similar.

The NCDOT PMS uses deterministic models to estimate the average values of two types of dependent variables of roadway families. One dependent variable is PCR, a pavement performance indicator that combines all visual distresses into one index. These models are referred to as performance models, which are used for Cost-Benefit Analysis (CBA); another dependent variable is indices of pavement distresses, including alligator cracking, bleeding, oxidation, patching, ride, rutting, and transverse cracking. These models are referred to as distress models, which are used to trigger treatment selection decision trees.

In both cases, the only independent variable is pavement age, which is determined from the time of construction, reconstruction, or overlay to the time of the last PCR survey. The NCDOT utilizes family models, which are based on the pavement type (asphalt and jointed concrete pavement (JCP)), functional classification (Interstate, U.S., NC, and SR), and AADT. In

addition, the NCDOT's PMS can support specific pavement section models. This research project focuses on developing pavement family models. Section models were not considered in this study.

2.4 Decision Trees

Once the condition of each pavement family has been determined, state DOTs can identify roadways that need maintenance and rehabilitation. Many states use decision trees that allow condition of the pavement to "trigger," or initiate, a treatment. The condition criteria can include a condition level based on a combined index, individual levels of certain distress, or rate of deterioration [32]. The condition criteria are converted into trigger values, or trigger points, which will trigger a treatment.

To trigger a treatment, a single trigger value or a series of trigger values, usually a range of values, can be used. The disadvantage with a single trigger value is that either the pavement section needs a treatment, or does not; there are no intermediate treatment options that can be assigned to more accurately handle differing pavement conditions. Therefore, many state DOTs use a range of trigger values to select different levels of treatments [6].

In some cases, a pavement section can be assigned treatments in more than one decision tree. To address this issue, a precedence of treatments must be established such that the selected treatment can address all of the problems encountered [33].

The NCDOT uses a range of trigger values in its decision trees. These trigger values are determined by individual levels of certain distress (alligator cracking, bleeding, transverse cracking, raveling, oxidation, rutting, etc.) and are based on the pavement type (asphalt and JCP) and two highway functional classifications (interstate, and non-interstate).

2.5 Cost-Benefit Analysis (CBA)

PMSs are decision support tools that can be used to conduct economic analysis to rank roadway sections. A true cost-benefit analysis (CBA) requires that the benefits and costs must both be in monetary units. Projects which have the greatest cost-benefit ratio are among the first projects to be recommended for maintenance, rehabilitation, and reconstruction. However, the benefits of public projects are usually too complicated to define [34]. Therefore, most state DOTs use the area under a performance curve, known as effectiveness, as a benefit surrogate [35, 36]. The effectiveness is larger if the remaining life of the pavement is longer and if the initial condition rating of the pavement is higher. The premise is that pavement sections with better condition and longer life provide more benefit. Remaining life can be based on individual distress types or a combined index (e.g., PCR). Because traffic is not directly considered in CBA, a low-volume road can have the same effectiveness as a high-volume road; however, the costs of repairing these two roads are much different. To address this issue, the effectiveness is adjusted by weight factors that are related to traffic.

As one type of CBA, the marginal CBA has proven to be very effective [37]. A typical marginal CBA consists of the following steps [37]:

1. Identify the feasible treatment for each analysis period based on the projected condition and established trigger levels;
2. Calculate the effectiveness (E) of each combination (effectiveness is generally the area under the performance curve multiplied by some function of traffic);
3. Calculate the cost (C) of each combination in net present value terms;
4. Calculate the cost-effectiveness (CE) of each combination as the ratio of E/C, where the highest value is the best;
5. Select the treatment alternative and time for each section with the best CE until the budget is exhausted; and
6. Calculate the marginal cost- effectiveness (MCE) of all other strategies for all section as

$$MCE = \frac{E_s - E_r}{C_s - C_r}$$

where:

follows: E_s = effectiveness of the strategy selected in step 5

E_r = effectiveness of the strategy for comparison

C_s = cost of the strategy selected in step 5

C_r = cost of the strategy for comparison

7. If the MCE is negative, or if E_r is less than E_s, the comparative strategy is eliminated from further consideration; if not, it replace the strategy selected in step 5; and
8. This process is repeated until no further selections can be made in any year of the analysis period.

The advantages of the marginal CBA include the ability to consider timing of rehabilitation, reconstruction, and maintenance; the capacity to find the best combination of management sections, alternative treatments, and time of applications; the capacity to complete strategic analysis; the capacity to assess the effects of different funding levels; and the results which are close to the optimum than from ranking approaches [6]. However, the main disadvantage of the marginal CBA is that reliable performance models are needed to provide accurate recommendations [6].

CBA is used by the NCDOT to optimize funding. The area under the performance curve is the Baseline Benefit. The estimated benefit of a proposed roadway maintenance activity is calculated by multiplying its Baseline Benefit by lane-miles (with a maximum of 4.0 to keep excessively long/wide pavements from dominating), and by a weight factor (currently the NCDOT uses 2.0 for Interstate highways, 1.66 for United States roads, 1.33 for NC roads, and 1.0 for Secondary roads). The estimated benefits are used to develop a ranked list of projects for the funding allocation purpose.

CHAPTER 3 PAVEMENT CONDITION DATA

This chapter describes how raw pavement condition data were obtained, merged, and then cleaned.

3.1 Introduction

The NCDOT has collected pavement condition data since 1982. Every two years, 100% of its flexible pavements and 0.2 mile of every mile of rigid pavement are surveyed [16].

The pavement condition indicator used by the NCDOT is the Pavement Condition Rating (PCR). A PCR ranges from 0 to 100 points, with 100 points indicating a perfect condition. A roadway section's PCR is obtained by subtracting deduction points for each type and level of severity of distress [38]. Typically, a section's PCR decreases over time. A rapid increase in the PCR usually indicates that a treatment has been applied to this section.

3.2 Data Sources

Two databases, *Asphalt_Ratings* and *Construction_Data*, were obtained from the NCDOT PMS. These two databases include all the raw data that were used for this research project. As shown in Figure 1, the database *Asphalt_Ratings* includes the following pavement condition information:

- **EFF_YEAR**: year the roadway section was surveyed;
- **NC_COUNTY**[*]: county name;
- **ROUTE1**[*]: route number;
- **OFFSET_FROM**: begin county milepost (MP) of the roadway section was surveyed;
- **OFFSET_TO**: end county MP of the roadway section was surveyed;
- **NC_PVMT_TYPE_CD_NAME:** P (plant mix), B (BST), or S (Slurry);
- **NC_SUB_RUR_CD_NAME:** S (Subdivision road), R (Rural road);
- **AADT**: Annual Average Daily Traffic;
- **RTG_NBR**: the PCR rating of the roadway section.

The database *Construction_Data* includes the following treatment related information (Figure2):

- **County**[*]: county name;
- **Route**[*]: route number;
- **Begin_MP**: begin county MP of the roadway section was treated;
- **End_MP**: end county MP of the roadway section was treated;
- **Year_Comp**: year the roadway section was treated.

NCDOT_Asphalt_Ratings

EFF_YEAR	COUNTY	NC_DIVISIOI	NC_COUNTY	ROUTE1	NC_DRCTN_	OFFSET_FROM	TO_DESC	OFFSET_TO	FROM_DESC
1982	1	7	001-Alamance	20000070		0	CL BURLIN	0.24	GUILFRD CO
1982	1	7	001-Alamance	20000070		0.24	SR 1309	1.272	CL BURLIN
1982	1	7	001-Alamance	20000070		1.272	WCL BURLIN	2.232	SR 1309
1982	1	7	001-Alamance	20000070		2.232	FORSETDALE	2.462	WCL BURLIN
1982	1	7	001-Alamance	20000070		2.462	BEG DIV HW	4.262	FORESTDALE
1982	1	7	001-Alamance	20000070	E	4.262	END DIV HW	5.202	BEG DIV HW
1982	1	7	001-Alamance	20000070		5.202	BEG DIV HW	5.692	END DIV HW
1982	1	7	001-Alamance	20000070	E	5.692	NC 87	6.052	BEG DIV HW
1982	1	7	001-Alamance	20000070	E	6.052	END DIV HW	7.072	NC 87
1982	1	7	001-Alamance	20000070		8.462	ECL BURLIN	9.042	SR 1719
1982	1	7	001-Alamance	20000070		9.042	WCL HAW RV	9.272	ECL BURLIN
1982	1	7	001-Alamance	20000070		9.272	NC 49	10.072	WCL HAW RV
1982	1	7	001-Alamance	20000070		10.072	NC 49	11.062	NC 49
1982	1	7	001-Alamance	20000070		11.062	ECL HAW RV	12.222	NC 49
1982	1	7	001-Alamance	20000070		12.222	SR 1940	13.922	ECL HAW RV
1982	1	7	001-Alamance	20000070		13.922	WCL MEBANE	15.602	SR 1940
1982	1	7	001-Alamance	20000070		15.602	NC 119	15.922	WCL MEBANE
1982	1	7	001-Alamance	20000070		15.922	SR 1962	16.002	NC 119
1982	1	7	001-Alamance	20000070		16.002	NC 119	16.192	SR 1962
1982	1	7	001-Alamance	20000070		16.192	ORANGE CO	16.552	NC 119
1982	1	7	001-Alamance	20600070	W	9.48	NC 62	10.28	BEG DIV HW
1982	1	7	001-Alamance	20600070	W	10.28	END DIV HW	11	NC 62
1982	1	7	001-Alamance	20600070	W	11.49	END DIV HW	12.43	BEG DIV HW
1982	1	7	001-Alamance	30000049		0	SR 1100	1.42	RANDLPH CO
1982	1	7	001-Alamance	30000049		1.42	SR 2375	2.13	SR 1100
1982	1	7	001-Alamance	30000049		2.13	SR 1104	3.13	SR 2375
1982	1	7	001-Alamance	30000049		3.13	SR 1005	4.51	SR 1104
1982	1	7	001-Alamance	30000049		4.51	SR 1109	5.68	SR 1005

Figure 1: Asphalt Ratings Database

In order to evaluate a roadway section's performance and treatment conditions, these two databases need to be merged together. This is a two-step process:

1. Use matching fields (with the * mark) in these two databases to locate and merge routes (e.g., route 20000070 in 001-Alamance county); and

2. Use mileposts to locate and merge roadway sections (e.g., MP 0 – 0.24 of route 20000070).

NCDOT_Construction_Data

County	Route	Lane Direction	Lane	Begin MP	End MP	Year Comp
001-Alamance	10600040	Increasing	All	15.16	16.055	2006
001-Alamance	20000070	All	All	0	0.992	1986
001-Alamance	20000070	All	All	0	2.432	1987
001-Alamance	20000070	All	All	1	2.432	1986
001-Alamance	20000070	All	All	2.232	4.072	1973
001-Alamance	20000070	All	All	2.432	4.262	1988
001-Alamance	20000070	All	All	2.582	4.262	1997
001-Alamance	20000070	All	All	4.172	4.262	1979
001-Alamance	20000070	Increasing	All	4.262	4.462	1979
001-Alamance	20000070	Increasing	All	4.262	4.352	1988
001-Alamance	20000070	Increasing	All	4.262	4.402	1997
001-Alamance	20000070	Increasing	All	4.352	5.202	1987
001-Alamance	20000070	Increasing	All	4.402	5.202	1985
001-Alamance	20000070	Increasing	All	4.992	5.202	1995
001-Alamance	20000070	All	All	5.202	5.272	1987
001-Alamance	20000070	All	All	5.202	5.692	1995
001-Alamance	20000070	Increasing	All	5.692	6.052	1995
001-Alamance	20000070	Increasing	All	5.982	6.362	1975
001-Alamance	20000070	Increasing	All	6.052	7.072	1987

Figure 2: Construction Database

In Step 2, mileposts (i.e., *OFFSET_FROM* vs. *Begin_MP*, and *OFFSET_TO* vs. *End_MP*) in these two databases oftentimes are different, as illustrated in Figure 3. The reason is that the start and end points of roadway maintenance activities are typically different from the start and end points the roadway surveyors selected, which are usually easily identified reference points along the roadways (e.g., intersections). If this issue is not addressed, a large amount of valid pavement data will not be included in the merged database.
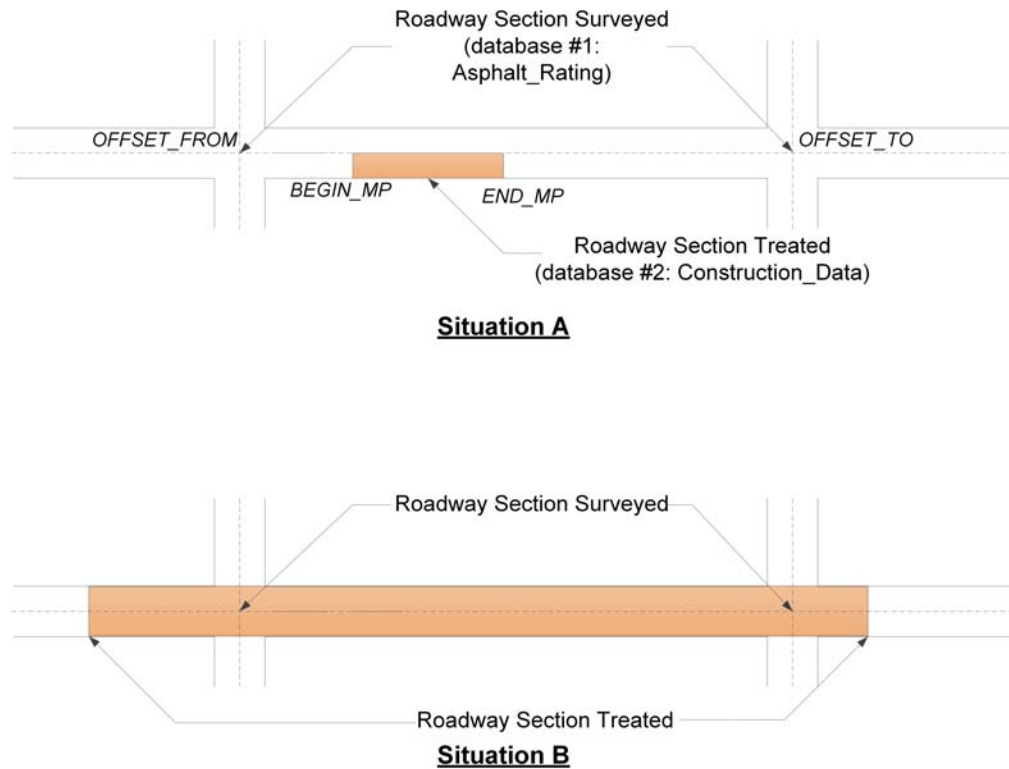
Figure 3: Relationships between Offset_From/To and Begin/End_MP

To address this issue, route 20000070 in Alamance County was studied, and a solid solution was found and applied to all routes. This process involved several steps:

1. All mileposts (*OFFSET_FROM/TO* and *Begin/End_MP*) of 20000070 in Alamance County were plotted (Figure 4);

2. *OFFSET_FROM/TO* and *Begin/End_MP* of roadway sections were studied;

3. A total of 9 spatial relations were identified and summarized in Figure 5; and

4. Merging criteria (Figure 5) were determined to preserve the majority of valid pavement condition data.

It is important to note that in Step 4, a 90% overlap in length is required for the data merging purpose. This is to avoid having too many short roadway segments in the final data set, which can potentially bias the statistical analysis results.

Figure 4:*OFFSET_FROM/TO* and *Begin/End_MP* of Route 20000070 in Alamance County

Figure 5: *OFFSET_FROM/TO* vs. *Begin/End_MP* and Database Merging Criteria

Once the databases are merged, the data set is subdivided into the following family data sets for further statistical analyses. Eighteen (18) roadway families were defined based on roadways' classifications and their AADT values (Table 1):
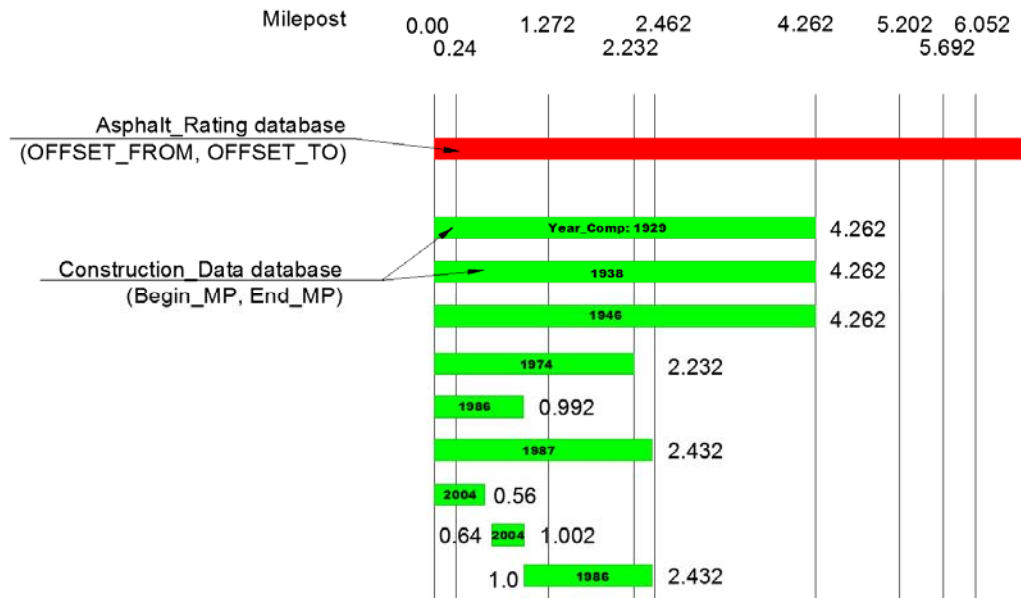
Table 1: List of Roadway Families

Classification	AADT	Family	Note
Interstate	0-50k	**Interstate 0-50k**	
	> 50k	**Interstate 50kplus**	
US routes	0-5k	**US 0-5k**	
	5-15k	**US 5-15k**	
	15-30k	**US 15-30k**	
	> 30k	**US 30kplus**	
North Carolina routes	0-1k	**NC 0-1k**	
	1-5k	**NC 1-5k**	
	5-15k	**NC 5-15k**	
	> 15k	**NC 15kplus**	
Secondary Routes	0-1k BSS	**SR 0-1k BSS**	Bituminous/Slurry Subdivision routes
	0-1k BSR	**SR 0-1k BSR**	Bituminous/Slurry Rural routes
	> 1k BSR	**SR 1kplus BSR**	Bituminous/Slurry Rural routes
	0-1k PS	**SR 0-1k PS**	Plant Mix Subdivision routes
	0-1k PR	**SR 0-1k PR**	Plant Mix Rural routes
	1-5k PR	**SR 1-5k PR**	Plant Mix Rural routes
	5-15k PR	**SR 5-15k PR**	Plant Mix Rural routes
	> 15k PR	**SR 15kplus PR**	Plant Mix Rural routes

3.3 Data Cleansing Process

To understand the characteristics of the data and to determine directions for further analysis, scatterplots of PCR vs. Age of all 18 families were developed. There were no obvious trends (PCR declines over time) found from these plots. One example is shown in Figure 6. This indicates that the merged data set needs to be cleaned.

Two causes of the lack of declining trends were identified by consulting NCDOT engineers: subjectivity of pavement raters and pavement treatments not being properly recorded, meaning that pavement age was not reset. The data cleansing process was then carried out to address this two issues. The premise of the data cleansing process is that a pavement's PCR ratings decrease continuously over time, until the pavement is treated later. Therefore, smaller "jumps" in PCR ratings represent variations in pavement raters' subjective opinions, and thus should be removed as bogus data points. Meanwhile, a larger "jump" (PCR ratings increase to more than 90) usually indicates the occurrence of a treatment, and thus the age of the pavement should be reset to zero. These two scenarios are illustrated in Figure 7.
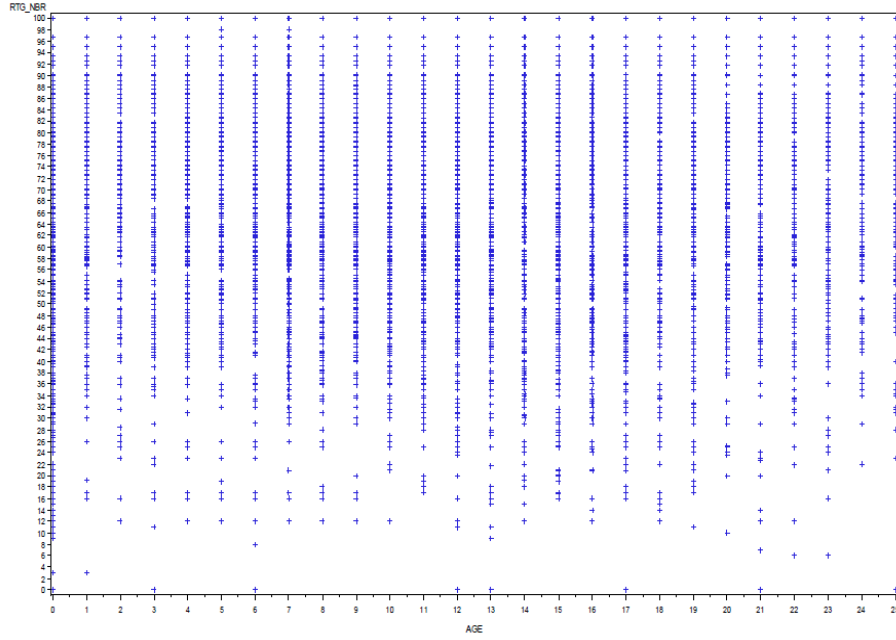
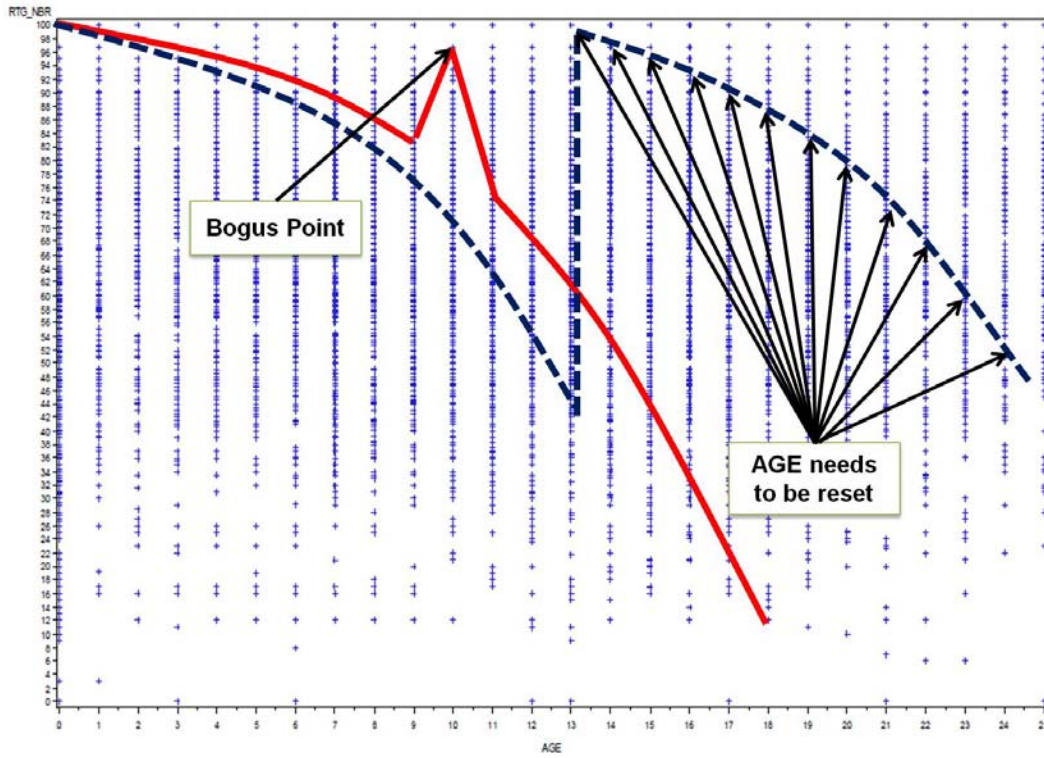Figure 6: Scatter Plot of PCR vs. Age (NC 5-15k)

Figure 7: Illustration of Bogus Points and Resetting Age (NC 5-15K)

The data cleansing procedure involved three steps:

1. Sub-divided roadway sections such that condition data from the same roadway section were grouped into one age_group (Figure 8).

|	EFF_YEAR	NC_COUNT	ROUTE1	OFFSET_FROM	OFFSET_TO	AADT	RTG_NBR	Begin MP	End MP	Year Comp	AGE	road_group	age_group	id
1	1982	092-Wake	30000098	13.755	14.491	2800	96.7	13.647	16.963	1979	3	532	1	1
2	1983	092-Wake	30000098	13.755	14.491	2800	96.7	13.647	16.963	1979	4	532	1	2
3	1984	092-Wake	30000098	13.755	14.491	2800	95	13.647	16.963	1979	5	532	1	3
4	1986	092-Wake	30000098	13.755	14.491	2800	96.7	13.647	16.963	1979	7	532	1	4
5	1982	092-Wake	30000098	14.491	15.851	2800	96.7	13.647	16.963	1979	3	532	2	1
6	1983	092-Wake	30000098	14.491	15.851	2800	96.7	13.647	16.963	1979	4	532	2	2
7	1984	092-Wake	30000098	14.491	15.851	2800	95	13.647	16.963	1979	5	532	2	3
8	1986	092-Wake	30000098	14.491	15.851	2800	96.7	13.647	16.963	1979	7	532	2	4
9	1982	092-Wake	30000098	15.851	17.821	2800	96.7	13.647	17.791	1970	12	532	3	1
10	1984	092-Wake	30000098	16.901	17.821	1500	71.7	13.647	17.791	1970	14	532	4	1
11	1986	092-Wake	30000098	16.901	17.821	1500	84.2	13.647	17.791	1970	16	532	4	2
12	1988	092-Wake	30000098	16.901	17.821	1500	100	13.647	17.791	1970	18	532	4	3
13	1990	092-Wake	30000098	16.901	17.821	1500	87.5	13.647	17.791	1970	20	532	4	4
14	1988	092-Wake	30000231	0	0.22	4100	74.2	0	0.21	1988	0	533	5	1
15	1990	092-Wake	30000231	0	0.22	4100	91.7	0	0.21	1988	2	533	5	2
16	1992	092-Wake	30000231	0	0.22	4100	96.7	0	0.21	1988	4	533	5	3
17	1994	092-Wake	30000231	0	0.22	4719	91.7	0	0.21	1988	6	533	5	4
18	1996	092-Wake	30000231	0	0.22	4719	81.7	0	0.21	1988	8	533	5	5
19	1998	092-Wake	30000231	0	0.22	4719	91.7	0	0.21	1988	10	533	5	6
20	2000	092-Wake	30000231	0	0.22	4719	86.7	0	0.21	1988	12	533	5	7
21	1982	092-Wake	30000231	0.22	0.8	3000	100	0.2	1.4	1980	2	533	6	1
22	1983	092-Wake	30000231	0.22	0.8	3000	100	0.2	1.4	1980	3	533	6	2
23	1984	092-Wake	30000231	0.22	0.8	3400	100	0.2	1.4	1980	4	533	6	3
24	1986	092-Wake	30000231	0.22	0.8	3400	96.7	0.2	1.4	1980	6	533	6	4
25	1988	092-Wake	30000231	0.22	0.8	3400	93.4	0.2	1.4	1980	8	533	6	5
26	1990	092-Wake	30000231	0.22	0.8	3400	96.7	0.2	1.4	1980	10	533	6	6
27	1992	092-Wake	30000231	0.22	0.8	3400	96.7	0.2	1.4	1980	12	533	6	7
28	1994	092-Wake	30000231	0.22	0.8	2749	91.7	0.2	1.4	1980	14	533	6	8
29	1996	092-Wake	30000231	0.22	0.8	2749	91.7	0.2	1.4	1980	16	533	6	9
30	1998	092-Wake	30000231	0.22	0.8	2749	86.7	0.2	1.4	1980	18	533	6	10
31	2000	092-Wake	30000231	0.22	0.8	2749	86.7	0.2	1.4	1980	20	533	6	11

Figure 8: An Example of Age Groups

2. In each age_group, the magnitude of three consecutive PCR ratings were compared to identify if a specific data point is a bogus data point (if so, it is labeled as "DEL1", "DEL2", or "DEL3"), and to determine if a data point's age needs to be reset (if so, it is labeled as "RESET") (Figure 9).

3. The following actions were performed to generate the final "clean" data: reset the AGE, removed bogus data points, removed duplicate records, removed data collected before 1990, removed data points that are older than 20 years, and removed data points if their PCR values are less than 90 when their AGE ≤ 1.

The scatter plot of the final "clean" data set of NC 5-15k is shown in Figure 10. Compared to Figure 6, the distribution of data points shows a more obvious trend.
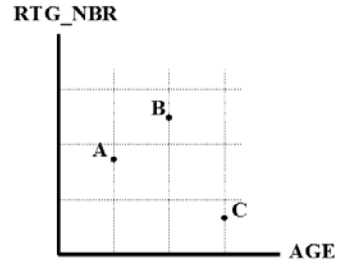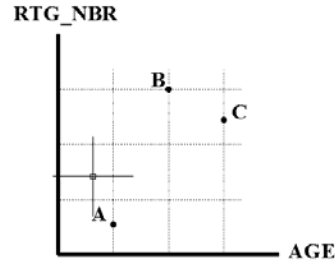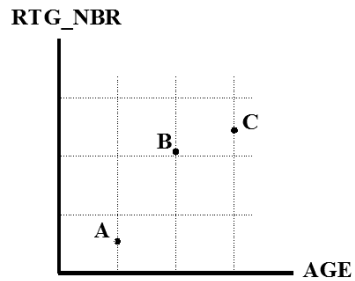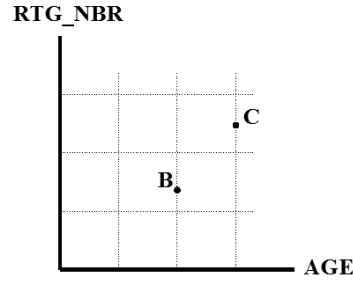
Figure 9: Bogus Data Points and Resetting Age Assessment Criteria
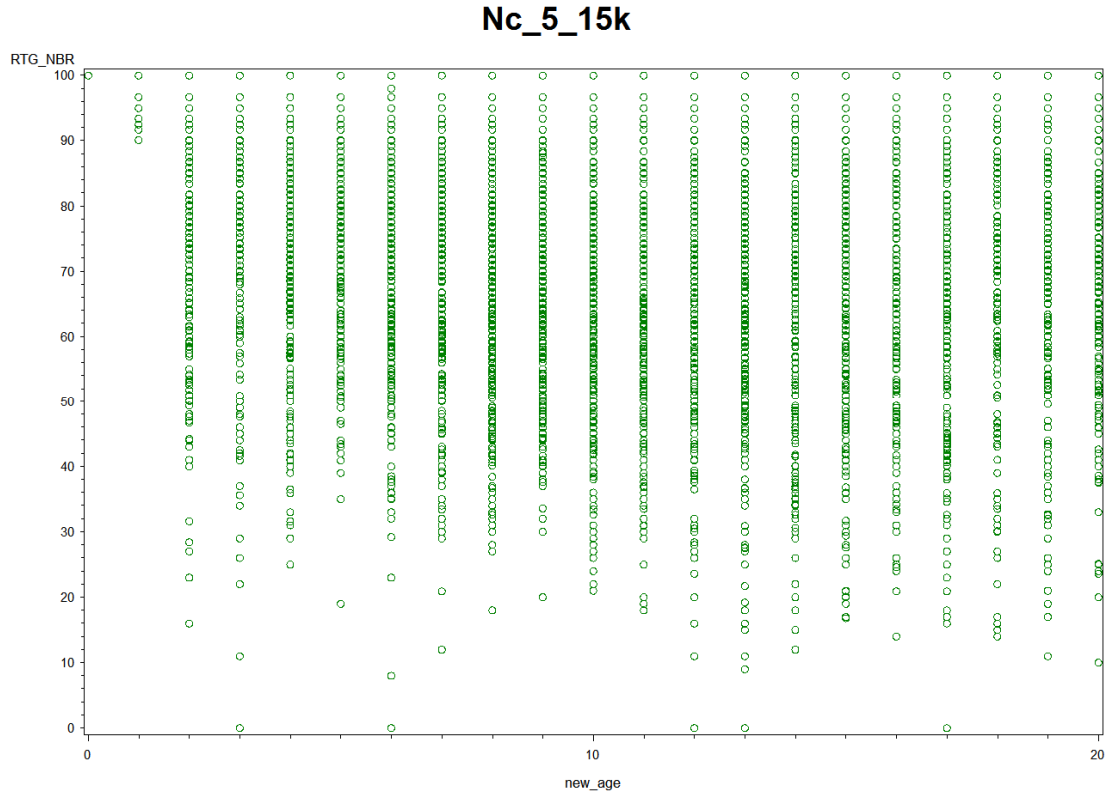
Figure 10: Scatterplot of PCR vs. Age of the Final Data for the NC 5-15k Family

Sample sizes of the "clean" family datasets are included in Table 2.

Table 2: Sample Sizes of Roadway Families

Family	Sample Size	Family	Sample Size
Interstate 0-50k	1,129	SR 0-1k BSS	9,259
Interstate 50kplus	374	SR 0-1k BSR	31,210
US 0-5k	6,235	SR 1kplus BSR	2,297
US 5-15k	11,268	SR 0-1k PS	7,485
US 15-30k	4,923	SR 0-1k PR	21,261
US 30kplus	1,312	SR 1-5k PR	9,571
NC 0-1k	3,243	SR 5-15k PR	3,306
NC 1-5k	13,396	SR 15kplus PR	749
NC 5-15k	8,829		
NC 15kplus	2,200		

CHAPTER 4 PAVEMENT PERFORMANCE MODELS

The NCDOT PMS accepts the following 7 types of performance model forms:

Exponential
Hyperbolic
Inverse Exponential
Linear
Piecewise Linear
Power
Sigmoidal

Figure 11: Accepted Performance Model Forms in the NCDOT PMS

Each model form was used to fit the final data, the sigmoidal model form was eventually chosen because it fit performance data well.

The mathematical expression a sigmoidal model is $y = \dfrac{a}{1 + e^{-\frac{x-b}{c}}}$

where
y: PCR rating, also referred to as RTG_NBR
x: pavement AGE
a, b, c: variables in the model

A sigmoidal model is a nonlinear model which necessities nonlinear regression analysis. However, repeat nonlinear regression of the same data will not always result in exactly the same *a, b,* and *c* values, as shown in Figures 12 through 14. This problem often referred to as divergence. To ameliorate this issue, it is important to find initial variable (*a, b,* and *c)* estimates that are close to the optimal values.
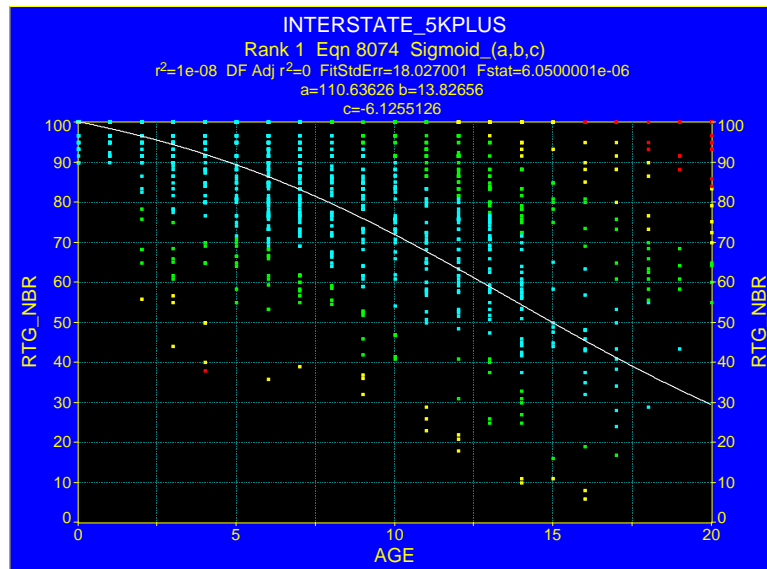
Figure 12: Nonlinear Regression Analysis – Trial One
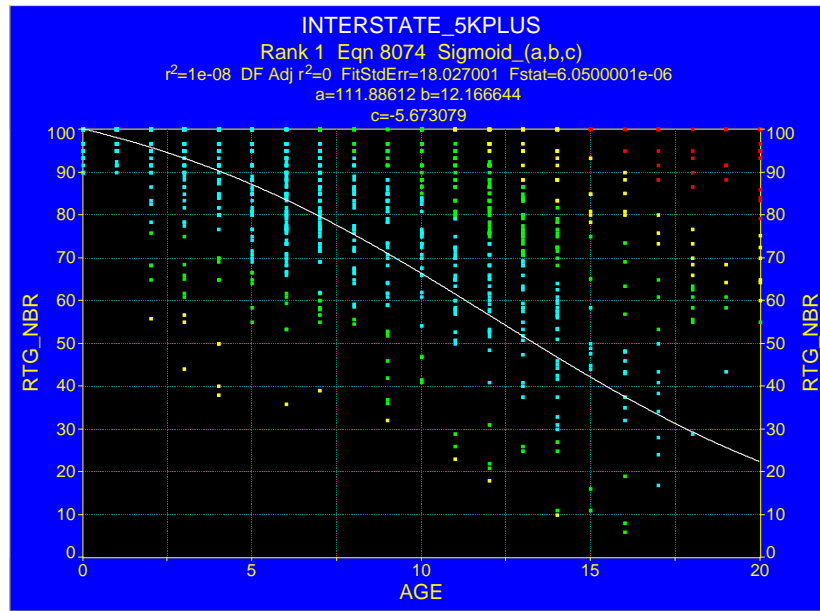
Figure 13: Nonlinear Regression Analysis – Trial Two
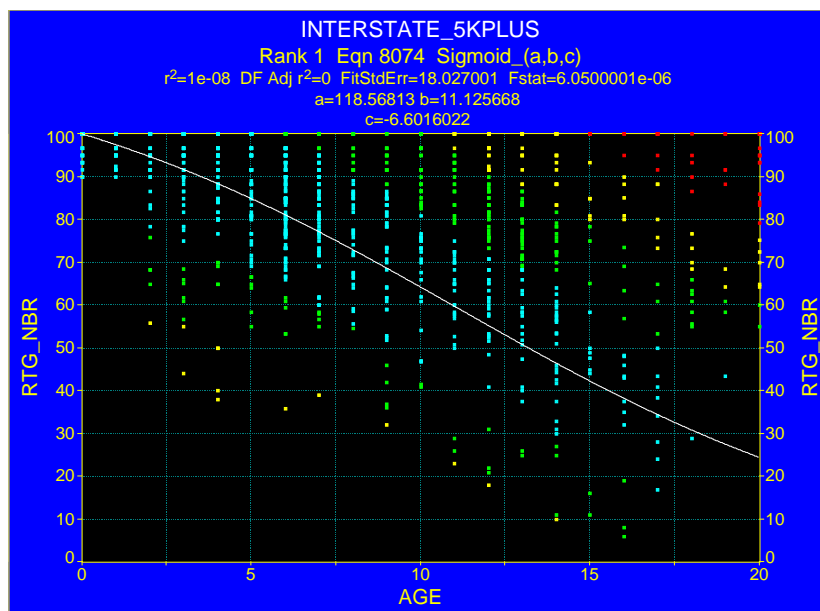
Figure 14: Nonlinear Regression Analysis – Trial Three

For clean data (no outliers, or minimum amount of outliers), initial *a*, *b*, and *c* estimates are not important because nonlinear regression will always converge on the same best-fit curve. However, when the initial data have large amounts of outliers, the nonlinear regression of the same data converges on different curves, as indicated by three different sets of *a, b*, and *c* values

in Figures 12-14. The initial a, b, and c estimates are important because without knowing them it is difficult to tell which resulting curve is better. Thus, an accurate initial estimates of a, b, and c variables is the necessary first step for nonlinear regression to converge on the best-fit curve.

4.1 Development of Sigmoidal Performance Models for Asphalt Pavements

This process began by calculating the initial estimates of variables a, b, and c. Then the next step was to fit the curve with these initial estimates, remove outliers, and then fit the data again. The final step was to compare the final curve with the one generated in the previous step, and select the better one.

Initial Estimates of Variables a, b, and c

Assume y = RTG_NBR, x = AGE, and the Sigmoidal model is $y = \dfrac{a}{1+e^{-\frac{x-b}{c}}}$,

Thus $a = y*(1+e^{-\frac{x-b}{c}})$

Since $a \geq y$, we let $a = 100$, which is the maximum rating number. This a value allows y to range from 0 to 100.

Thus,

$$y = \frac{100}{1+e^{-\frac{x-b}{c}}}$$

$$\Rightarrow \ln y = \ln 100 - \ln(1+e^{-\frac{x-b}{c}})$$

$$\Rightarrow \ln(1+e^{-\frac{x-b}{c}}) = \ln 100 - \ln y$$

$$\Rightarrow 1+e^{-\frac{x-b}{c}} = e^{\ln 100 - \ln y}$$

$$\Rightarrow e^{-\frac{x-b}{c}} = e^{\ln 100 - \ln y} - 1$$

$$\Rightarrow -\frac{x-b}{c} = \ln(e^{\ln 100 - \ln y} - 1)$$

Let $Y = \ln(e^{\ln 100 - \ln y} - 1), then$

$$-\frac{x-b}{c} = Y$$

$$\Rightarrow Y = -\frac{1}{c}x + \frac{b}{c}$$

From the last equation, a linear regression of Y on x can provide initial estimates of b and c. Figure 15 is a SAS output that shows initial estimates of variables a, b, and c for all roadway families.

```
🖷 Results
⊞ 📊 Gplot:  ncdot.Interstate_0_25k, a=100, b=21.641329947, c=-4.465430523
⊞ 📊 Gplot:  ncdot.Interstate_25_50k, a=100, b=21.844280465, c= -4.51730273
⊞ 📊 Gplot:  ncdot.Interstate_50_75k, a=100, b=25.664935003, c= -5.41081476
⊞ 📊 Gplot:  ncdot.Interstate_75kplus, a=100, b=30.247156788, c=-5.780393496
⊞ 📊 Gplot:  ncdot.US_0_5k, a=100, b=18.317238424, c=-5.108880074
⊞ 📊 Gplot:  ncdot.US_5_15k, a=100, b=19.654024094, c=-5.497932403
⊞ 📊 Gplot:  ncdot.US_15_30k, a=100, b=22.305387285, c=-6.139004573
⊞ 📊 Gplot:  ncdot.US_30kplus, a=100, b=24.937248451, c=-6.601039562
⊞ 📊 Gplot:  ncdot.Nc_0_1k, a=100, b=19.092087878, c=-4.695447576
⊞ 📊 Gplot:  ncdot.Nc_1_5k, a=100, b= 18.11932281, c= -4.87567318
⊞ 📊 Gplot:  ncdot.Nc_5_15k, a=100, b=21.105421389, c=-6.162015129
⊞ 📊 Gplot:  ncdot.Nc_15_30k, a=100, b=22.295958965, c=-5.916493801
⊞ 📊 Gplot:  ncdot.NC_30kplus, a=100, b=20.048145914, c=-5.386459176
⊞ 📊 Gplot:  ncdot.SR_0_1k_BSS, a=100, b=22.163870234, c=-5.211135908
⊞ 📊 Gplot:  ncdot.SR_0_1k_BSR, a=100, b=20.954934774, c= -5.78949075
⊞ 📊 Gplot:  ncdot.SR_1_5k_BSR, a=100, b=25.993358977, c=-8.161815865
⊞ 📊 Gplot:  ncdot.SR_5_15k_BSR, a=100, b=27.524327018, c=-7.430428573
⊞ 📊 Gplot:  ncdot.SR_15kplus_BSR, a=100, b=23.730487986, c=-5.285503223
⊞ 📊 Gplot:  ncdot.SR_0_1k_PS, a=100, b= 27.81288517, c=-5.274313916
⊞ 📊 Gplot:  ncdot.SR_0_1k_PR, a=100, b=25.004929854, c=-5.452294411
⊞ 📊 Gplot:  ncdot.SR_1_5k_PR, a=100, b=23.328193291, c=-5.394356716
⊞ 📊 Gplot:  ncdot.SR_5_15k_PR, a=100, b=25.080993229, c=-6.113287416
⊞ 📊 Gplot:  ncdot.SR_15kplus_PR, a=100, b=25.504207641, c=-5.990675332
```

Figure 15. SAS Output of Initial Estimates of Variables *a, b*, and *c*

Effects of Variables *a, b*, and *c* on Curvature

It was observed that the *a* value determines the starting point of the curve, the *b* value determines the horizontal shift of the curve, and the *c* value determines the slope of the curve (Figures 16 and 17). To conduct nonlinear regression, at least one variable must be allowed to change. Since the performance curve is always going through the (0, 100) point, the initial estimate of *a* is a constant, 100. The only value that could be varied for sigmoidal curves is either the *b* or the *c* value; the next step is to determine which value can be allowed to vary.

The processes for determining which variable should be allowed to change began by examining the curves plotted with different initial estimates. To what extent the curves shift horizontally determines how quickly the roadway deteriorates, and this is the focus of this research project. Therefore, it was decided to fix *a* (the curve's starting point, assigning an initial value of 100) and *c* (the slope of the curve), and allow *b* (horizontal shift of the curve) to change. The statistical software SAS was used to perform the nonlinear regression analysis.
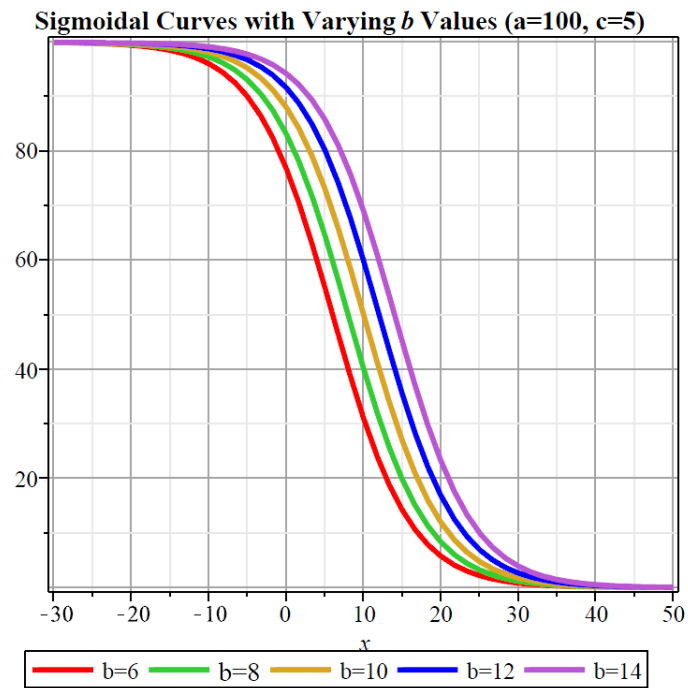
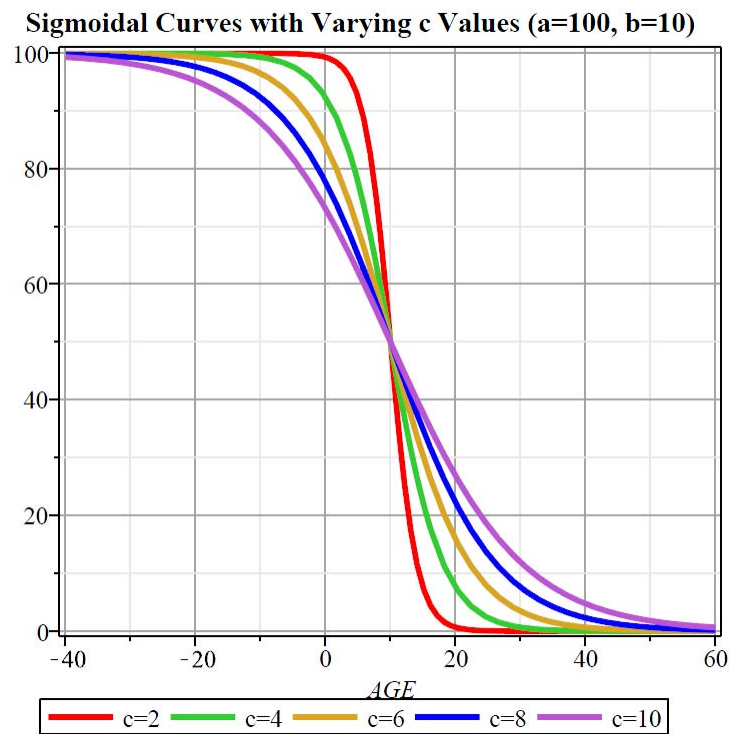Figure 15: The Effect of the *b* Values on Curvature

Figure 16: The Effect of the *c* Values on Curvature

The parameters of the final sigmoidal performance models are presented in Table 3. The model curves are presented in Appendix A.

Table 3: Sigmoidal Performance Models Parameters for
Asphalt Pavements

Family	a	b	c
Interstate 0-50k	103	13.279338	-3.90298117
Interstate 50kplus	106.5	11.543032	-4.22120151
US 0-5k	111	10.696665	-4.84709871
US 5-15k	112	10.680751	-5.08752204
US 15-30k	111	11.410580	-5.22795058
US 30kplus	110	13.800296	-5.94639491
NC 0-1k	109	11.514693	-4.77975216
NC 1-5k	109	11.139896	-4.60677705
NC 5-15k	116	10.147803	-5.51110763
NC 15kplus	113	11.610107	-5.69966240
SR 0-1k BSS	109	12.276801	-5.20011550
SR 0-1k BSR	114	10.565166	-5.43811337
SR 1kplus BSR	153	4.897949	-7.75560091
SR 0-1k PS	105	18.966769	-5.75770043
SR 0-1k PR	105	17.064609	-5.80059901
SR 1-5k PR	107	14.592391	-5.48888438
SR 5-15k PR	112	13.323878	-6.31525169
SR 15kplus PR	113	14.553692	-7.20789683

4.2 Development of Sigmoidal Performance Models for JCP Pavements

Different from the performance models developed for asphalt pavement families, the JCP performance models were created by combining all the datasets together. Family models were not developed mainly because of the small sample size of JCP pavements. No new NC JCP routes have been built in North Carolina for a long time, thus NC routes were not included in the analysis. Condition data collected from 1975 forward were used because more modern pavement designs were adopted in that year.

Age of JCP roadways was not reset during the data cleansing process. The reason was that the JCP pavements have a much longer service life than asphalt pavements. It was observed that if a JCP pavement's age is reset, the model curve becomes fairly steep (PCR would drop to 70 in the 7th or 8th year). The nonlinear regression analysis process was performed in a similar manner to develop the sigmoidal model. The results are shown in Table 4 and Figure 18.

Table 4: Sigmoidal Performance Models Parameters for JCP Pavements

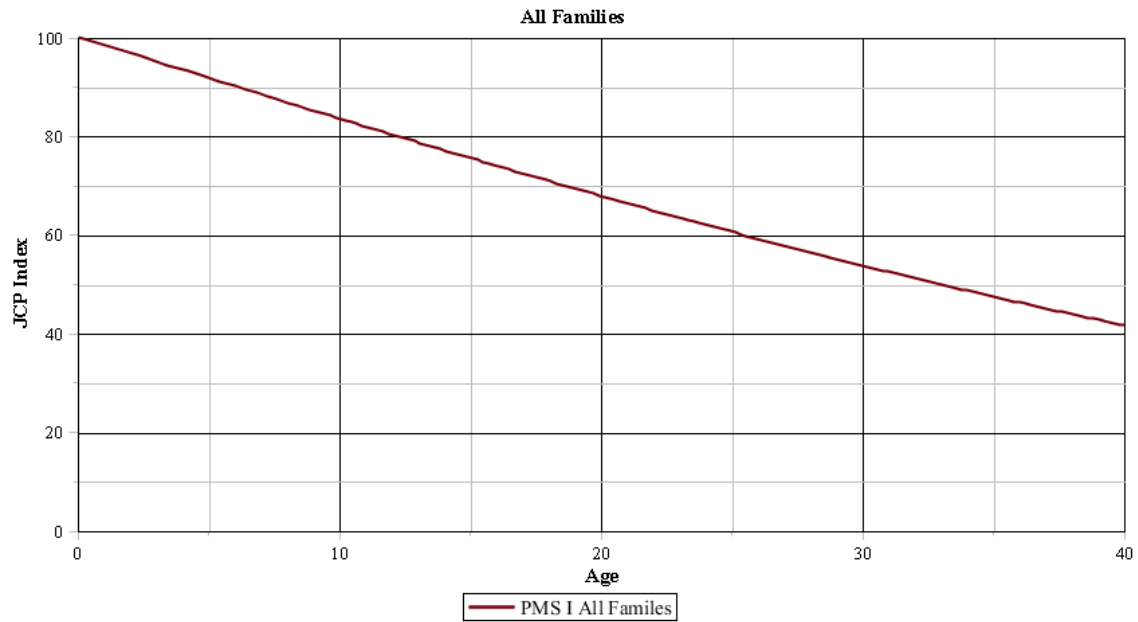| Family	a	b	c
Interstate, US, SR	200	-0.144846685	-29.8908026

Figure 18: JCP performance curve

CHAPTER 5 PAVEMENT DISTRESS MODELS

Pavement distress models depict relationships between distress index values and pavement age. Different methods were used to develop distress models for different distresses, as described in the following sections.

5.1 Alligator Cracking Models

According to the NCDOT Pavement Condition Survey Manual [39], alligator cracking is rated as "Percentage of the section exhibiting each of four severity levels: N = None, L = Light, M = Moderate, and S = Severe." Among the condition data collected by the NCDOT PMU, alligator cracking ratings are the only continuous data (i.e., percentages), all other distress ratings are categorical (i.e., None/Light/Moderate/Severe, or N/L/M/S).

Since each roadway section has four numeric alligator cracking ratings, e.g., a SR route has 60%/20%/15%/5% of N/L/M/S, respectively, it is necessary to calculate a composite index value that can represent the overall alligator cracking condition of this roadway section. After doing this for all roadways, and regressing composite index values against pavement age, alligator cracking models can be developed.

The NCDOT PMU uses a Maximum Allowable Extent (MAE) spreadsheet (Figure 19) to perform test computations of alligator cracking index values. In this spreadsheet, L/M/S ratings are entered into the orange cells (i.e., low_sev_in, med_sev_in, and high_sev_in), and the composite index value is calculated and displayed in the yellow cell. In the example below (Figure 19), L/M/S ratings are 0, 20%, and 40%, respectively. The alligator cracking index value is calculated as 17.

MAE Amounts and Threshold Amounts are two sets of crucial thresholds. By definitions from the spreadsheet (Figure 19), MAE Amounts include low_sev_mae_in, med_sev_mae_in, and high_sev_mae_in, and these parameters are "the extent amounts that maximize deduction for that severity"; Threshold Amounts include low_sev_threshold_in, med_sev_threshold_in, and high_sev_threshold_in, and these parameters are "lowest possible score for that severity when it occurs alone."

In the example below (Figure 19), low_sev_mae_in, med_sev_mae_in, and high_sev_mae_in are 100, 80, and 50, respectively; low_sev_threshold_in, med_sev_threshold_in, and high_sev_threshold_in are 75, 40, and 0, respectively. It means that Light alligator cracking can be present up to 100% of the roadway section being surveyed, Moderate alligator cracking can be rated up to 80% (cracking exists in more than 80% of the roadway section should use 80%), and Severe alligator cracking can be rated up to 50% (cracking exists in more than 50% of the roadway section should use 50%). It should be noted that the rating in this section refers to as the percentage of observed cracking at the particular severity level. When a roadway section only has Light alligator cracking, and the rating is 100%, the composite index value is 75. Similarly, when a roadway section only has Moderate alligator cracking, and the rating is 80%, the composite index value is 40; and when a roadway section only has Severe alligator cracking, and the rating is 50%, the composite index value is 0.

In developing new alligator cracking models, the focus was to evaluate and adjust the MAE Amounts and the Threshold Amounts when necessary, such that the models can better fit the data. The premise of this process is that a) the current windshield data have large amounts of new information, therefore the MAE Amounts and the Threshold Amounts need to be adjusted; and b) the adjusted MAE Amounts and the Threshold Amounts should provide alligator cracking index values that have a similar distribution to the existing index. This is to ensure that a comparison of CBA results from new models and the ones from the existing models is meaningful.

f_mae(a.ALGTR_LOW_PCT,a.ALGTR_MDRT_PCT, a.ALGTR_HGH_PCT,null,100, 80, 50,75,40,0,0,0,0)

INPUTS	
OUTPUT	

Distress Values passed into the function. Distresses with less than three severities should pass null to low then med in that order. Function return MAE index with 100 as good 0 as bad

low_sev_in	0	
med_sev_in	20	*OK* - Sum distress total is 100 or less
high_sev_in	40	

The normalizing factor will normalize absolute distress amounts null indicates no normailzation required

normalizing_in	null

MAE Amounts (Low Med and High) are the Extent amounts that maximize deduction for that severity

low_sev_mae_in	100
med_sev_mae_in	80
high_sev_mae_in	50

Threshold Amounts are lowest possible score for that severity when it occurs alone

low_sev_threshold_in	75
med_sev_threshold_in	40
high_sev_threshold_in	0

Begin deduct scores are the extent value when point deductions begin for each severity level

low_sev_begin	0	distr_low	0
med_sev_begin	0	distr_med	20
high_sev_begin	0	distr_high	40

d1	0		
d2	15	d2c	15
d3	80	d3c	83

Alligator Cracking Index Value	17

Figure 19: MAE Functions for Alligator Cracking

In the example below, Interstate 0-50k was studied to illustrate the model development process. The first step was to obtain the distribution of the alligator cracking index (NC_AC_ALGTR_CRK_IND) calculated from the existing parameters (Figure 20). This distribution will be used later as the baseline distribution to select the appropriate MAE Amounts and the Threshold Amounts.
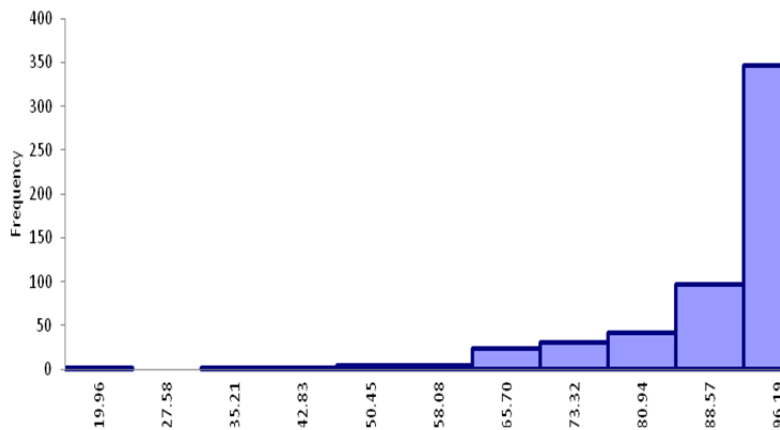
Figure 20: Histogram of NC_AC_ALGTR_CRK_IND

Then the distributions of Light, Moderate, and Severe ratings of alligator cracking (ALGTR_LOW_PCT, ALGTR_MDRT_PCT, and ALGTR_HGH_PCT in the data) were obtained using Palisade@Risk. These distributions were then assigned to the corresponding cells in the spreadsheet, i.e., low_sev_in, med_sev_in, and high_sev_in cell (Figure 19). Then four Monte Carlo simulations were performed (10,000 iterations for each simulation) to check the impact of input values (low_sev_in, med_sev_in, and high_sev_in) on the index values (NC_AC_ALGTR_CRK_IND). Results of these 4 simulations are shown in Figures 21-24.
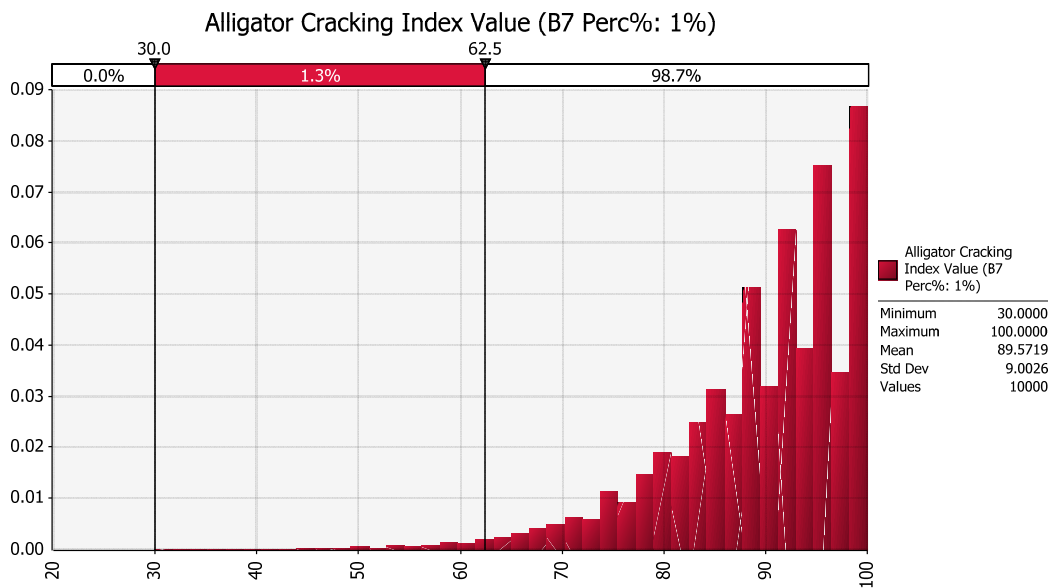

Figure 17: Monte Carlo Simulation #1: MAE 80, 60, 20; Thresholds 60, 30, 0
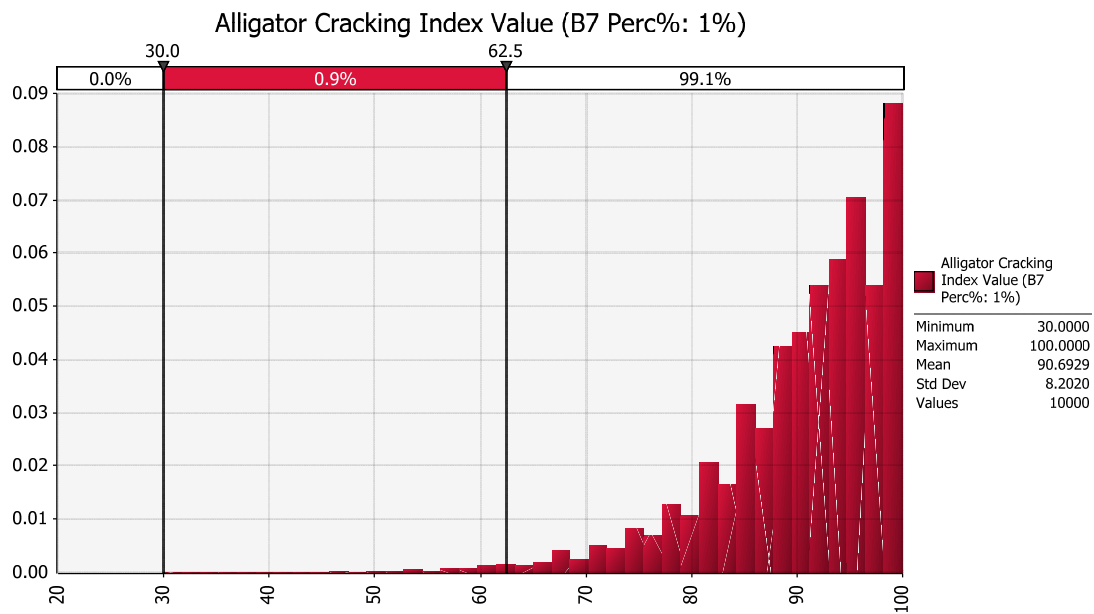
Figure 18: Monte Carlo Simulation #2: MAE 80, 60, 30; Thresholds 60, 30, 0
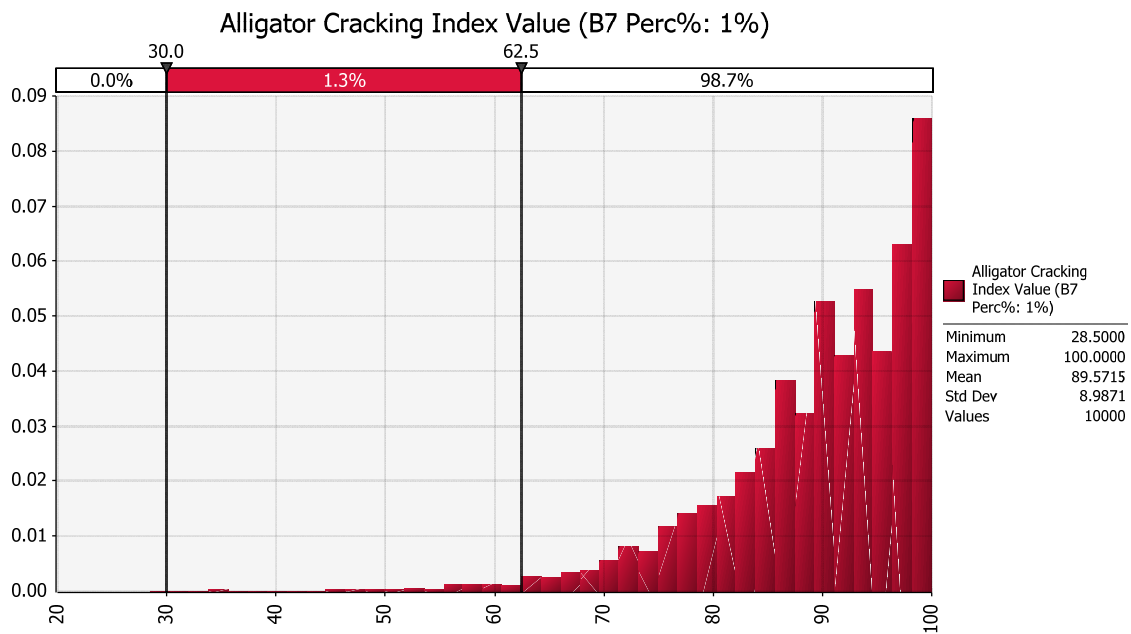
Figure 19: Monte Carlo Simulation #3: MAE 90, 60, 20; Thresholds 60, 30, 0
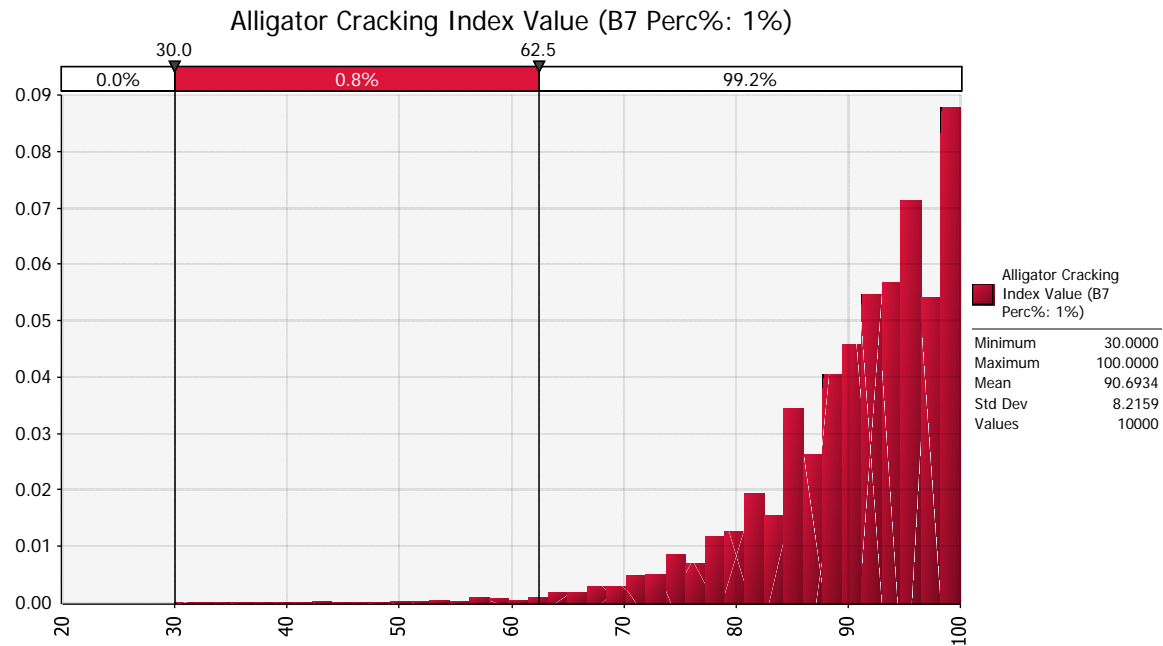
Figure 20: Monte Carlo Simulation #4: MAE 90, 60, 30; Thresholds 60, 30, 0

The distribution of alligator cracking index in simulation #3 matched the existing one in Figure 21 closely. Thus the parameters used in simulation #3 were used to develop alligator cracking models (Figure 25). The model developing process was the same as the one used for developing asphalt performance models. Table 5 summarizes alligator cracking model parameters. Model curves are included in Appendix B.

```
low_sev_mae_in=90;
med_sev_mae_in=60;
high_sev_mae_in=20;

low_sev_threshold_in=60;
med_sev_threshold_in=30;
high_sev_threshold_in=0;
```

Figure 21: MAE Values and Thresholds

Table 5: Parameters of Alligator Cracking Models

Family	a	b	c
Interstate 0-50k	101.5	14.0211056	-3.53095802
Interstate 50kplus	100	12.6607472	-2.29018097
US 0-5k	104	11.612373	-3.58275199
US 5-15k	106	11.5795503	-4.18042773
US 15-30k	105	12.3778905	-4.23437947
US 30kplus	106	14.9975902	-5.40762521
NC 0-1k	104	11.4065889	-3.48094943
NC 1-5k	104	11.1023861	-3.44273936
NC 5-15k	107	11.336956	-4.23571034
NC 15kplus	106	10.9351767	-3.95019747
SR 0-1k BSS	104	13.072674	-4.04117461
SR 0-1k BSR	104	13.5579605	-4.20618266
SR 1kplus BSR	107	15.6673761	-5.89713991
SR 0-1k PS	102	20.3212437	-5.31060197
SR 0-1k PR	102	17.4718827	-4.66530073
SR 1-5k PR	103	15.1340476	-4.36651276
SR 5-15k PR	105	14.3880108	-4.91391038
SR 15kplus PR	107	12.7571909	-4.78183054

5.2 Transverse Cracking Models

According to the NCDOT Pavement Condition Survey manual, transverse cracking is "Block/Transverse/Reflective Cracking, rated with one letter of either N = None, L = Light, M = Moderate, or S = Severe." Thus transverse cracking ratings can only take one of the four possible values (N/L/M/S), and the counts of the number of different values were collected. This means that transverse cracking ratings are categorical data with an ordinal ranking.

Among 7 types of performance model forms that are accepted by the NCDOT PMS (Figure 11), the Piecewise Linear (PL) model is the most appropriate one to describe how a pavement surface deteriorates over time: during the first several years of its service life, a pavement section has no cracks; then cracks appear, grow, and progress from a lower severity level to a higher one. PL models use straight lines between solved coordinates to describe different rates of deterioration over different ranges of the independent variable (in a PMS the independent variable is usually age of pavements). An example of a PL model is shown in Figure 26. In this figure, the solved coordinates are called breakpoints (i.e., A, B, and C points). These breakpoints graphically represent coordinates where the slope of the linear function changes. Between two consecutive breakpoints, the rate of deterioration remains constant until the next discontinuity.
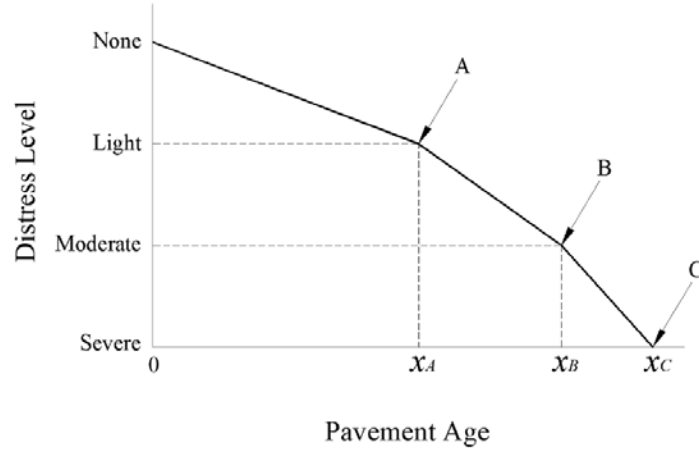
Figure 22: An Example of a Piecewise Linear Model

In Figure 26, the A point represents the pavement age when more Moderate transverse cracking starts to be observed. In other words, when pavement age is older than x_A, the probability of observing Moderate transverse cracking is greater than the probability of observing Light transverse cracking. Therefore, if the probability curves of Light and Moderate transverse cracking can be plotted, their intersection can then be determined. From this intersection, the corresponding pavement age x_A can be obtained. This provides the ordinates of the A point in Figure 26. Similarly, the ordinates of the B and C points can be obtained. With these information, a PL model is developed.

The development of transverse cracking models involved several steps.

1. Perform categorical data analysis to calculate individual distress level probabilities. In order to predict a variable with more than two possible ordinal levels, an extension of the logistic regression model, ordinal logistic regression models was used. Let Y be an ordinal variable, and let $P(Y \leq j)$ denote the probability that Y falls in level j or below. Essentially $P(Y \leq j)$ is a cumulative probability. Its formula can be written as:

$$P(Y \leq j) = P(Y = 1) + \cdots + P(Y = j),$$

where $j = 1, 2, \ldots (J-1)$, J is the total number of levels that Y can have.

The ratio of cumulative probabilities can be described by the cumulative logistic regression formula:

$$\log\left[\frac{P(Y \leq j)}{1 - P(Y \leq j)}\right] = \log\left[\frac{P(Y \leq j)}{P(Y > j)}\right] = \alpha_j + \beta x,$$

where $j = 1, 2, \ldots (J-1)$, α_j and β are coefficients.

Essentially this formula treats the variable as binary by considering whether the variable falls into the "*j* or below" category or the "above *j*" category. An ordinal logistic regression can be conducted to obtain the coefficients α_j and β. Then individual distress level probabilities can be calculated.

2. Plot individual distress level probability curves (probabilities over age) and find the intersections. An example of the probability curves is shown in Figure 27. The red curve is the probability curve of None transverse cracking, the green curve is for Light transverse cracking, the yellow curve is for Moderate transverse cracking, and the blue curve is for Severe transverse cracking. The intersections of these four curves are determined. As discussed before, these intersections are breakpoints of a piecewise linear curve.

3. Develop the piecewise linear curve by connecting these breakpoints. When a pavement section is newly constructed or treated (when its age is zero), there is no cracks. Thus the start point of the piecewise linear curve is always (*0, None*). Since transverse cracking has 4 distress severity levels (N/L/M/S), there are a total of 4 probability curves and 3 breakpoints. The ordinates of other 3 breakpoints are: (x_A, *Light*), (x_B, *Moderate*), and (x_C, *Severe*). The NCDOT PMU uses a transverse cracking index value of 80 to represent Light, 40 to represent Moderate, and 0 to represent Severe. Therefore, the ordinates of breakpoints can also be written as (x_A, *80*), (x_B, *40*), and (x_C, *0*). Using the Interstate 0-50k family as an example, the model development process is illustrated in Figures 28 and 29.
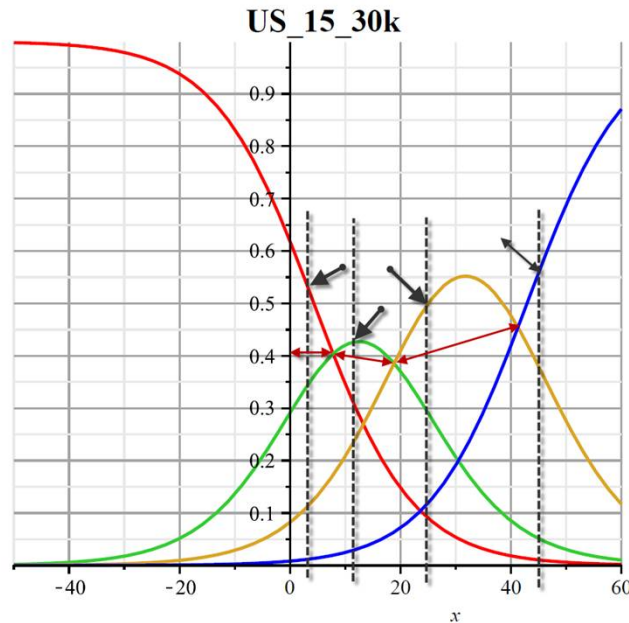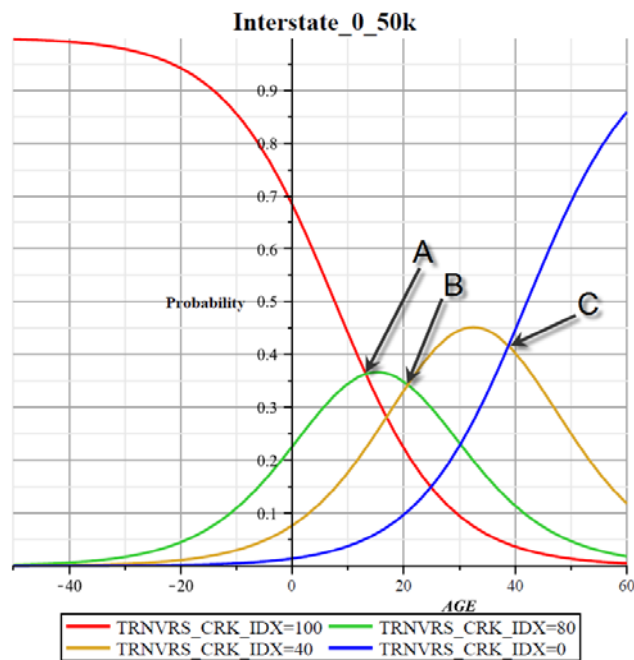

Figure 23: US 15_30k Probability vs. Age

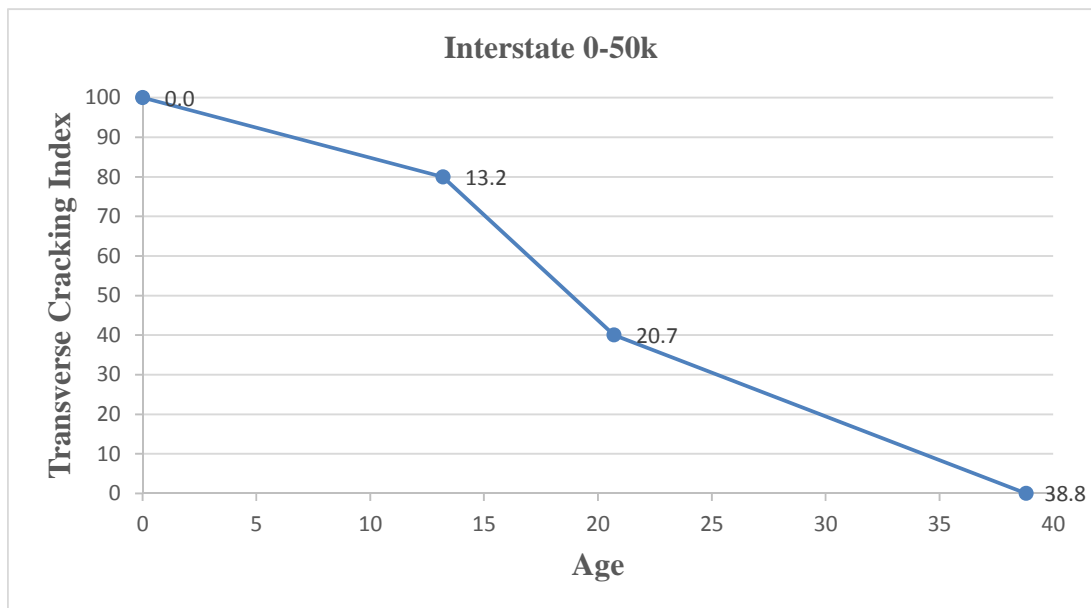Figure 24: Interstate 0-50k Probability vs. Age

Figure 25: Transverse Cracking Models of Interstate 0-50k

Transverse cracking model parameters are tabulated in Table 6. The model curves are included in Appendix C.

Table 6: Parameters of Transverse Cracking Models

Family	A (AGE, IDX=80)	B (AGE, IDX=40)	C (AGE, IDX=0)
Interstate 0-50k	13.2	20.7	38.8
Interstate 50kplus	10.9	15.7	27.6
US 0-5k	4.9	12.7	38.8
US 5-15k	7.7	14.6	39.0
US 15-30k	7.8	18.9	41.3
US 30kplus	13.1	27.2	63.7
NC 0-1k	14.8	21.8	49.3
NC 1-5k	5.1	15.5	43.1
NC 5-15k	4.6	15.7	43.0
NC 15kplus	11.7	20.7	55.2
SR 0-1k BSS	25.3	30.7	54.0
SR 0-1k BSR	37.5	43.6	95.8
SR 1kplus BSR	31.1	49.7	139.1
SR 0-1k PS	17.7	27.9	50.9
SR 0-1k PR	15.9	26.3	57.0
SR 1-5k PR	12.4	25.0	54.8
SR 5-15k PR	12.0	27.7	55.0
SR 15kplus PR	12.5	28.2	51.4

5.3 Oxidation Models

Oxidation is "rated with one of the two letters, (N, S)." Ratings for oxidation are also categorical data with an ordinal ranking. Therefore the same method used for transverse tracking was used for oxidation. The difference is that there are only two oxidation distress levels, thus two probability curves were plotted, and one intersection were obtained (Figures 30 and 31). In addition, it was noticed that there were no severe ratings for BSS, BSR roadways.
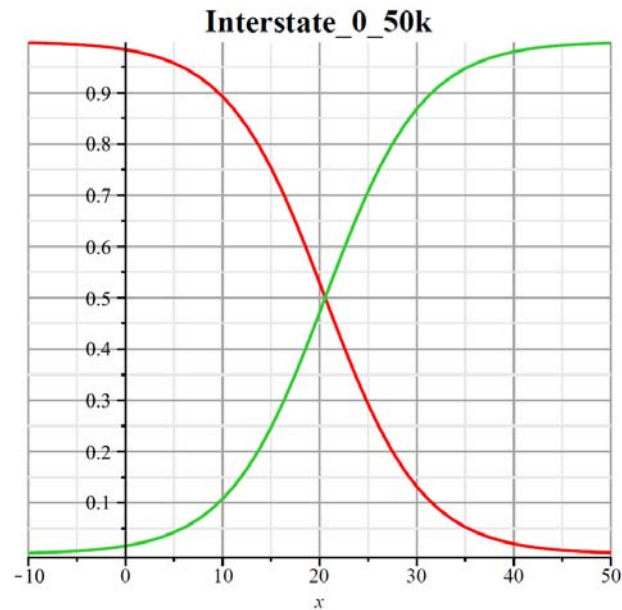
Figure 26: Oxidation Probability Curves
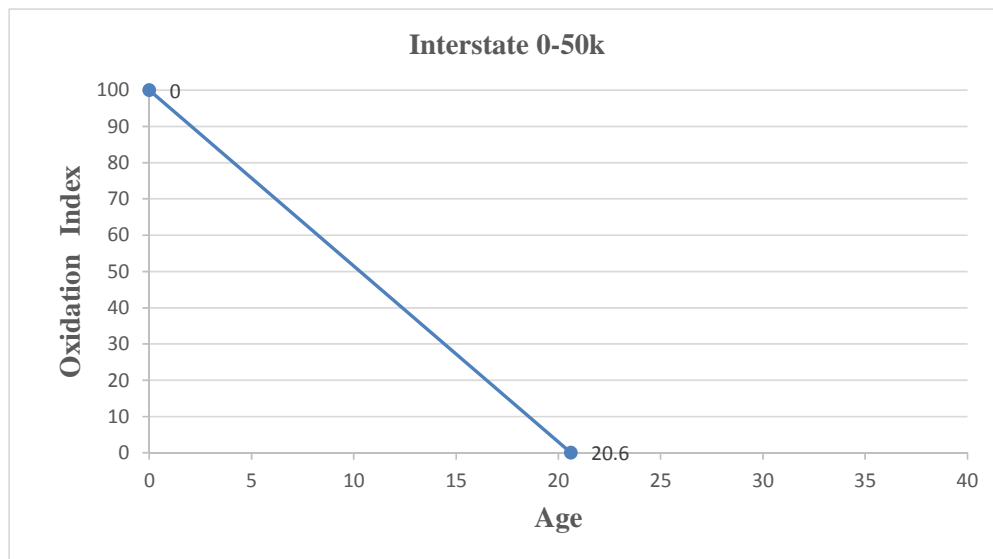
Figure 27: Oxidation Piecewise Linear Curve of Interstate 0-50k

Oxidation model parameters are tabulated in Table 7. The model curves are included in Appendix D.

Table 7: Parameters of Oxidation Models

Family	A (AGE, IDX=0)
Interstate 0-50k	20.6
Interstate 50kplus	19.3
US 0-5k	28.0
US 5-15k	36.7
US 15-30k	32.3
US 30kplus	53.9
NC 0-1k	29.7
NC 1-5k	30.3
NC 5-15k	37.8
NC 15kplus	48.3
SR 0-1k BSS	N/A
SR 0-1k BSR	N/A
SR 1kplus BSR	N/A
SR 0-1k PS	30.8
SR 0-1k PR	30.6
SR 1-5k PR	38.0
SR 5-15k PR	47.2
SR 15kplus PR	29.2

5.4 Bleeding Models

Bleeding is "rated with one of the four letters, (N, L, M, S)." Ratings for bleeding are also categorical data with an ordinal ranking. Therefore the same method used for transverse tracking was used for bleeding. It was observed that all Interstate routes' ratings were 100's, thus Interstate families' curves could not be developed. For US, NC and SR routes, the results were not satisfactory because there were not enough data to support informative conclusions (Figures 32 through 35).
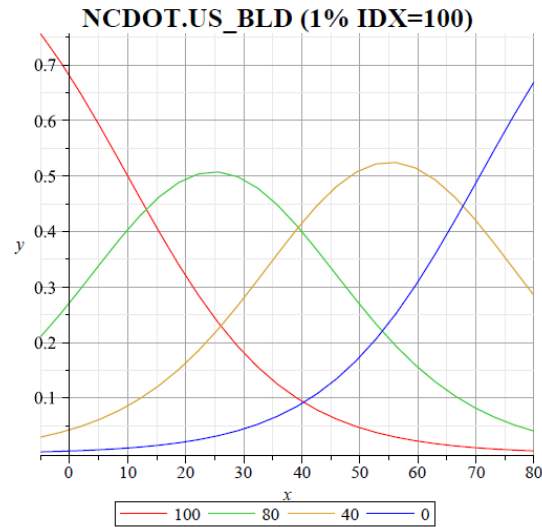
NCDOT.US_BLD (1% IDX=100)

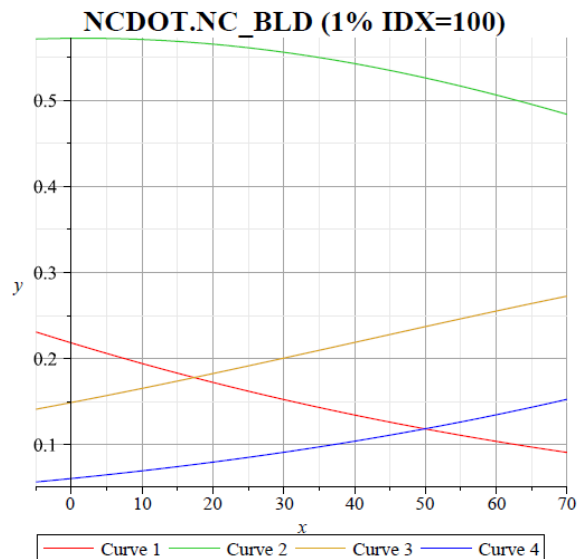Figure 28: US Bleeding Probability vs. Age

NCDOT.NC_BLD (1% IDX=100)

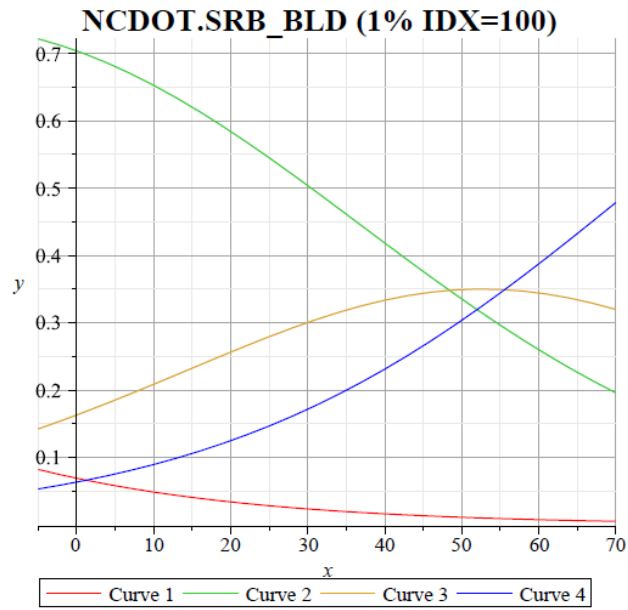Figure 29: NC Bleeding Probability vs. Age
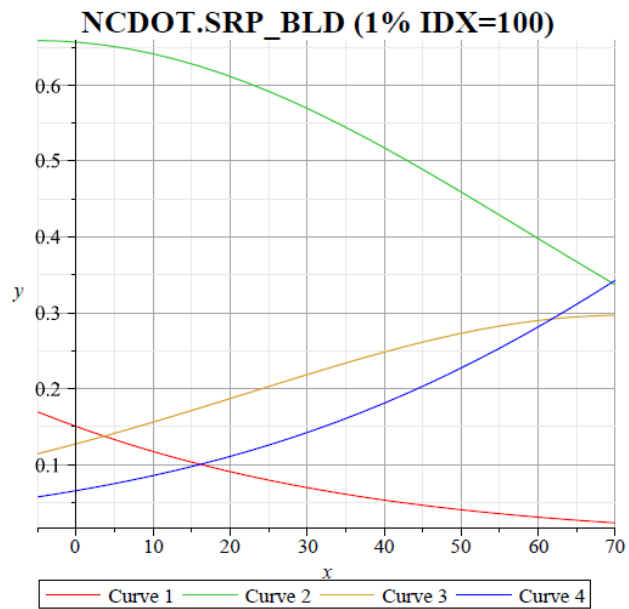
Figure 30: SR Bleeding Probability vs. Age

Figure 31: SRP Bleeding Probability vs. Age

5.5 Patching Models

Patching is "rated with one of the four letters, (N, L, M, S)." Ratings for patching are also categorical data with an ordinal ranking. Therefore the same method used for transverse tracking was used for patching.

It was observed that the patching data have significantly more None and Light than Moderate and Severe. This means that a roadway did not get an "L" rating unless it has been patched very extensively. The resulting piecewise curves developed using all the raw data were not reasonable. To address this issue, 10% of None and Severe ratings were randomly selected to be included in the categorical analysis. It should be noted that the 10% was used to ensure that the sample size of None and Light ratings is approximately the same as that of Moderate and Severe ratings. This way the models were unbiased because they were not overly affected by None and Light ratings. It was also observed that individual family curves were not reasonable. Therefore, 5 data sets (Interstate, US, NC, SR_B, and SR_P) were combined and analyzed, and corresponding piecewise curves were developed. Figures 36 and 37 show the probability curves and the piecewise linear curve of the Interstate family. Patching model parameters are tabulated in Table 8. The model curves are included in Appendix F.
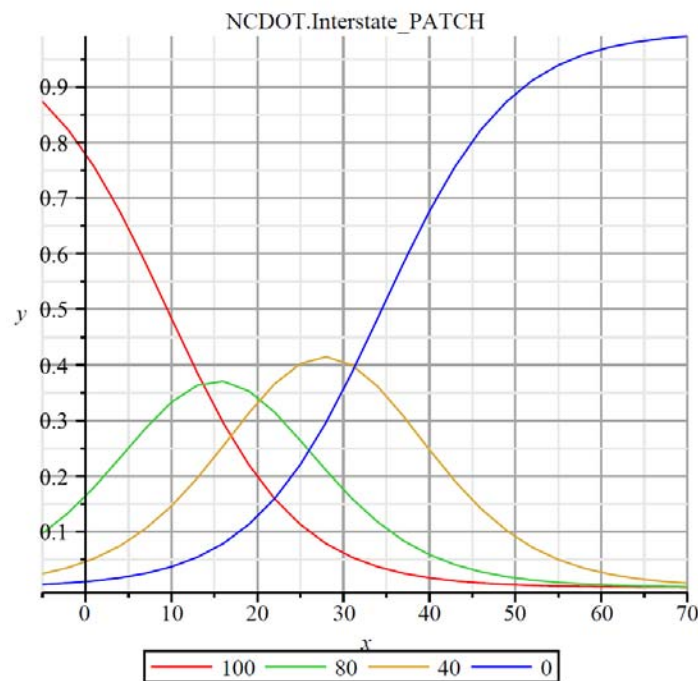
Figure 32: Probability vs. Age of Patching (Interstate)
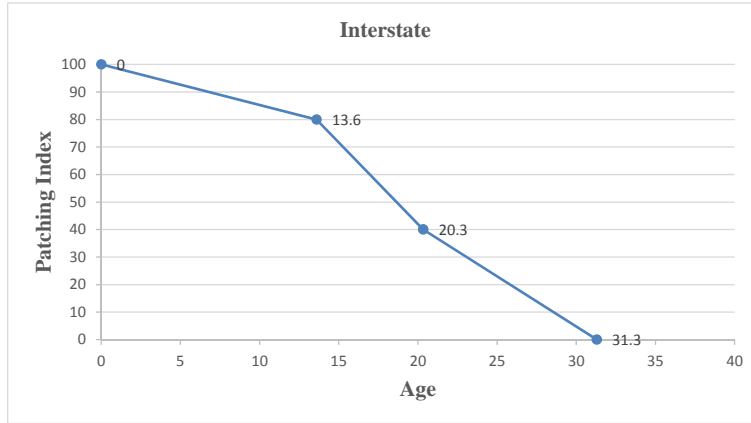
Figure 33: Interstate Patching Index vs. Age

Table 8: Parameters of Patching Models

Family	A (AGE, IDX=80)	B (AGE, IDX=40)	C (AGE, IDX=0)
Interstate	13.6	20.3	31.3
US	12.9	26.5	53.5
NC	9.3	20.9	43.9
SR_B	8.3	22.5	44.7
SR_P	12.4	30.8	62.0

5.6 Ride Models

Ride Quality is "rated with one of the three letters as follows: L = Light (Average), M = Moderate (Slightly Rough), S = Severe (Rough)." Ratings for ride quality are also categorical data with an ordinal ranking. Therefore the same method used for transverse tracking was used for ride quality.

Ride model parameters are tabulated in Table 9. The model curves are included in Appendix H.

Table 9: Parameters of Ride Models

Family	A (AGE, IDX=50)	B (AGE, IDX=0)
Interstate	14.2	N/A
US	10.9	42.9
NC	11.1	41.5
SR_B	5.0	56.9
SR_P	18.7	55.2

5.7 Rutting Models

Rutting is "rated with one of the four letters, (N, L, M, S)." Ratings for rutting are also categorical data with an ordinal ranking. Therefore the same method used for transverse tracking was used for rutting. In addition, an overall SR curve (including both SR_B and SR_P) was developed. Figures 38 and 39 show the model development process for the Interstate family.
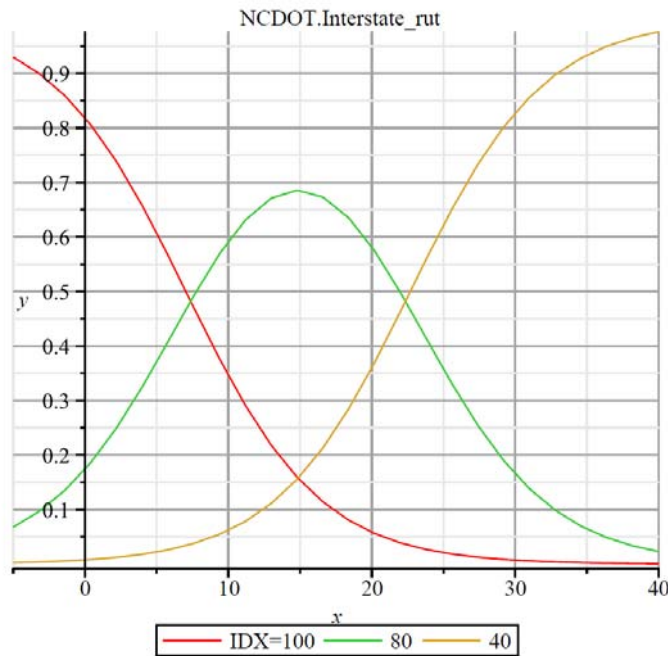
Figure 34: Interstate Rut Probability vs. Age

Figure 35: Interstate Rut Index vs. Age

Rutting model parameters are tabulated in Table 10. The model curves are included in Appendix G.

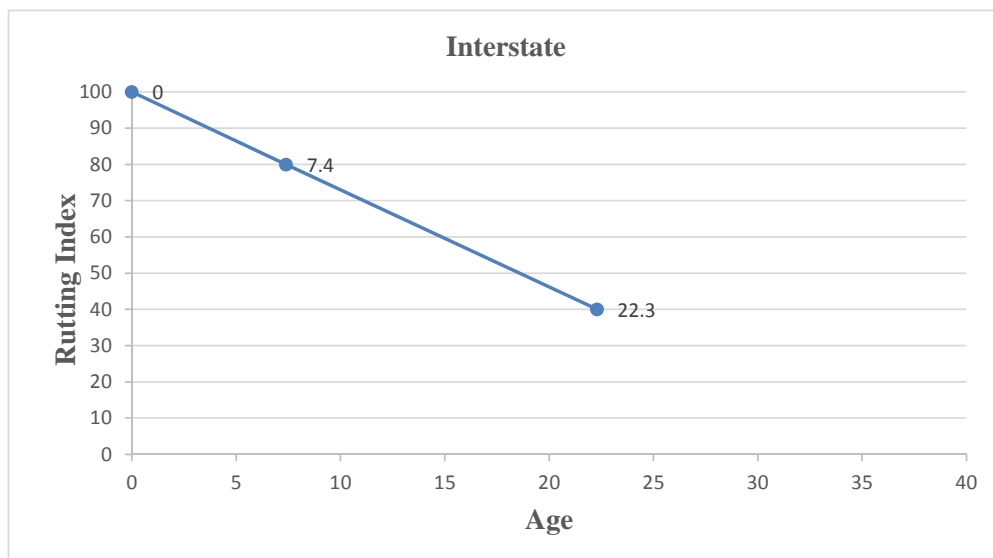Table 10: Parameters of Rutting Models

Family	A (AGE, IDX=80)	B (AGE, IDX=40)	C (AGE, IDX=0)
Interstate	7.4	22.3	N/A
US	13.7	31.6	53.0
NC	15.0	35.2	56.8
SR_B	9.5	36.6	71.1
SR_P	28.8	53.6	80.5

CHAPTER 6 WEIGHT FACTORS FOR COST BENEFIT ANALYSIS (CBA)

In the NCDOT PMS, Cost Benefit Analysis (CBA) has been used to conduct funding analyses. Essentially CBA is an optimization process which recommends a group of candidate roadways for maintenance. The optimization process ensures that the total construction costs are within the budget constraints, meanwhile the benefit of maintaining this group of roadways is maximized.

The estimated benefit of a proposed maintenance activity is largely determined by the roadway's weight factor (currently the NCDOT uses 2.0 for Interstate, 1.66 for US routes, 1.33 for NC routes, and 1.0 for Secondary routes). Once the new deterioration models are developed and implemented, a new set of CBA weight factors should be developed in order to avoid underestimating or overestimating the maintenance benefit.

Steps for the determination of weight factors include:

1. Identify a set of possible weight factors;
2. Run CBA using this set of factors;
3. Derive the relationship between the NCDOT Rating Number vs. Weight Factor; and
4. Determine the ideal weight factors.

Identify a Set of Possible Weight Factors

To generate a candidate pool, upper and lower limits of weight factors for Interstate, US, NC, and SR were determined as (1.1, 3.0), (1.1, 2.66), (1.1, 2.33), and (1.0, 1.0), respectively, with an 0.1 increments. This means, for example, Interstate weight factors can take the values of 1.1, 1.2, 1.3, ..., 2.8, 2.9, 3.0. To be compatible with the existing weight factors, SR's weight factor remains to be 1.0.

A total of 5,236 sets of possible weight factors were obtained after all combinations were considered. The condition that weight factors of Interstate, US, NC, and SR routes should be in descending order should be met in a PMS. Applying this constraint, there were 1,098 sets of valid weight factors. The correlation between weight factors were checked in order to avoid the multicollinearity issue (e.g., weight factors for Interstate are closely related to weight factors for US, etc.). Eventually 33 sets of weight factors were selected to run CBA, as shown in Table 11.

Run CBA using this set of factors

The abovementioned 33 sets of weight factors were used to run CBA for all 14 Divisions in North Carolina. That was a total of 462 CBA. The results are included in Appendices J and K.

CBA configurations were determined after consulting NCDOT engineers, as follows:

- Analysis length: 3 years;
- Cost constraints (the divisions and their corresponding allocated annual funding were carefully determined to allow typical deterioration of the roadway network, without over- or underfunding maintenance activities):

- – Divisions 1, 2, 3, 8, 11, 12, 13, and 14: $25 million per year;
- – Division 4: $30 million per year; and
- – Divisions 5 and 10: $35 million per year.
- Target constraint: the NCDOT Rating Number should be between 0.7 and 0.8. This means that the overall NCDOT pavement performance rating should be between 70 to 80 once the proposed maintenance activities are implemented within three years.

Table 11: Candidate Weight Factors

Interstate	US	NC	SR
2.0	1.7	1.3	1.0
1.3	1.2	1.1	1.0
3.0	2.7	2.3	1.0
1.8	1.4	1.2	1.0
2.9	1.5	1.3	1.0
2.4	2.1	1.8	1.0
2.7	2.1	1.4	1.0
2.1	1.8	1.1	1.0
2.2	2.0	1.8	1.0
2.7	2.3	2.0	1.0
2.9	1.4	1.3	1.0
2.6	2.4	1.6	1.0
2.0	1.5	1.2	1.0
2.9	1.7	1.1	1.0
1.9	1.4	1.3	1.0
2.9	2.5	1.7	1.0
1.8	1.7	1.5	1.0
2.9	2.6	2.1	1.0
2.6	1.5	1.3	1.0
2.8	2.5	1.3	1.0
3.0	2.6	1.6	1.0
2.8	2.4	1.4	1.0
1.9	1.8	1.1	1.0
2.5	2.2	1.3	1.0
2.2	2.1	1.3	1.0
2.8	1.7	1.3	1.0
2.4	2.0	1.3	1.0
2.3	2.1	1.9	1.0
3.0	2.6	1.2	1.0
3.0	1.9	1.7	1.0
2.4	1.8	1.3	1.0
2.2	1.8	1.2	1.0
1.7	1.4	1.3	1.0

Derive the relationship between the NCDOT Rating Number vs. Weight Factor

Regression analyses were conducted to derive the relationships between the NCDOT Rating Number and Weight Factors, for $25 M per year budget (Figure 40), $30 M per year budget (Figure 41), $35 M per year budget (Figure 42), and for all 14 Divisions (Figure 43).

Determine the ideal weight factors

Since weight factors of Interstate, US, NC, and SR routes should be in descending order, the intersection of the Interstate trend line and the US trend line (Figure 40) is the highest value that the NCDOT Rating Number can achieve. From this intersection downward, a horizontal line was drawn, and the x ordinates where this line meets the three trend lines are the corresponding weight factors (Tables 12, 13, 14, and 15). Note that in these tables, x1, x2, and x3 represent the weight factors for Interstate, US, and NC, respectively. As mentioned earlier, the weight factor for SR is 1.0.

Weight factors for Divisions 1, 2, 3, 8, 11, 12, 13, and 14 ($25 million per year), Division 4 ($30 million per year), and Divisions 5 and 10 ($35 million per year) are included in Tables 12, 13, and 14, respectively.

The following weight factors (highlighted in Table 15) are recommended to NCDOT engineers:

- All 14 Divisions: 2.00 for Interstate, 1.72 for US, and 1.23 for NC. Compared to the existing NCDOT weight factors (2.00 for Interstate, 1.66 for US, and 1.33 for NC), additional importance was applied to US routes.

Figure 36: NCDOT Rating Number vs. Weight Factor ($25 M per Year)

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Table 12: Weight Factors for the $25 M per Year Budget Scenario

	x	y
Intersection of Interstate and US	1.83607	0.74075

	Goal	x1	x2	x3
NCDOT Rating Number	0.7407	1.89	1.84	1.29
	0.7406	2.00	1.86	1.32
	0.7405	2.11	1.87	1.34
	0.7404	2.22	1.89	1.37
	0.7403	2.33	1.90	1.39
	0.7402	2.44	1.91	1.41
	0.7401	2.56	1.93	1.44
	0.7400	2.67	1.94	1.46

Figure 37: NCDOT Rating Number vs. Weight Factor ($30 M per Year)

Table 13: Weight Factors for the $30 M per Year Budget Scenario

	x	y
Intersection of US and NC	1.37306	0.7157

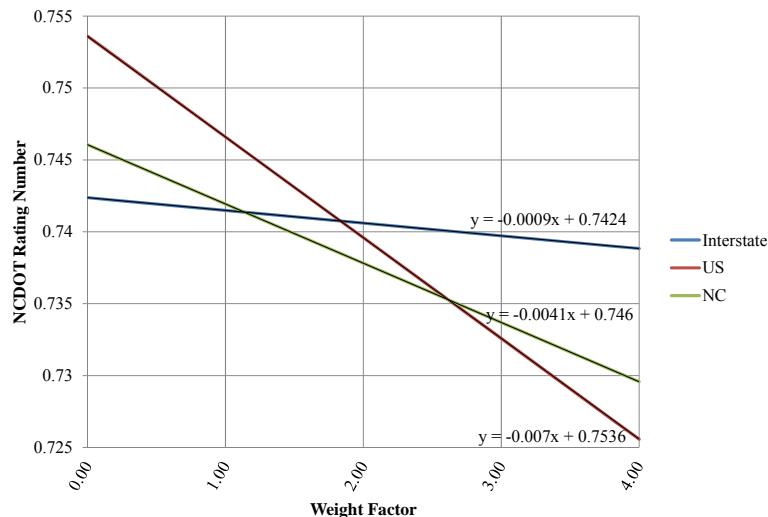|	Goal	x1	x2	x3
NCDOT Rating Number	0.7150	1.98	1.49	1.40
	0.7149	2.00	1.51	1.40
	0.7148	2.02	1.53	1.41
	0.7147	2.04	1.54	1.41
	0.7146	2.06	1.56	1.42
	0.7145	2.08	1.58	1.42
	0.7144	2.10	1.59	1.42
	0.7143	2.12	1.61	1.43

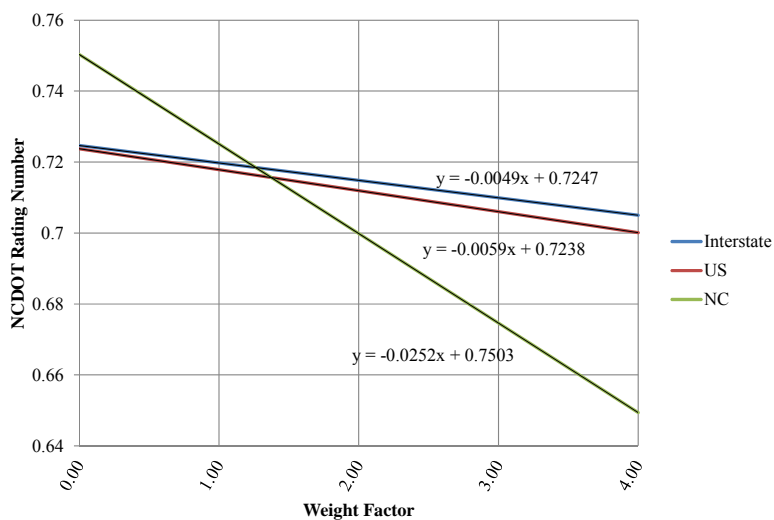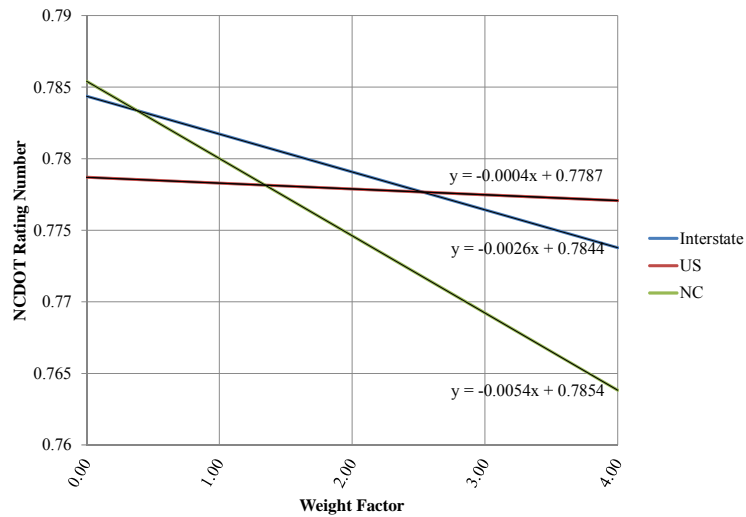

Figure 38: NCDOT Rating Number vs. Weight Factor ($35 M per Year)

Table 14: Weight Factors for the $35 M per Year Budget Scenario

	x	y
Intersection of Interstate and US	2.59091	0.77766

	Goal	x1	x2	x3
NCDOT Rating Number	0.7777	2.58	2.50	1.43
	0.7778	2.54	2.25	1.41
	0.7779	2.50	2.00	1.39
	0.7780	2.46	1.75	1.37
	0.7781	2.42	1.50	1.35
	0.7782	2.38	1.25	1.33
	0.7783	2.35	1.00	1.31
	0.7784	2.31	0.75	1.30
	0.7785	2.27	0.50	1.28
	0.7786	2.23	0.25	1.26
	0.7787	2.19	0.00	1.24

Figure 39: NCDOT Rating Number vs. Weight Factor (All 14 Divisions)

Table 15: Weight Factors for all 14 Divisions

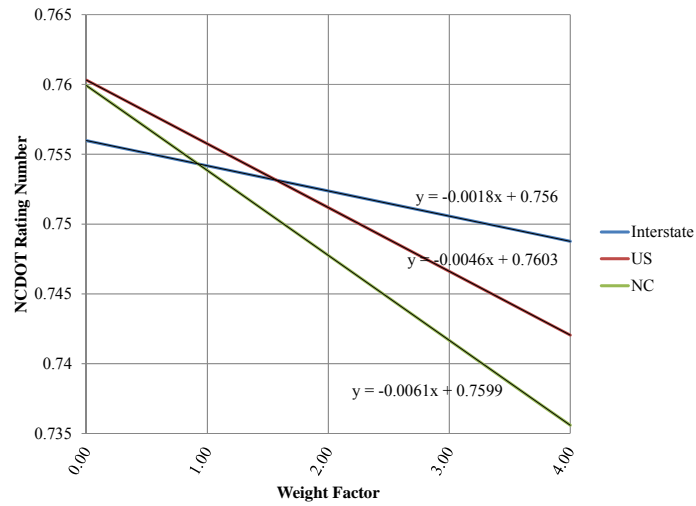|	x	y
Intersection of Interstate and US	1.53571	0.75324

	Goal	x1	x2	x3
NCDOT Rating Number	0.7532	1.56	1.54	1.10
	0.7531	1.61	1.57	1.11
	0.7530	1.67	1.59	1.13
	0.7529	1.72	1.61	1.15
	0.7528	1.78	1.63	1.16
	0.7527	1.83	1.65	1.18
	0.7526	1.89	1.67	1.20
	0.7525	1.94	1.70	1.21
	0.7524	2.00	1.72	1.23
	0.7523	2.06	1.74	1.25
	0.7522	2.11	1.76	1.26
	0.7521	2.17	1.78	1.28
	0.7520	2.22	1.80	1.30
	0.7519	2.28	1.83	1.31
	0.7518	2.33	1.85	1.33
	0.7517	2.39	1.87	1.34
	0.7516	2.44	1.89	1.36
	0.7515	2.50	1.91	1.38

The performance and distress models and new weight factors developed in this research project have been implemented in the NCDOT PMS by the engineers in the PMU. In addition, PMU Engineers evaluated the appropriateness of trigger points on the decision trees, and made significant adjustment to trigger values especially for alligator cracking. They also created an entirely separate decision tree using the update PCR models.

CHAPTER 7 DEVELOPMENT OF UPDATE GUIDELINES

A key requirement of a successful PMS is that performance and distress models and CBA should be updated regularly to reflect deterioration patterns and new roadway information, such as traffic volumes, new construction materials and pavement design. To achieve this, criteria that trigger updates of deterioration models and weight factors were defined, as follows:

<u>Performance Models</u>

Every two years when new pavement condition data become available, performance models should be evaluated by fitting them using the updated data (existing data plus new data). Since performance models are nonlinear models, the R-squared value is not the appropriate Goodness-of-Fit indicator. Instead, Standard Error of the Regression (S) should be used.

When the ratio of $S_{updated\_data}$ and $S_{existing\_data}$ is greater than 1.10, meaning a 10% increase in the standard error, it is recommended that new performance models should be developed. 10% was chosen as the criterion because any percentages greater than it is assumed to start having large impact on CBA. In this case, $S_{updated\_data}$ represents the standard error when fitting the updated data, $S_{existing\_data}$ represents the standard error when fitting the existing data.

<u>Distress Models</u>

Most distress models in the NCDOT PMS are piecewise linear models. Every two years when new pavement condition data become available, distress models should be checked by fitting them using the updated data (existing data plus new data). When the average shift of x ordinates (i.e., pavement age) of breakpoints is greater than 2 years, new distress models are recommended to be developed.

<u>Weight Factors for CBA</u>

CBA is largely dependent on performance models. Therefore whenever new performance models are developed, weight factors of CBA should be evaluated and updated if necessary. Every two years when new pavement condition data become available, CBA should be performed to check if the NCDOT Rating Number is between 0.7 and 0.8. If the NCDOT Rating Number is less than 0.7, weight factors of CBA should be updated.

<u>Procedures of evaluating and updating pavement deterioration models and weight factors</u>

In this study, pavement deterioration models and weight factors were developed and determined using more than 5,000 lines of SAS code, and SAS macros were extensively used to save a substantial amount of time and efforts that were required by various statistical analyses. Therefore, understanding how macro variables are resolved is key to the use of the products of this study. Researchers at UNC Charlotte can provide periodic evaluations of existing pavement deterioration models and weight factors, and meanwhile provide technical trainings to PMU personnel on how to update performance and distress models and weight factors using SAS.

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

This chapter presents conclusions of this research project and recommendations for further avenues of research.

8.1. Conclusions

- A data cleansing method was developed and successfully used to prepare the raw pavement condition data for developing performance and distress models. There were two types of abnormalities in the raw data: bogus data points due to human raters' subjectivity, and pavement age not being reset after treatments. The data cleansing method developed in this study was able to identify these abnormalities by comparing all three consecutive PCR ratings, remove the bogus data and reset pavement age.

- The sigmoidal model form is more appropriate than other forms accepted by the NCDOT PMS in predicting pavement performance and alligator cracking. The NCDOT PMS accepts 7 model forms, and all these forms were used to fit the performance data and the alligator cracking data. The sigmoidal model form described the deterioration trends much better.

- An approach to building piecewise linear distress models was successfully developed to process ordinal categorical distress ratings with more than two severity levels. An extensive literature review indicated that this approach was the first attempt to address this type of distress data. The approach considers the categorical nature of the distress data, uses ordinal logistic regression analysis to derive individual distress probabilities, and calculates ordinates of breakpoints for piecewise linear models.

- Large amounts of data are needed in order to develop reasonable deterioration models. In the NCDOT PMS, distress ratings and pavement age are stored in two separate databases. The data merging and cleansing process removed bogus ratings and observations of roadway sections that are very short in length, resulting in the final data set having a smaller sample size. This smaller sample size still fulfilled the strict sample size requirements of nonlinear regression analysis (sigmoidal models) and ordinal logistic analysis (piecewise linear models) because the NCDOT PMU's databases contain large amounts of historic condition data collected since 1985.

- Reasonable analysis length, cost and target constraints for CBA are crucial for determining appropriate weight factors. North Carolina has 14 Divisions. Because types and lengths of roadways managed by each Division are different, annual budget allocated to each Division varies. It appears that the same CBA assumptions should not be used for all divisions.

8.2 Recommendations

- To improve data quality for increased PMS performance, it is recommended that 1) raters should record maintenance activities when observed. This allows pavement age to be accurately reset instead of judging from the magnitudes of PCR jumps; and 2) a centralized database should be developed that contains both pavement performance ratings and pavement construction history. This database eliminates the need to merge multiple databases, and more importantly preserves pavement sections presenting valuable pavement performance information that otherwise are purged during the database merging process.

- For asphalt SR routes, a comparison of pavement performance between minor rehabilitation and major rehabilitation/construction/reconstruction is recommended. This comparison can add a new decision tree variable to the NCDOT PMS, which can enable a more accurate funding analysis.

- This research project focused on asphalt and JCP pavements, and composite pavements are considered as a part of asphalt pavements, even though they perform differently. It is recommended that deterioration models for composite pavements be developed in future efforts.

- Even though some SR routes carry significant amount of traffic, their performance was evaluated with other low volume SR routes. It is recommended that future deterioration models be developed based on roadway systems (e.g., AADT), and not classifications (Interstate, US, NC, and SR).

- It is recommended to subdivide the current 18 roadway families into three regions. The reason is that for example, Interstate 0-50k routes in the Mountains region perform differently than the ones in the Piedmont region, and similarly roadways belong to other families perform differently in different regions. Therefore, additional models (e.g., Interstate 0-50k_Mountains, Interstate 0-50k_Piedmont, and Interstate 0-50k_Coastal) should be developed, if possible, to enhance functionality of the NCDOT PMS.

- It is recommended that additional weight factors should be developed that consider highway use categories such as Statewide (National Highway System), Regional and Subregional (local) roads.
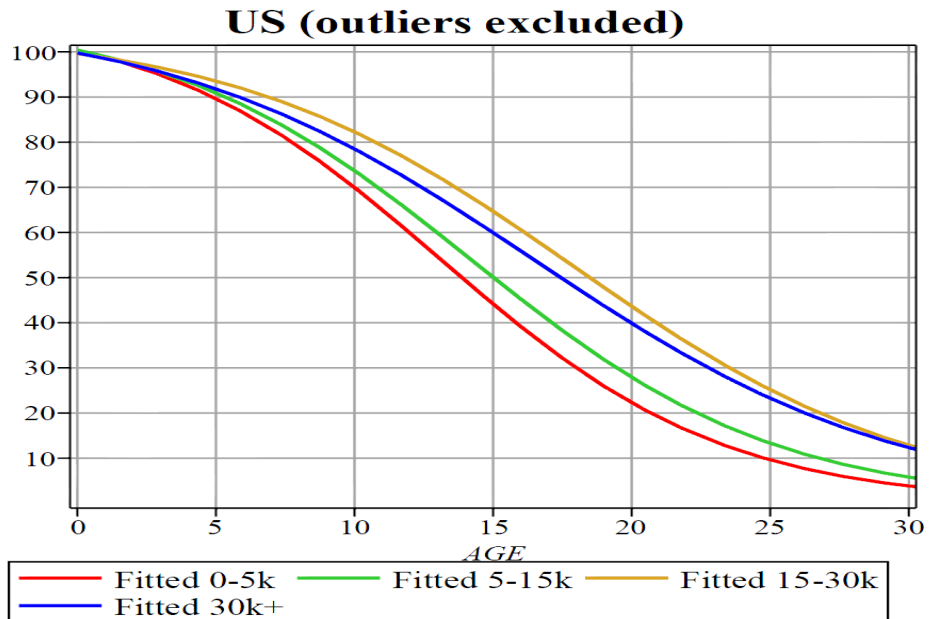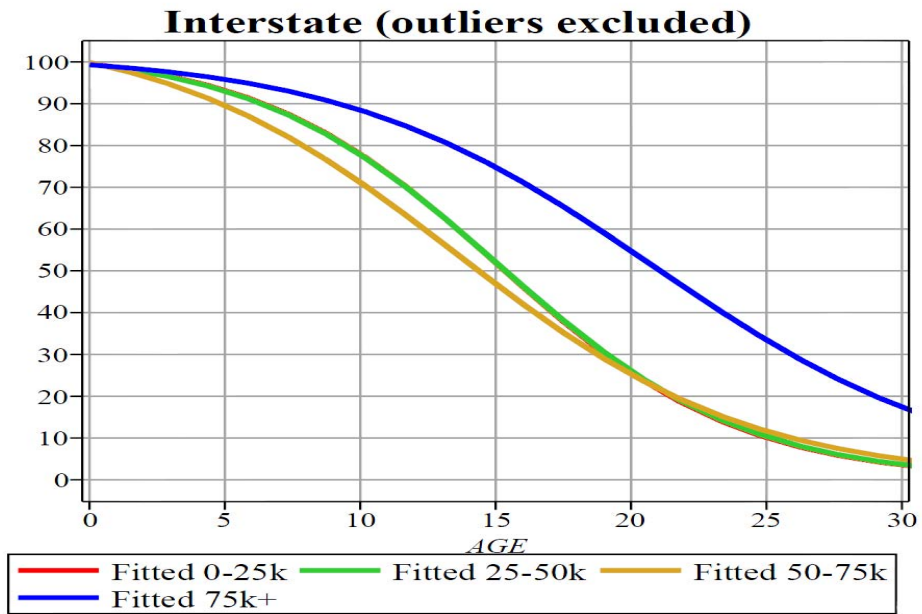
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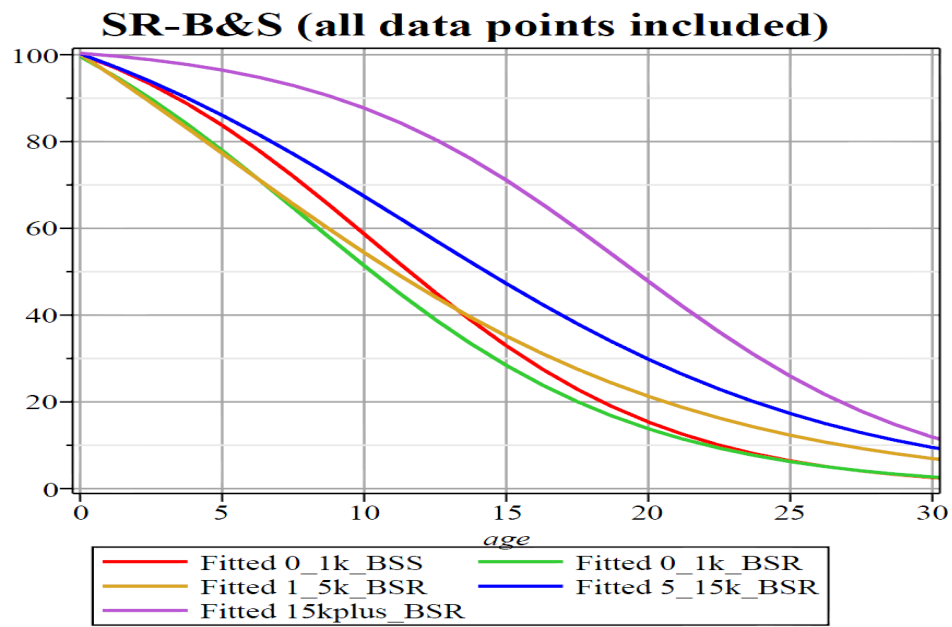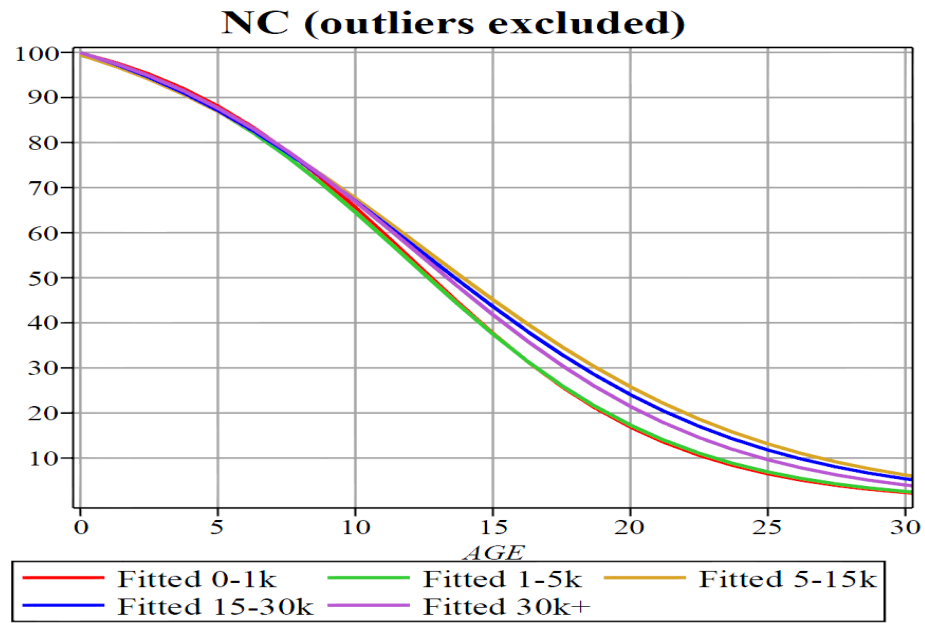
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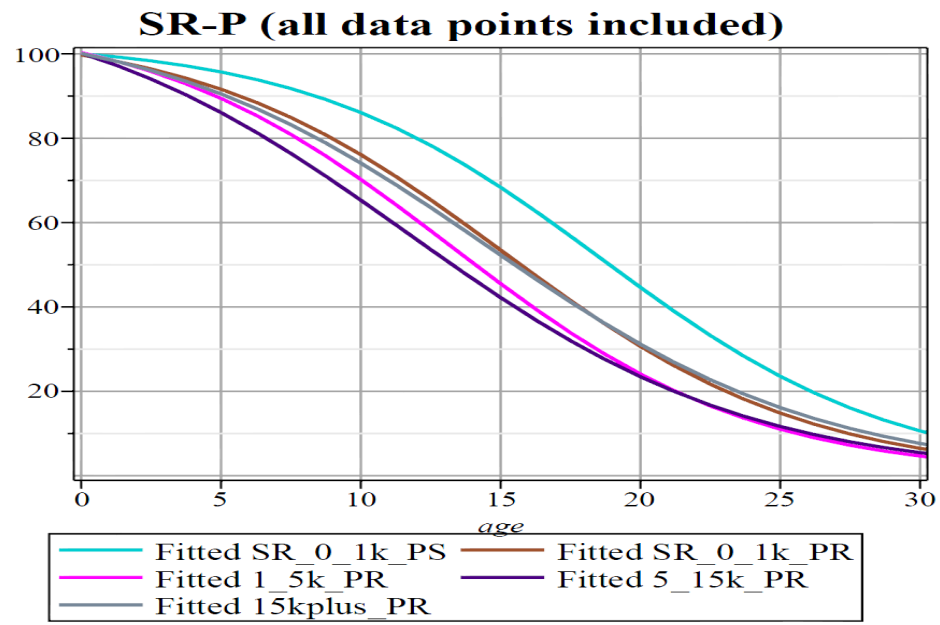
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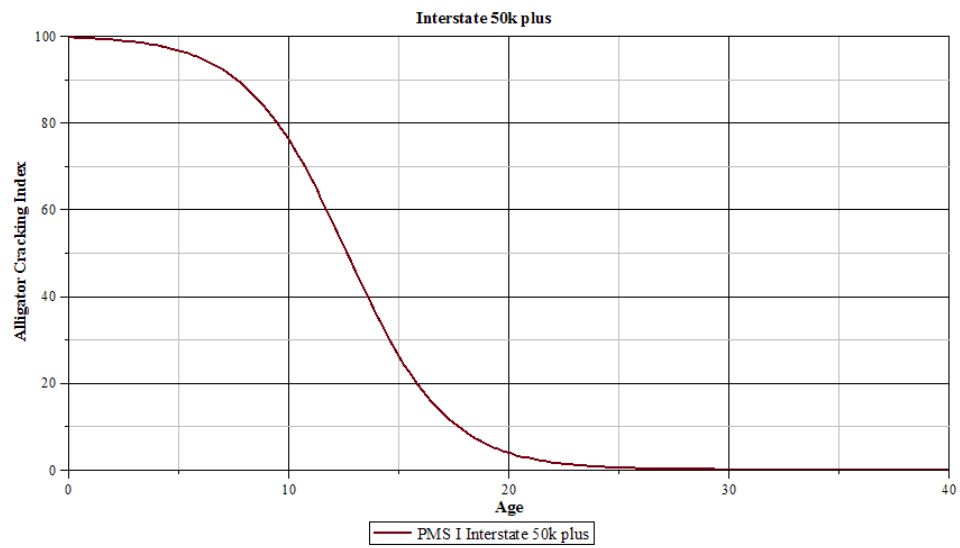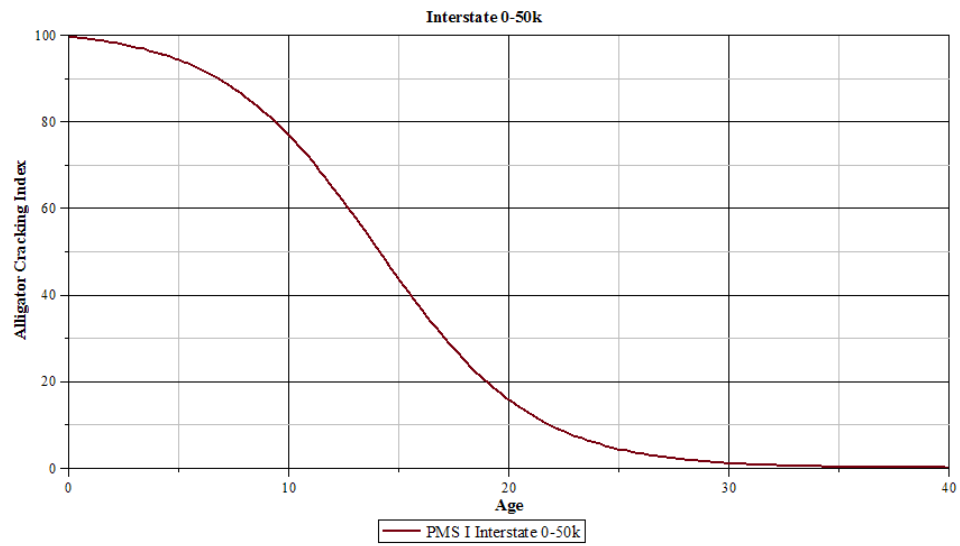39. *Pavement Condition Survey Manual 2012*. (2012). Raleigh: North Carolina Department of Transportation.

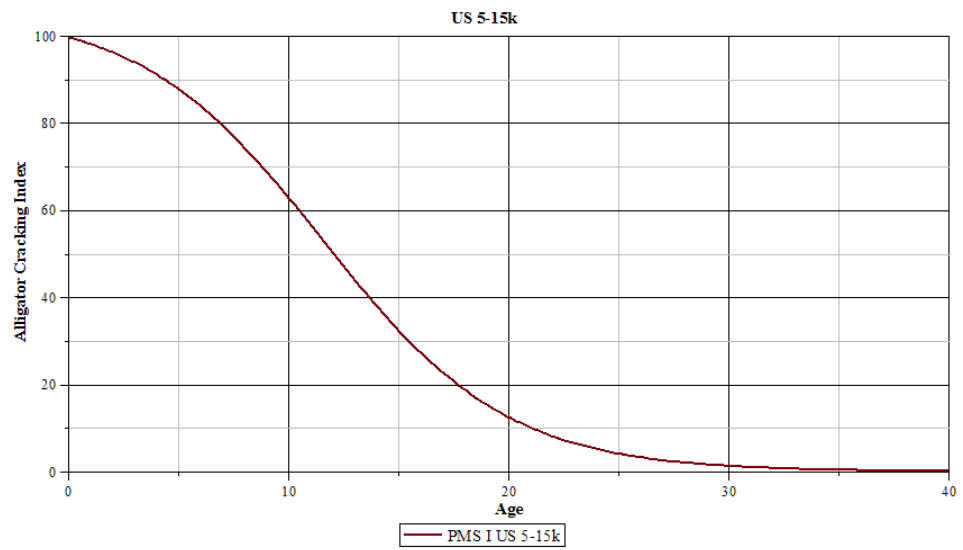# Appendix A – Asphalt Pavement Performance Models

Interstate (outliers excluded)

Legend:
- Fitted 0-25k
- Fitted 25-50k
- Fitted 50-75k
- Fitted 75k+

US (outliers excluded)

Legend:
- Fitted 0-5k
- Fitted 5-15k
- Fitted 15-30k
- Fitted 30k+

NC (outliers excluded)

Legend: Fitted 0-1k, Fitted 1-5k, Fitted 5-15k, Fitted 15-30k, Fitted 30k+

SR-B&S (all data points included)

Legend: Fitted 0_1k_BSS, Fitted 0_1k_BSR, Fitted 1_5k_BSR, Fitted 5_15k_BSR, Fitted 15kplus_BSR

SR-P (all data points included)

Legend:
- Fitted SR_0_1k_PS
- Fitted SR_0_1k_PR
- Fitted 1_5k_PR
- Fitted 5_15k_PR
- Fitted 15kplus_PR

Appendix B – Alligator Cracking Models

Interstate 0-50k

PMS I Interstate 0-50k

Interstate 50k plus

PMS I Interstate 50k plus

US 0-5k

US 5-15k

US 15-30k

US 30k plus

NC 0-1k

Alligator Cracking Index vs *Age*

— PMS I NC 0-1k

NC 1-5k

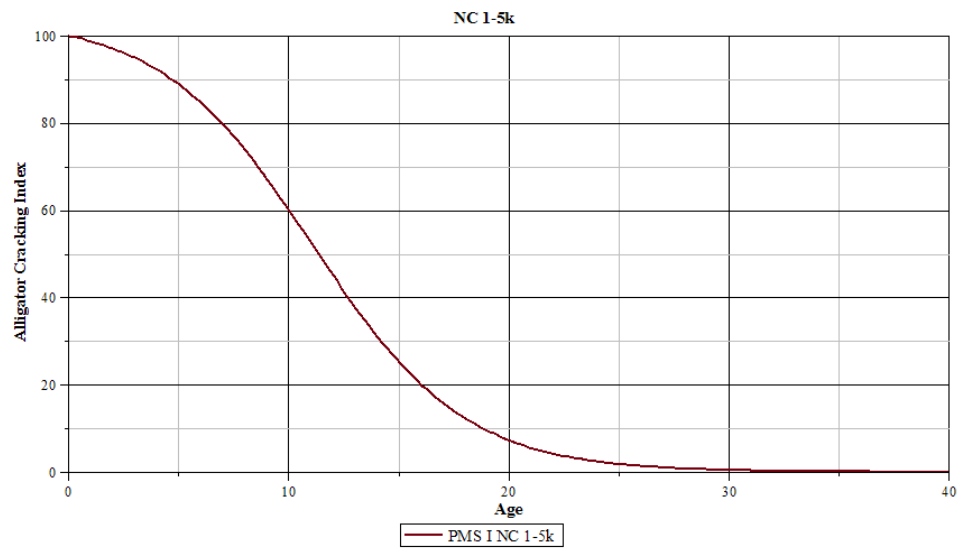*Alligator Cracking Index* vs *Age*

— PMS I NC 1-5k

NC 5-15k

NC 15k plus

64

SR 0-1k BSS

SR 0-1k BSR

SR 1k plus BSR

(Alligator Cracking Index vs. Age)

PMS SR 1k plus BSR

SR 0-1k PS

(Alligator Cracking Index vs. Age)

PMS I SR 0-1k PS

SR 0-1k PR

SR 1-5k PR

SR 5-15k PR

SR 15k plus PR

68

Appendix C – Transverse Cracking Models

Interstate_0_50k

Interstate_50kplus

US_0_5k

US_5_15k

US_15_30k

US_30kplus

71

Nc_0_1k

Nc_1_5k

Nc_5_15k

NC_15kplus

SR_0_1k_BSS

SR_0_1k_BSR

74

SR_1kplus_BSR

SR_0_1k_PS

SR_0_1k_PR

SR_5_15k_PR

SR_15kplus

Interstate 0-50k

Interstate 50k plus

US 0-5k

US 5-15k

US 15-30k

US 30k plus

NC 0-1k

NC 1-5k

NC 5-15k

NC 15k plus

SR 0-1k BSS

SR 0-1k BSR

SR 1k plus BSR

SR 0-1k PS

SR 0-1k PR

SR 1-5k PR

SR 5-15k PR

SR 15k plus PR
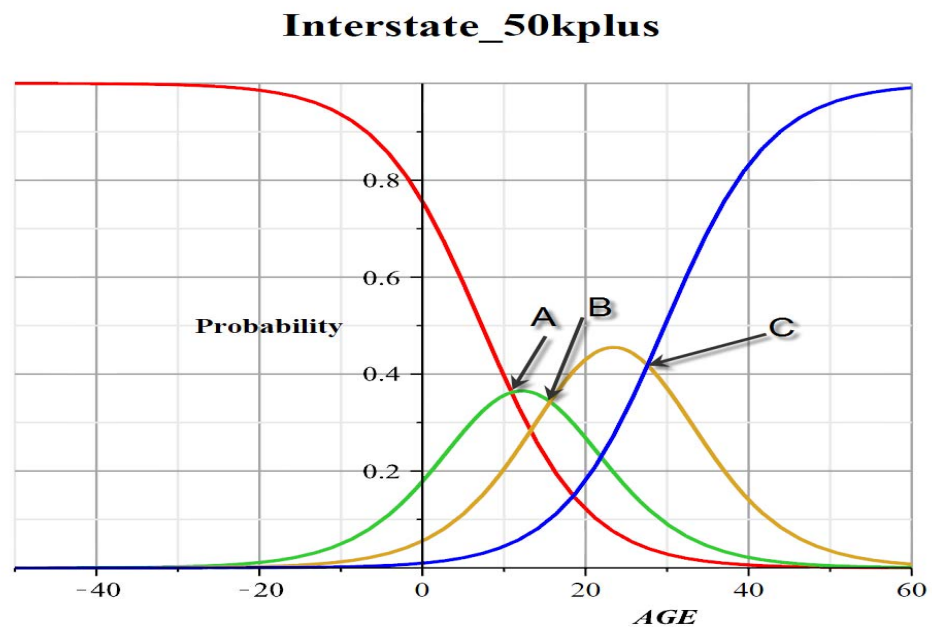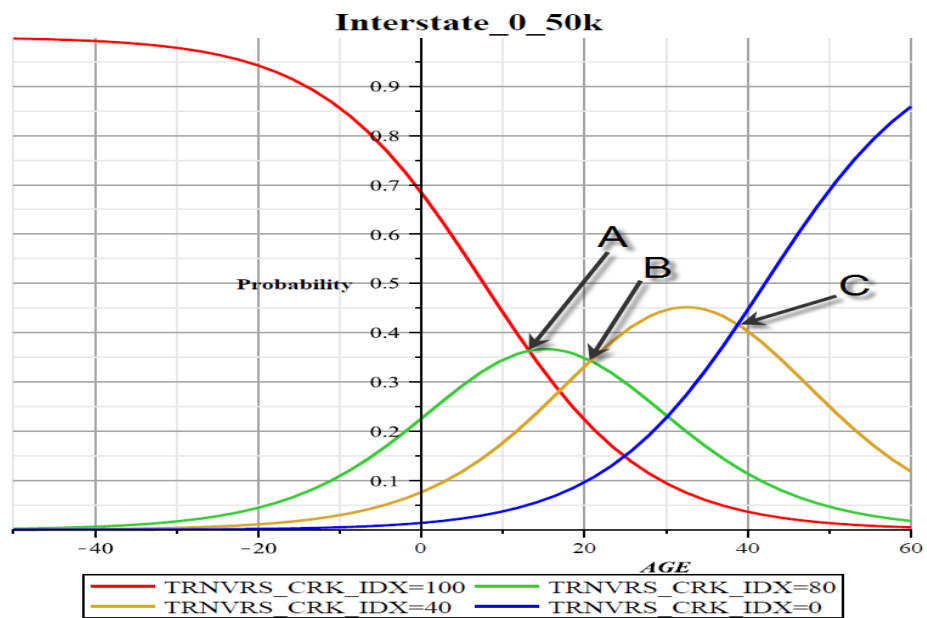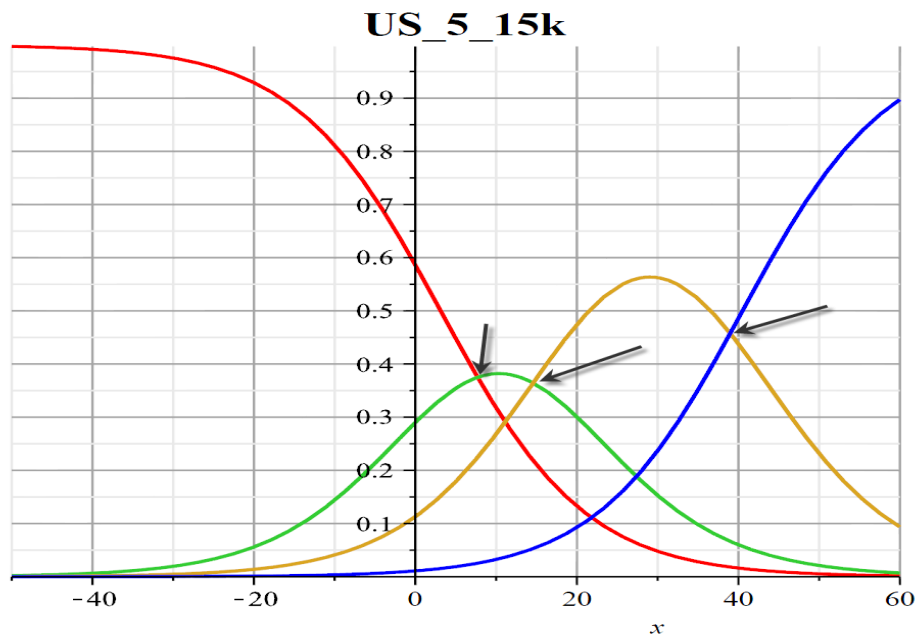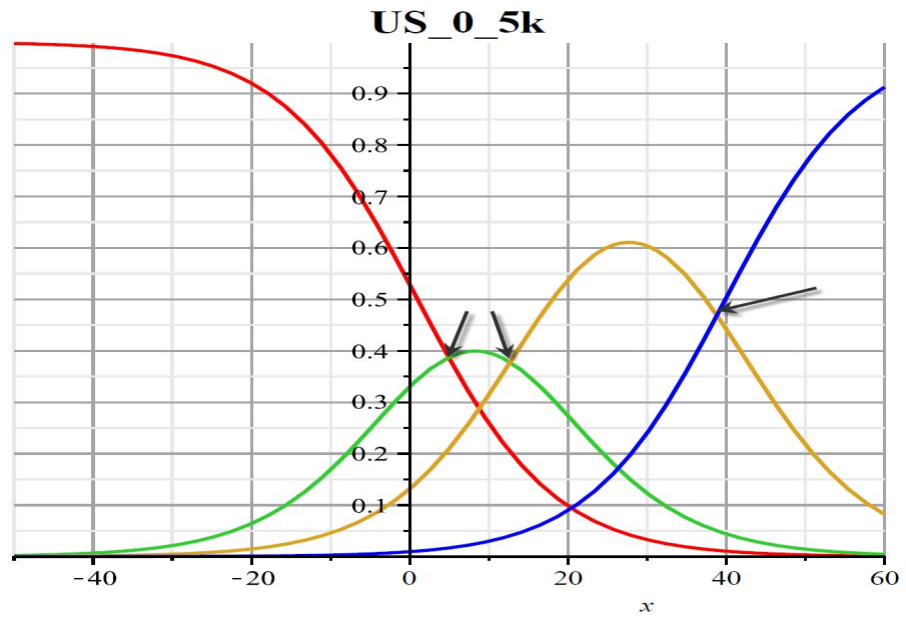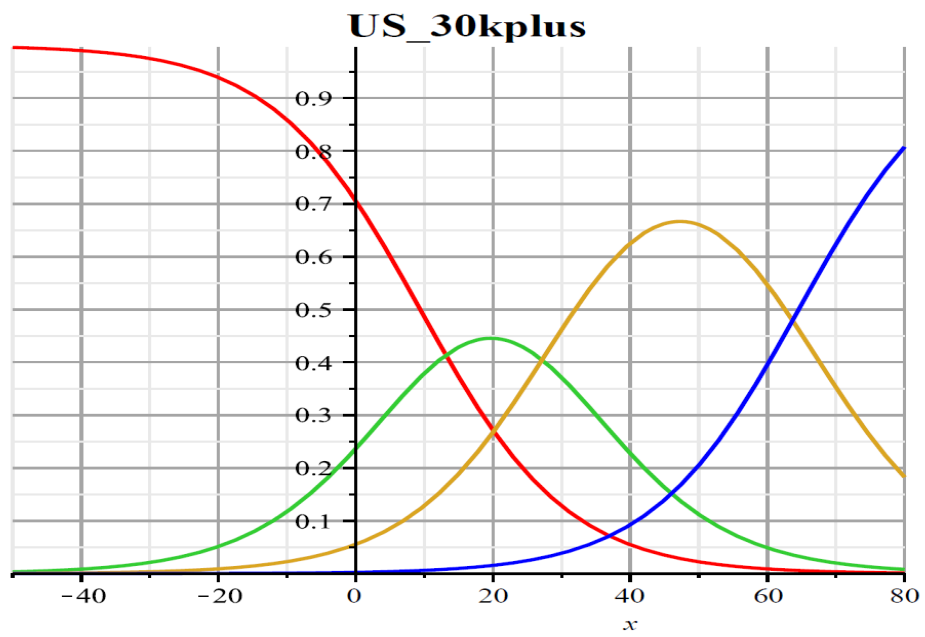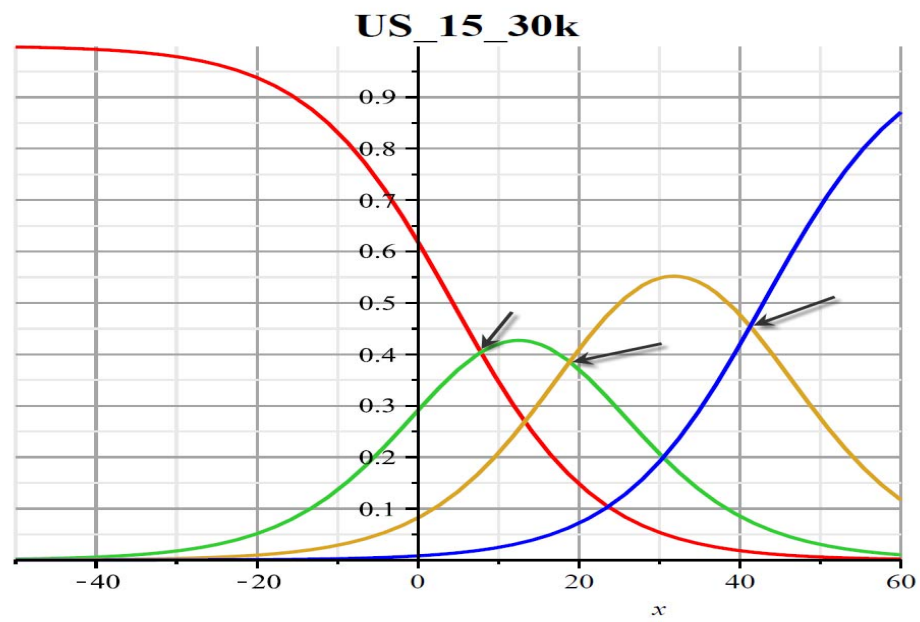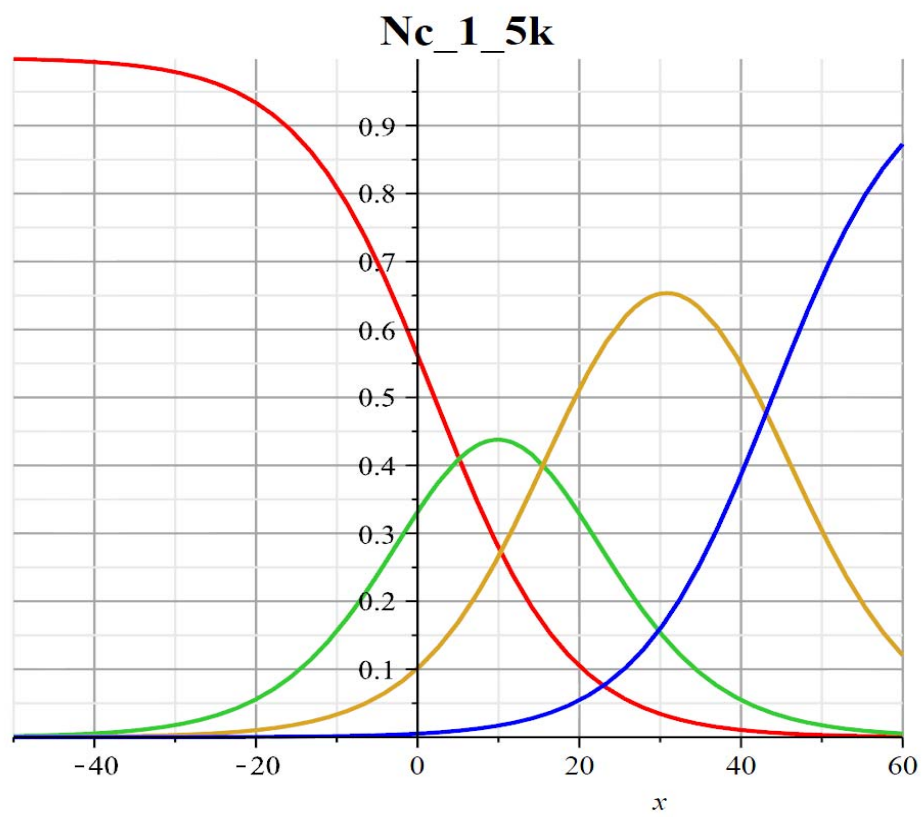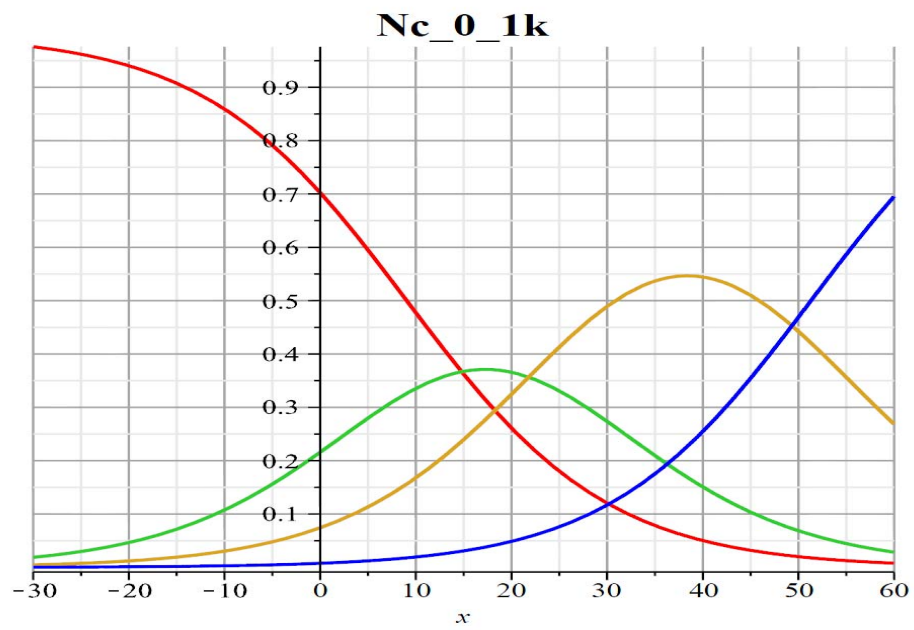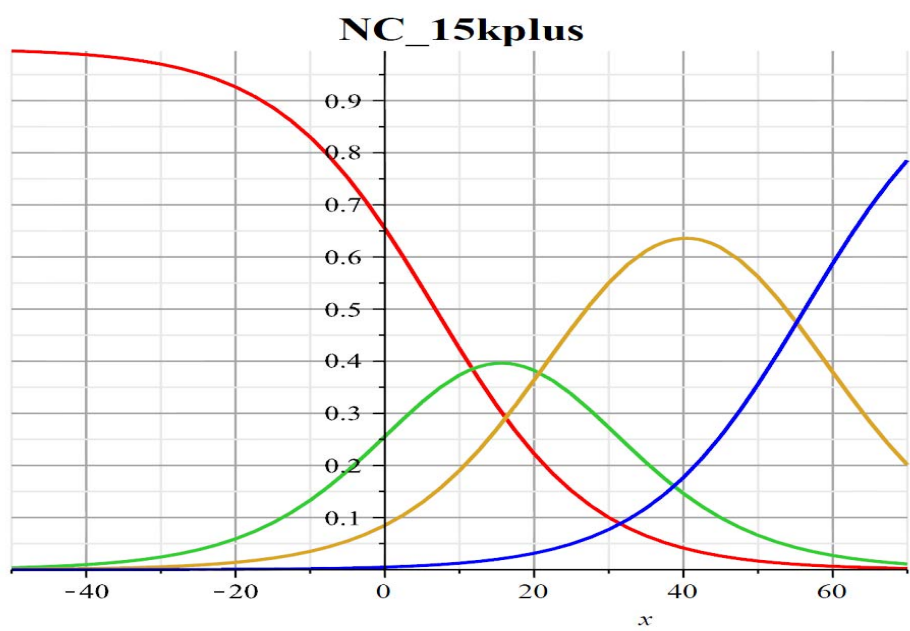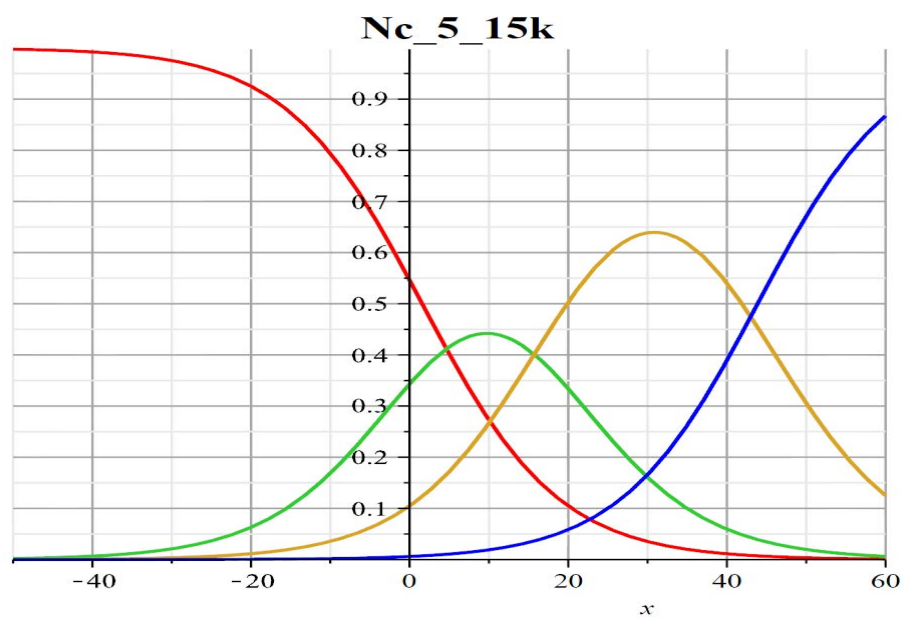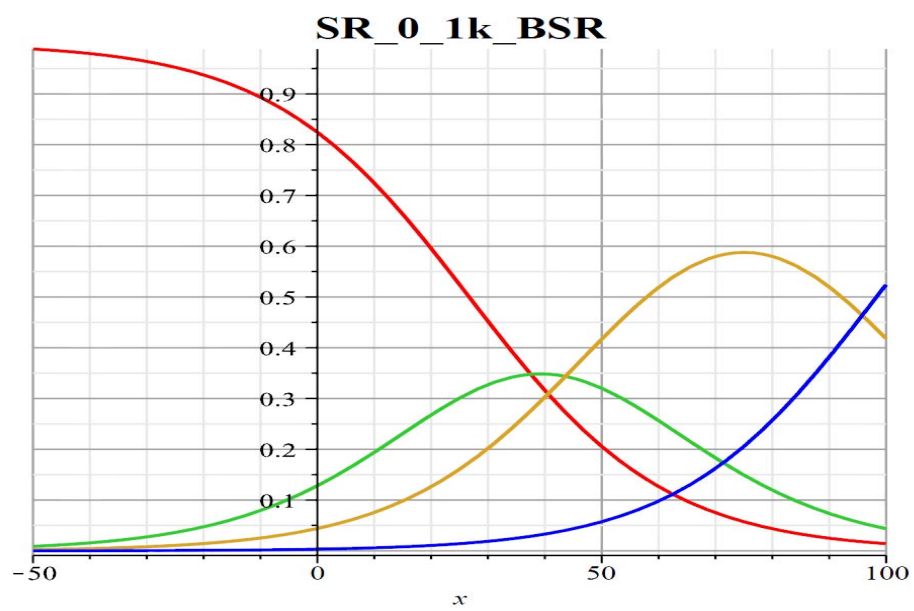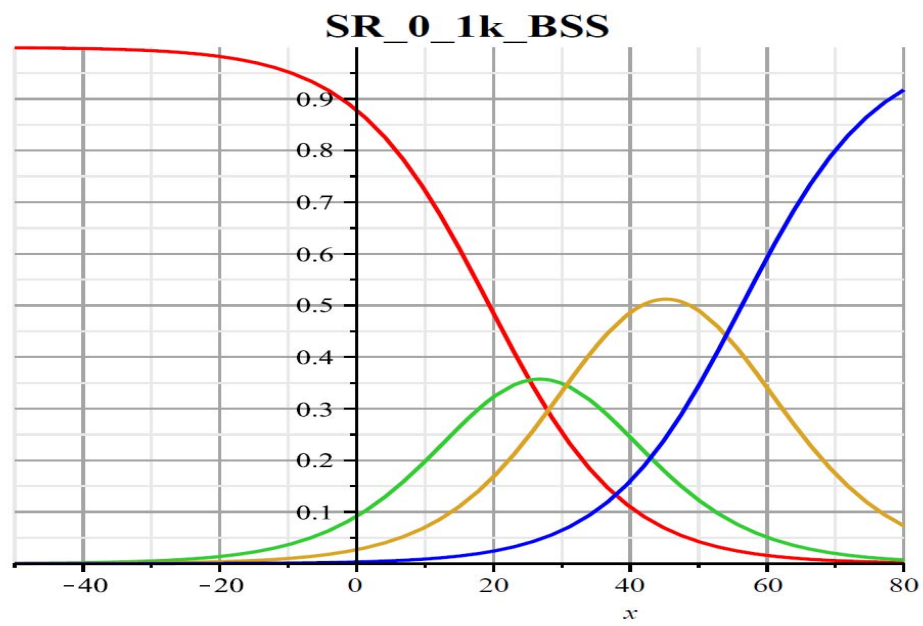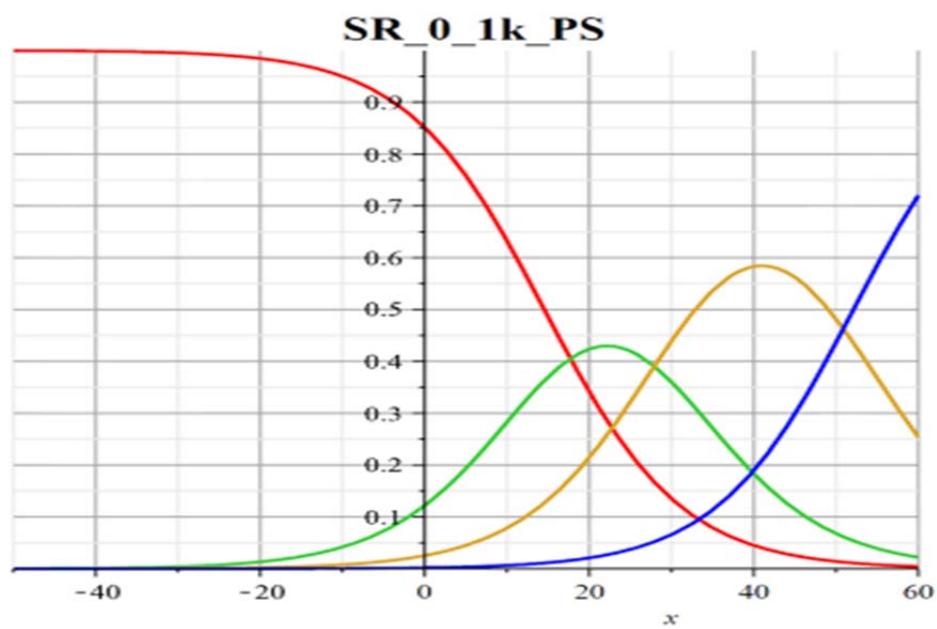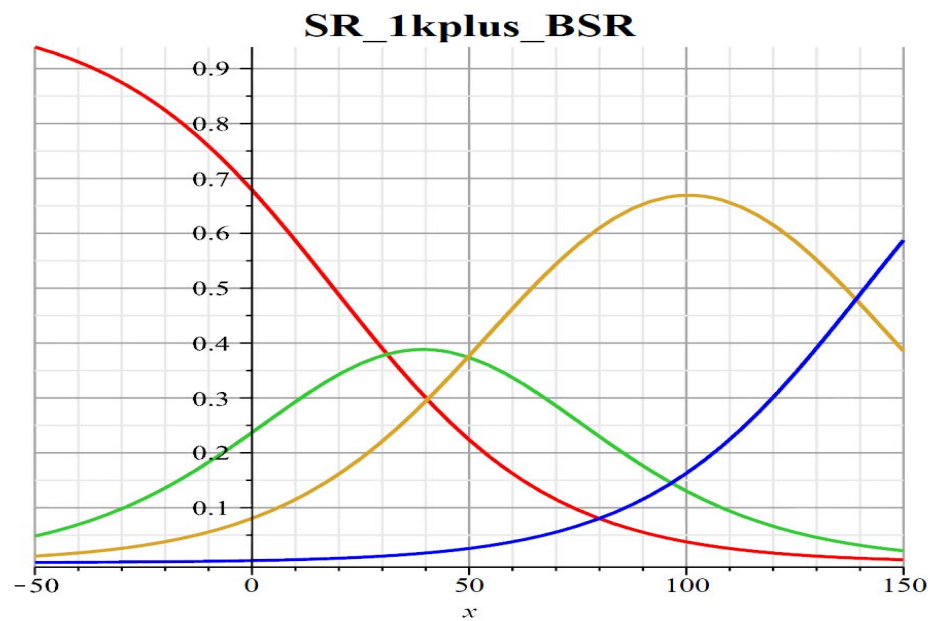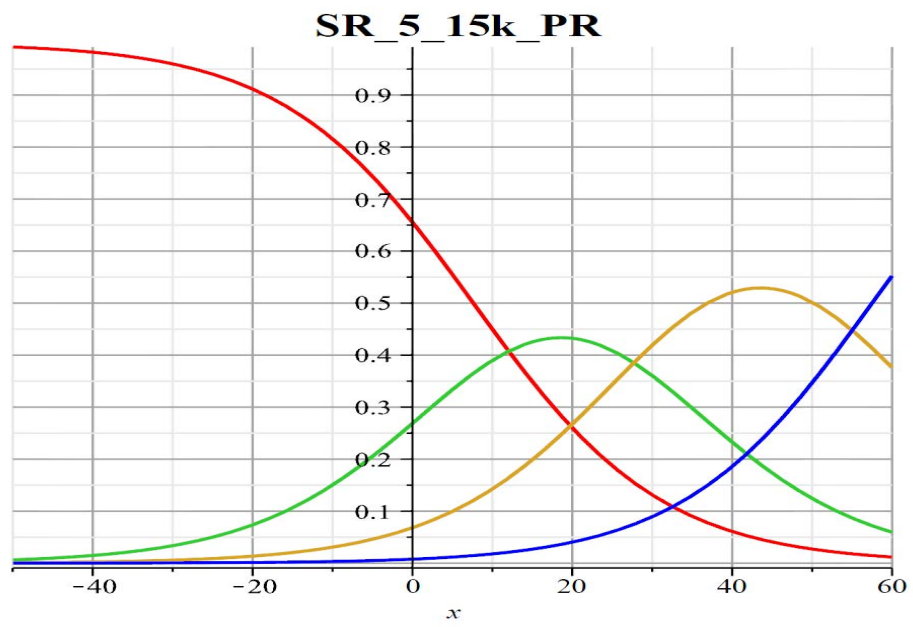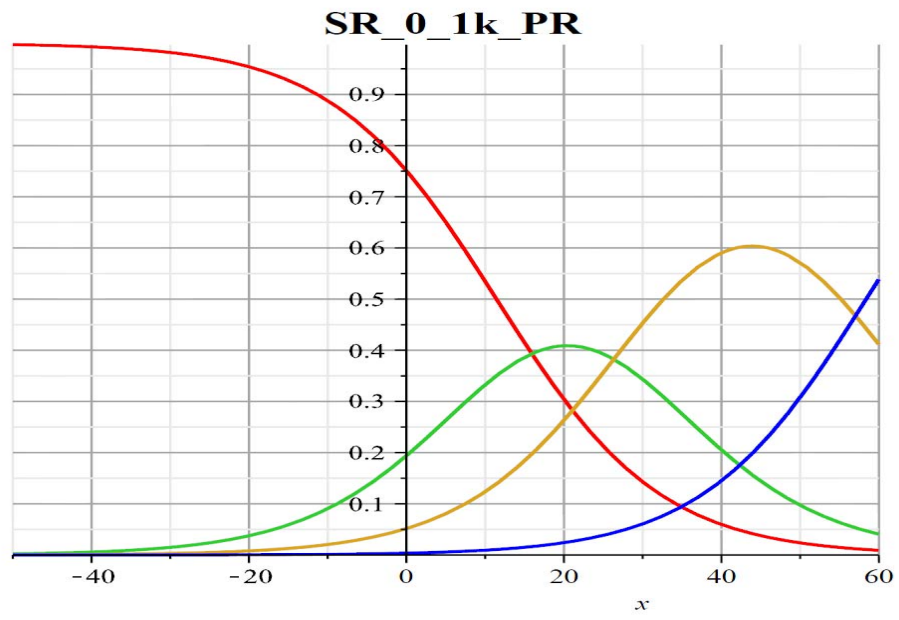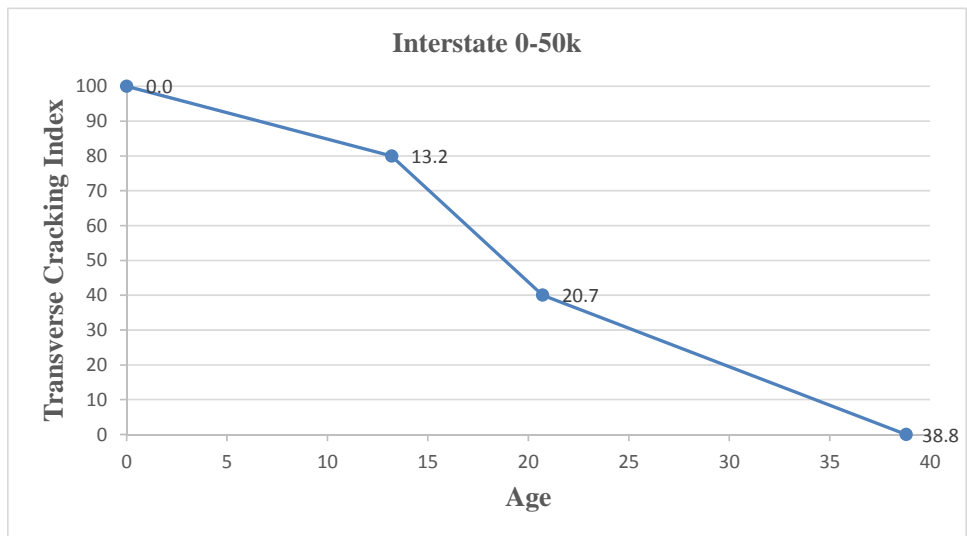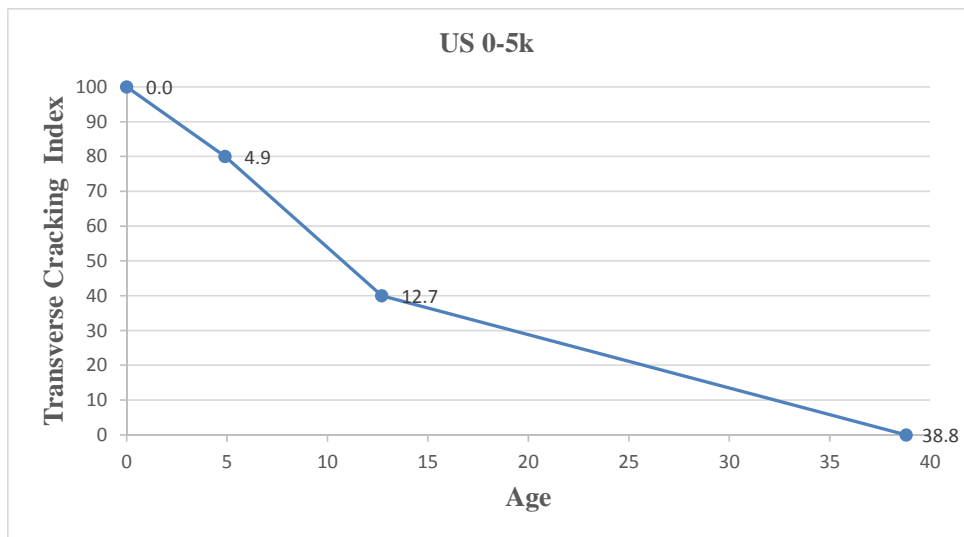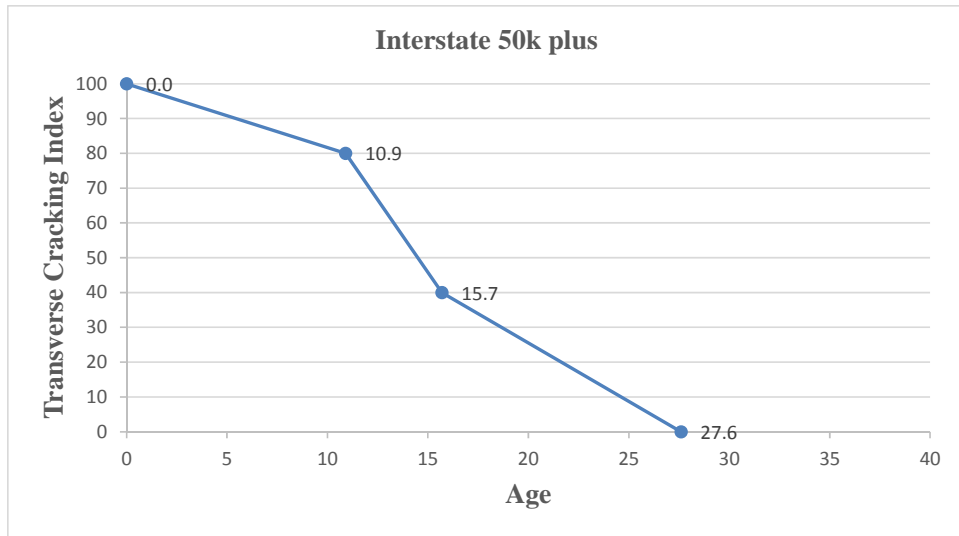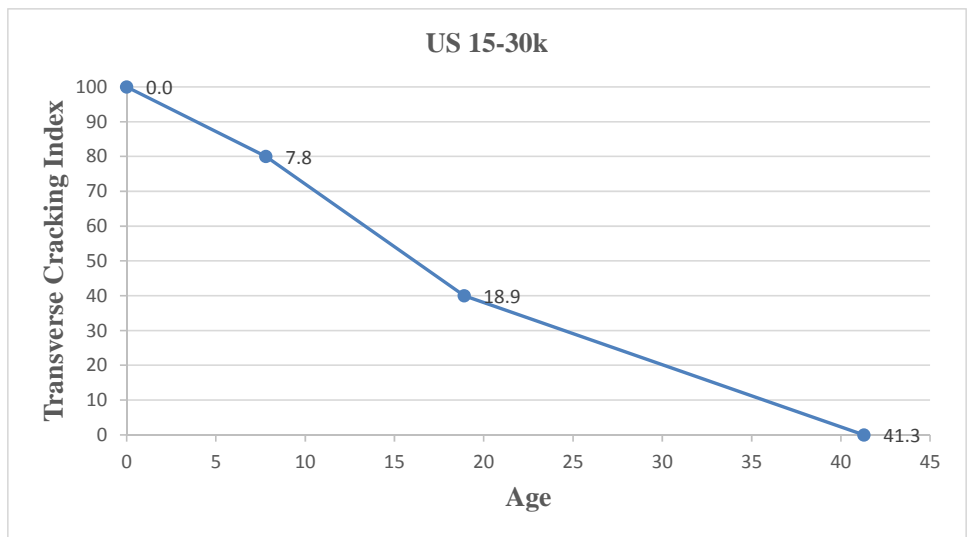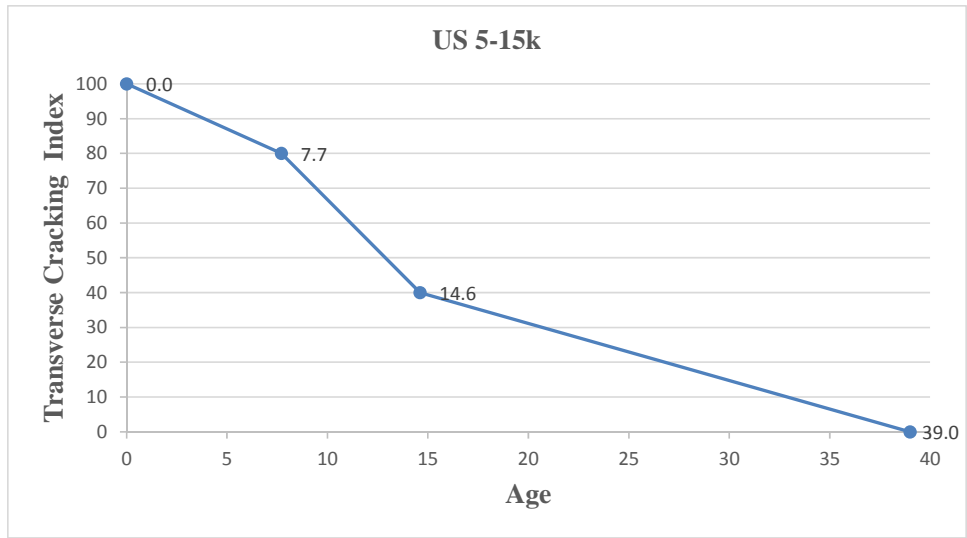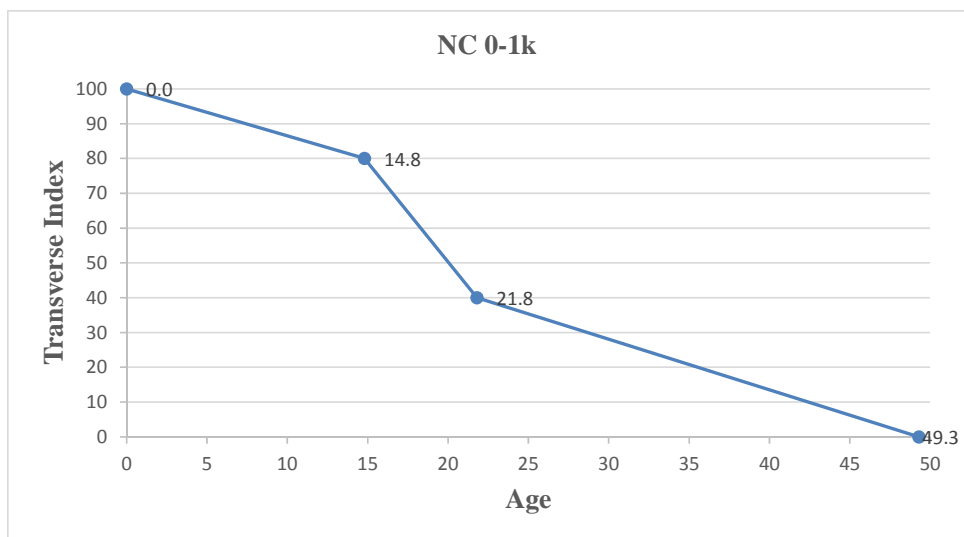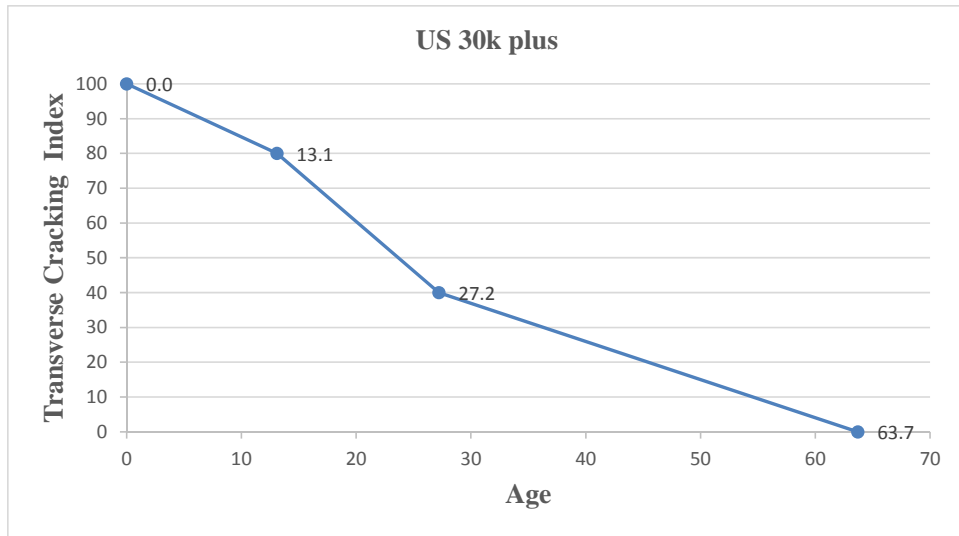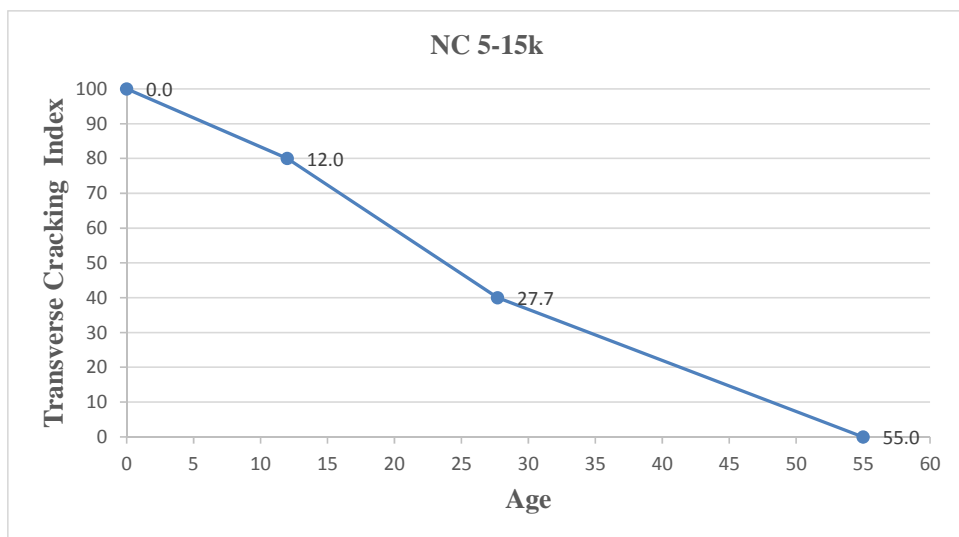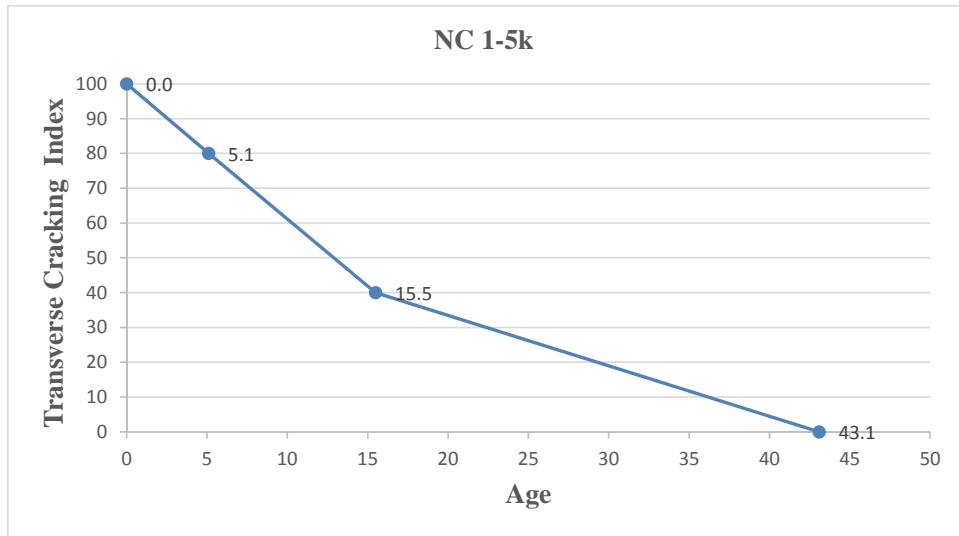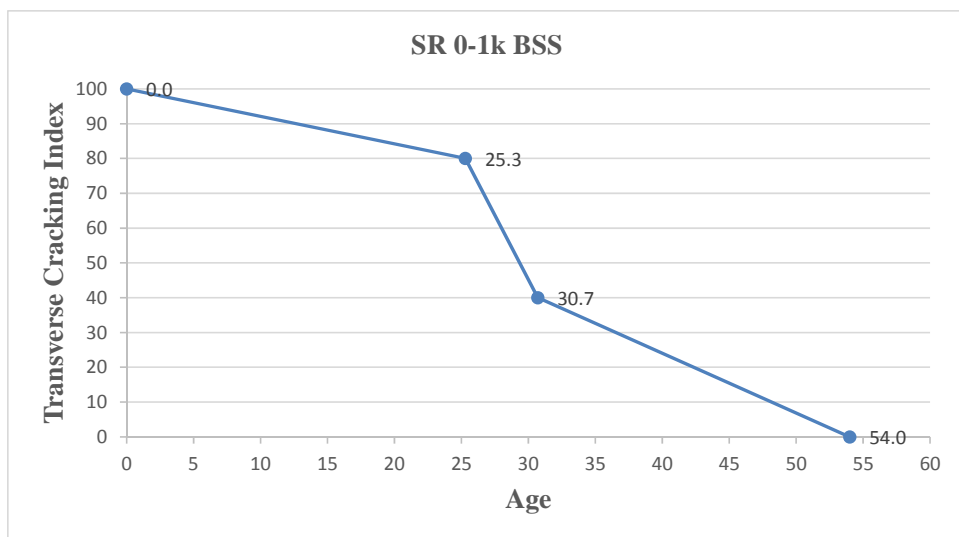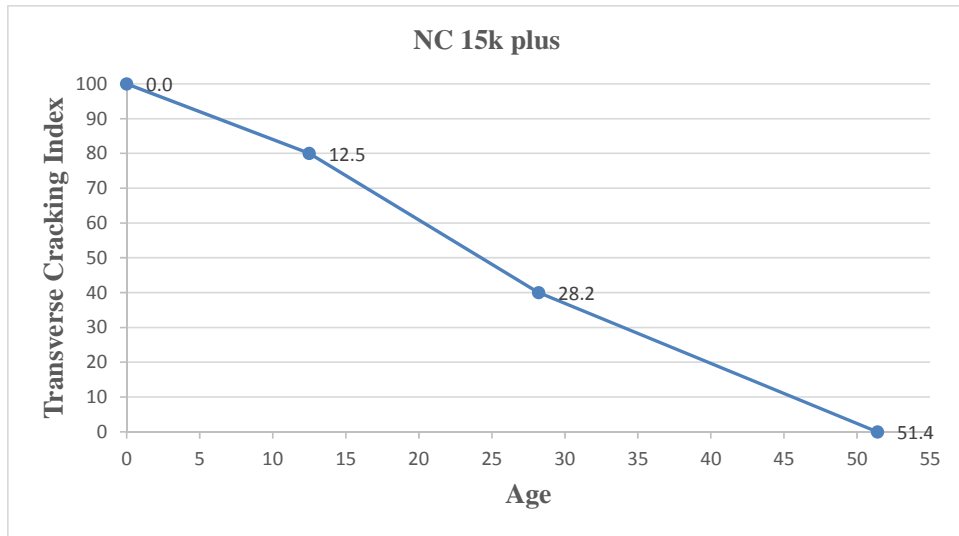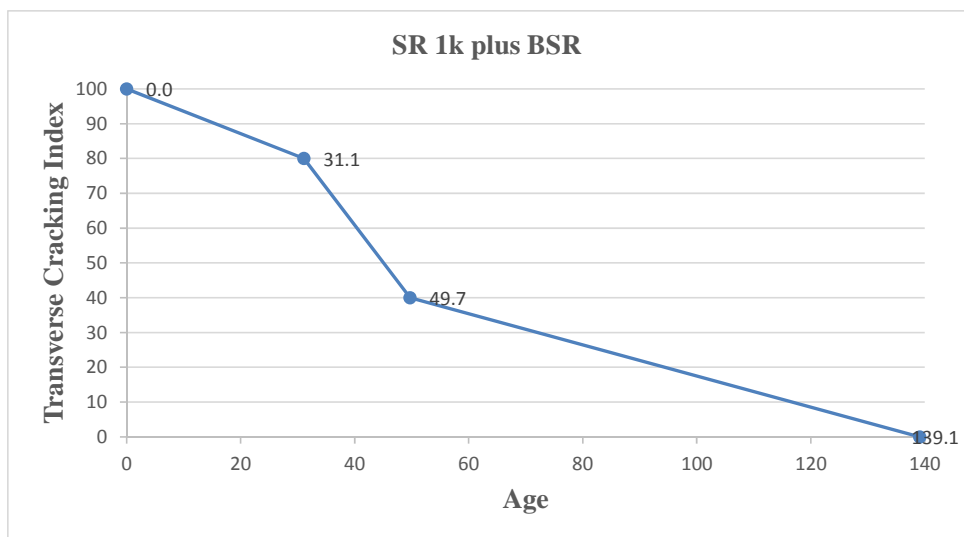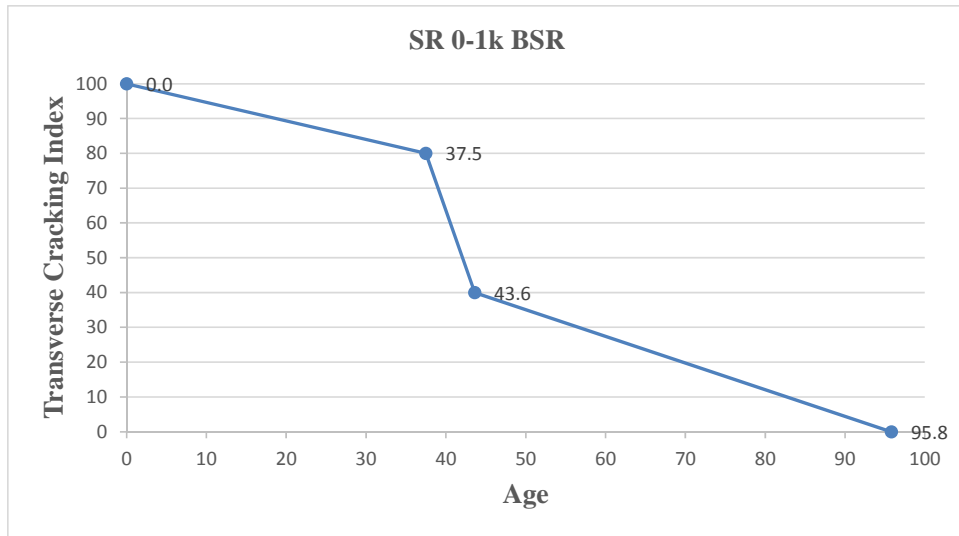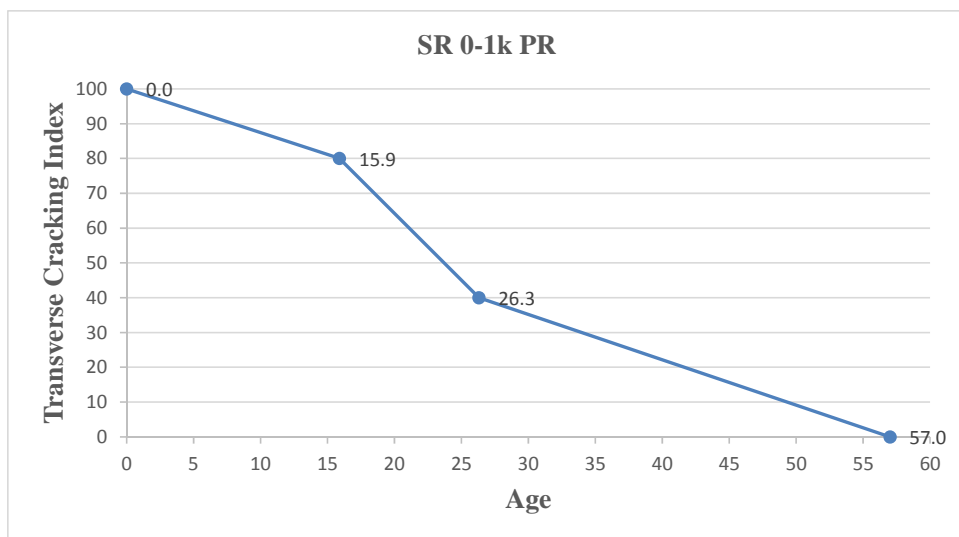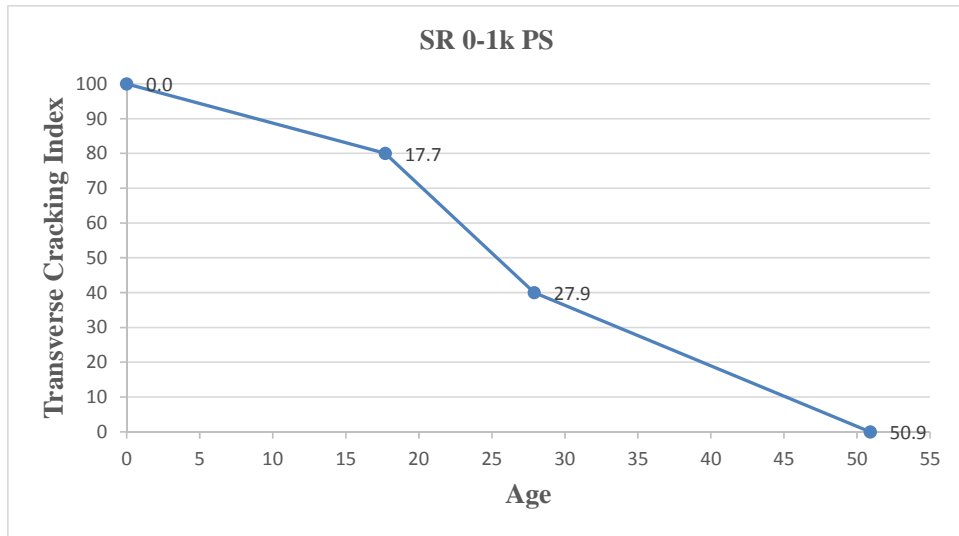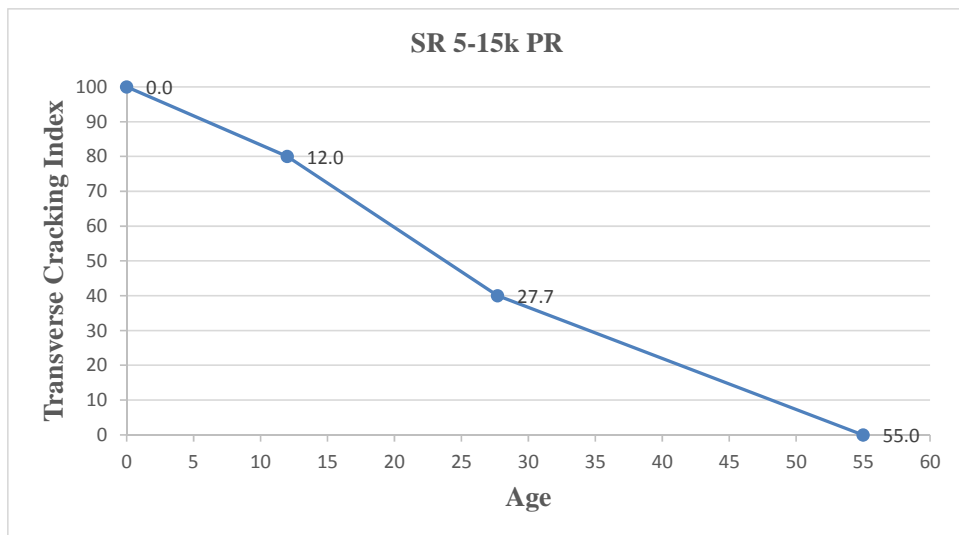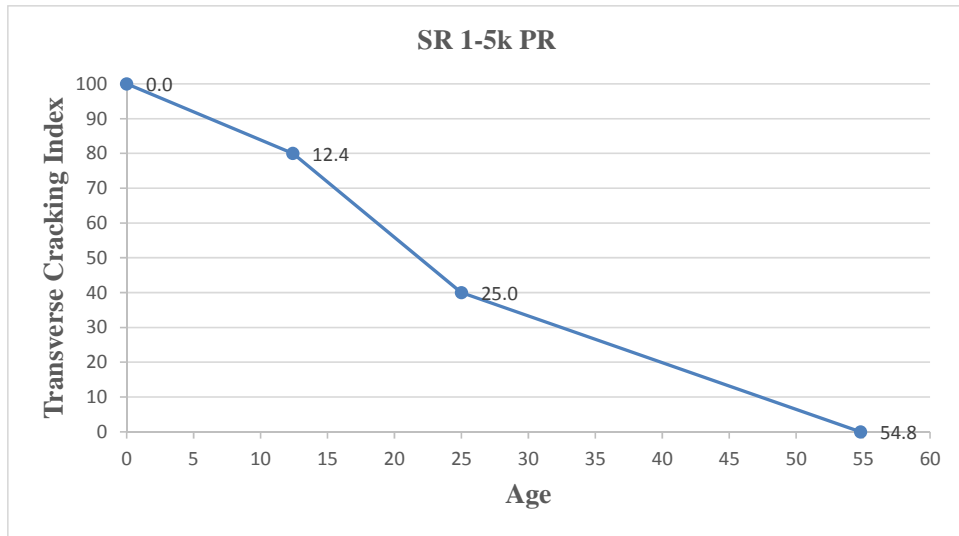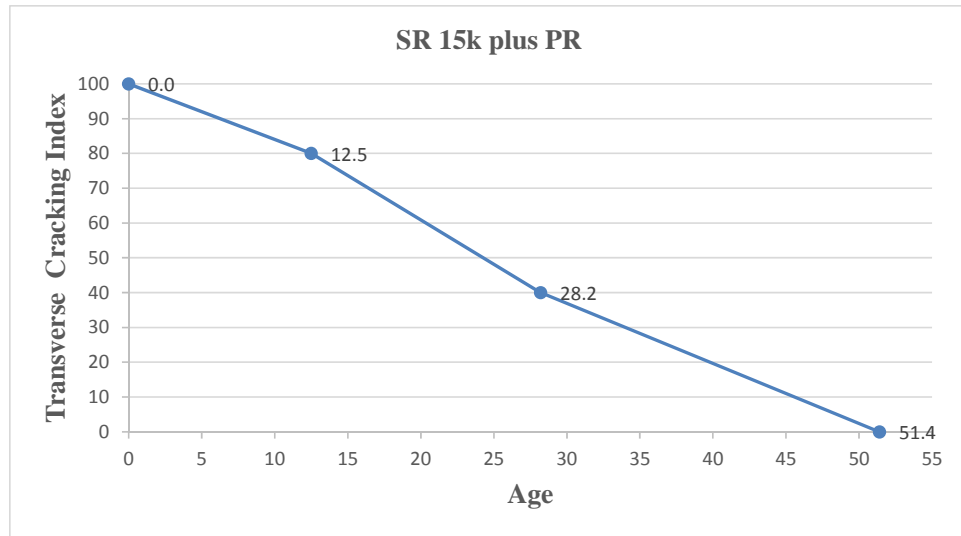
Appendix D – Oxidation Models

Interstate_0_50k

US_0_5k

Interstate_50kplus

US_15_30k

US_5_15k

US_30kplus

NC_0_1k

NC_1_5k

NC_5_15k

NC_15kplus

91

SR_0_1k_PS

SR_0_1k_PR

92

SR_1_5k_PR

SR_5_15k_PR

SR_15kplus_PR

Interstate 0-50k

Interstate 50k plus

US 0-5k

US 5-15k

US 15-30k

US 30k plus

NC 0-1k

NC 1-5k

NC 5-15k

NC 15k plus

SR 0-1k PS

SR 0-1k PR

SR 1-5k PR

SR 5-15k PR

SR 15k plus PR

Appendix E – Bleed Models

NCDOT.US_BLD (1% IDX=100)

NCDOT.NC_BLD (1% IDX=100)

NCDOT.SRB_BLD (1% IDX=100)

NCDOT.SRP_BLD (1% IDX=100)
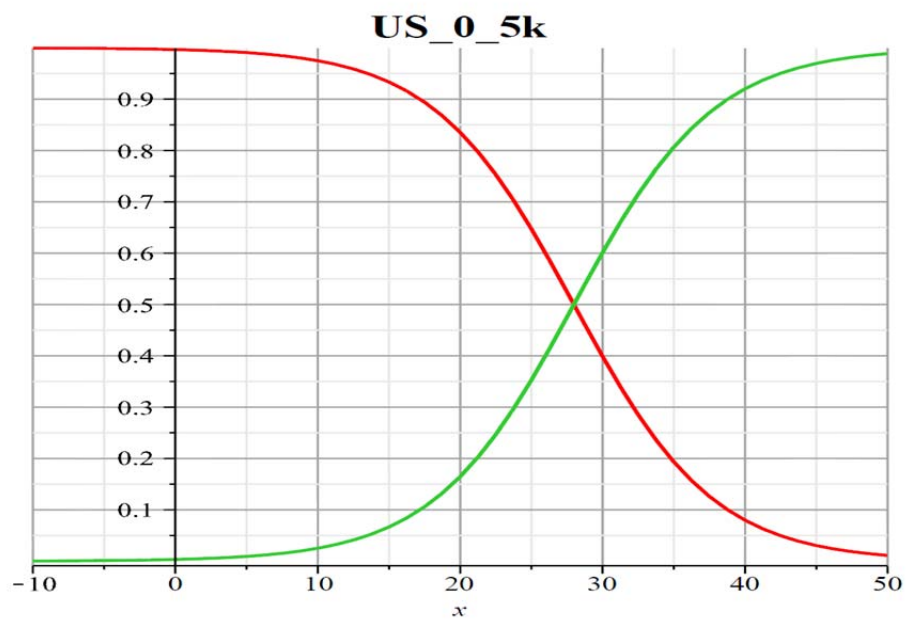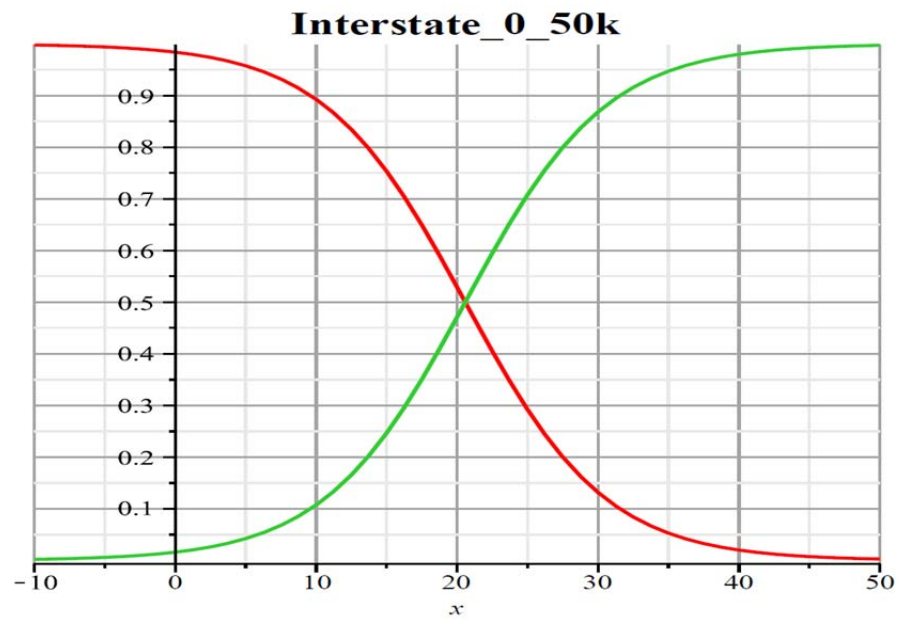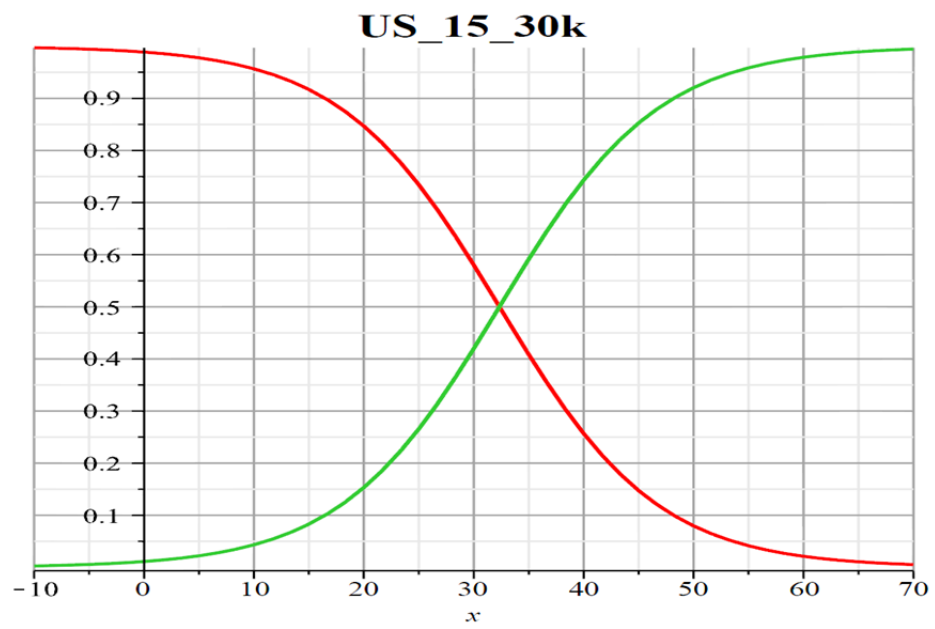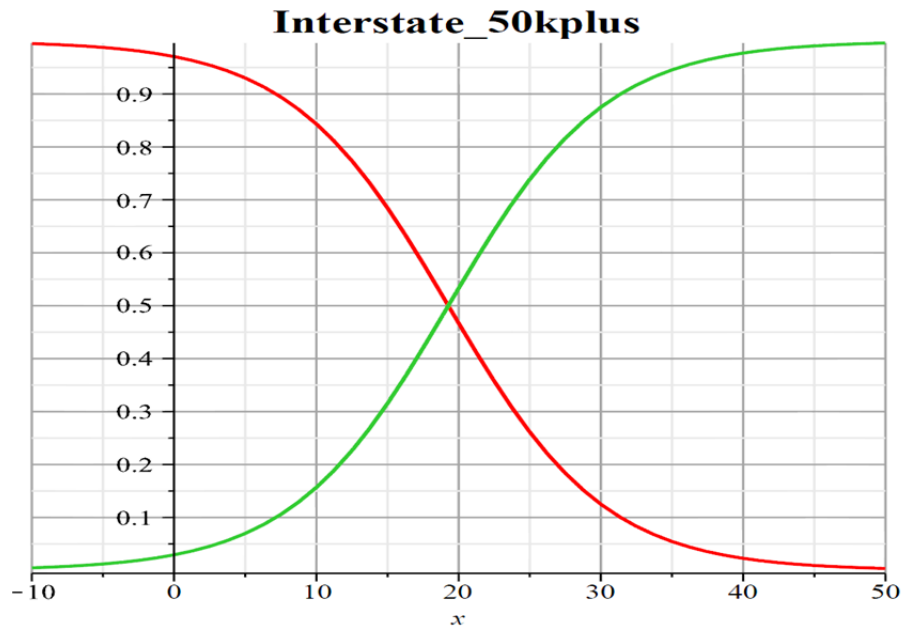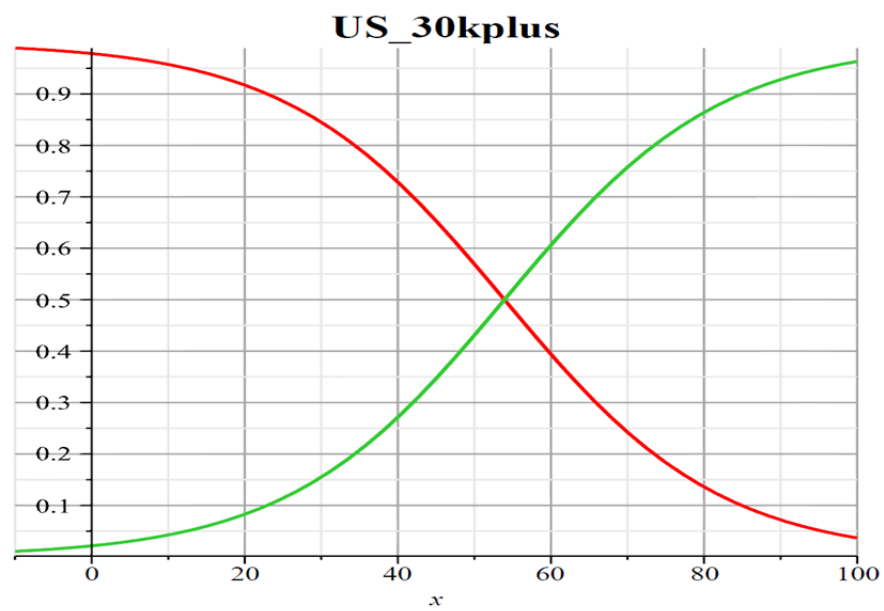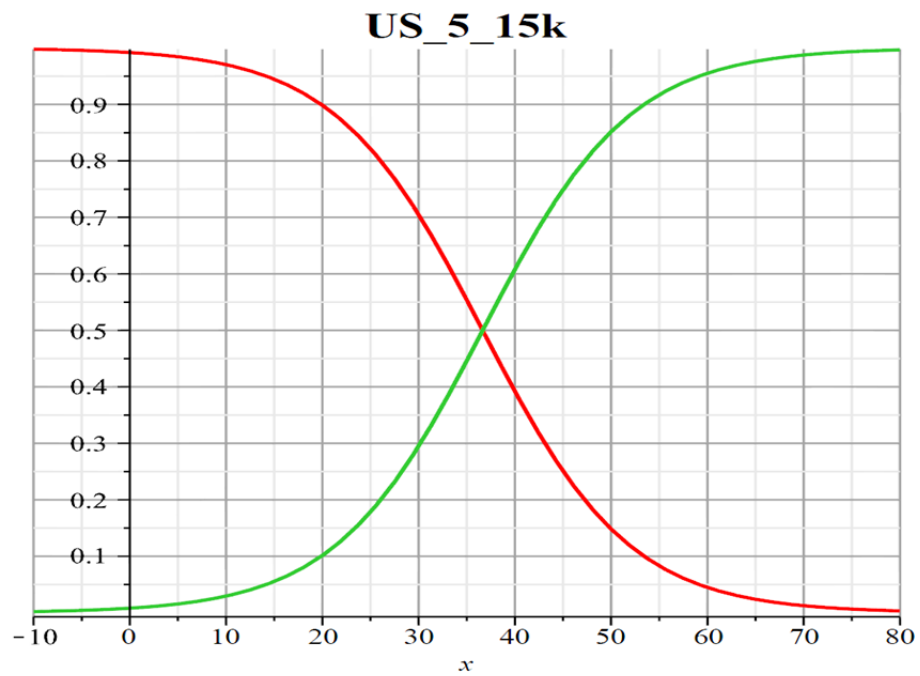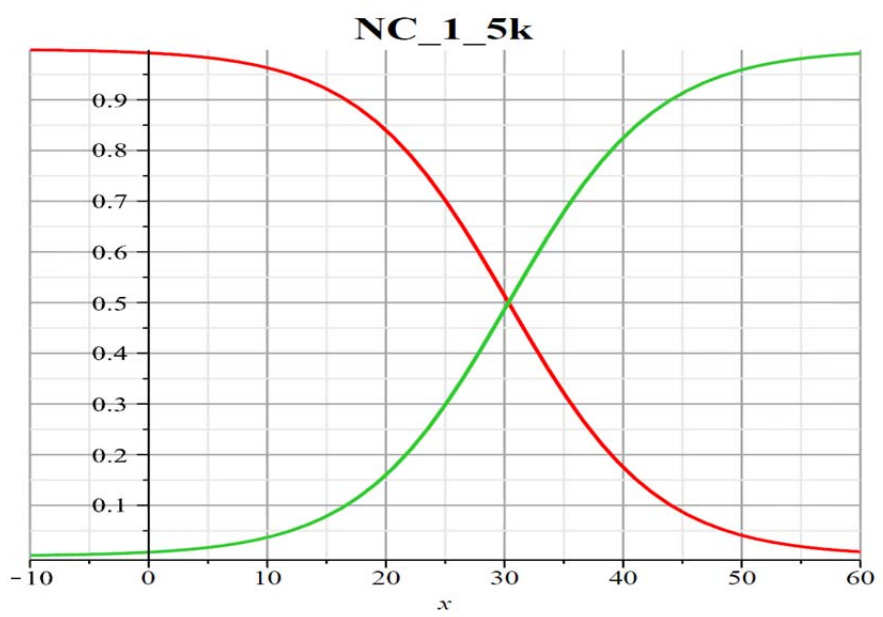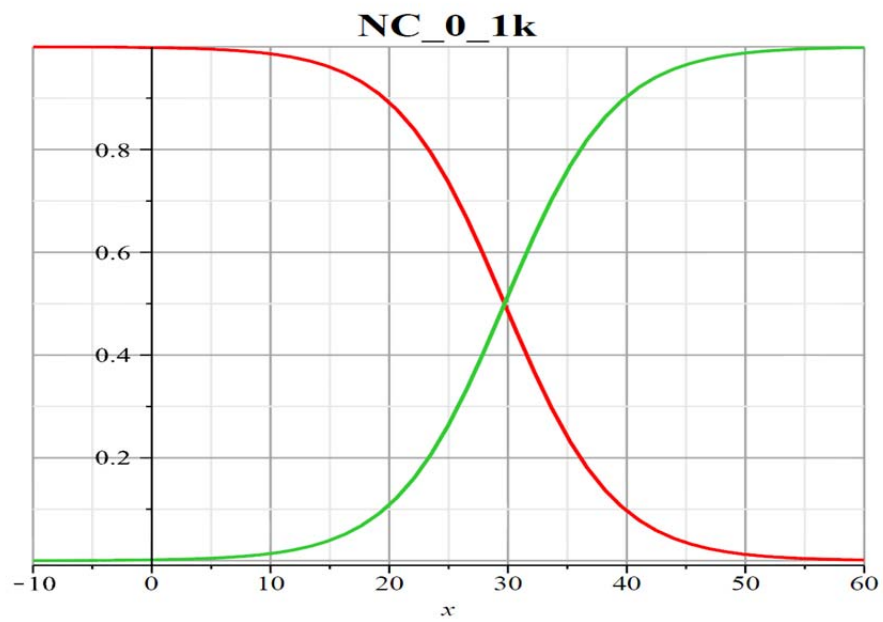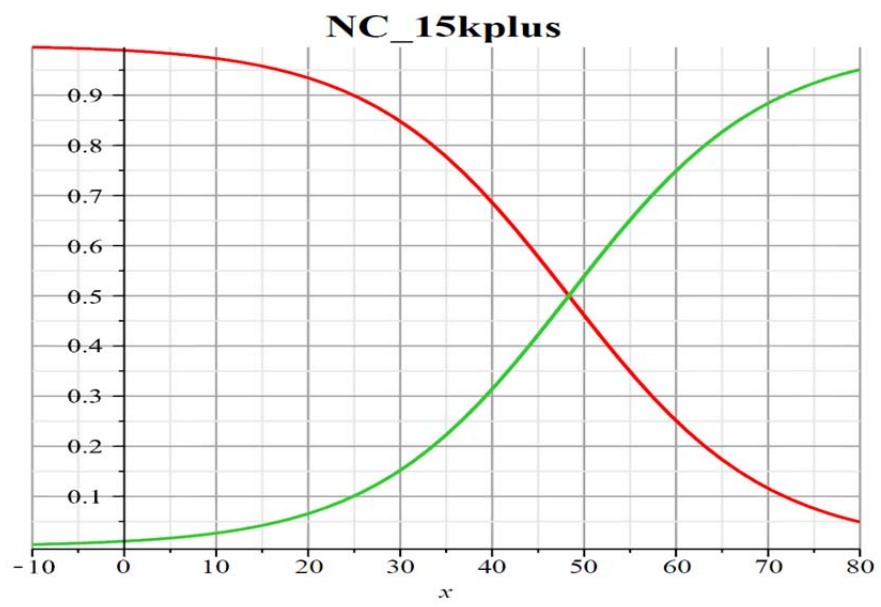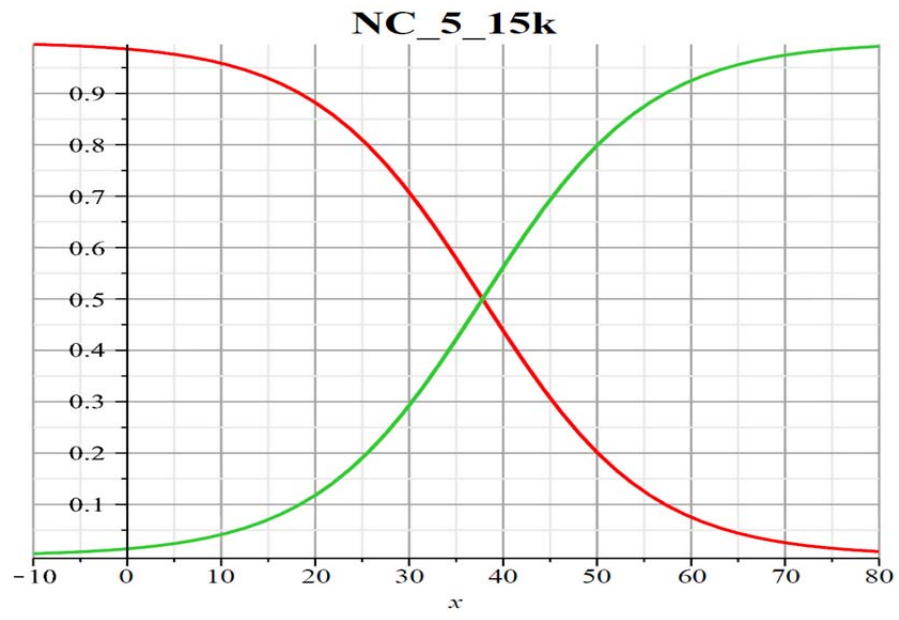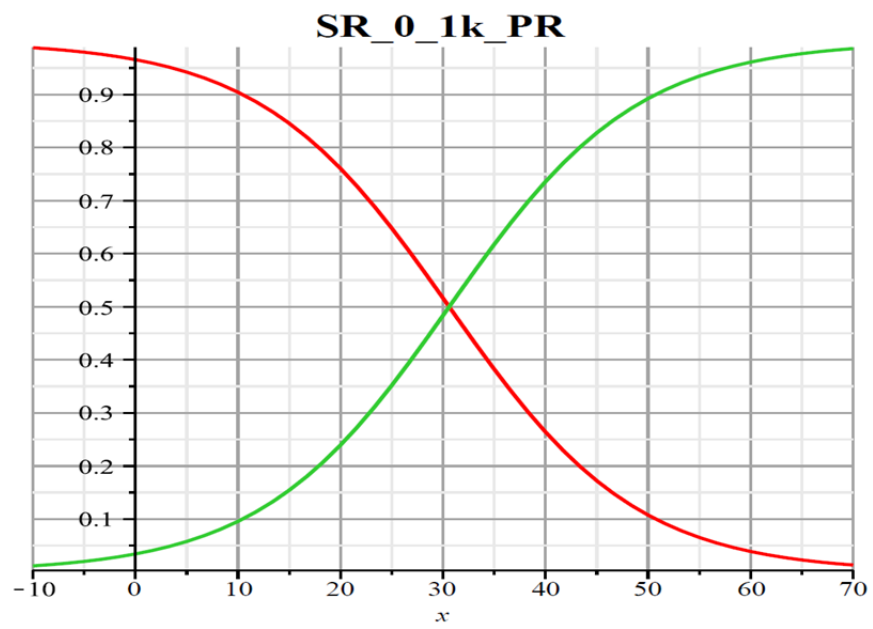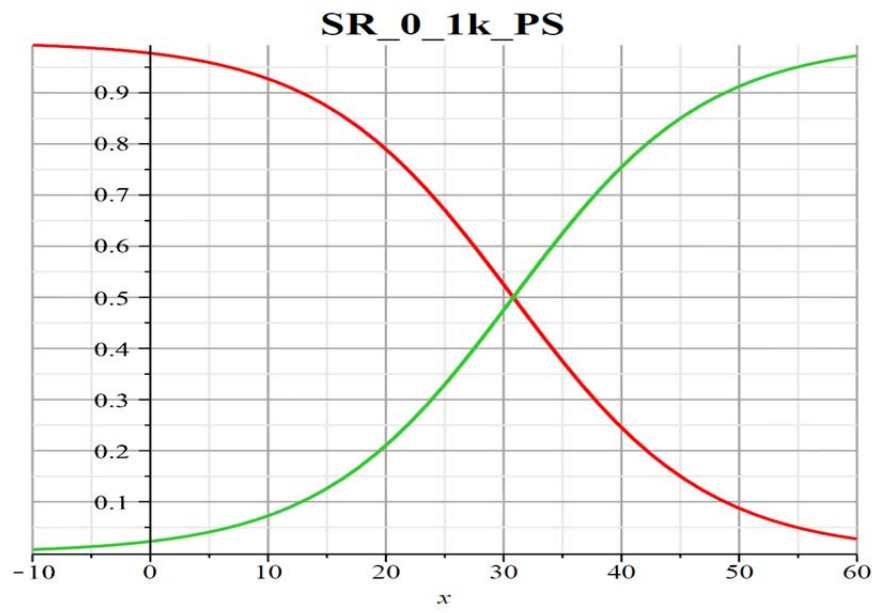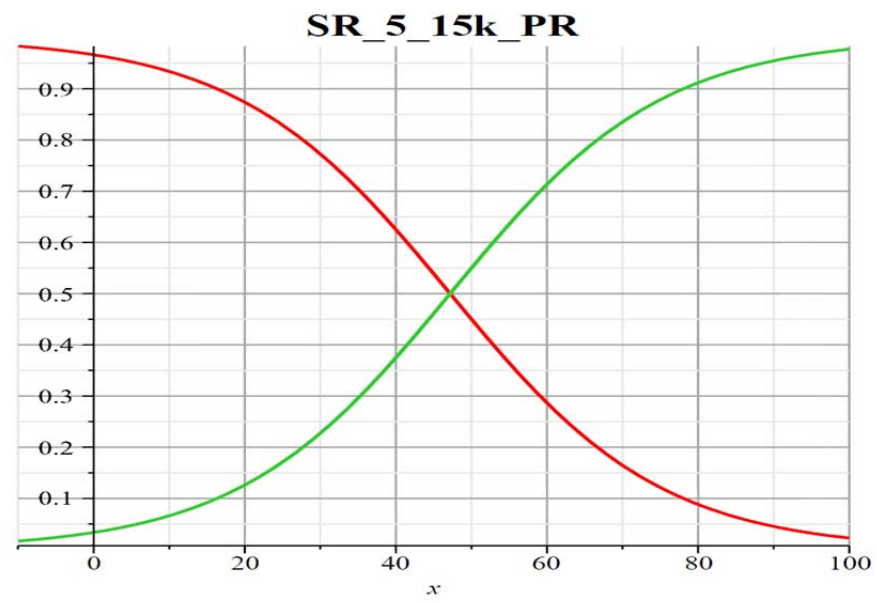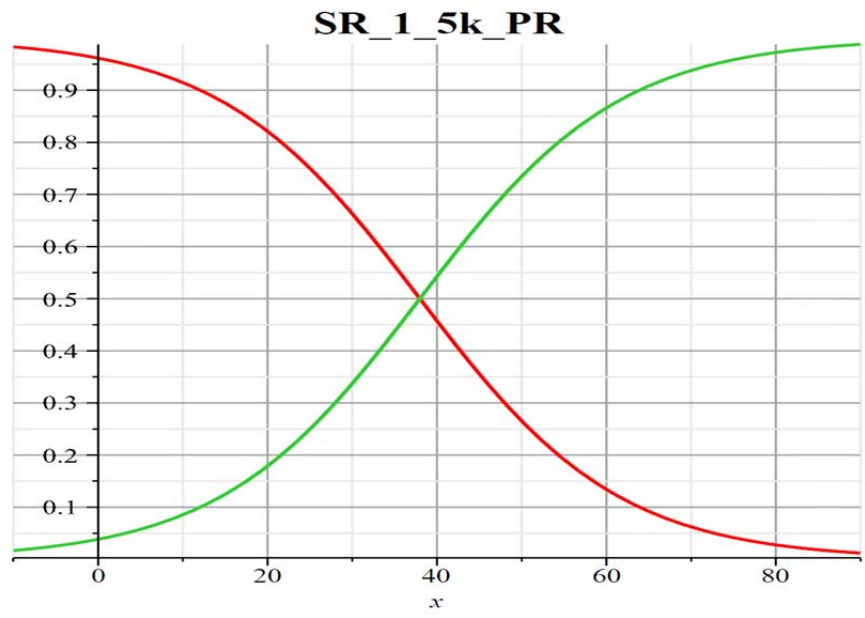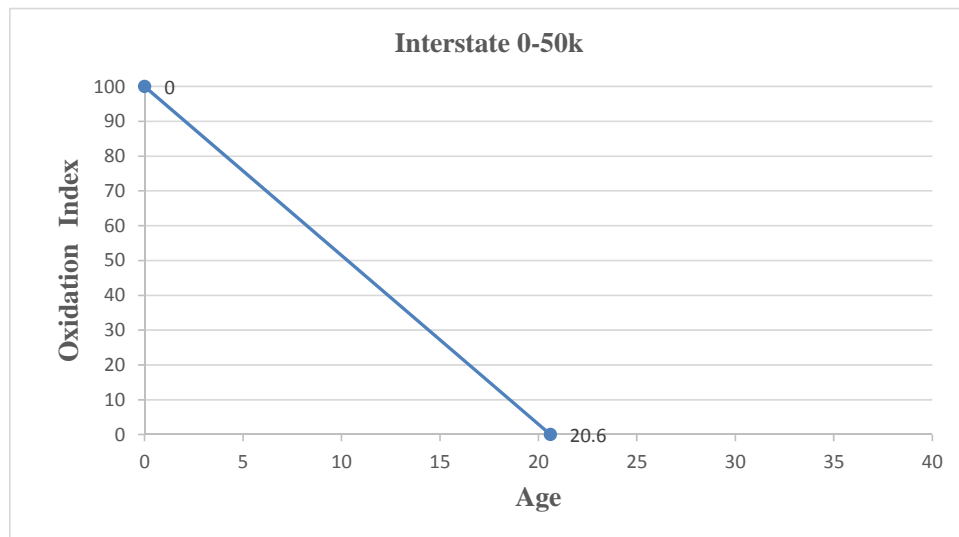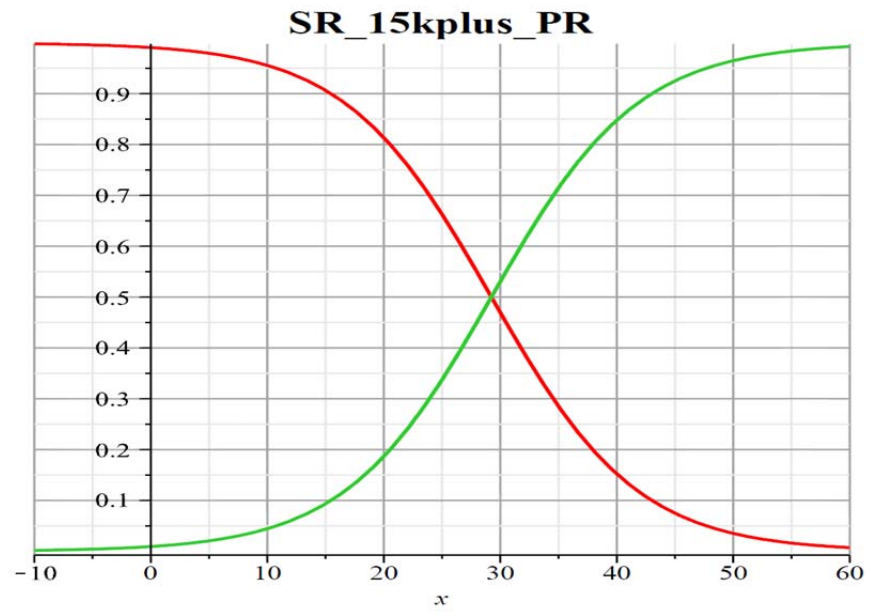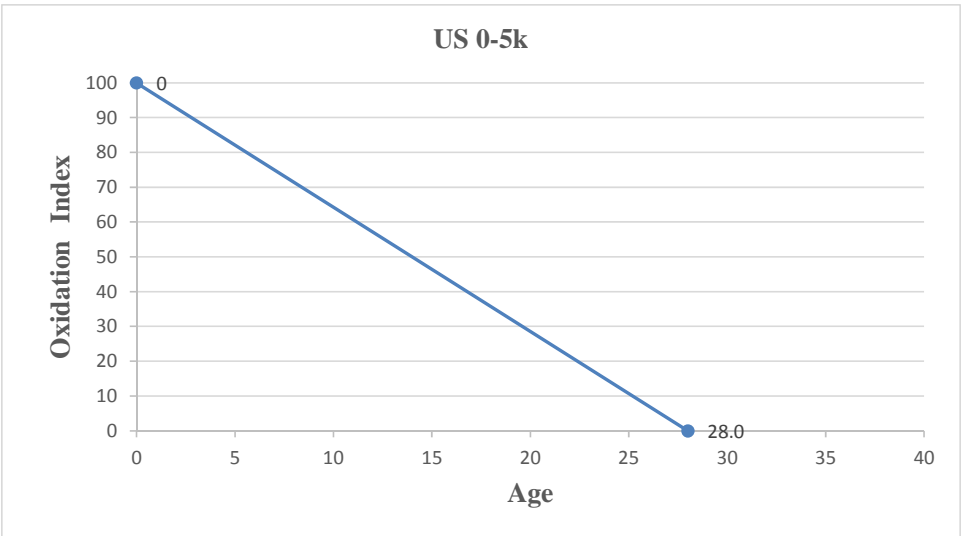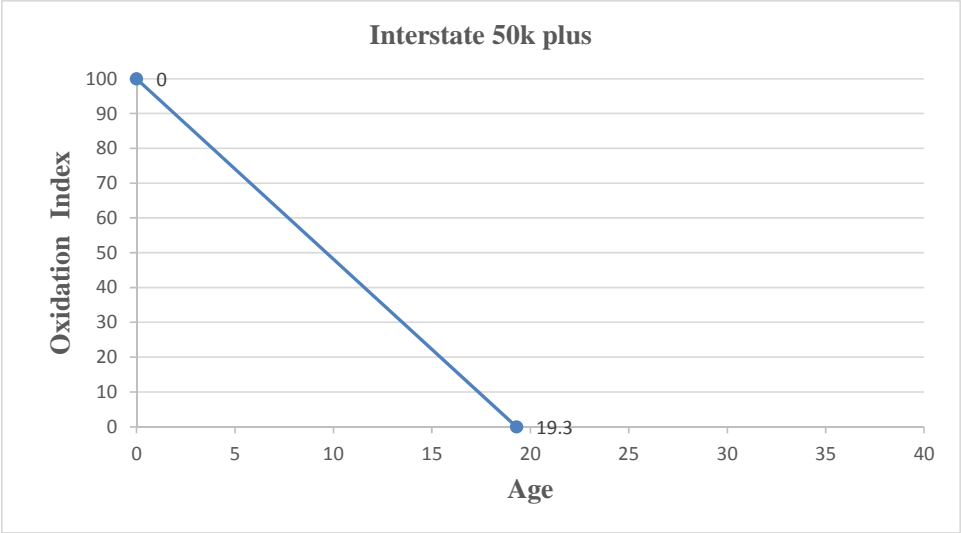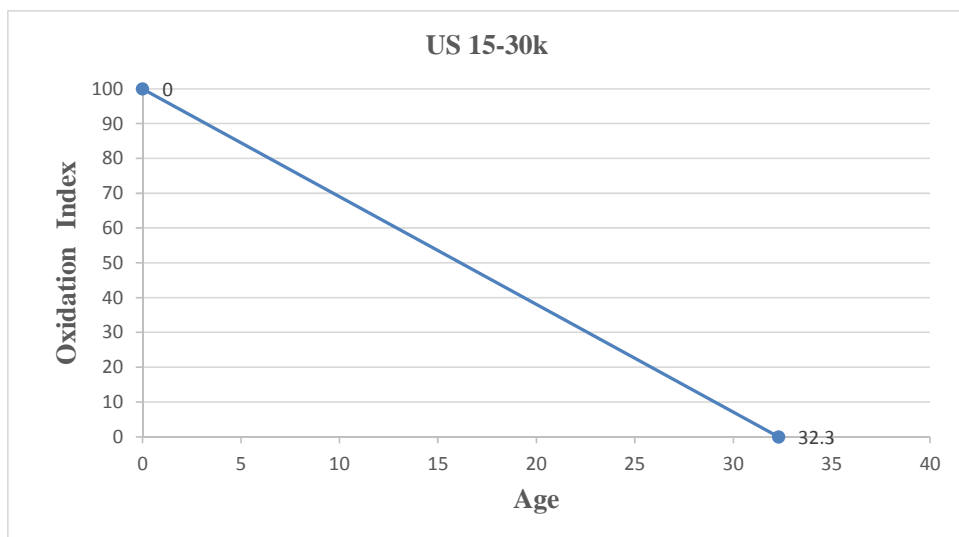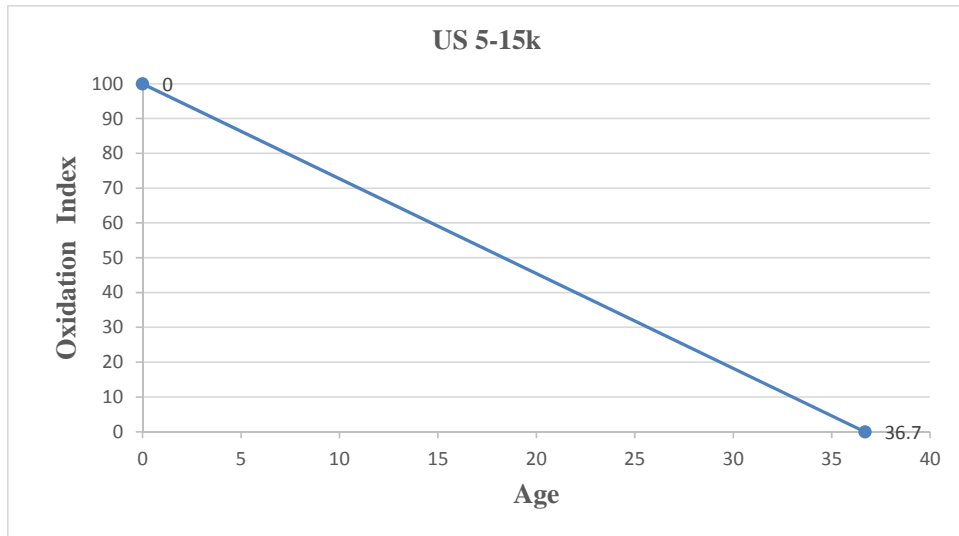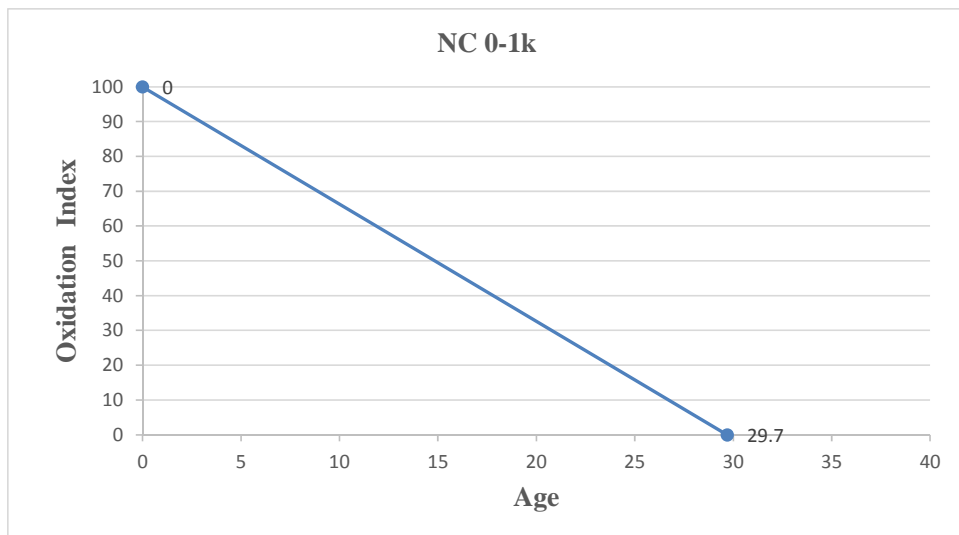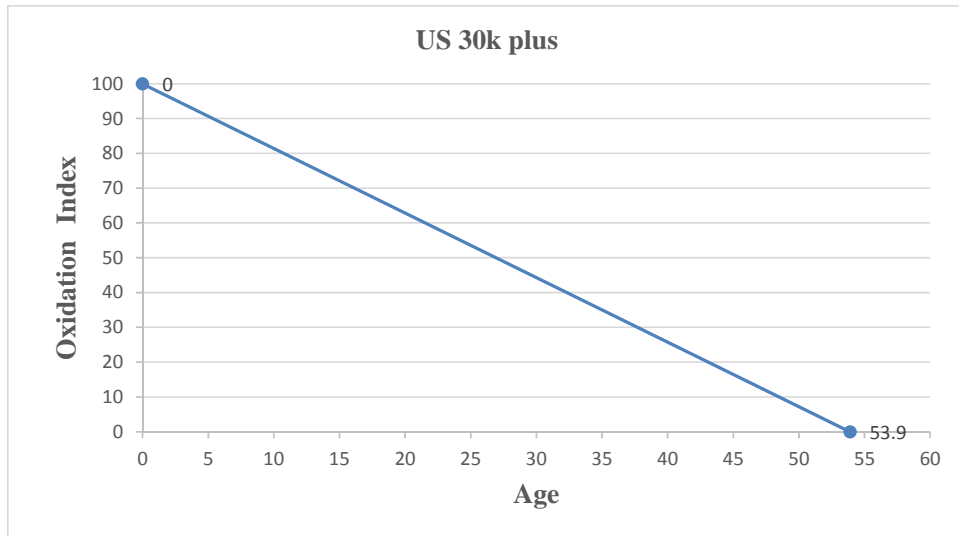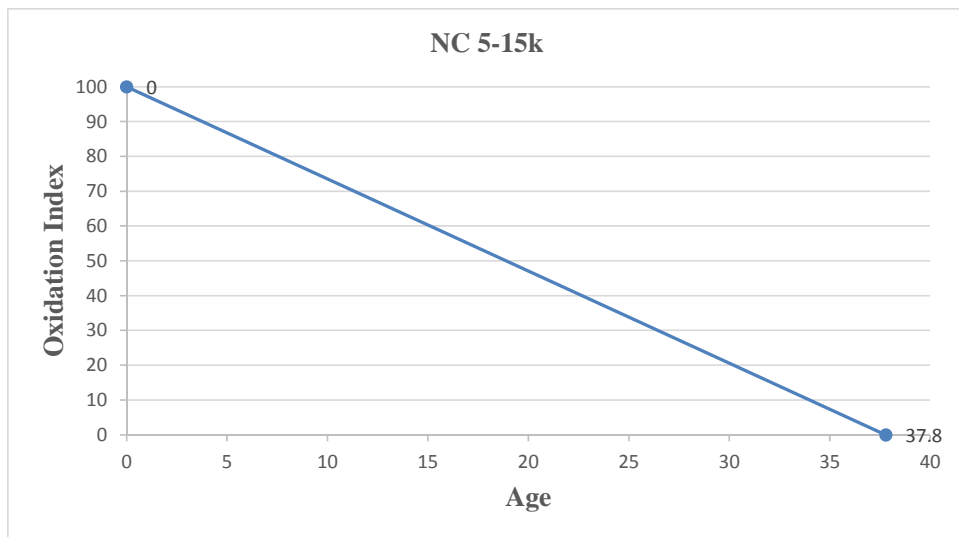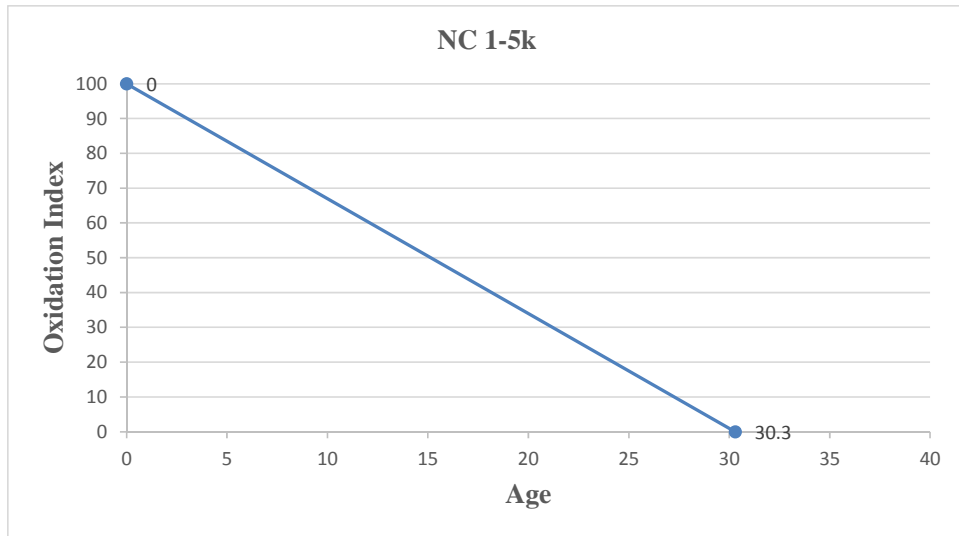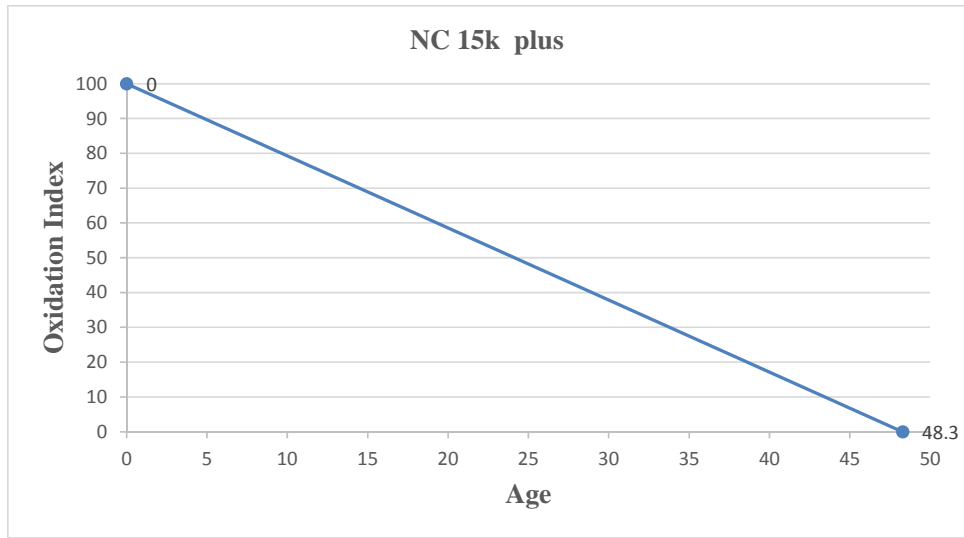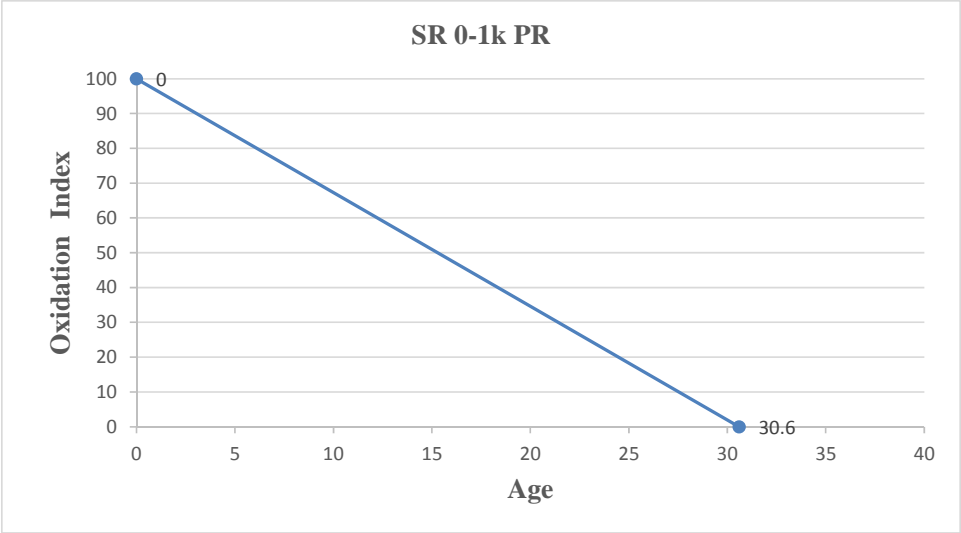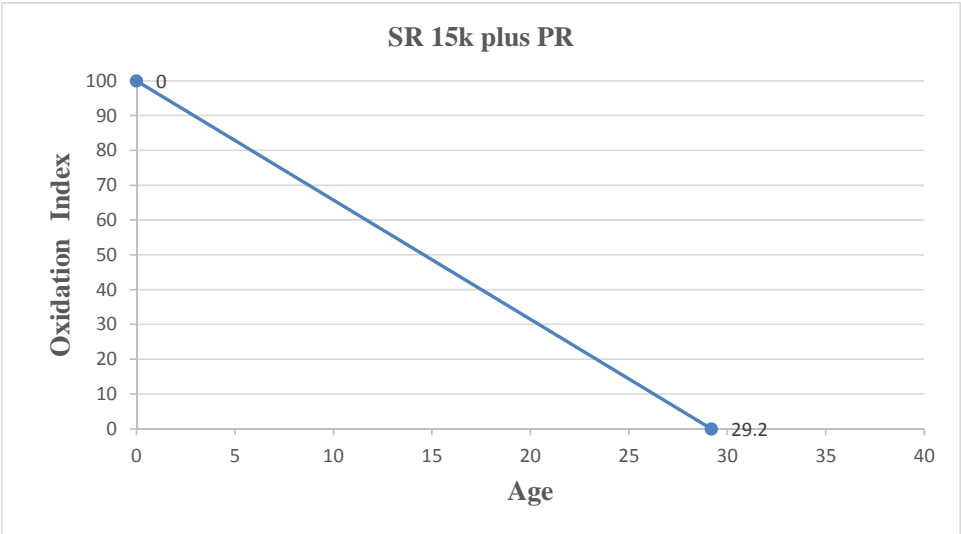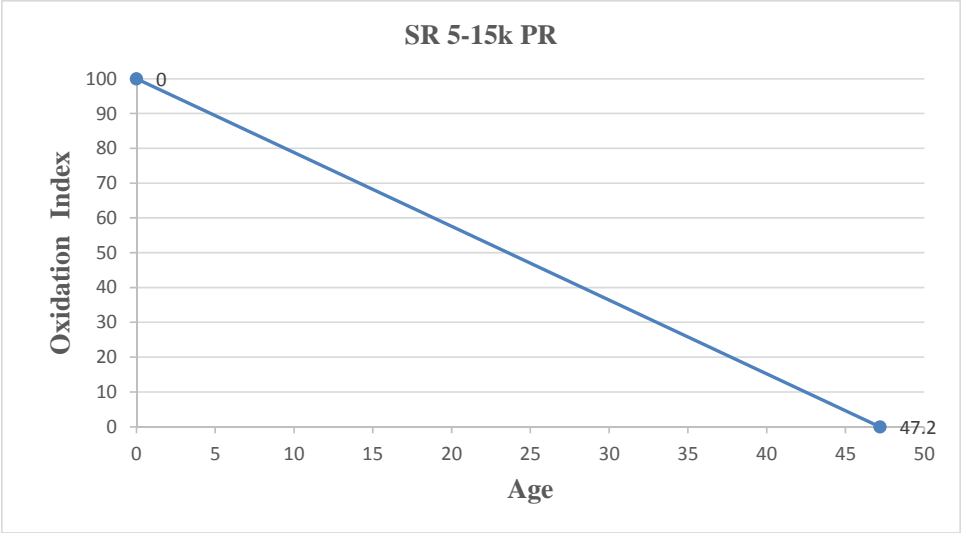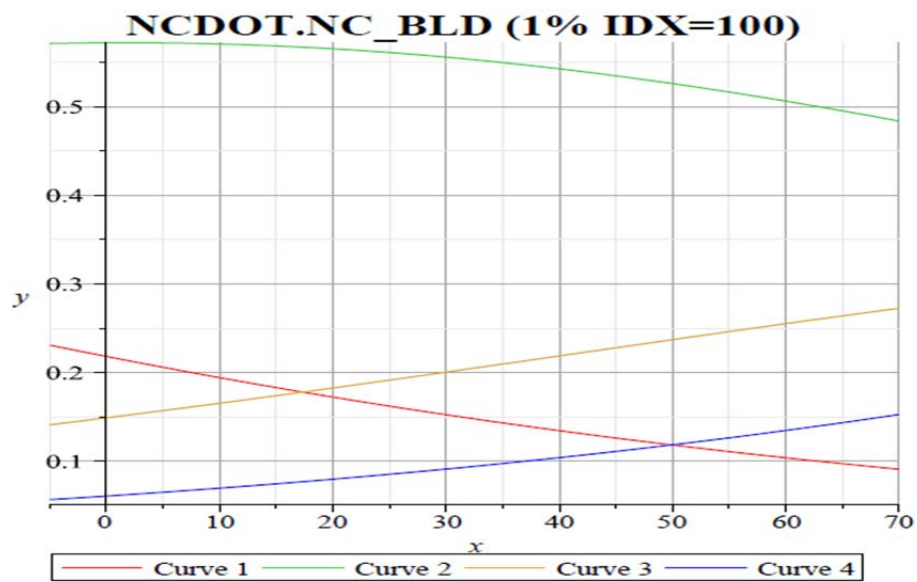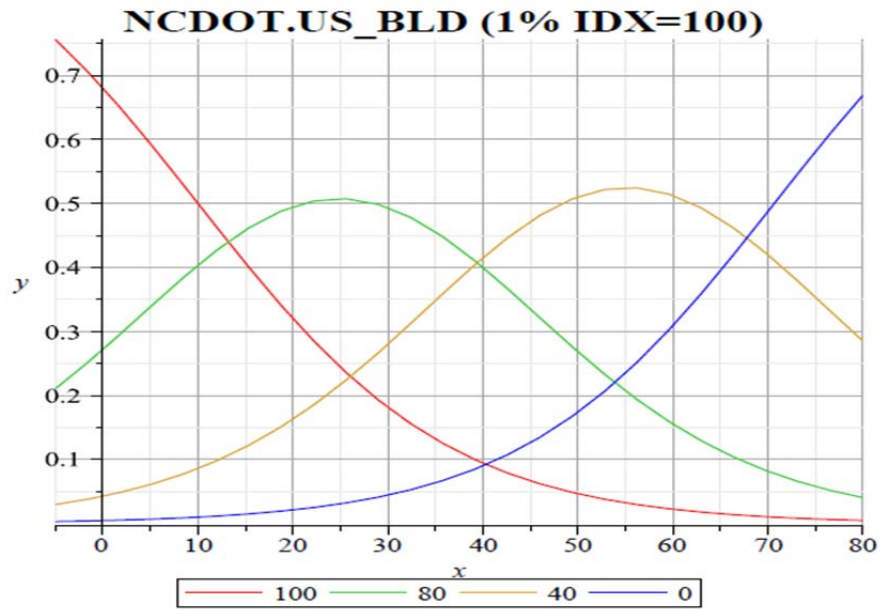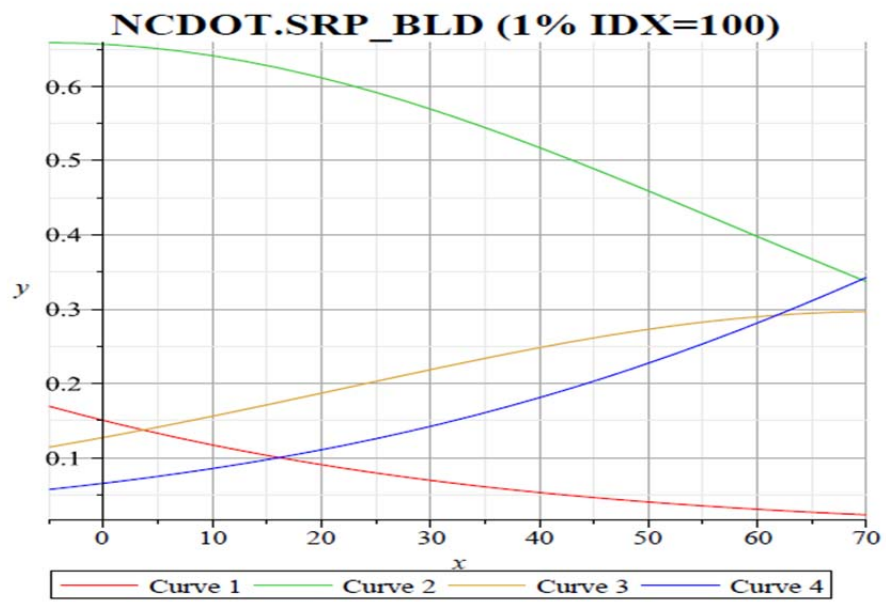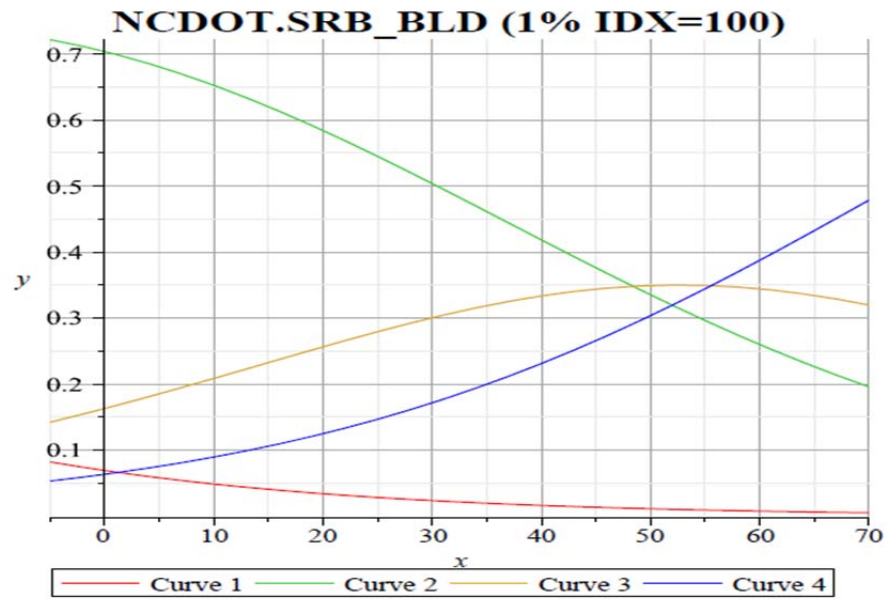
Appendix F – Patching Models

NCDOT.Interstate_PATCH

NCDOT.US_PATCH

NCDOT.NC_PATCH

NCDOT.SRB_PATCH

NCDOT.SRP_PATCH

Curve 1 — Curve 2 — Curve 3 — Curve 4

Interstate

US

NC

SR B

SR P
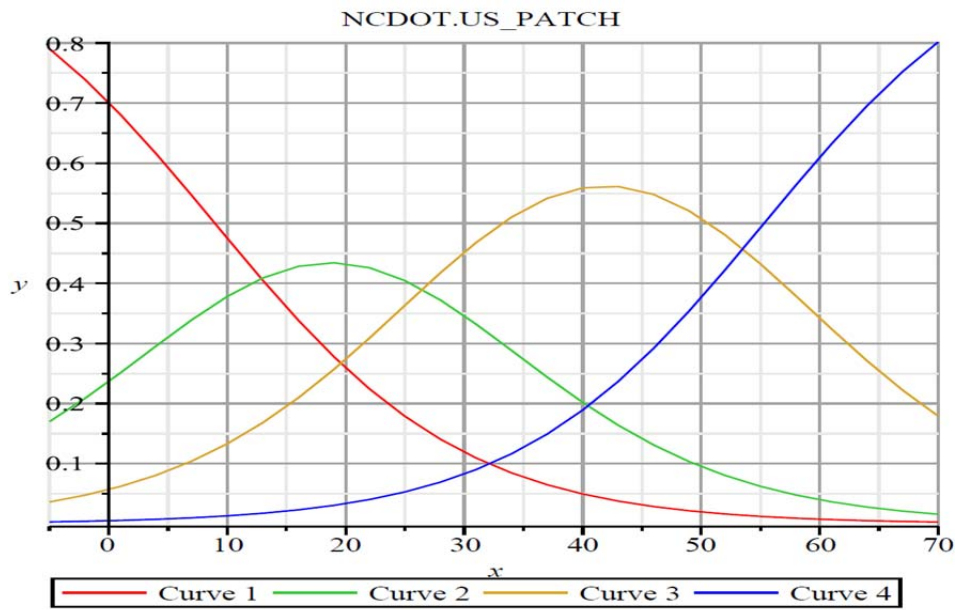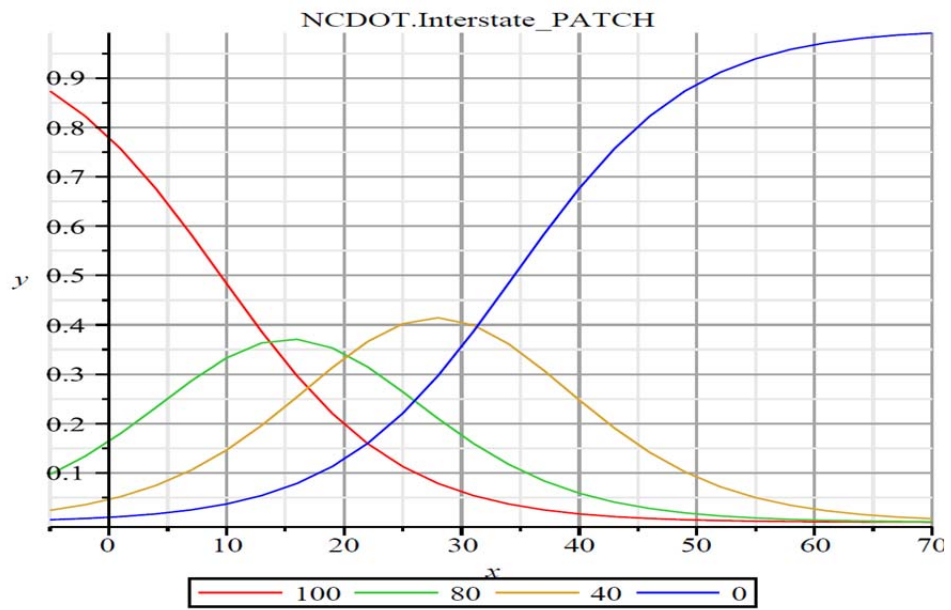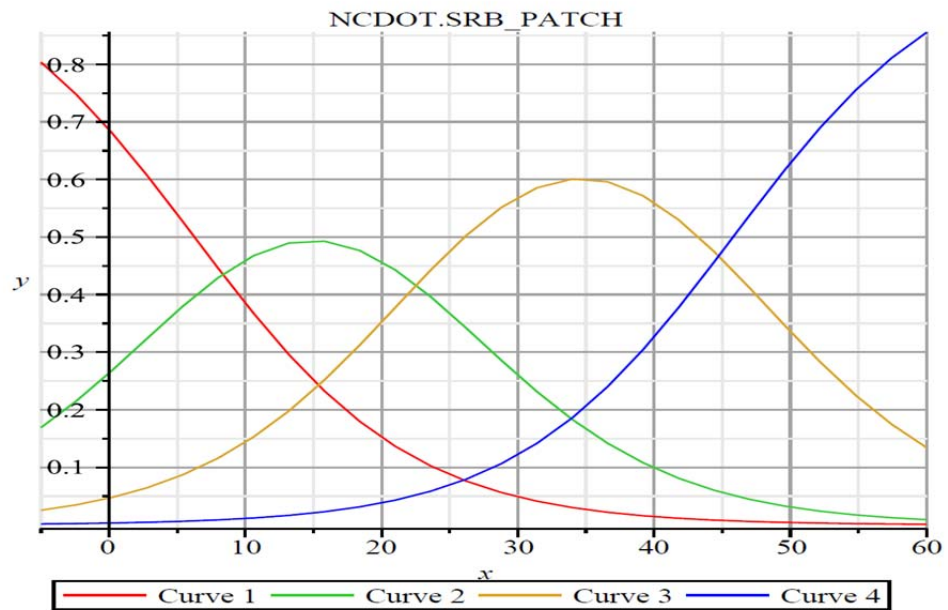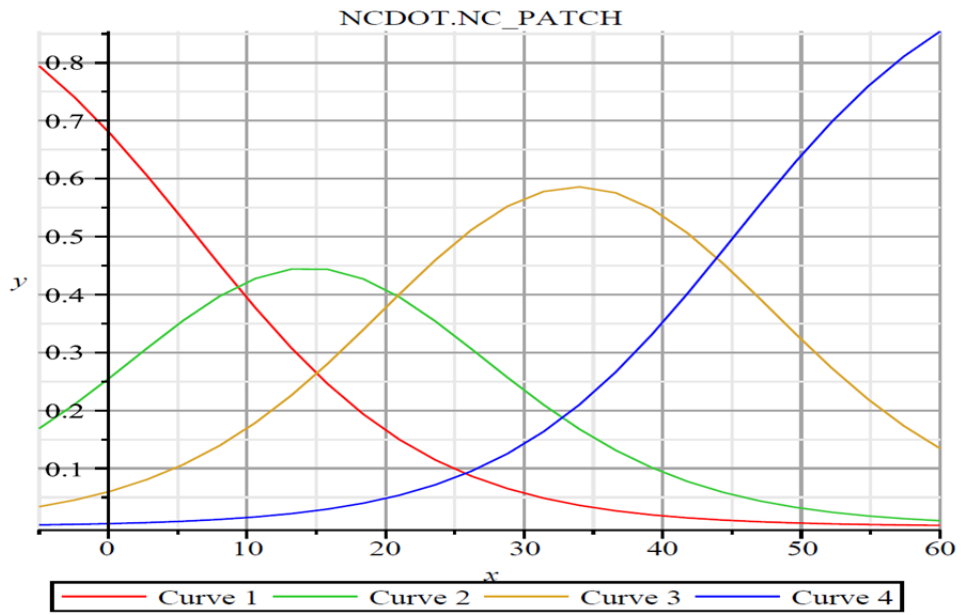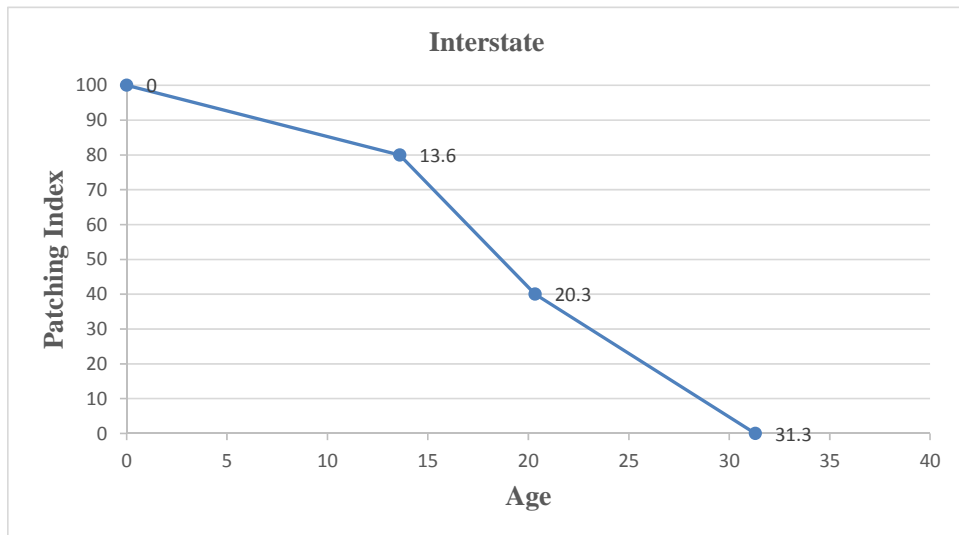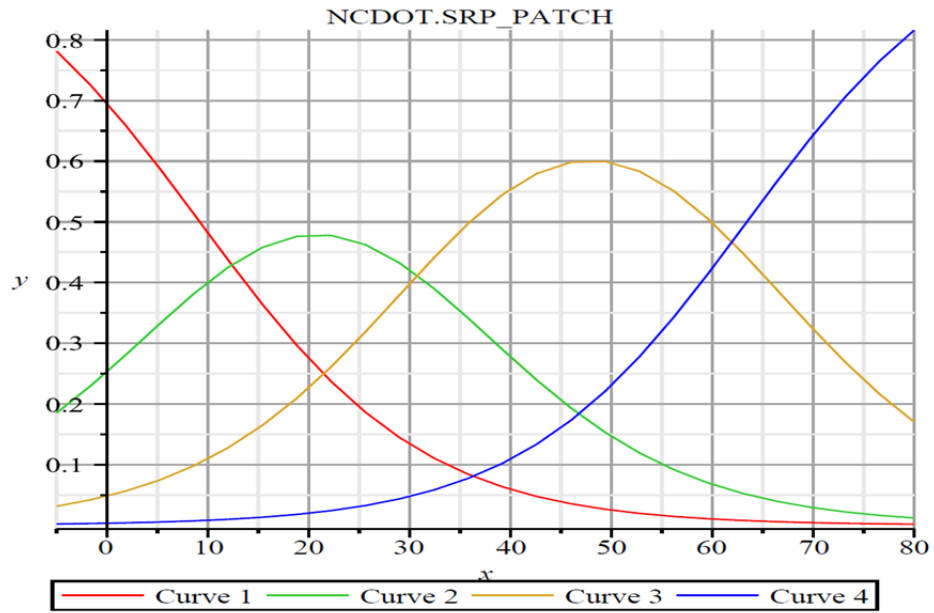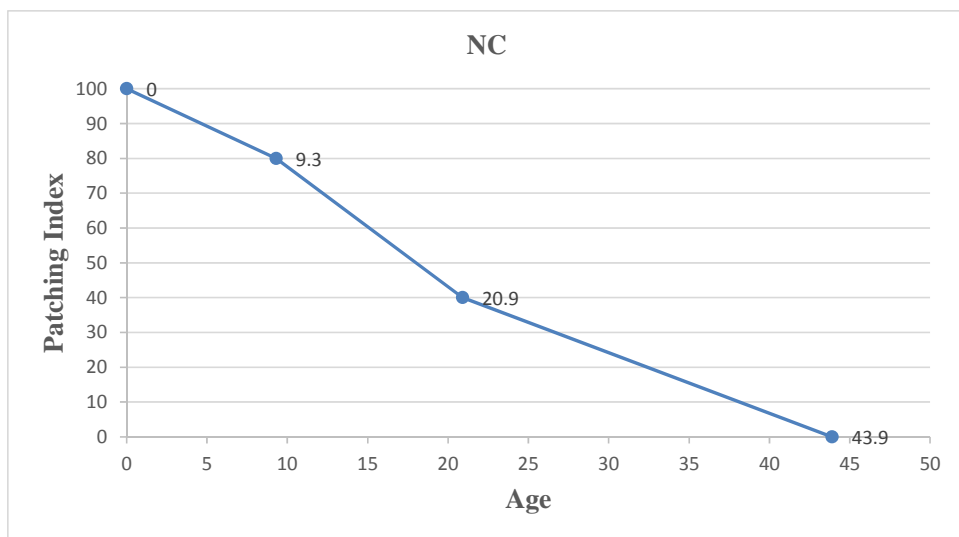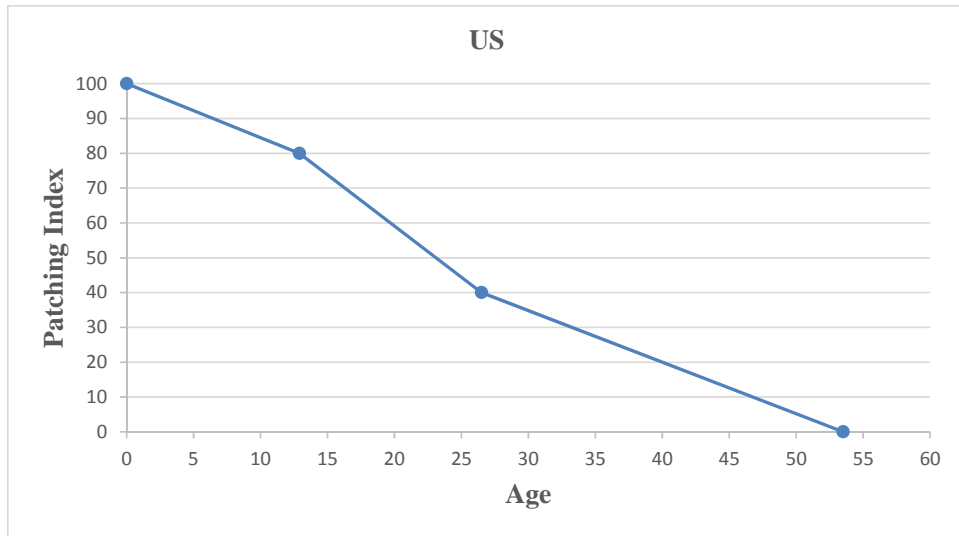
Appendix G – Rutting Models

NCDOT.Interstate_rut

NCDOT.US_rut

NCDOT.NC_rut

NCDOT.SRB_rut

NCDOT.SRP_rut

NCDOT.SR_rut

111

Interstate

US

NC

SR B

SR P

Rutting Index vs Age

0	100
28.8	80
53.6	40
80.5	0

Appendix H – Ride Models

NCDOT.Interstate_RIDE

NCDOT.US_RIDE

NCDOT.NC_RIDE

NCDOT.SRB_RIDE

NCDOT.SRP_RIDE

Interstate

SR B

SR P
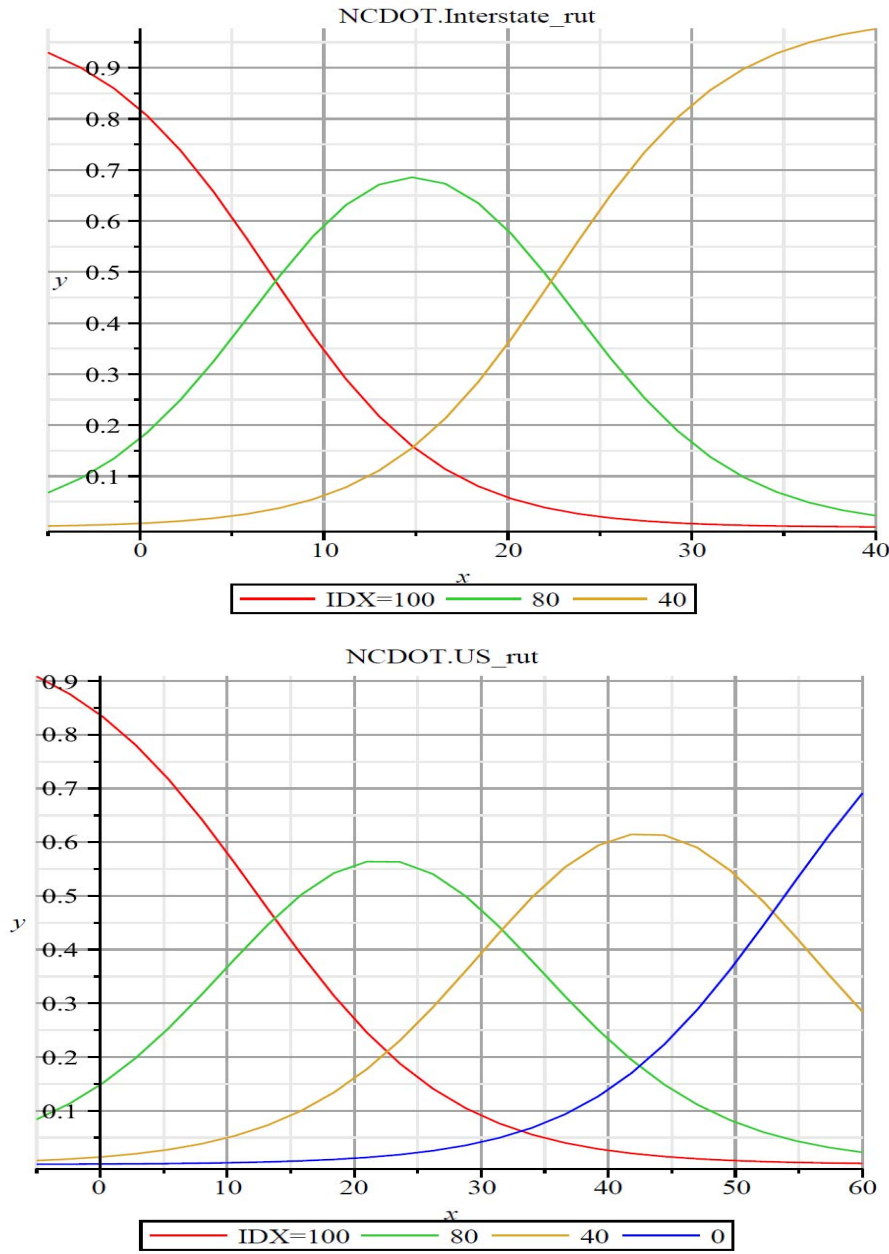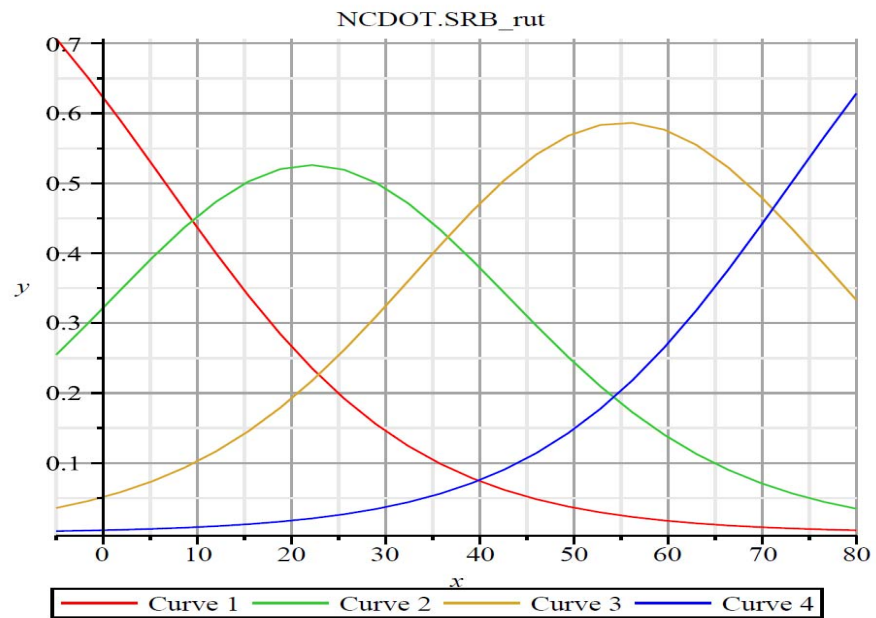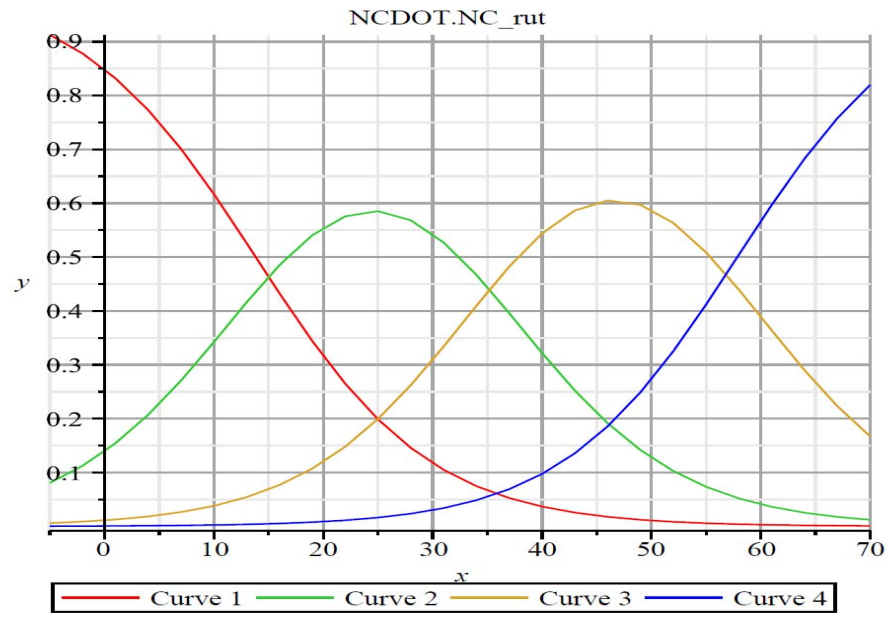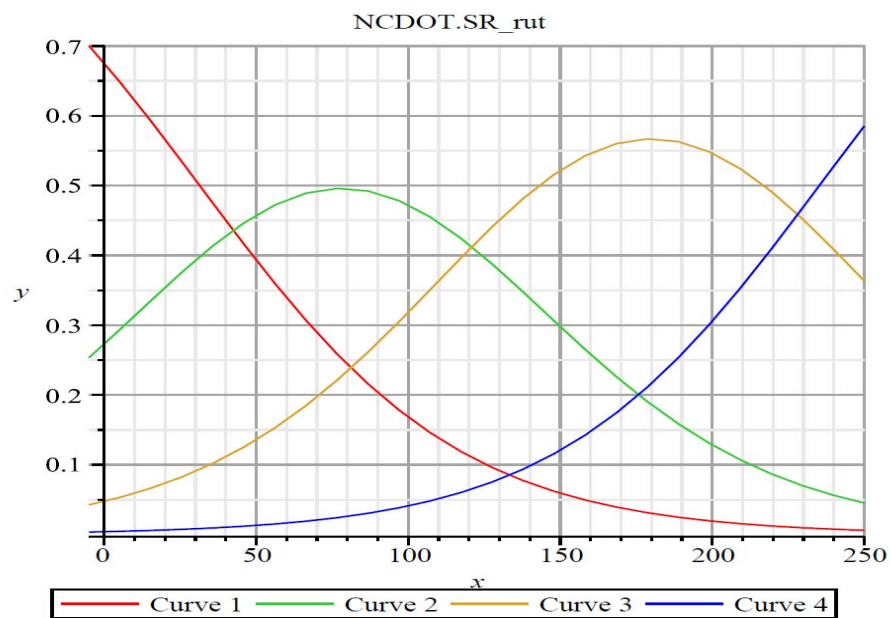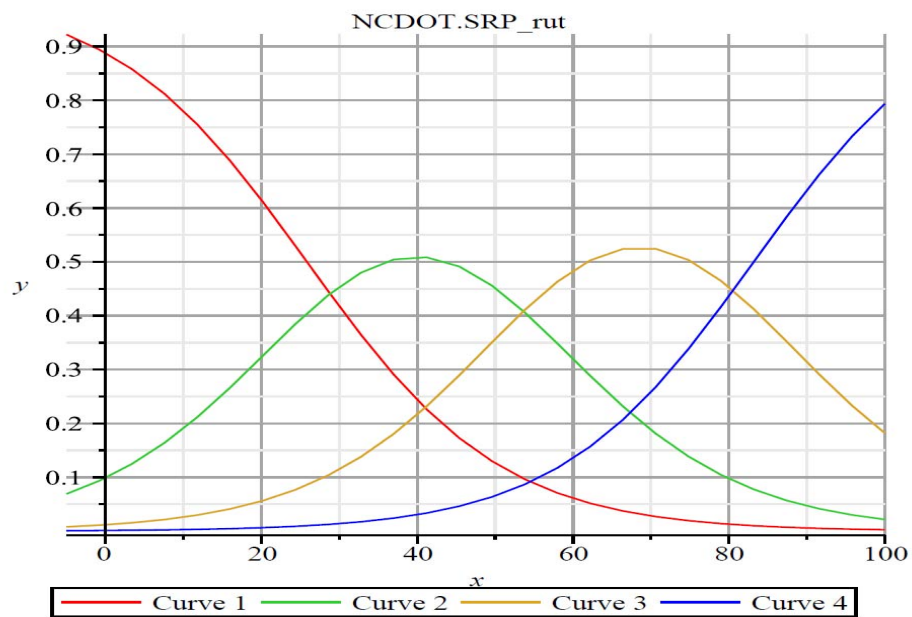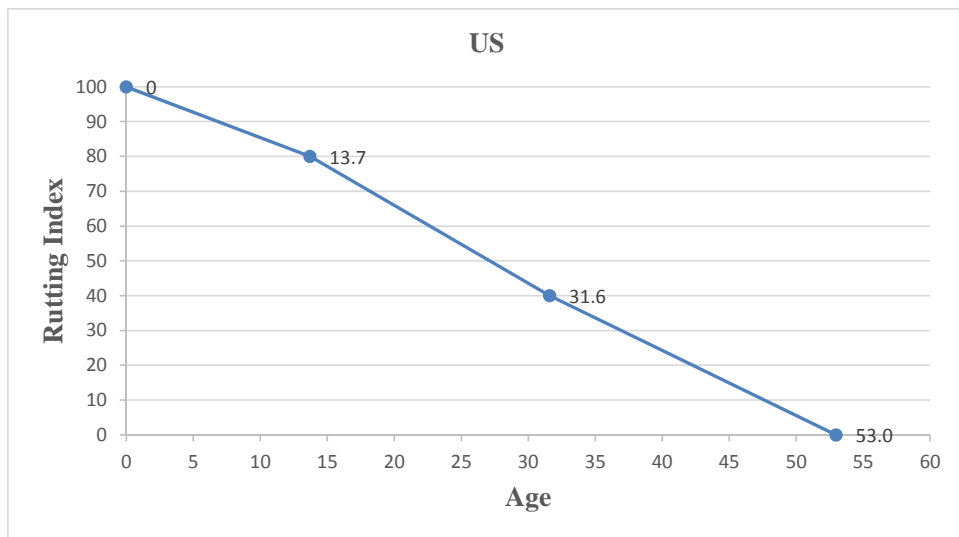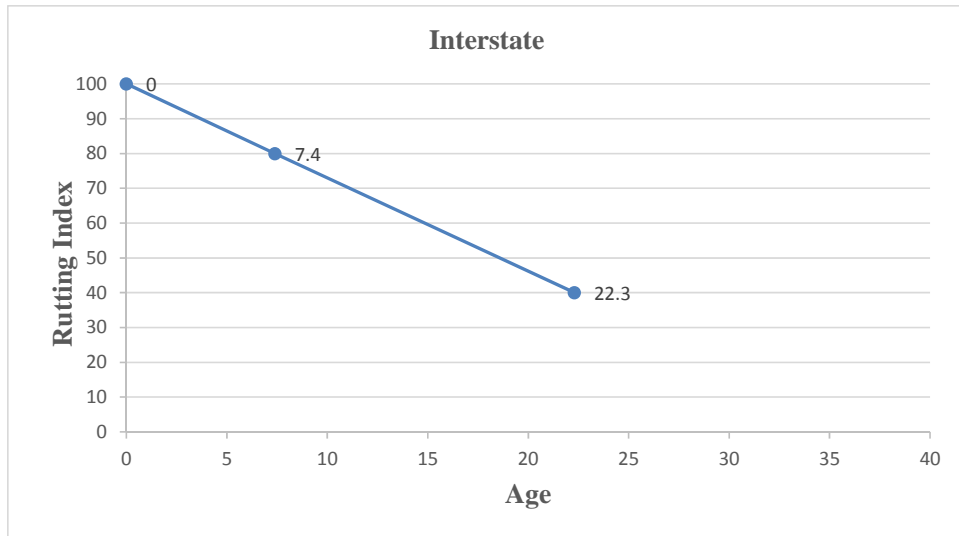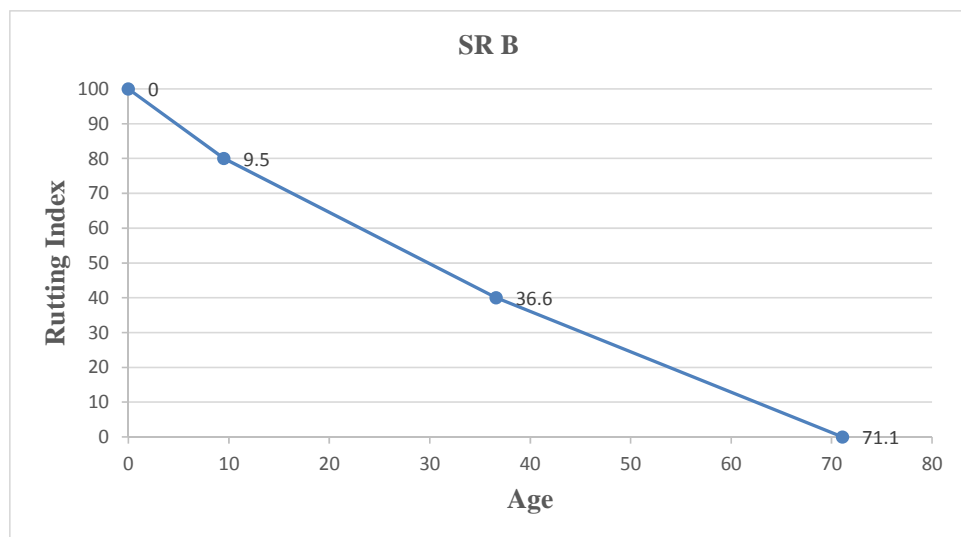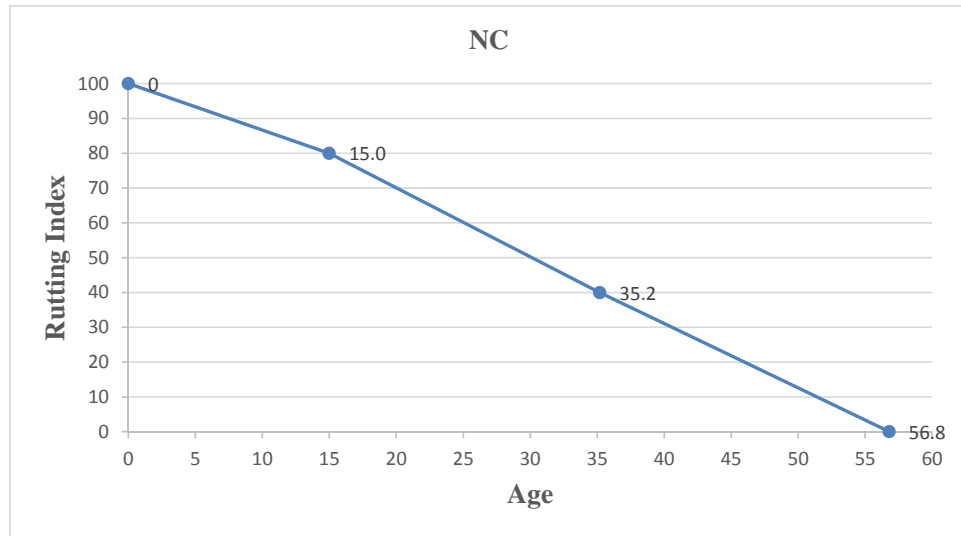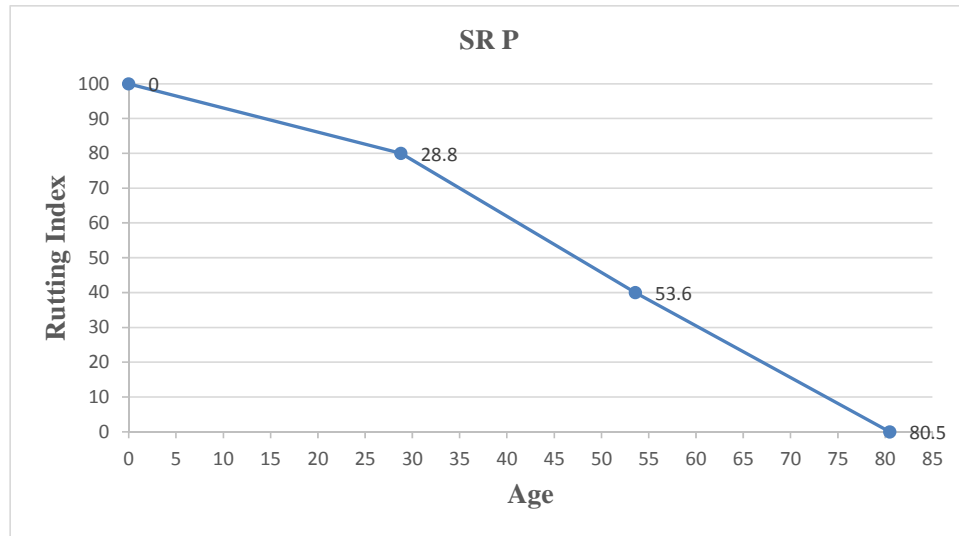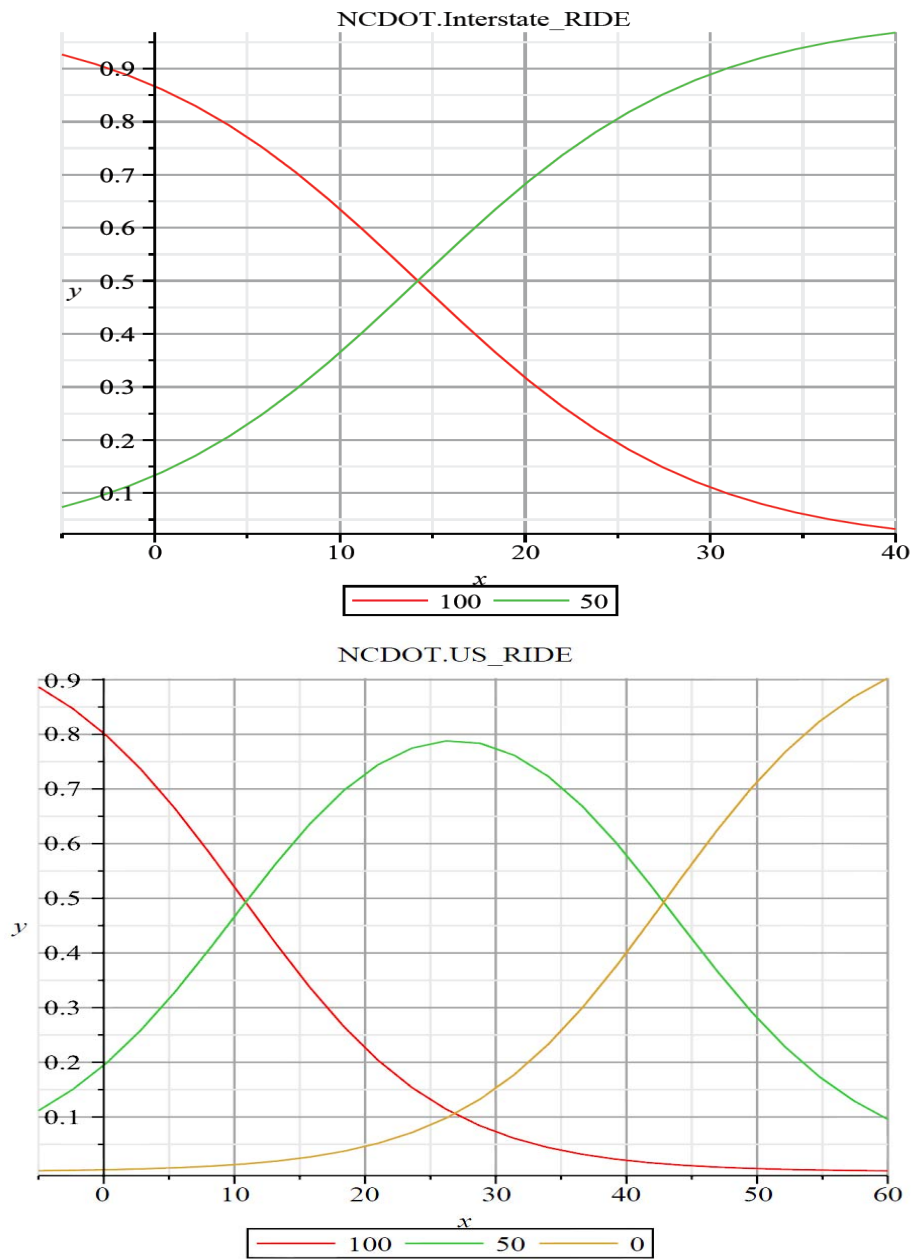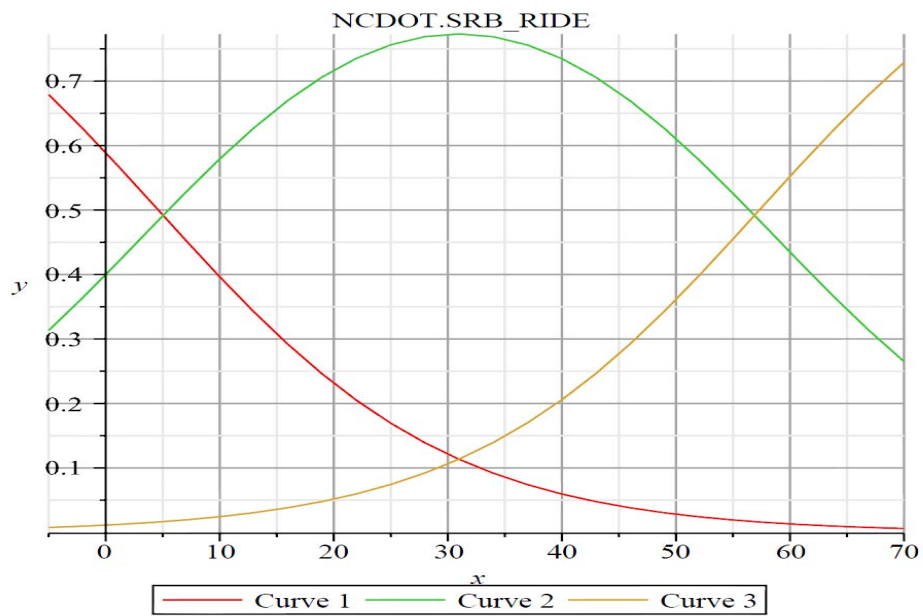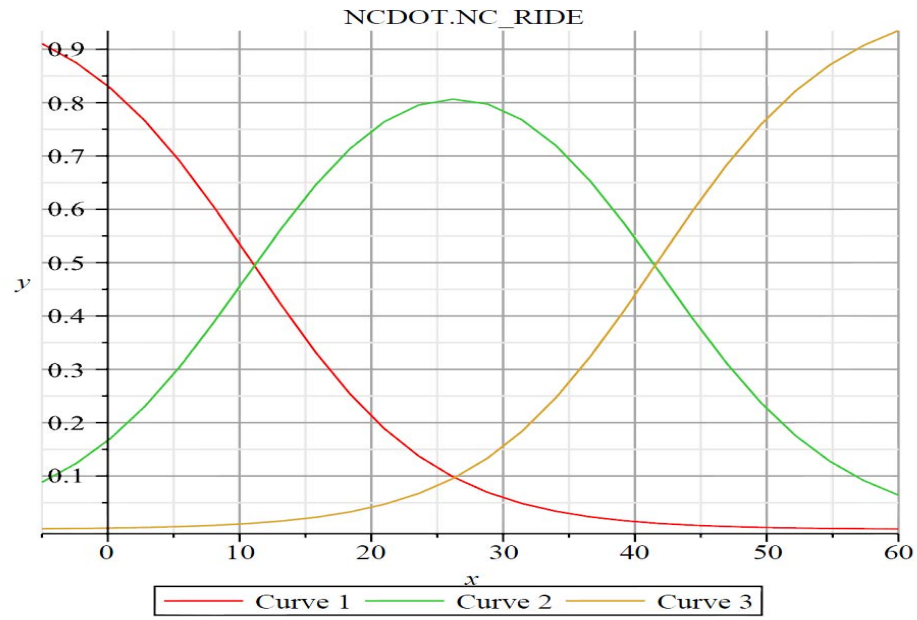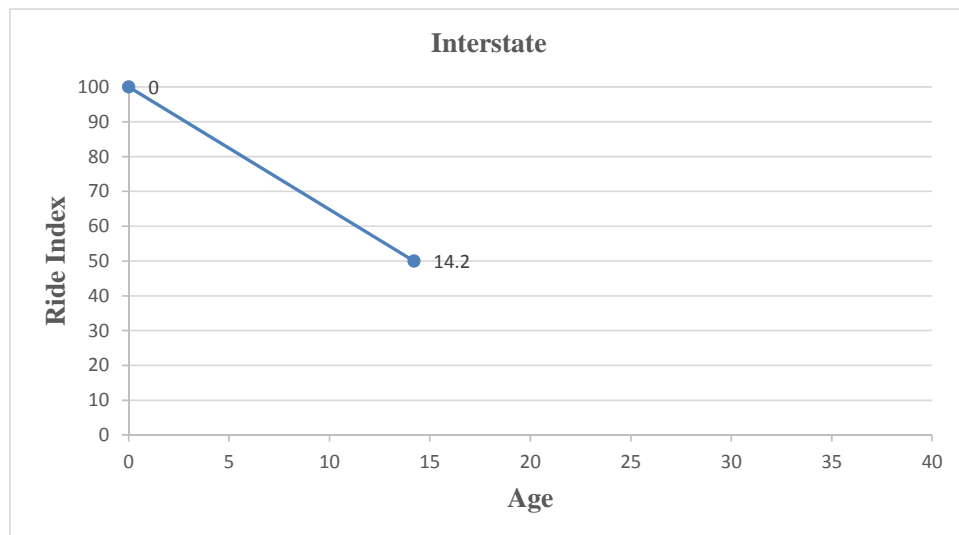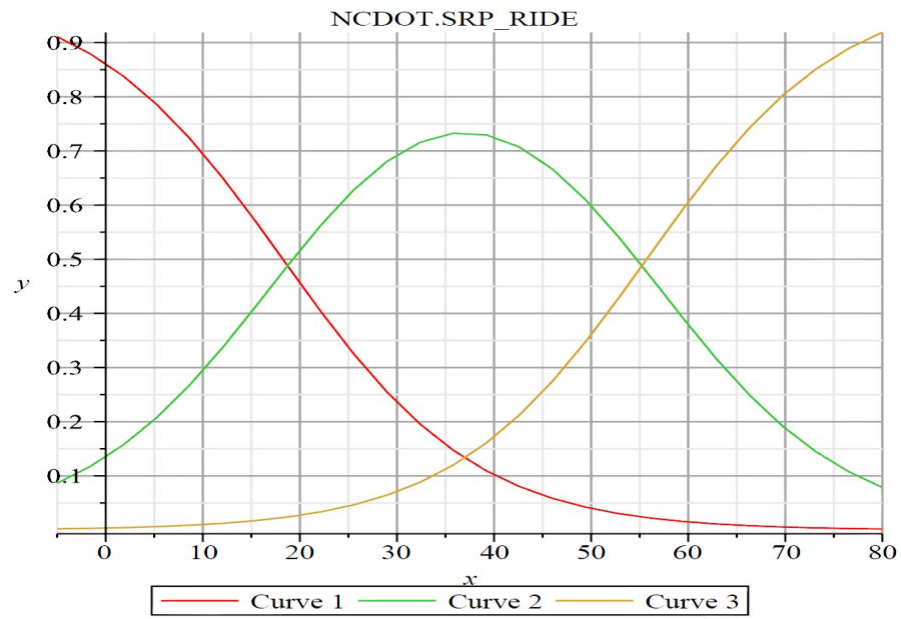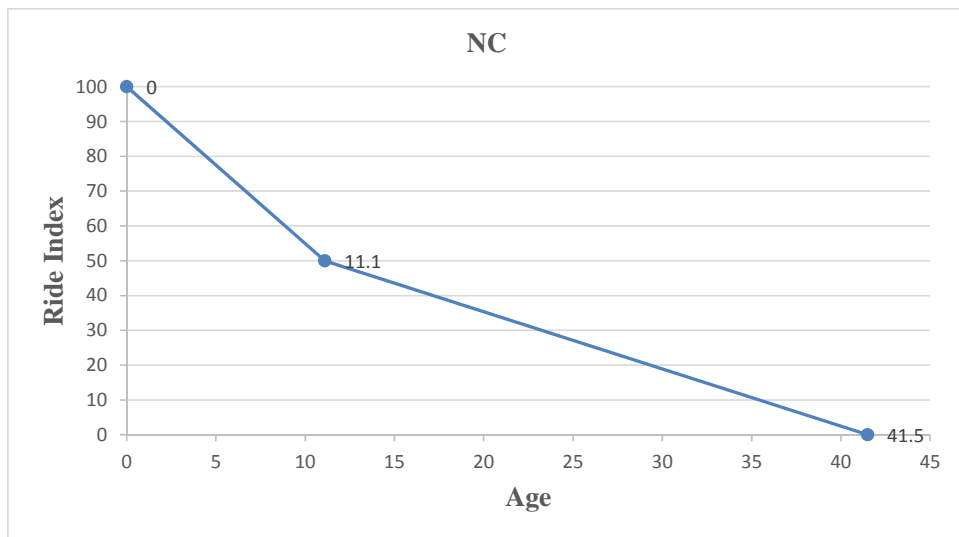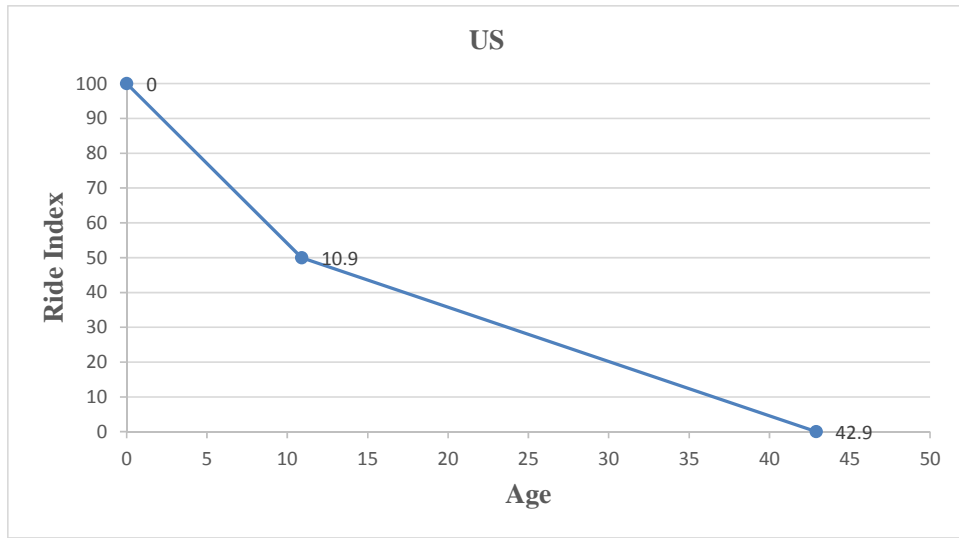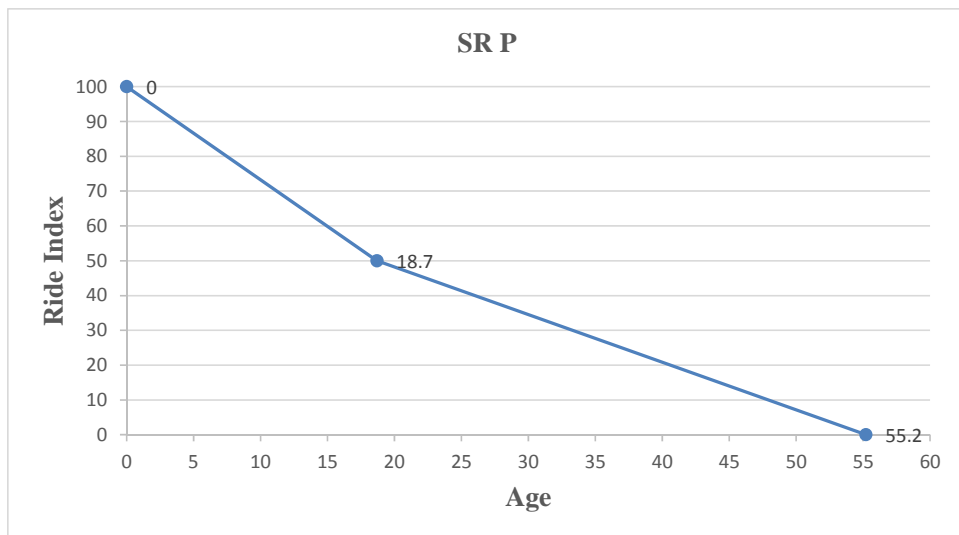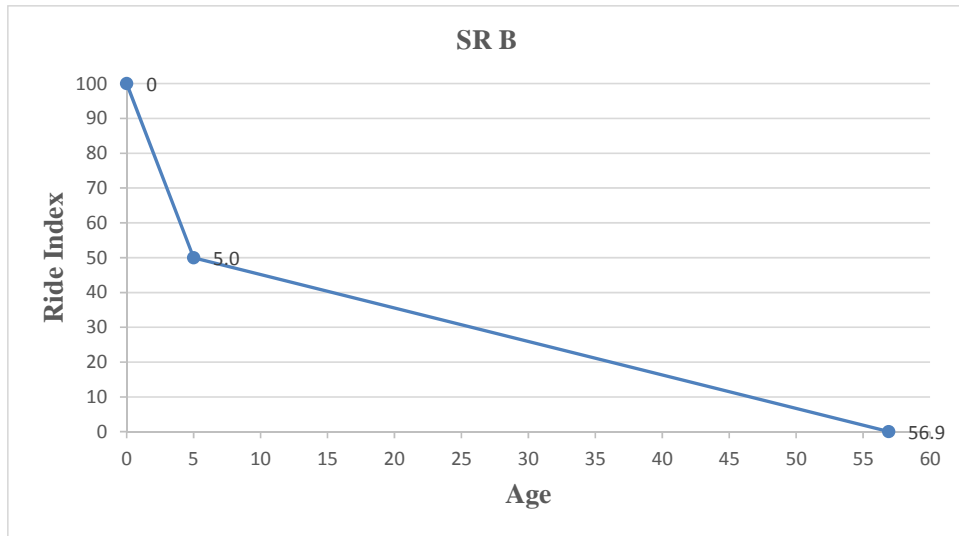
Appendix I – JCP Pavement Performance Models

Rank 1 Eqn 8017 sas2(a)
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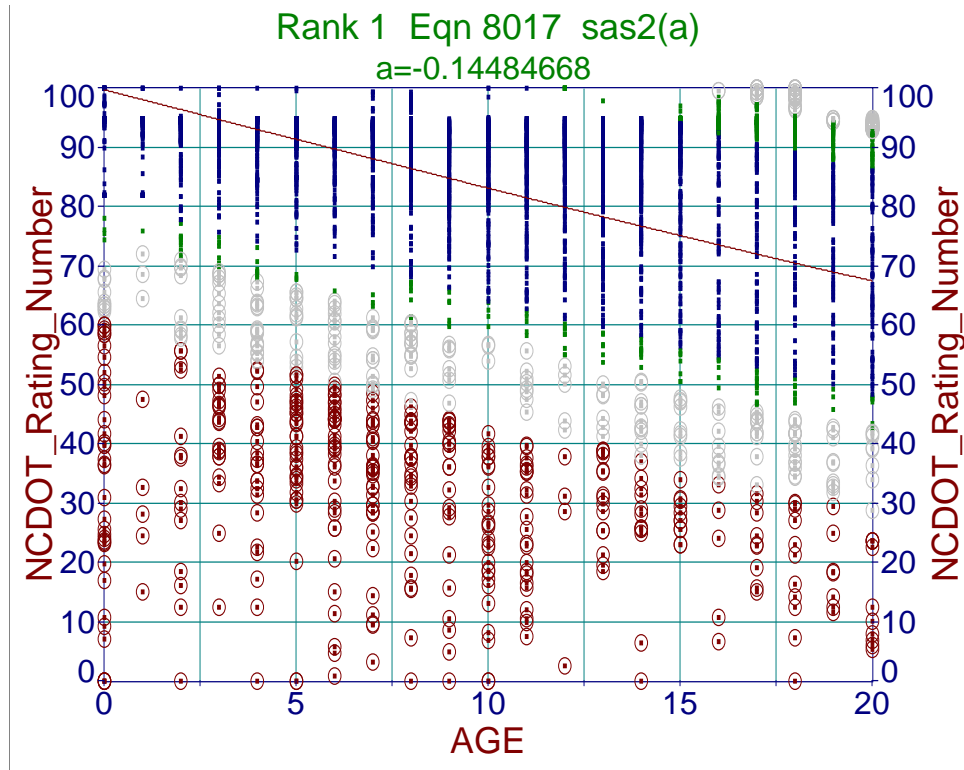
Appendix J – CBA Results (I)

Division 1

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Avergae)
1	2	1.66	1.33	1	$ 74,788,992.00	1829665.08	0.70	0.71	0.71	0.7067
2	1.3	1.2	1.1	1	$ 74,769,285.00	1886500.68	0.71	0.72	0.72	0.7167
3	3	2.66	2.33	1	$ 74,857,202.00	1744766.57	0.68	0.71	0.71	0.7000
4	1.8	1.4	1.2	1	$ 74,707,112.00	1850593.48	0.71	0.72	0.72	0.7167
5	2.9	1.5	1.3	1	$ 74,924,801.00	1836384.77	0.70	0.72	0.72	0.7163
6	2.4	2.1	1.8	1	$ 74,883,208.00	1771857.72	0.69	0.71	0.71	0.7033
7	2.7	2.1	1.4	1	$ 74,802,782.00	1803501.58	0.69	0.71	0.71	0.7033
8	2.1	1.8	1.1	1	$ 74,654,972.00	1852158.80	0.70	0.72	0.72	0.7133
9	2.2	2	1.8	1	$ 74,802,074.00	1771768.17	0.69	0.71	0.71	0.7033
10	2.7	2.3	2	1	$ 74,897,922.00	1757332.02	0.69	0.71	0.71	0.7033
11	2.9	1.4	1.3	1	$ 74,858,579.00	1845825.88	0.71	0.72	0.72	0.7167
12	2.6	2.4	1.6	1	$ 74,716,525.00	1766632.45	0.69	0.71	0.71	0.7033
13	2	1.5	1.2	1	$ 74,927,509.00	1843917.02	0.71	0.72	0.72	0.7167
14	2.9	1.7	1.1	1	$ 74,897,153.00	1857374.88	0.70	0.72	0.72	0.7133
15	1.9	1.4	1.3	1	$ 74,858,579.00	1845825.88	0.71	0.72	0.72	0.7167
16	2.9	2.5	1.7	1	$ 74,959,182.00	1758195.42	0.69	0.71	0.71	0.7033
17	1.8	1.7	1.5	1	$ 74,788,332.00	1796631.17	0.70	0.71	0.71	0.7067
18	2.9	2.6	2.1	1	$ 74,860,877.00	1748629.53	0.68	0.71	0.71	0.7000
19	2.6	1.5	1.3	1	$ 74,924,801.00	1836384.77	0.70	0.72	0.72	0.7133
20	2.8	2.5	1.3	1	$ 74,816,133.00	1800860.27	0.69	0.71	0.71	0.7033
21	3	2.6	1.6	1	$ 74,736,344.00	1763507.31	0.68	0.71	0.71	0.7000
22	2.8	2.4	1.4	1	$ 74,852,658.00	1791010.91	0.69	0.71	0.71	0.7033
23	1.9	1.8	1.1	1	$ 74,654,972.00	1852158.80	0.70	0.72	0.72	0.7133
24	2.5	2.2	1.3	1	$ 74,809,246.00	1808343.11	0.69	0.71	0.71	0.7033
25	2.2	2.1	1.3	1	$ 74,831,598.00	1821055.12	0.69	0.71	0.71	0.7033
26	2.8	1.7	1.3	1	$ 74,758,133.00	1829766.70	0.70	0.71	0.71	0.7067
27	2.4	2	1.3	1	$ 74,830,946.00	1826507.35	0.70	0.71	0.71	0.7067
28	2.3	2.1	1.9	1	$ 74,719,905.00	1769761.38	0.69	0.71	0.71	0.7033
29	3	2.6	1.2	1	$ 74,880,796.00	1810447.45	0.69	0.72	0.72	0.7100
30	3	1.9	1.7	1	$ 74,718,784.00	1774072.59	0.69	0.71	0.71	0.7033
31	2.4	1.8	1.3	1	$ 74,727,216.00	1828314.48	0.70	0.71	0.71	0.7067
32	2.2	1.8	1.2	1	$ 74,922,399.00	1841146.67	0.70	0.72	0.71	0.7100
33	1.7	1.4	1.3	1	$ 74,858,579.00	1845825.88	0.71	0.72	0.72	0.7167

Division 2

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$74,840,402.00	1819491.37	0.69	0.71	0.72	0.7067
2	1.3	1.2	1.1	1	$74,792,610.00	1870878.04	0.69	0.72	0.73	0.7133
3	3	2.66	2.33	1	$74,934,127.00	1703569.48	0.68	0.70	0.72	0.7000
4	1.8	1.4	1.2	1	$74,869,083.00	1841224.14	0.69	0.72	0.73	0.7133
5	2.9	1.5	1.3	1	$74,884,299.00	1826713.96	0.69	0.72	0.72	0.7100
6	2.4	2.1	1.8	1	$74,828,477.00	1744615.11	0.69	0.71	0.72	0.7067
7	2.7	2.1	1.4	1	$74,850,048.00	1794721.53	0.69	0.71	0.72	0.7067
8	2.1	1.8	1.1	1	$74,836,136.00	1847186.60	0.69	0.72	0.72	0.7100
9	2.2	2	1.8	1	$74,829,682.00	1746735.67	0.69	0.71	0.72	0.7067
10	2.7	2.3	2	1	$74,892,879.00	1734973.45	0.69	0.70	0.72	0.7033
11	2.9	1.4	1.3	1	$74,872,473.00	1829088.83	0.69	0.72	0.73	0.7133
12	2.6	2.4	1.6	1	$74,858,785.00	1739165.49	0.69	0.71	0.72	0.7067
13	2	1.5	1.2	1	$74,918,977.00	1841246.45	0.69	0.72	0.73	0.7133
14	2.9	1.7	1.1	1	$74,830,790.00	1848445.77	0.69	0.72	0.72	0.7100
15	1.9	1.4	1.3	1	$74,872,473.00	1829088.83	0.69	0.72	0.73	0.7133
16	2.9	2.5	1.7	1	$74,683,683.00	1739023.88	0.69	0.71	0.72	0.7067
17	1.8	1.7	1.5	1	$74,779,580.00	1779912.00	0.69	0.71	0.72	0.7067
18	2.9	2.6	2.1	1	$74,870,893.00	1721548.39	0.69	0.70	0.72	0.7033
19	2.6	1.5	1.3	1	$74,884,299.00	1826713.96	0.69	0.72	0.72	0.7100
20	2.8	2.5	1.3	1	$74,711,630.00	1782797.54	0.69	0.72	0.73	0.7133
21	3	2.6	1.6	1	$74,628,474.00	1740927.50	0.69	0.71	0.72	0.7067
22	2.8	2.4	1.4	1	$74,803,128.00	1770968.99	0.69	0.71	0.72	0.7067
23	1.9	1.8	1.1	1	$74,836,136.00	1847186.60	0.69	0.72	0.72	0.7100
24	2.5	2.2	1.3	1	$74,718,745.00	1793805.88	0.69	0.71	0.72	0.7067
25	2.2	2.1	1.3	1	$74,929,781.00	1804125.07	0.69	0.71	0.72	0.7067
26	2.8	1.7	1.3	1	$74,804,638.00	1822805.34	0.69	0.71	0.72	0.7067
27	2.4	2	1.3	1	$74,784,459.00	1808540.29	0.69	0.71	0.72	0.7067
28	2.3	2.1	1.9	1	$74,861,503.00	1739256.30	0.69	0.70	0.72	0.7033
29	3	2.6	1.2	1	$74,684,523.00	1785253.87	0.69	0.72	0.73	0.7133
30	3	1.9	1.7	1	$74,947,930.00	1751340.19	0.69	0.71	0.72	0.7067
31	2.4	1.8	1.3	1	$74,785,708.00	1816949.68	0.69	0.71	0.72	0.7067
32	2.2	1.8	1.2	1	$74,822,467.00	1829339.05	0.69	0.72	0.72	0.7100
33	1.7	1.4	1.3	1	$74,872,473.00	1829088.83	0.69	0.72	0.73	0.7133

Division 3

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.7	1.3	1	$74,855,734.00	2058249.09	0.72	0.72	0.72	0.7200
2	1.3	1.2	1.1	1	$74,839,861.00	2104363.86	0.73	0.73	0.73	0.7300
3	3	2.7	2.3	1	$74,756,323.00	1942673.53	0.69	0.70	0.70	0.6967
4	1.8	1.4	1.2	1	$74,958,298.00	2084454.26	0.73	0.72	0.72	0.7233
5	2.9	1.5	1.3	1	$74,885,551.00	2066270.00	0.73	0.72	0.72	0.7233
6	2.4	2.1	1.8	1	$74,694,165.00	2007027.64	0.71	0.71	0.71	0.7100
7	2.7	2.1	1.4	1	$74,962,031.00	2020450.32	0.71	0.71	0.71	0.7100
8	2.1	1.8	1.1	1	$74,825,239.00	2057278.24	0.72	0.72	0.72	0.7200
9	2.2	2	1.8	1	$74,839,997.00	2008978.51	0.71	0.71	0.71	0.7100
10	2.7	2.3	2	1	$74,764,074.00	1981783.04	0.70	0.70	0.70	0.7000
11	2.9	1.4	1.3	1	$74,877,649.00	2065384.66	0.73	0.72	0.72	0.7233
12	2.6	2.4	1.6	1	$74,897,349.00	1999663.19	0.70	0.71	0.71	0.7067
13	2	1.5	1.2	1	$74,701,862.00	2074528.78	0.73	0.72	0.72	0.7267
14	2.9	1.7	1.1	1	$74,951,413.00	2073144.78	0.73	0.72	0.72	0.7267
15	1.9	1.4	1.3	1	$74,877,649.00	2065384.66	0.73	0.72	0.72	0.7267
16	2.9	2.5	1.7	1	$74,847,732.00	1986065.90	0.70	0.70	0.70	0.7000
17	1.8	1.7	1.5	1	$74,811,357.00	2039584.10	0.72	0.72	0.72	0.7200
18	2.9	2.6	2.1	1	$74,896,219.00	1966982.40	0.69	0.70	0.70	0.6967
19	2.6	1.5	1.3	1	$74,885,551.00	2066270.00	0.73	0.72	0.72	0.7267
20	2.8	2.5	1.3	1	$74,850,380.00	2006805.01	0.70	0.71	0.71	0.7067
21	3	2.6	1.6	1	$74,411,565.00	1991841.28	0.70	0.70	0.70	0.7000
22	2.8	2.4	1.4	1	$74,799,816.00	2003398.30	0.71	0.71	0.71	0.7100
23	1.9	1.8	1.1	1	$74,825,239.00	2057278.24	0.72	0.72	0.72	0.7200
24	2.5	2.2	1.3	1	$74,863,414.00	2024498.56	0.71	0.71	0.71	0.7100
25	2.2	2.1	1.3	1	$74,832,156.00	2032560.15	0.71	0.71	0.71	0.7100
26	2.8	1.7	1.3	1	$74,870,993.00	2058836.98	0.72	0.72	0.72	0.7200
27	2.4	2	1.3	1	$74,930,166.00	2034276.00	0.71	0.71	0.71	0.7100
28	2.3	2.1	1.9	1	$74,727,933.00	2000685.61	0.70	0.71	0.71	0.7067
29	3	2.6	1.2	1	$74,853,286.00	2013160.63	0.70	0.71	0.71	0.7067
30	3	1.9	1.7	1	$74,915,579.00	2013996.57	0.71	0.71	0.71	0.7100
31	2.4	1.8	1.3	1	$74,735,553.00	2049845.98	0.72	0.71	0.71	0.7167
32	2.2	1.8	1.2	1	$74,708,229.00	2057547.81	0.72	0.72	0.71	0.7167
33	1.7	1.4	1.3	1	$74,877,649.00	2065384.66	0.73	0.72	0.72	0.7233

Division 4

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.7	1.3	1	$89,666,648.00	2094877.34	0.74	0.71	0.71	0.7200
2	1.3	1.2	1.1	1	$89,909,457.00	2202339.87	0.76	0.73	0.73	0.7400
3	3	2.7	2.3	1	$89,888,968.00	1993128.60	0.70	0.68	0.68	0.6867
4	1.8	1.4	1.2	1	$89,944,483.00	2148190.84	0.75	0.72	0.71	0.7267
5	2.9	1.5	1.3	1	$89,981,146.00	2106213.68	0.74	0.71	0.70	0.7167
6	2.4	2.1	1.8	1	$89,832,619.00	2022912.35	0.72	0.69	0.69	0.7000
7	2.7	2.1	1.4	1	$89,873,281.00	2033411.85	0.73	0.70	0.70	0.7100
8	2.1	1.8	1.1	1	$89,867,197.00	2110881.53	0.74	0.71	0.72	0.7233
9	2.2	2	1.8	1	$89,577,494.00	2025297.55	0.73	0.69	0.69	0.7033
10	2.7	2.3	2	1	$89,697,654.00	2015407.58	0.72	0.69	0.69	0.7000
11	2.9	1.4	1.3	1	$89,678,463.00	2104431.42	0.75	0.71	0.71	0.7233
12	2.6	2.4	1.6	1	$89,830,442.00	2011540.02	0.72	0.70	0.70	0.7067
13	2	1.5	1.2	1	$89,846,040.00	2139217.03	0.75	0.71	0.71	0.7233
14	2.9	1.7	1.1	1	$89,680,565.00	2127580.70	0.74	0.71	0.71	0.7200
15	1.9	1.4	1.3	1	$89,818,269.00	2108323.65	0.75	0.71	0.71	0.7233
16	2.9	2.5	1.7	1	$89,767,118.00	2011369.97	0.72	0.69	0.70	0.7033
17	1.8	1.7	1.5	1	$89,870,820.00	2046730.53	0.74	0.70	0.70	0.7133
18	2.9	2.6	2.1	1	$89,886,230.00	2007330.22	0.71	0.68	0.69	0.6933
19	2.6	1.5	1.3	1	$89,823,647.00	2107652.37	0.75	0.71	0.71	0.7233
20	2.8	2.5	1.3	1	$89,646,843.00	2004631.71	0.72	0.71	0.71	0.7133
21	3	2.6	1.6	1	$89,569,475.00	2005570.30	0.72	0.70	0.70	0.7067
22	2.8	2.4	1.4	1	$89,708,632.00	2004368.40	0.72	0.70	0.71	0.7100
23	1.9	1.8	1.1	1	$89,787,732.00	2110562.20	0.75	0.72	0.72	0.7300
24	2.5	2.2	1.3	1	$89,904,126.00	2036730.19	0.73	0.71	0.71	0.7167
25	2.2	2.1	1.3	1	$89,711,792.00	2041719.96	0.73	0.71	0.71	0.7167
26	2.8	1.7	1.3	1	$89,799,765.00	2099497.76	0.74	0.70	0.70	0.7133
27	2.4	2	1.3	1	$89,848,795.00	2054185.42	0.73	0.71	0.71	0.7167
28	2.3	2.1	1.9	1	$89,651,237.00	2019028.19	0.72	0.69	0.69	0.7000
29	3	2.6	1.2	1	$89,676,528.00	1996952.12	0.72	0.71	0.71	0.7133
30	3	1.9	1.7	1	$89,665,773.00	2030319.96	0.73	0.69	0.69	0.7033
31	2.4	1.8	1.3	1	$89,721,671.00	2088280.27	0.74	0.71	0.71	0.7200
32	2.2	1.8	1.2	1	$89,711,260.00	2100800.93	0.74	0.71	0.71	0.7200
33	1.7	1.4	1.3	1	$89,818,269.00	2108323.65	0.75	0.71	0.71	0.7233

Division 5

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$ 104,781,628.00	3027813.51	0.74	0.74	0.75	0.7433
2	1.3	1.2	1.1	1	$ 104,854,964.00	3087256.31	0.74	0.75	0.75	0.7467
3	3	2.66	2.33	1	$ 104,760,075.00	2796775.48	0.74	0.75	0.76	0.7500
4	1.8	1.4	1.2	1	$ 104,938,063.00	3069875.80	0.74	0.74	0.75	0.7433
5	2.9	1.5	1.3	1	$ 104,828,550.00	3034116.22	0.75	0.74	0.75	0.7467
6	2.4	2.1	1.8	1	$ 104,907,568.00	2879166.78	0.74	0.75	0.75	0.7467
7	2.7	2.1	1.4	1	$ 104,845,408.00	2900085.35	0.74	0.74	0.75	0.7433
8	2.1	1.8	1.1	1	$ 104,594,241.00	3008398.99	0.74	0.74	0.75	0.7433
9	2.2	2	1.8	1	$ 104,873,190.00	2909710.11	0.74	0.75	0.75	0.7467
10	2.7	2.3	2	1	$ 104,879,475.00	2875298.41	0.74	0.75	0.75	0.7467
11	2.9	1.4	1.3	1	$ 104,849,336.00	3046351.62	0.75	0.74	0.75	0.7467
12	2.6	2.4	1.6	1	$ 104,701,650.00	2858427.19	0.74	0.74	0.75	0.7433
13	2	1.5	1.2	1	$ 104,868,292.00	3057178.11	0.74	0.74	0.75	0.7433
14	2.9	1.7	1.1	1	$ 104,929,091.00	3022744.59	0.74	0.74	0.75	0.7433
15	1.9	1.4	1.3	1	$ 104,968,892.00	3065432.90	0.74	0.74	0.75	0.7433
16	2.9	2.5	1.7	1	$ 104,848,001.00	2851406.96	0.74	0.75	0.75	0.7467
17	1.8	1.7	1.5	1	$ 104,795,716.00	3026717.17	0.74	0.74	0.75	0.7433
18	2.9	2.6	2.1	1	$ 104,683,683.00	2809915.77	0.74	0.75	0.75	0.7467
19	2.6	1.5	1.3	1	$ 104,832,509.00	3042203.79	0.74	0.74	0.75	0.7433
20	2.8	2.5	1.3	1	$ 104,946,845.00	2865175.96	0.74	0.74	0.75	0.7433
21	3	2.6	1.6	1	$ 104,751,792.00	2837793.99	0.74	0.75	0.75	0.7467
22	2.8	2.4	1.4	1	$ 104,832,550.00	2863092.99	0.74	0.74	0.75	0.7433
23	1.9	1.8	1.1	1	$ 104,964,005.00	3009719.48	0.74	0.74	0.75	0.7433
24	2.5	2.2	1.3	1	$ 104,923,299.00	2905394.27	0.74	0.74	0.75	0.7433
25	2.2	2.1	1.3	1	$ 104,942,792.00	2908480.81	0.74	0.74	0.75	0.7433
26	2.8	1.7	1.3	1	$ 104,928,884.00	3006669.44	0.74	0.74	0.75	0.7433
27	2.4	2	1.3	1	$ 104,925,945.00	2912146.55	0.74	0.74	0.75	0.7433
28	2.3	2.1	1.9	1	$ 104,898,863.00	2875891.87	0.74	0.75	0.75	0.7467
29	3	2.6	1.2	1	$ 104,675,305.00	2842750.01	0.74	0.75	0.75	0.7467
30	3	1.9	1.7	1	$ 104,927,919.00	2948644.19	0.74	0.74	0.75	0.7433
31	2.4	1.8	1.3	1	$ 104,954,664.00	3001058.10	0.74	0.74	0.75	0.7433
32	2.2	1.8	1.2	1	$ 104,839,547.00	3005966.15	0.74	0.74	0.75	0.7433
33	1.7	1.4	1.3	1	$ 104,917,626.00	3076865.31	0.74	0.74	0.75	0.7433

Division 6

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$ 104,931,349.00	2255413.48	0.84	0.85	0.86	0.8500
2	1.3	1.2	1.1	1	$ 104,860,120.00	2290419.88	0.85	0.86	0.87	0.8600
3	3	2.66	2.33	1	$ 104,544,319.00	2149968.51	0.82	0.84	0.85	0.8367
4	1.8	1.4	1.2	1	$ 104,896,509.00	2281271.85	0.85	0.85	0.87	0.8567
5	2.9	1.5	1.3	1	$ 104,848,683.00	2255442.51	0.85	0.85	0.86	0.8533
6	2.4	2.1	1.8	1	$ 104,703,562.00	2204556.60	0.83	0.84	0.85	0.8400
7	2.7	2.1	1.4	1	$ 104,670,457.00	2241183.33	0.84	0.85	0.86	0.8500
8	2.1	1.8	1.1	1	$ 104,854,880.00	2281616.86	0.85	0.85	0.86	0.8533
9	2.2	2	1.8	1	$ 104,907,888.00	2208649.91	0.83	0.84	0.85	0.8400
10	2.7	2.3	2	1	$ 104,857,231.00	2186143.92	0.83	0.84	0.85	0.8400
11	2.9	1.4	1.3	1	$ 104,839,143.00	2253949.87	0.85	0.85	0.86	0.8533
12	2.6	2.4	1.6	1	$ 104,793,999.00	2203837.32	0.83	0.84	0.85	0.8400
13	2	1.5	1.2	1	$ 104,803,884.00	2275612.02	0.85	0.85	0.86	0.8533
14	2.9	1.7	1.1	1	$ 104,927,698.00	2276989.62	0.85	0.85	0.86	0.8533
15	1.9	1.4	1.3	1	$ 104,640,328.00	2266945.62	0.85	0.85	0.86	0.8533
16	2.9	2.5	1.7	1	$ 104,925,159.00	2190797.92	0.84	0.85	0.85	0.8467
17	1.8	1.7	1.5	1	$ 104,808,057.00	2260358.92	0.84	0.85	0.86	0.8500
18	2.9	2.6	2.1	1	$ 104,755,717.00	2171319.82	0.83	0.84	0.85	0.8400
19	2.6	1.5	1.3	1	$ 104,848,683.00	2255442.51	0.85	0.85	0.86	0.8533
20	2.8	2.5	1.3	1	$ 104,584,336.00	2214092.64	0.84	0.85	0.86	0.8500
21	3	2.6	1.6	1	$ 104,671,502.00	2191057.46	0.84	0.85	0.86	0.8500
22	2.8	2.4	1.4	1	$ 104,880,127.00	2211763.94	0.84	0.85	0.86	0.8500
23	1.9	1.8	1.1	1	$ 104,848,703.00	2281947.45	0.85	0.85	0.86	0.8533
24	2.5	2.2	1.3	1	$ 104,839,437.00	2239515.56	0.84	0.85	0.86	0.8500
25	2.2	2.1	1.3	1	$ 104,732,705.00	2243549.04	0.84	0.85	0.86	0.8500
26	2.8	1.7	1.3	1	$ 104,909,843.00	2253268.21	0.85	0.85	0.86	0.8533
27	2.4	2	1.3	1	$ 104,472,297.00	2251240.39	0.84	0.85	0.86	0.8500
28	2.3	2.1	1.9	1	$ 104,776,273.00	2207612.12	0.83	0.84	0.85	0.8400
29	3	2.6	1.2	1	$ 104,793,689.00	2227909.58	0.85	0.85	0.86	0.8533
30	3	1.9	1.7	1	$ 104,672,887.00	2207342.22	0.84	0.84	0.85	0.8433
31	2.4	1.8	1.3	1	$ 104,935,732.00	2262246.24	0.85	0.85	0.86	0.8533
32	2.2	1.8	1.2	1	$ 104,876,085.00	2269586.98	0.85	0.85	0.86	0.8533
33	1.7	1.4	1.3	1	$ 104,742,069.00	2278875.97	0.84	0.85	0.86	0.8500

Division 7

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$ 104,805,838.00	2672538.96	0.74	0.74	0.76	0.7467
2	1.3	1.2	1.1	1	$ 104,826,213.00	2714813.55	0.74	0.75	0.77	0.7533
3	3	2.66	2.33	1	$ 104,832,568.00	2567807.23	0.73	0.75	0.76	0.7467
4	1.8	1.4	1.2	1	$ 104,886,052.00	2694917.12	0.74	0.74	0.76	0.7467
5	2.9	1.5	1.3	1	$ 104,790,652.00	2673379.47	0.74	0.74	0.76	0.7467
6	2.4	2.1	1.8	1	$ 104,663,867.00	2626246.93	0.73	0.74	0.76	0.7433
7	2.7	2.1	1.4	1	$ 104,880,142.00	2639527.18	0.74	0.75	0.76	0.7500
8	2.1	1.8	1.1	1	$ 104,833,039.00	2677170.99	0.74	0.75	0.76	0.7500
9	2.2	2	1.8	1	$ 104,905,007.00	2639448.57	0.74	0.74	0.76	0.7467
10	2.7	2.3	2	1	$ 104,838,106.00	2618955.14	0.73	0.75	0.76	0.7467
11	2.9	1.4	1.3	1	$ 104,910,171.00	2682613.72	0.74	0.74	0.76	0.7467
12	2.6	2.4	1.6	1	$ 104,720,187.00	2621312.98	0.74	0.75	0.76	0.7500
13	2	1.5	1.2	1	$ 104,771,733.00	2681299.89	0.74	0.74	0.76	0.7467
14	2.9	1.7	1.1	1	$ 104,895,597.00	2671486.69	0.74	0.75	0.76	0.7500
15	1.9	1.4	1.3	1	$ 104,937,013.00	2688182.52	0.74	0.74	0.76	0.7467
16	2.9	2.5	1.7	1	$ 104,852,659.00	2614671.32	0.74	0.75	0.76	0.7500
17	1.8	1.7	1.5	1	$ 104,860,435.00	2666323.88	0.74	0.74	0.76	0.7467
18	2.9	2.6	2.1	1	$ 104,817,610.00	2582300.28	0.73	0.75	0.76	0.7467
19	2.6	1.5	1.3	1	$ 104,823,077.00	2682463.30	0.74	0.74	0.76	0.7467
20	2.8	2.5	1.3	1	$ 104,682,172.00	2617397.18	0.74	0.75	0.76	0.7500
21	3	2.6	1.6	1	$ 104,840,454.00	2598679.42	0.74	0.75	0.76	0.7500
22	2.8	2.4	1.4	1	$ 104,919,001.00	2618128.12	0.74	0.75	0.76	0.7500
23	1.9	1.8	1.1	1	$ 104,863,991.00	2642575.64	0.74	0.74	0.76	0.7467
24	2.5	2.2	1.3	1	$ 104,904,524.00	2637164.95	0.74	0.75	0.76	0.7500
25	2.2	2.1	1.3	1	$ 104,837,779.00	2644082.54	0.74	0.75	0.76	0.7500
26	2.8	1.7	1.3	1	$ 104,746,410.00	2663738.50	0.74	0.74	0.76	0.7467
27	2.4	2	1.3	1	$ 104,821,165.00	2656094.64	0.74	0.75	0.76	0.7500
28	2.3	2.1	1.9	1	$ 104,918,086.00	2621468.11	0.73	0.74	0.76	0.7433
29	3	2.6	1.2	1	$ 104,927,010.00	2604954.76	0.75	0.75	0.76	0.7533
30	3	1.9	1.7	1	$ 104,661,952.00	2638211.77	0.74	0.74	0.75	0.7433
31	2.4	1.8	1.3	1	$ 104,789,209.00	2662461.19	0.74	0.74	0.76	0.7467
32	2.2	1.8	1.2	1	$ 104,880,466.00	2669913.85	0.74	0.75	0.76	0.7500
33	1.7	1.4	1.3	1	$ 104,937,013.00	2688182.52	0.74	0.74	0.76	0.7467

Division 8

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$74,988,528.00	2511204.91	0.79	0.79	0.78	0.7867
2	1.3	1.2	1.1	1	$74,935,841.00	2540787.30	0.80	0.79	0.78	0.7900
3	3	2.66	2.33	1	$74,921,282.00	2458174.90	0.78	0.79	0.78	0.7833
4	1.8	1.4	1.2	1	$74,779,758.00	2532097.98	0.79	0.79	0.78	0.7867
5	2.9	1.5	1.3	1	$74,979,109.00	2519468.64	0.79	0.79	0.78	0.7867
6	2.4	2.1	1.8	1	$74,969,157.00	2481011.18	0.79	0.79	0.78	0.7867
7	2.7	2.1	1.4	1	$74,924,980.00	2496443.89	0.79	0.79	0.78	0.7867
8	2.1	1.8	1.1	1	$74,864,720.00	2533440.89	0.79	0.79	0.78	0.7867
9	2.2	2	1.8	1	$74,820,784.00	2480787.30	0.79	0.79	0.78	0.7867
10	2.7	2.3	2	1	$74,778,014.00	2473222.54	0.79	0.79	0.78	0.7867
11	2.9	1.4	1.3	1	$74,921,564.00	2523296.97	0.79	0.79	0.78	0.7867
12	2.6	2.4	1.6	1	$74,967,759.00	2480639.30	0.79	0.79	0.78	0.7867
13	2	1.5	1.2	1	$74,953,271.00	2530094.81	0.79	0.79	0.78	0.7867
14	2.9	1.7	1.1	1	$74,944,746.00	2532590.74	0.79	0.79	0.78	0.7867
15	1.9	1.4	1.3	1	$74,958,227.00	2524824.88	0.79	0.79	0.78	0.7867
16	2.9	2.5	1.7	1	$74,965,926.00	2471101.53	0.79	0.79	0.78	0.7867
17	1.8	1.7	1.5	1	$74,845,918.00	2500032.64	0.79	0.79	0.78	0.7867
18	2.9	2.6	2.1	1	$74,759,452.00	2463889.98	0.79	0.79	0.78	0.7867
19	2.6	1.5	1.3	1	$74,831,027.00	2519115.20	0.79	0.79	0.78	0.7867
20	2.8	2.5	1.3	1	$74,872,537.00	2496203.98	0.79	0.79	0.78	0.7867
21	3	2.6	1.6	1	$74,787,524.00	2474408.46	0.79	0.79	0.78	0.7867
22	2.8	2.4	1.4	1	$74,811,598.00	2487946.87	0.79	0.79	0.78	0.7867
23	1.9	1.8	1.1	1	$74,864,720.00	2533440.89	0.79	0.79	0.78	0.7867
24	2.5	2.2	1.3	1	$74,976,380.00	2503385.64	0.79	0.79	0.78	0.7867
25	2.2	2.1	1.3	1	$74,928,055.00	2504259.89	0.79	0.79	0.78	0.7867
26	2.8	1.7	1.3	1	$74,903,254.00	2515748.45	0.79	0.79	0.78	0.7867
27	2.4	2	1.3	1	$74,925,730.00	2505072.22	0.79	0.79	0.78	0.7867
28	2.3	2.1	1.9	1	$74,880,426.00	2476789.25	0.79	0.79	0.78	0.7867
29	3	2.6	1.2	1	$74,884,642.00	2495778.45	0.79	0.79	0.78	0.7867
30	3	1.9	1.7	1	$74,988,222.00	2488436.95	0.79	0.79	0.78	0.7867
31	2.4	1.8	1.3	1	$74,968,265.00	2514913.41	0.79	0.79	0.78	0.7867
32	2.2	1.8	1.2	1	$74,920,481.00	2529246.23	0.79	0.79	0.78	0.7867
33	1.7	1.4	1.3	1	$74,958,227.00	2524824.88	0.79	0.79	0.78	0.7867

Division 9

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$ 104,767,188.00	3014808.56	0.81	0.81	0.83	0.8167
2	1.3	1.2	1.1	1	$ 104,825,290.00	3031065.31	0.81	0.82	0.84	0.8233
3	3	2.66	2.33	1	$ 104,475,078.00	2941776.89	0.81	0.81	0.83	0.8167
4	1.8	1.4	1.2	1	$ 104,932,110.00	3023169.42	0.81	0.81	0.84	0.8200
5	2.9	1.5	1.3	1	$ 104,899,896.00	2988032.91	0.81	0.81	0.82	0.8133
6	2.4	2.1	1.8	1	$ 104,782,885.00	2984665.73	0.81	0.81	0.83	0.8167
7	2.7	2.1	1.4	1	$ 104,813,392.00	2984339.95	0.81	0.81	0.83	0.8167
8	2.1	1.8	1.1	1	$ 104,676,854.00	3013155.00	0.81	0.81	0.83	0.8167
9	2.2	2	1.8	1	$ 104,941,627.00	2991021.68	0.81	0.81	0.83	0.8167
10	2.7	2.3	2	1	$ 104,897,639.00	2971702.80	0.81	0.81	0.83	0.8167
11	2.9	1.4	1.3	1	$ 104,889,421.00	2993224.33	0.81	0.81	0.82	0.8133
12	2.6	2.4	1.6	1	$ 104,789,363.00	2983897.67	0.81	0.81	0.83	0.8167
13	2	1.5	1.2	1	$ 104,911,509.00	3021731.93	0.81	0.81	0.83	0.8167
14	2.9	1.7	1.1	1	$ 104,872,869.00	2976300.11	0.81	0.81	0.82	0.8133
15	1.9	1.4	1.3	1	$ 104,799,661.00	3023208.21	0.81	0.81	0.83	0.8167
16	2.9	2.5	1.7	1	$ 104,768,299.00	2956031.98	0.80	0.81	0.83	0.8133
17	1.8	1.7	1.5	1	$ 104,822,267.00	3002418.57	0.81	0.81	0.83	0.8167
18	2.9	2.6	2.1	1	$ 104,843,659.00	2959247.18	0.81	0.81	0.83	0.8167
19	2.6	1.5	1.3	1	$ 104,805,610.00	3005960.77	0.81	0.81	0.83	0.8167
20	2.8	2.5	1.3	1	$ 104,804,436.00	2978517.43	0.81	0.81	0.83	0.8167
21	3	2.6	1.6	1	$ 104,835,684.00	2951944.55	0.80	0.81	0.83	0.8133
22	2.8	2.4	1.4	1	$ 104,840,904.00	2977124.14	0.81	0.81	0.83	0.8167
23	1.9	1.8	1.1	1	$ 104,676,854.00	3013155.00	0.81	0.81	0.83	0.8167
24	2.5	2.2	1.3	1	$ 104,741,718.00	2994992.53	0.81	0.81	0.83	0.8167
25	2.2	2.1	1.3	1	$ 104,682,508.00	3008675.37	0.81	0.81	0.83	0.8167
26	2.8	1.7	1.3	1	$ 104,858,087.00	2980011.20	0.81	0.81	0.82	0.8133
27	2.4	2	1.3	1	$ 104,767,646.00	3008764.20	0.81	0.81	0.83	0.8167
28	2.3	2.1	1.9	1	$ 104,773,625.00	2983716.24	0.81	0.81	0.83	0.8167
29	3	2.6	1.2	1	$ 104,935,684.00	2962861.55	0.81	0.81	0.83	0.8167
30	3	1.9	1.7	1	$ 104,967,802.00	2958181.33	0.81	0.81	0.83	0.8167
31	2.4	1.8	1.3	1	$ 104,893,360.00	3005979.04	0.81	0.81	0.83	0.8167
32	2.2	1.8	1.2	1	$ 104,813,386.00	3009977.60	0.81	0.81	0.83	0.8167
33	1.7	1.4	1.3	1	$ 104,716,484.00	3025189.62	0.81	0.81	0.83	0.8167

Division 10

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$ 104,769,058.00	2486077.49	0.72	0.73	0.76	0.7367
2	1.3	1.2	1.1	1	$ 104,951,530.00	2508567.55	0.74	0.75	0.78	0.7567
3	3	2.66	2.33	1	$ 104,724,456.00	2327602.63	0.70	0.71	0.73	0.7133
4	1.8	1.4	1.2	1	$ 104,867,641.00	2496953.71	0.73	0.73	0.76	0.7400
5	2.9	1.5	1.3	1	$ 104,664,041.00	2454239.85	0.72	0.72	0.75	0.7300
6	2.4	2.1	1.8	1	$ 104,958,986.00	2432993.47	0.71	0.72	0.75	0.7267
7	2.7	2.1	1.4	1	$ 104,821,116.00	2438027.13	0.71	0.72	0.74	0.7233
8	2.1	1.8	1.1	1	$ 104,949,538.00	2474223.53	0.72	0.73	0.76	0.7367
9	2.2	2	1.8	1	$ 104,882,602.00	2431972.76	0.71	0.72	0.75	0.7267
10	2.7	2.3	2	1	$ 104,771,726.00	2381663.09	0.71	0.71	0.74	0.7200
11	2.9	1.4	1.3	1	$ 104,944,215.00	2459855.31	0.72	0.72	0.75	0.7300
12	2.6	2.4	1.6	1	$ 104,908,291.00	2407393.42	0.71	0.72	0.74	0.7233
13	2	1.5	1.2	1	$ 104,963,355.00	2487963.37	0.73	0.73	0.76	0.7400
14	2.9	1.7	1.1	1	$ 104,699,904.00	2451261.45	0.72	0.72	0.75	0.7300
15	1.9	1.4	1.3	1	$ 104,980,263.00	2491850.73	0.73	0.73	0.76	0.7400
16	2.9	2.5	1.7	1	$ 104,856,301.00	2369623.13	0.71	0.72	0.74	0.7233
17	1.8	1.7	1.5	1	$ 104,769,063.00	2468476.39	0.72	0.72	0.76	0.7333
18	2.9	2.6	2.1	1	$ 104,891,727.00	2341076.52	0.70	0.71	0.74	0.7167
19	2.6	1.5	1.3	1	$ 104,660,985.00	2469658.19	0.72	0.72	0.75	0.7300
20	2.8	2.5	1.3	1	$ 104,786,707.00	2372859.32	0.71	0.72	0.74	0.7233
21	3	2.6	1.6	1	$ 104,921,956.00	2349829.72	0.71	0.72	0.74	0.7233
22	2.8	2.4	1.4	1	$ 104,892,350.00	2409173.92	0.71	0.72	0.74	0.7233
23	1.9	1.8	1.1	1	$ 104,949,538.00	2474223.53	0.72	0.73	0.76	0.7367
24	2.5	2.2	1.3	1	$ 104,928,010.00	2427269.36	0.72	0.72	0.75	0.7300
25	2.2	2.1	1.3	1	$ 104,821,107.00	2451916.54	0.72	0.72	0.75	0.7300
26	2.8	1.7	1.3	1	$ 104,908,387.00	2468881.12	0.72	0.72	0.75	0.7300
27	2.4	2	1.3	1	$ 104,885,781.00	2444128.34	0.72	0.72	0.75	0.7300
28	2.3	2.1	1.9	1	$ 104,693,462.00	2419198.00	0.71	0.72	0.75	0.7267
29	3	2.6	1.2	1	$ 104,770,665.00	2350901.76	0.71	0.72	0.74	0.7233
30	3	1.9	1.7	1	$ 104,534,459.00	2421528.86	0.71	0.71	0.74	0.7200
31	2.4	1.8	1.3	1	$ 104,888,704.00	2467259.00	0.72	0.72	0.75	0.7300
32	2.2	1.8	1.2	1	$ 104,767,504.00	2473046.19	0.72	0.73	0.76	0.7367
33	1.7	1.4	1.3	1	$ 104,980,263.00	2491850.73	0.73	0.73	0.76	0.7400

Division 11

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$ 74,889,569.00	2680080.30	0.74	0.77	0.77	0.7600
2	1.3	1.2	1.1	1	$ 74,881,872.00	2694078.25	0.75	0.78	0.79	0.7733
3	3	2.66	2.33	1	$ 74,980,743.00	2652831.16	0.72	0.75	0.74	0.7367
4	1.8	1.4	1.2	1	$ 74,878,134.00	2683079.75	0.75	0.78	0.78	0.7700
5	2.9	1.5	1.3	1	$ 74,943,990.00	2681064.91	0.74	0.77	0.78	0.7633
6	2.4	2.1	1.8	1	$ 74,927,549.00	2667648.61	0.73	0.76	0.76	0.7500
7	2.7	2.1	1.4	1	$ 74,822,324.00	2678090.53	0.73	0.76	0.76	0.7500
8	2.1	1.8	1.1	1	$ 74,961,267.00	2684581.16	0.74	0.77	0.77	0.7600
9	2.2	2	1.8	1	$ 74,949,846.00	2673980.64	0.73	0.76	0.76	0.7500
10	2.7	2.3	2	1	$ 74,956,713.00	2661079.96	0.73	0.75	0.75	0.7433
11	2.9	1.4	1.3	1	$ 74,954,894.00	2680622.19	0.74	0.77	0.78	0.7633
12	2.6	2.4	1.6	1	$ 74,806,512.00	2678075.15	0.73	0.76	0.75	0.7467
13	2	1.5	1.2	1	$ 74,929,049.00	2682201.96	0.74	0.78	0.78	0.7667
14	2.9	1.7	1.1	1	$ 74,929,818.00	2684552.23	0.74	0.77	0.77	0.7600
15	1.9	1.4	1.3	1	$ 74,954,894.00	2680622.19	0.74	0.78	0.78	0.7667
16	2.9	2.5	1.7	1	$ 74,961,197.00	2679609.09	0.73	0.76	0.75	0.7467
17	1.8	1.7	1.5	1	$ 74,865,416.00	2679375.49	0.74	0.77	0.77	0.7600
18	2.9	2.6	2.1	1	$ 74,957,819.00	2652420.33	0.72	0.75	0.75	0.7400
19	2.6	1.5	1.3	1	$ 74,943,990.00	2681064.91	0.74	0.77	0.78	0.7633
20	2.8	2.5	1.3	1	$ 74,940,381.00	2681667.02	0.73	0.76	0.75	0.7467
21	3	2.6	1.6	1	$ 74,973,416.00	2680359.08	0.73	0.76	0.75	0.7467
22	2.8	2.4	1.4	1	$ 74,926,385.00	2682929.38	0.73	0.76	0.75	0.7467
23	1.9	1.8	1.1	1	$ 74,961,267.00	2684581.16	0.74	0.77	0.77	0.7600
24	2.5	2.2	1.3	1	$ 74,929,806.00	2680560.95	0.73	0.76	0.76	0.7500
25	2.2	2.1	1.3	1	$ 74,913,672.00	2680431.95	0.73	0.77	0.76	0.7533
26	2.8	1.7	1.3	1	$ 74,883,347.00	2678676.86	0.74	0.77	0.77	0.7600
27	2.4	2	1.3	1	$ 74,913,672.00	2680309.97	0.74	0.77	0.76	0.7567
28	2.3	2.1	1.9	1	$ 74,901,806.00	2667237.30	0.73	0.76	0.76	0.7500
29	3	2.6	1.2	1	$ 74,879,083.00	2675634.43	0.73	0.76	0.75	0.7467
30	3	1.9	1.7	1	$ 74,897,137.00	2674317.92	0.73	0.76	0.76	0.7500
31	2.4	1.8	1.3	1	$ 74,840,841.00	2679099.41	0.74	0.77	0.77	0.7600
32	2.2	1.8	1.2	1	$ 74,913,849.00	2678234.45	0.74	0.77	0.77	0.7600
33	1.7	1.4	1.3	1	$ 74,954,894.00	2680622.19	0.74	0.78	0.78	0.7667

Division 12

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$ 74,887,930.00	2787775.51	0.74	0.74	0.74	0.7400
2	1.3	1.2	1.1	1	$ 74,952,571.00	2832938.53	0.75	0.75	0.75	0.7500
3	3	2.66	2.33	1	$ 74,943,151.00	2654127.00	0.72	0.74	0.73	0.7300
4	1.8	1.4	1.2	1	$ 74,933,451.00	2813041.79	0.74	0.75	0.74	0.7433
5	2.9	1.5	1.3	1	$ 74,793,721.00	2785404.75	0.74	0.74	0.73	0.7367
6	2.4	2.1	1.8	1	$ 74,719,116.00	2710315.10	0.73	0.74	0.73	0.7367
7	2.7	2.1	1.4	1	$ 74,955,987.00	2744791.00	0.74	0.74	0.73	0.7367
8	2.1	1.8	1.1	1	$ 74,905,095.00	2808542.87	0.74	0.75	0.74	0.7433
9	2.2	2	1.8	1	$ 74,829,840.00	2716116.10	0.73	0.74	0.73	0.7333
10	2.7	2.3	2	1	$ 74,780,109.00	2685455.87	0.73	0.74	0.73	0.7333
11	2.9	1.4	1.3	1	$ 74,905,459.00	2787519.45	0.74	0.74	0.74	0.7400
12	2.6	2.4	1.6	1	$ 74,930,374.00	2708217.72	0.73	0.74	0.73	0.7333
13	2	1.5	1.2	1	$ 74,830,543.00	2807090.51	0.74	0.75	0.74	0.7433
14	2.9	1.7	1.1	1	$ 74,931,711.00	2814810.74	0.74	0.74	0.74	0.7400
15	1.9	1.4	1.3	1	$ 74,829,981.00	2794254.57	0.74	0.75	0.74	0.7467
16	2.9	2.5	1.7	1	$ 74,925,780.00	2703122.59	0.73	0.74	0.73	0.7333
17	1.8	1.7	1.5	1	$ 74,783,234.00	2762181.00	0.74	0.74	0.74	0.7400
18	2.9	2.6	2.1	1	$ 74,778,300.00	2670715.64	0.73	0.74	0.73	0.7333
19	2.6	1.5	1.3	1	$ 74,839,925.00	2788740.43	0.74	0.74	0.74	0.7400
20	2.8	2.5	1.3	1	$ 74,957,037.00	2742287.10	0.73	0.74	0.74	0.7367
21	3	2.6	1.6	1	$ 74,885,554.00	2702283.78	0.73	0.74	0.73	0.7333
22	2.8	2.4	1.4	1	$ 74,947,836.00	2734472.90	0.73	0.74	0.73	0.7333
23	1.9	1.8	1.1	1	$ 74,905,095.00	2808542.87	0.74	0.75	0.74	0.7433
24	2.5	2.2	1.3	1	$ 74,695,302.00	2743354.49	0.74	0.74	0.74	0.7400
25	2.2	2.1	1.3	1	$ 74,824,678.00	2755333.37	0.74	0.74	0.74	0.7400
26	2.8	1.7	1.3	1	$ 74,918,581.00	2786463.87	0.74	0.74	0.73	0.7367
27	2.4	2	1.3	1	$ 74,918,578.00	2761414.61	0.74	0.74	0.74	0.7400
28	2.3	2.1	1.9	1	$ 74,946,195.00	2708368.31	0.73	0.74	0.73	0.7333
29	3	2.6	1.2	1	$ 74,888,087.00	2745754.86	0.73	0.74	0.74	0.7367
30	3	1.9	1.7	1	$ 74,861,251.00	2736763.57	0.73	0.74	0.73	0.7333
31	2.4	1.8	1.3	1	$ 74,808,376.00	2776727.80	0.74	0.74	0.74	0.7400
32	2.2	1.8	1.2	1	$ 74,909,365.00	2790682.13	0.74	0.74	0.74	0.7400
33	1.7	1.4	1.3	1	$ 74,829,981.00	2794254.57	0.74	0.75	0.74	0.7467

Division 13

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$ 74,912,782.00	2084334.66	0.78	0.76	0.78	0.7733
2	1.3	1.2	1.1	1	$ 74,890,323.00	2112288.05	0.78	0.77	0.78	0.7767
3	3	2.66	2.33	1	$ 74,802,084.00	2002727.03	0.78	0.77	0.79	0.7800
4	1.8	1.4	1.2	1	$ 74,928,159.00	2094182.20	0.78	0.76	0.78	0.7733
5	2.9	1.5	1.3	1	$ 74,976,528.00	2083480.77	0.78	0.76	0.78	0.7733
6	2.4	2.1	1.8	1	$ 74,767,379.00	2037969.11	0.78	0.77	0.78	0.7767
7	2.7	2.1	1.4	1	$ 74,763,934.00	2049922.94	0.78	0.76	0.78	0.7733
8	2.1	1.8	1.1	1	$ 74,879,985.00	2088907.64	0.78	0.76	0.78	0.7733
9	2.2	2	1.8	1	$ 74,876,253.00	2042462.21	0.78	0.77	0.78	0.7767
10	2.7	2.3	2	1	$ 74,727,319.00	2023983.90	0.78	0.77	0.79	0.7800
11	2.9	1.4	1.3	1	$ 74,851,067.00	2082408.31	0.78	0.76	0.78	0.7733
12	2.6	2.4	1.6	1	$ 74,886,466.00	2023387.31	0.78	0.77	0.78	0.7767
13	2	1.5	1.2	1	$ 74,900,816.00	2091449.40	0.78	0.76	0.78	0.7733
14	2.9	1.7	1.1	1	$ 74,845,465.00	2088712.65	0.78	0.76	0.78	0.7733
15	1.9	1.4	1.3	1	$ 74,950,931.00	2090499.44	0.78	0.76	0.78	0.7733
16	2.9	2.5	1.7	1	$ 74,810,863.00	2015081.99	0.78	0.77	0.78	0.7767
17	1.8	1.7	1.5	1	$ 74,878,249.00	2073364.64	0.78	0.76	0.78	0.7733
18	2.9	2.6	2.1	1	$ 74,729,334.00	2007514.44	0.78	0.77	0.79	0.7800
19	2.6	1.5	1.3	1	$ 74,944,898.00	2087497.34	0.78	0.76	0.78	0.7733
20	2.8	2.5	1.3	1	$ 74,846,535.00	2036942.11	0.78	0.77	0.78	0.7767
21	3	2.6	1.6	1	$ 74,855,317.00	2017700.48	0.78	0.77	0.78	0.7767
22	2.8	2.4	1.4	1	$ 74,790,547.00	2032493.49	0.78	0.77	0.78	0.7767
23	1.9	1.8	1.1	1	$ 74,879,985.00	2088907.64	0.78	0.76	0.78	0.7733
24	2.5	2.2	1.3	1	$ 74,831,206.00	2044092.72	0.78	0.76	0.78	0.7733
25	2.2	2.1	1.3	1	$ 74,962,892.00	2058580.56	0.78	0.76	0.78	0.7733
26	2.8	1.7	1.3	1	$ 74,944,084.00	2072202.19	0.78	0.76	0.78	0.7733
27	2.4	2	1.3	1	$ 74,751,924.00	2054424.04	0.78	0.76	0.78	0.7733
28	2.3	2.1	1.9	1	$ 74,806,345.00	2037360.99	0.78	0.77	0.78	0.7767
29	3	2.6	1.2	1	$ 74,879,888.00	2041921.65	0.78	0.77	0.78	0.7767
30	3	1.9	1.7	1	$ 74,947,297.00	2046016.20	0.78	0.76	0.78	0.7733
31	2.4	1.8	1.3	1	$ 74,909,928.00	2069368.06	0.78	0.76	0.78	0.7733
32	2.2	1.8	1.2	1	$ 74,953,056.00	2076152.55	0.78	0.76	0.78	0.7733
33	1.7	1.4	1.3	1	$ 74,850,078.00	2092452.10	0.78	0.76	0.78	0.7733

Division 14

ID	Interstate	US	NC	SR	Total Cost	Total Benefit	NCDOT Rating Number (year 1)	NCDOT Rating Number (year 2)	NCDOT Rating Number (year 3)	NCDOT Rating Number (Average)
1	2	1.66	1.33	1	$ 74,844,954.00	2228818.61	0.71	0.73	0.76	0.7333
2	1.3	1.2	1.1	1	$ 74,949,064.00	2275789.24	0.72	0.75	0.78	0.7500
3	3	2.66	2.33	1	$ 74,856,337.00	2130221.83	0.69	0.73	0.76	0.7267
4	1.8	1.4	1.2	1	$ 74,839,879.00	2260922.68	0.71	0.74	0.77	0.7400
5	2.9	1.5	1.3	1	$ 74,837,530.00	2242659.86	0.71	0.74	0.76	0.7367
6	2.4	2.1	1.8	1	$ 74,903,172.00	2173476.85	0.70	0.73	0.76	0.7300
7	2.7	2.1	1.4	1	$ 74,833,238.00	2172368.36	0.70	0.73	0.76	0.7300
8	2.1	1.8	1.1	1	$ 74,961,201.00	2220668.52	0.71	0.73	0.76	0.7333
9	2.2	2	1.8	1	$ 74,773,042.00	2183229.74	0.70	0.73	0.76	0.7300
10	2.7	2.3	2	1	$ 74,683,454.00	2141051.17	0.70	0.73	0.76	0.7300
11	2.9	1.4	1.3	1	$ 74,860,828.00	2244900.88	0.72	0.74	0.77	0.7433
12	2.6	2.4	1.6	1	$ 74,884,019.00	2143657.24	0.70	0.73	0.76	0.7300
13	2	1.5	1.2	1	$ 74,954,090.00	2255921.70	0.71	0.74	0.77	0.7400
14	2.9	1.7	1.1	1	$ 74,750,490.00	2222368.82	0.71	0.73	0.76	0.7333
15	1.9	1.4	1.3	1	$ 74,887,912.00	2263511.65	0.71	0.74	0.77	0.7400
16	2.9	2.5	1.7	1	$ 74,864,705.00	2133539.61	0.70	0.73	0.76	0.7300
17	1.8	1.7	1.5	1	$ 74,911,110.00	2213422.22	0.71	0.73	0.76	0.7333
18	2.9	2.6	2.1	1	$ 74,844,256.00	2130587.60	0.70	0.73	0.76	0.7300
19	2.6	1.5	1.3	1	$ 74,818,023.00	2242879.75	0.71	0.74	0.77	0.7400
20	2.8	2.5	1.3	1	$ 74,699,711.00	2144290.22	0.69	0.73	0.76	0.7267
21	3	2.6	1.6	1	$ 74,755,836.00	2139470.07	0.69	0.73	0.76	0.7267
22	2.8	2.4	1.4	1	$ 74,602,084.00	2142478.51	0.70	0.73	0.76	0.7300
23	1.9	1.8	1.1	1	$ 74,961,201.00	2220668.52	0.71	0.73	0.76	0.7333
24	2.5	2.2	1.3	1	$ 74,930,002.00	2157606.51	0.70	0.73	0.76	0.7300
25	2.2	2.1	1.3	1	$ 74,838,543.00	2170136.21	0.70	0.73	0.76	0.7300
26	2.8	1.7	1.3	1	$ 74,724,802.00	2211928.54	0.71	0.73	0.76	0.7333
27	2.4	2	1.3	1	$ 74,910,843.00	2186544.13	0.70	0.73	0.76	0.7300
28	2.3	2.1	1.9	1	$ 74,719,760.00	2174053.72	0.70	0.73	0.76	0.7300
29	3	2.6	1.2	1	$ 74,868,858.00	2156646.10	0.69	0.73	0.76	0.7267
30	3	1.9	1.7	1	$ 74,860,631.00	2189116.90	0.71	0.73	0.76	0.7333
31	2.4	1.8	1.3	1	$ 74,925,873.00	2201914.97	0.71	0.73	0.76	0.7333
32	2.2	1.8	1.2	1	$ 74,919,840.00	2203052.60	0.71	0.73	0.76	0.7333
33	1.7	1.4	1.3	1	$ 74,887,912.00	2263511.65	0.71	0.74	0.77	0.7400

Appendix K – CBA Results (II)
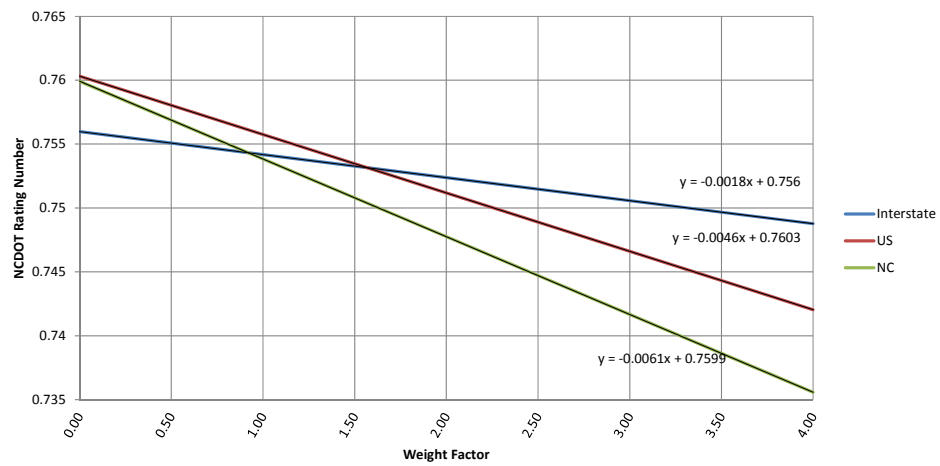
NCDOT Rating Number vs. Weight Factor ($25M per yr)

Legend:
- Interstate
- US
- NC

Equations shown on chart:
- $y = -0.0009x + 0.7424$
- $y = -0.0041x + 0.746$
- $y = -0.007x + 0.7536$

X-axis: Weight Factor

Y-axis: NCDOT Rating Number

NCDOT Rating Number vs. Weight Factor ($30M per yr)

Legend:
- Interstate
- US
- NC

Equations shown on chart:
- $y = -0.0049x + 0.7247$
- $y = -0.0059x + 0.7238$
- $y = -0.0252x + 0.7503$

X-axis: Weight Factor

Y-axis: NCDOT Rating Number

NCDOT Rating Number vs. Weight Factor ($35M per yr)

y = -0.0004x + 0.7787

y = -0.0026x + 0.7844

y = -0.0054x + 0.7854

Interstate
US
NC

NCDOT Rating Number

Weight Factor

NCDOT Rating Number vs. Weight Factor (All Divisions)

y = -0.0018x + 0.756

y = -0.0046x + 0.7603

y = -0.0061x + 0.7599

Interstate
US
NC

NCDOT Rating Number

Weight Factor

Total Benefit vs. Weight Factor ($25M per yr)

y = -2827.1x + 2E+06

y = -44464x + 2E+06

y = -54187x + 2E+06

Interstate
US
NC

Total Benefit vs. Weight Factor ($30M per yr)

y = -7990.9x + 2E+06

y = -38352x + 2E+06

y = -93589x + 2E+06

Interstate
US
NC

137

Total Benefit vs. Weight Factor ($35M per yr)

y = -16203x + 3E+06

y = -39623x + 3E+06

y = -73498x + 3E+06

Legend: Interstate, US, NC

Total Benefit vs. Weight Factor (All Divisions)

y = -7973.2x + 2E+06

y = -47854x + 2E+06

y = -58342x + 2E+06

Legend: Interstate, US, NC

138