RESEARCH & DEVELOPMENT

Evaluation of Benefit Weight Factors and Decision Trees for Automated Distress Data Models

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Evaluation of Benefit Weight Factors and Decision Trees for Automated Distress Data Models

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Abstract

A Pavement Management System (PMS) becomes an effective decision-making tool when its performance models are accurate, and its trigger points (values) and benefit weight factors are precisely calibrated. Since 2011, NCDOT began collecting pavement distress data using automated methods. These data were make available to this study. New distress and performance models were developed to take advantage of the increased data quality and quantity. These new models present different deterioration rates, benefit curves, and decision trees. Therefore, new trigger points and benefit weight factors were determined to reflect the new changes. The findings of this study can assist the NCDOT Pavement Management Unit (PMU) to make effective maintenance and rehabilitation decisions.

Key Words Pavement Management System, Automated Data, Performance Model, Distress Model, Weight Factor, Cost Benefit Analysis, Decision Tree	Distribution Statement		
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EXECUTIVE SUMMARY

A Pavement Management System (PMS) becomes an effective decision-making tool when its performance models are accurate, and its trigger points (values) and benefit weight factors are precisely calibrated. Since 2011, NCDOT began collecting pavement distress data using automated methods. Once new performance models are developed, they can present different deterioration rates, benefit curves, and decision trees. Such impacts on trigger points and benefit weight factors need to be evaluated, and new values need to be determined if necessary. This study was conducted to meet these needs.

In this study, automated data collected in 2013, 2014, and 2015 were analyzed in order to determine maximum allowable extent (MAE) input and threshold values. Then these raw data were cleaned and used to develop distress and performance models for 10 asphalt pavement (ASP) families and concrete (JCP) pavements. Cost-benefit analysis (CBA) was performed to determine the benefit weight factors on decision trees.

Primary findings of this study include:

- The newly developed distress models can be implemented into the NCDOT PMS with preliminary trigger points determined.
- MAE input values are essential in obtaining correct distress index values. Percentiles of distress index values and input from NCDOT engineers are the key information to derive appropriate MAE input values.
- Collecting importance scores of JCP distresses from NCDOT engineers and researchers is an imperative step in calculating PCR values of JCP pavements. The scores are accurate as attested by the robustness of JCP models.
- For ASP pavements, newly developed PCR curves are visually comparable to PCR curves developed using manual data.
- A new set of Weight factors were determined by performing CBA analysis and statistical regression. They are: 2.68 for Interstate, 1.26 for US, 1.16 for NC, and 1.0 for SR.

Recommendations for further avenues of research are:

- Pretreatment condition can have significantly impact on treatment performance. It is recommended to include pretreatment condition as a grouping factor when develop performance models. For example, the Interstate 0-50k family can be divided into three sub-families based on Good/Fair/Poor pretreatment condition: Interstate 0-50k/Good, Interstate 0-50k/Fair, and Interstate 0-50k/Poor, and three family models can be developed to more accurately predict pavement performance.
- More advanced image recognition techniques are recommended to be used to improve the quality of raw performance data. One such technique is deep learning, which has proven to be superior to traditional computer vision algorithms and if trained appropriately can improve the quality over time.

- To transition the NCDOT PMS to full-use of automated data, the following tasks are recommended:

    Step 1. Redefining roadway families by adjusting AADT breakpoints for more consistent performance within families.

    Step 2. Developing new distress and performance models once more automated data become available.

    Step 3. Loading automated data and newly developed models (Step 2) into the NCDOT PMS.

    Step 4. Determining a new set of benefit weight factors using cost-benefit analysis (CBA).

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CHAPTER 1 INTRODUCTION

1.1 Background

Pavement performance models play a critical role in a Pavement Management System (PMS). Agencies use these models to predict pavement deterioration and treatment improvements in condition, to conduct need analysis to identify all pavement sections that need work as their performance curves reach certain trigger points, and to prioritize and optimize the selection of candidate sections and treatments through Cost-Benefit Analysis (CBA). Generally, trigger points on decision trees and benefit weight factors are carefully determined through rigorous data analyses. This enables a PMS to provide practical information to agencies for effectively managing pavements.

Automated distress data collection methods have gained a significant impetus recently. In 2004, some 30 agencies were collecting pavement surface images and sensor data using automated means. To date, that number has grown to more than 35. Several factors contribute to the transition from manual methods to automated methods, including increasing demands for network-level pavement condition data, personnel safety, efficiency of data collection, and data consistency. During this transition phase, usually performance models will be updated to take advantage of the increased data quality and quantity.

1.2 State of the Art, Science, and Practice

Pavement condition data have been collected by NCDOT using a manual method since 1982. These manual data were used to develop the Department's pavement performance models, identify trigger points on decision trees, and benefit weight factors. Since the fall of 2011, NCDOT has employed automated distress data collection for its Interstate and Primary (US and NC) routes. Compared to its manual method, NCDOT's automated method collects a few more distress types for asphalt, composite, and joined concrete pavements.

1.3 Purpose and Scope

This research project was performed to develop new performance models using three years of automated data. These models not only have new regression coefficients, but also have new prediction variables (new distress types). As a result, deterioration rates (affecting trigger points), benefit curves (affecting benefit weight factors), and decision trees will be different from those determined by the manual data. To assist the NCDOT Pavement Management Unit (PMU) in making effective maintenance and rehabilitation decisions, it is necessary to evaluate its PMS's trigger points and benefit weight factors after new performance models become available.

1.4 Research Approach

To address the aforementioned needs, this research will be conducted to:

- Develop distress and performance models using newly collected automated data;

- Evaluate trigger points on new decision trees for optimal reflection of pavement conditions; and
- Determine ideal benefit weight factors for optimal selections of roadways and treatments.

1.5 Organization of the Report

An introduction to the research project, research needs and objectives are presented in Chapter 1. A comprehensive literature review is provided in Chapter 2. Development of pavement distress and performance models is discussed in Chapter 3. Chapter 4 focuses on the determination of trigger points on decision trees. Chapter 5 presents the derivation of weight factors for cost-benefit analysis. Chapter 6 discusses findings and conclusions. Recommendations for future research is included in Chapter 7. Chapter 8 provides the implementation and technology transfer plan.

Appendices A and B include scatter plots and box plots of raw data and cleaned data. Appendices C through G present distress and performance curves of ASP and JCP pavements. Appendices H and J include 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.

2.1 Automated Data Collection

An automated pavement condition survey consists of data collected by vehicles outfitted with digital line-scan cameras and non-contact sensors. According to Timm and McQueen (2004), these digital line-scan cameras are capable of capturing pavement images that can exceed a resolution of 6,000 pixels per line. These vehicles travel at normal speeds while distress classification software analyzes data collected, making this method cost-effective, safe and efficient. Through research and the availability of new technology, many SHAs are transitioning from manual pavement condition surveys to automated pavement condition surveys. This transition has taken place in attempt to eliminate safety risks, efficiency issues, and objectiveness that are present with manual surveys.

With increased interest to transition from manual to automated data, a multitude of research has been conducted to compare the two data collection techniques. Timm and McQueen (2004) conducted a study of manual versus automated pavement for the Alabama Department of Transportation, Groeger et al. (2003) conducted a similar study for the Naval Pavement Center of Expertise, and Wang et al. (2003) conducted a network crack study using automated data for Arkansas. The results of these studies found that automated pavement condition data is an appreciated tool that will benefit SHAs with less subjective and more accurate data, the ability to survey an entire network in a time efficient manner, and a safer means of collecting data on high-speed interstates.

In 2004, McGhee et al. developed pavement condition indices of automated data for the Virginia DOT (McGhee 2004). For flexible pavements, distresses were categorized as wheel load related and non-load related. Their corresponding indices, the Load Related Distress Rating (LDR) and the Non-Load Related Distress Rating (NDR), were presented. For rigid pavements, the Slab Distress Rating (SDR) and the Joint Faulting Index (JFI) were developed for Jointed Concrete Pavements (JCPs), and the Concrete Distress Rating (CDR) and the Concrete Punchout Rating (CPR) were developed for Continuously Reinforced Concrete Pavements (CRCs).

Previous research has shown that automated surveys are a feasible and efficient method for collecting pavement data, however, This relatively new technology does not come without issues, (Groeger et al., 2003). One issue with this method is that most pavement management systems have been developed for manual data, which differs significantly from automated data. There are a multitude of different distress types collected with the use of the automated survey method as compared to the manual method. This issue makes the transition to a fully automated system difficult for SHAs who are hesitant to redesign their PMS to be fully compatible with the automated survey method.

The NCDOT has collected automated pavement condition data since 2011 with the publication of the agency's "Digital Imagery Distress Evaluation Handbook" (Mastin 2011). This handbook specified that beginning in the fall of 2011, "interstate and primary condition surveys will be conducted using high speed digital imagery and automated/semi-automated data processing". Since then, two contractors have been acquired by the state for data collection purposes.

One contractor is responsible for collecting automated pavement condition data with distance measuring, laser, and imaging equipment in compliance with the Digital Imagery Distress Evaluation Handbook. NCDOT's automated distress handbook specifies that data collectors must survey the rightmost travel lane with downward digital images covering a width of fourteen feet. To ensure quality data with identifiable distresses, pavement condition surveys are not conducted when weather conditions result in poor roadway visibility (NCDOT 2010).

A separate contractor is responsible for evaluating the automated data and must comply with section 1.3 General Distress Evaluation Rules of NCDOT's automated distress handbook. There are a multitude of rules that the data processor must comply with, however in terms of this research, it is important to reference rule seven of section 1.3 which states how distresses will be rated and quantified (NCDOT 2011). In addition to section 1.3, the following standards are also examples of standards the data collector must comply with (refer to "NCDOT Digital Imagery Distress Evaluation Handbook" for a complete list of standards and procedures):

- Automated data collection equipment shall conform to the latest version of ASTM Designation E1656/E1656M "Standard Guide for Classification of Automated Pavement Condition Survey Equipment".
- All inertial profilers shall be a Class 1 Inertial Profiler per ASTM E950.
- Data collection contractor will evaluate pavement surface distresses on 100% of the pavement sections (continuous) utilizing the downward and forward perspective images.

Since 2011, NCDOT has collected pavement condition data of asphalt and composite, JCP, and CRC pavements (Interstate, US and NC routes) using automated methods on an annual basis.

2.2 Composite Pavement Performance Index

There are various methods SHAs use to combine individual pavement distress types into a single composite index that describes the total performance of a roadway. There is also no unanimous composite index scale that is used from state to state as some agencies calculate a present serviceability rating (PSR), present serviceability index (PSI), or pavement condition index (PCI) (Ganesan et al. 2006). The PSR, a rating of pavement performance based on ride quality, was developed in the 1960s at the AASHO Road Test (TRB 2007). After the AASHO Road Test, the U.S. Army Corps of Engineers (USACE) developed the PCI, a more objective and complex index valued from 0 to 100. The USACE's PCI was further standardized in ASTM D5340 and ASTM D6433. This method, or variations of this method, is used by many SHAs because various distresses and their severity result in deductions from the "perfect" condition, valued at 100. Timm and McQueen (2004) call this method the "deduct value approach" in which a composite index is deducted from a perfect score based on distress severity and an associated weight factor correlating to the type of distress and its effect on the overall performance. This method is used by ALDOT, which uses a composite pavement condition index called Pavement Condition Rating (PCR). In addition to ALDOT, NCDOT also uses PCR to rate pavement conditions. An adequate pavement condition rating for NCDOT's network is defined as a PCR index of 80 or greater (NCDOT 2010).

2.3 Decision Trees

Decision trees are used to establish a criteria for when to perform various maintenance strategies such as minor maintenance and overlay. Each "branch" on a decision tree represents a condition such as pavement type, distress type and severity, traffic volume, and functional classification (Hicks et al 2000). Once a composite performance index is established and analyzed it can trigger a particular treatment on a PMS decision tree based on its overall condition or specific distress. Hicks et al (2000) identified that the issue with decision trees based on a composite performance index is the inability to appropriately address actual distress conditions such as cracking. Because of this, Hicks et al. developed decision trees using a range of trigger values that independently address pavement roughness, rutting, cracking, and raveling.

NCDOT uses decision trees in their PMS to determine when to conduct various maintenance activities. Similar to Hicks decision trees, NCDOT uses a range of trigger values that independently address pavement distress (alligator cracking, bleeding, transverse cracking, raveling, oxidation, rutting, etc.) and are based on pavement type (asphalt and JCP) and two highway functional classifications (interstate and non-interstate) (Chen et al. 2013).

2.4 Trigger Points on Decision Trees

MacLeod (2008) validated trigger values for pavement management rehabilitation for Public Works and Government Services Canada, Parks Canada and the Yukon Government. Over 3,900 data points were used to plot cumulative percentages of three treatment strategies against Pavement Condition Index (PCI). These three strategies include: routine maintenance, overlay within two years, or major rehabilitation within two years. The plot showed distinct "breakpoints" on three strategy curves, and their corresponding PCI values were designated as trigger values.

An example of determining a set of multiple trigger values is presented in AASHTO's Pavement Management Guide (AASHTO 2001). A trigger value is selected when the pavement condition changes to a different level. Typically condition levels are defined based on an economic analysis.

2.5 Benefit Weight Factors

AASHTO defines "a surrogate for the benefit provided by the maintenance or rehabilitation treatment" as "the area between the curves with treatment and without treatment". For a given pavement performance curve, this surrogate can be calculated using a numerical integration approach.

In the NCDOT PMS, the estimated benefit of a proposed roadway maintenance activity is calculated by multiplying its benefit by lane-miles (with a maximum of 4.0 to keep excessively long/wide pavements from dominating), and by a weight factor (2.0 for Interstate highways, 1.72 for United States roads, 1.23 for NC roads, and 1.0 for Secondary roads). The analysis package used in the NCDOT PMS allows for prioritization and optimization of pavement sections and treatments under multiple constraints, for instance, maximizing the overall benefit or condition estimate for given budget goals.

2.6 Analytic Hierarchy Process

The use of the Analytic Hierarchy Process (AHP) provides an effective approach to evaluate a situation or alternative in terms of multiple criteria. AHP is a multi-criteria decision-making approach introduced by Thomas L. Saaty in 1977 (Saaty 1977). This methodology uses a hierarchical structure to break a problem down into major components such as objectives, criteria, sub criteria, and alternatives. Data pertaining to the overall objective is derived using a set of pairwise comparisons, which is used to determine the weights or importance of certain criteria (Triantaphyllou and Mann 1995). Sun and Gu (2011) have researched the advantages of using AHP and have developed a new methodology for pavement condition assessment and project prioritization using this process. Because it is difficult and subjective to directly assign weights to various performance indicators, Sun and Gu used AHP to determine weight factors for individual performance indicators such as roughness, deflection index, deterioration ratio, rut depth, and friction coefficient.

To determine weight factors for individual pavement distresses, Sun and Gu surveyed a group of 34 pavement engineers to develop a paired comparison matrix. The survey involved discussions, negotiations, and trade-offs between Sun, Gu, and pavement engineers to develop a single paired comparison matrix for asphalt and concrete pavements of the freeway in Jiangsu Province, China. With the use of algorithms, a weight vector is derived from a paired comparison matrix (Forman and Gass 2001; Sun and Grenberg 2006). Weight factors for individual pavement indices can be developed using this method to eliminate subjectivity and provide a composite performance index that correlates closely to the actual performance of a roadway.

CHAPTER 3 PAVEMENT DISTRESS AND PERFORMANCE MODELS

The procedure of developing pavement distress and performance models is described in this chapter.

3.1 Pavement Condition Data

In 2011, Mastin specified automated data collection and rating procedures for NCDOT (Mastin 2011). Since then, NCDOT has collected pavement condition data of asphalt and composite (ASP), JCP, and CRC pavements (Interstate, US and NC routes) using automated methods on an annual basis. A few new types of distress data have been collected, as shown in Table 1 below:

Table 1: Types of Distresses Collected by NCDOT's Manual Method and Automated Method

	Asphalt and Composite Pavements (Flexible Pavements in the manual method)	Jointed Concrete Pavements (JCPs)	Continuously Reinforced Concrete Pavements (CRCs)
Manual Collection Method	Alligator Cracking, Transverse Cracking, Rutting, Raveling, Oxidation, Bleeding, Patching	Concrete Patching, Asphalt Patching, Longitudinal Cracking, Transverse Cracking, Corner Breaks, Spalling, Joint Seal Damage, Faulting	Concrete Patching, Asphalt Patching, Longitudinal Cracking, Transverse Cracking, Punch Outs, Narrow Cracking, Y-Cracking
Automated Collection Method	Transverse Cracking, Longitudinal Cracking (Non-Wheel Path), Longitudinal Lane Joint Cracking, Alligator Cracking, Patching, Delamination, Bleeding, Rutting, Raveling, Reflection Cracking of Transverse Joints, Reflection Cracking of Longitudinal Joints	Corner Breaks, Joint Seal Condition (Transverse and Longitudinal), Joint Spalling (Transverse and Longitudinal), Linear Cracking (Transverse and Longitudinal), Shattered Slabs, PCC Patching and Deterioration, Asphalt Patching	Transverse Cracking, Clustered Cracking, Punchouts and Spalled "Y" Cracking, PCC Patching and Deterioration, Longitudinal Cracking, Joint Spalling (Longitudinal), Longitudinal Joint Seal Condition

Table 1 shows that pavement performance data were collected from 12 distresses for ASP, from 11 distresses for JCP, and from 7 distresses for CRC. It should be noted that:

1) CRC pavements were not included in this study because they make up a very small percentage of the NC roadway system.

2) Some ASP and JCP distresses were not studied because of their small severity ratings. In other words, most likely these stresses are not commonly found in NC pavements. Details of collected distresses and if they were studied are included in Table 2.
3) Aggregated ASP and JCP data collected in 2013, 2014, and 2015 were provided by NCDOT and used to develop performance models in this study. An excerpt of ASP data is shown in Table 3.
4) AADT and Age data were provided by NCDOT.

Table 2: ASP and JCP Distresses Collected by NCDOT

Pavement	Distress	Unit	Severity	Analyzed in This Study?
ASP	Transverse Cracking	Linear Feet	L/M/H	Yes
	Reflective Transverse Cracking	Linear Feet	L/M/H	Yes
	Longitudinal Cracking	Linear Feet	L/H	Yes
	Reflective Longitudinal Cracking	Linear Feet	L/M/H	No
	Longitudinal Lane Joint	Linear Feet	L/H	Yes
	Alligator Cracking	Square Feet	L/M/H	Yes
	Patching Area - Non Wheel Path	Square Feet	Single Rating	Yes
	Patching Area - Wheel Path	Square Feet	Single Rating	Yes
	Delamination	Square Feet	Single Rating	No
	Bleeding	Square Feet	L/H	No
	Rutting - Maximum Average Depth	Inch	Single Rating	Yes
	Ravelling	Square Feet	L/M/H	No
JCP	Corner Breaks	# of Slabs	L/H	Yes
	Transverse Joint Seal	# of Joints	Single Rating	No
	Longitudinal Joint Seal	# of Slabs	Single Rating	No
	Transverse Joint Spalling	# of Slabs	L/M/H	Yes
	Longitudinal Joint Spalling	# of Slabs	Single Rating	Yes
	Transverse Cracking	# of Slabs	L/H	Yes
	Longitudinal Cracking	# of Slabs	L/H	Yes
	Shattered Slabs	# of Slabs	Single Rating	No
	Concrete Patching	# of Slabs	L/M/H	Yes
	Asphalt Patching	# of Slabs	Single Rating	Yes
	Joint Fault	# of Joints	N/L/M/H	Yes

In Table 2, N/L/M/S represents None, Light, Moderate, and High severity level, respectively.

Table 3: An Excerpt of ASP Data

ROUTE1	EFF_YEAR	COUNTY	OFFSET_FROM	OFFSET_TO	LEFT_IRI	RIGHT_IRI	NC_IRI_L_R_AVG	SEC_WIDTH	TRNSVRS_LOW_LF	TRNSVRS_MDRT_LF	TRNSVRS_HGH_LF
10000095	2015	66	0	1.81	79	78	79	29	700	104	12
10000095	2015	66	1.81	3.11	61	61	61	26	214	24	0
10000095	2015	66	3.11	4.58	52	46	49	26	336	98	0
10000095	2015	66	4.58	6.58	53	53	53	26	739	193	24
10000095	2015	66	6.58	7.501	55	55	55	26	169	86	0
10400095	2015	66	0	1.495	54	57	55	27	397	108	0
10400095	2015	66	1.495	2.905	55	54	55	27	806	72	0
10400095	2015	66	2.905	4.375	51	51	51	27	152	9	0
10400095	2015	66	4.375	6.375	53	55	54	27	197	23	0
10400095	2015	66	6.375	7.49	99	99	99	27	95	27	0
20000013	2015	8	0	2	92	93	92	27	11978	68	4
20000013	2015	8	2	3.98	89	83	86	27	10260	49	0
20000013	2015	8	3.98	6.35	84	86	85	27	13421	143	0
20000013	2015	8	6.35	8.35	90	93	91	27	13509	879	56
20000013	2015	8	8.35	9.556	100	105	102	27	6318	712	16
20000013	2015	8	9.556	10.911	100	95	98	28	5031	0	0
20000013	2015	8	10.911	12.368	139	135	137	28	627	0	0
20000013	2015	8	12.368	13.682	112	115	114	28	270	10	0
20000013	2015	8	13.682	15.309	156	176	166	24	3538	294	27
20000013	2015	8	15.309	16.689	127	163	145	24	3235	188	0
20000013	2015	8	16.689	18.095	115	136	125	24	4466	134	10

3.2 Pavement Distress Models

3.2.1 Composite Distress Index Values

Typically each roadway section, ASP or JCP, has several types of distresses. Each distress has different severity ratings. These ratings at varying severity levels should be aggregated to create a composite distress index of a particular distress, and the index values can then be used to develop a distress model that depicts how distresses in this roadway section deteriorate over time. The process of developing composite distress indices includes three steps.

Step One: Normalize the Condition Data.

Distress data has different units (linear feet or square feet). To aggregate these distresses, it is necessary to use normalization equations (Table 4) to convert individual distress ratings into unit less ratios.

Table 4: Normalization of ASP and JCP Pavement Condition Data

Pavement	Distress	Normalization Equation
ASP	Transverse Cracking	{(Transverse Cracking + Reflection Transverse Cracking) / (Length * 5280)}
	Reflective Transverse Cracking	
	Longitudinal Cracking	{Longitudinal Cracking / (Length * 5280)}
	Longitudinal Lane Joint	{Longitudinal Lane Joint / (Length * 5280)}
	Alligator Cracking	{Alligator Cracking / (Length * 7 * 5280)}*100
	Patching Area - Non Wheel Path	{Patching Area / (Length * 5280 * (Section width / Number of Lanes - 7))}*100
	Patching Area - Wheel Path	{Patching Area / (Length * 7 * 5280)}*100

	Rutting - Maximum Average Depth	100 - 100 * (Maximum Average Rut Depth) ^ 2
JCP	Corner Breaks	Corner Break / Length
	Transverse Joint Spalling	Transverse Joint Spalled / Length
	Longitudinal Joint Spalling	Longitudinal Joint Spalled / Length
	Transverse Cracking	Transverse Cracking / Length
	Longitudinal Cracking	Longitudinal Cracking / Length
	Concrete Patching	PCC Patch / Length
	Asphalt Patching	Asphalt Patch / Length
	Joint Fault	Joint Fault / Length

Step Two: Determine Maximum Allowable Extent (MAE) Input and Threshold Values.

As indicated in Chen's study (Chen et al. 2013), MAE input and threshold values need to be determined in order to calculate distress index values. MAE input values were obtained by calculating and analyzing percentiles of distresses at various severity levels (Figure 1) and working with NCDOT engineers. The final MAE input and threshold values are included in Table 5.

PMSIII Transverse_Low AutoAggASPAADT

Obs	P_80	P_81	P_82	P_83	P_84	P_85	P_86	P_87	P_88	P_89	P_90	P_91	P_92	P_93	P_94	P_95	P_96	P_97	P_98	P_99	P_100
1	0.27850	0.28901	0.29920	0.30926	0.32058	0.33149	0.34353	0.35702	0.37247	0.38731	0.40388	0.42424	0.44593	0.47109	0.50123	0.53846	0.58485	0.64299	0.71889	0.87396	4.33049

PMSIII Transverse_Mod AutoAggASPAADT

Obs	P_80	P_81	P_82	P_83	P_84	P_85	P_86	P_87	P_88	P_89	P_90	P_91	P_92	P_93	P_94	P_95	P_96	P_97	P_98	P_99	P_100
1	0.11026	0.11679	0.12372	0.13092	0.13896	0.14792	0.15708	0.16711	0.17813	0.18962	0.20346	0.21836	0.23438	0.25584	0.28002	0.30987	0.34244	0.39200	0.46224	0.61222	2.19875

PMSIII Transverse_High AutoAggASPAADT

Obs	P_80	P_81	P_82	P_83	P_84	P_85	P_86	P_87	P_88	P_89	P_90	P_91	P_92	P_93	P_94	P_95	P_96	P_97	P_98	P_99	P_100
1	0.022451	0.024225	0.026231	0.028227	0.030687	0.033190	0.035719	0.039165	0.042766	0.046673	0.051420	0.056771	0.063163	0.070060	0.078598	0.090488	0.10680	0.12879	0.15616	0.21515	1.13538

Figure 1: An Excerpt of Distress Percentiles

Table 5: MAE Input Values for ASP and JCP Pavements

Pavement	Distress	Severity	MAE Input	MAE Threshold
ASP	Transverse Cracking & Reflective Transverse Cracking	L	1.2000	60
		M	0.8000	30
		H	0.4000	0
	Longitudinal Cracking	L	0.7041	60
		H	0.6165	0
	Longitudinal Lane Joint	L	0.2500	60
		H	0.1500	0
	Alligator Cracking	L	30.9077	60
		M	4.7015	30

		H	2.0000	0
	Patching - Non Wheel Path	Single	16.0566	0
	Patching - Wheel Path	Single	23.2562	0
	Rutting	Single	99.3600	NA
JCP	Corner Breaks	L	6.8213	60
		H	0.0000	0
	Transverse Joint Spalling	L	62.8571	60
		M	17.2084	30
		H	12.1317	0
	Longitudinal Joint Spalling	Single	65.1303	0
	Transverse Cracking	L	31.1558	60
		H	24.5464	0
	Longitudinal Cracking	L	30.6644	60
		H	11.8421	0
	Concrete Patching	L	9.6491	60
		M	0.0000	30
		H	0.0000	0
	Asphalt Patching	Single	6.0000	0
	Joint Fault	L	61.0000	60
		M	12.8806	30
		H	1.1111	0

Step Threes: Calculate Composite Distress Index Values.

After MAE input and threshold values are determined, they are put into a MAE spreadsheet developed by the NCDOT Pavement Management Unit (PMU) to calculate composite distress index values. A screenshot of the MAE spreadsheet is shown in Figure 2.

INPUTS				
OUTPUT				
	Square Feet	Length		
Distress Low	**8125**	**1.335**		
Distress Moderate	**288**	**1.335**		
Distress Severe	**72**	**1.335**		
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	**16.46683529**			
med_sev_in	**0.583685977**	*OK* - Sum distress total is 100 or less		
high_sev_in	**0.145921494**			
The normalizing factor will normalize absolute distress amounts null indicates no normalization required				
normalizing_in	null			
MAE Amounts (Low Med and High) are the Extent amounts that maximize deduction for that severity				
low_sev_mae_in	30.9077			
med_sev_mae_in	4.7015			
high_sev_mae_in	2			
Threshold Amounts are lowest possible score for that severity when it occurs alone				
low_sev_threshold_in	60			
med_sev_threshold_in	30			
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	16.4668
med_sev_begin	0		distr_med	0.5837
high_sev_begin	0		distr_high	0.1459
d1	21.3109			
d2	8.6906		d2c	28.1495
d3	7.2950		d3c	33.3910
Alligator Cracking Index Value	**66.6090**			

Figure 2: The MAE Spreadsheet

3.2.2 Distress Model Form

A previous study (Chen et al. 2013) indicated that the sigmoidal model form is appropriate to be used to develop pavement distress models. Therefore, this model form was selected and used in this study.

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

where

y: Distress index values

x: Age

a, *b*, *c*: Model parameters

Equation (1) shows that pavement age is used as an independent variable to predict distress index values, the dependent variable. In order to include another important independent variable, traffic volumes, in the statistical analysis, several roadway families were developed based on their traffic volumes. These roadway families are:

- 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

To better understand the naming convention, the family "Interstate 0-50k" includes Interstate roadway sections that have an Average Annual Daily Traffic (AADT) volume between 0 to 50,000. The family "Interstate 50k plus" includes Interstate roadway sections that have an AADT greater than 50,000. A total of 10 roadway families and their corresponding deterioration models were developed in this study.

3.2.3 The Range of Pavement Age

After distress index values of each family were calculated, they were plotted against pavement age. One of these boxplots is shown in Figure 3. From these boxplots, it can be observed that after 13 years, distress index values jump to a higher level and then deteriorate following a similar trend observed in the first 13 years. The jump is probably caused by NCDOT preventative maintenance activities, which should reset pavement age back to 0. However, the proven three-point method (Chen et al. 2013) needs at least 4 years of consecutive pavement distress ratings from each roadway section, which is not the case for this study (only three years). Therefore, it was decided to use pavement distress data that have age less than or equal to 13 years to develop distress models.

3.2.4 Data Cleansing

The scatter plot (Figure 4) and box plot (Figure 5) of Alligator Cracking index values by age indicate that outliers exist where low index values were collected for new pavements (lower left corner) and where high index values were collected for older pavements (top region). This is a common situation for all distress types. To remove these outliers, the following steps were taken for all types of distresses:

if AGE = **0** and Distress Index Value < **100** then delete;
if AGE = **1** and Distress Index Value < **95** then delete;
if AGE = **2** and Distress Index Value < **90** then delete;

if AGE = 3 and Distress Index Value < 85 then delete;
if AGE > 1 and Distress Index Value > 99 then delete;
if AGE > 2 and Distress Index Value > 95 then delete;

As an example, the scatter plot and box plot of cleaned alligator cracking data are shown in Figure 6 and Figure 7. The cleaned data were then used to develop all distress models.

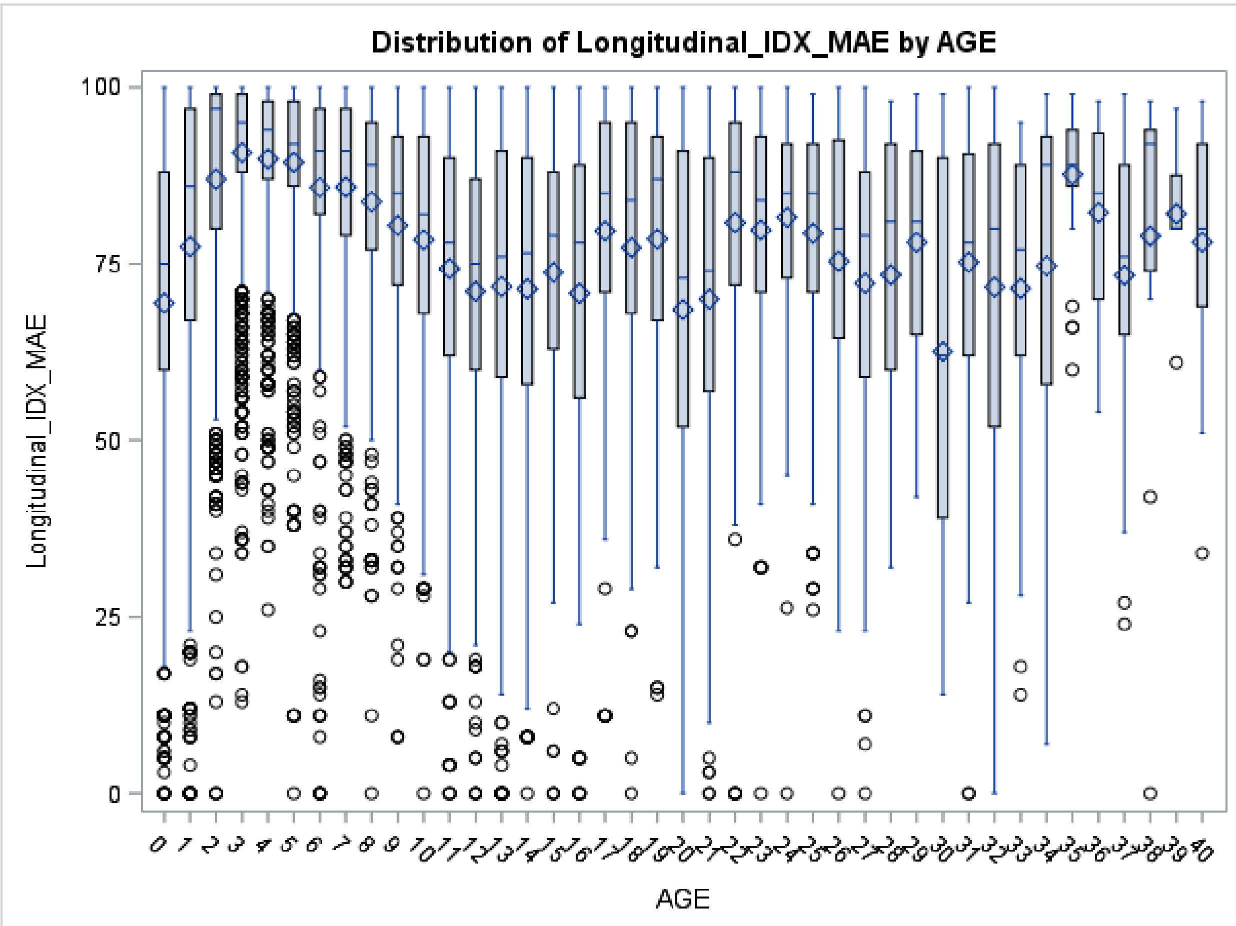

Figure 3: Boxplot of Longitudinal Cracking Index Values by Age (US 5-15k)

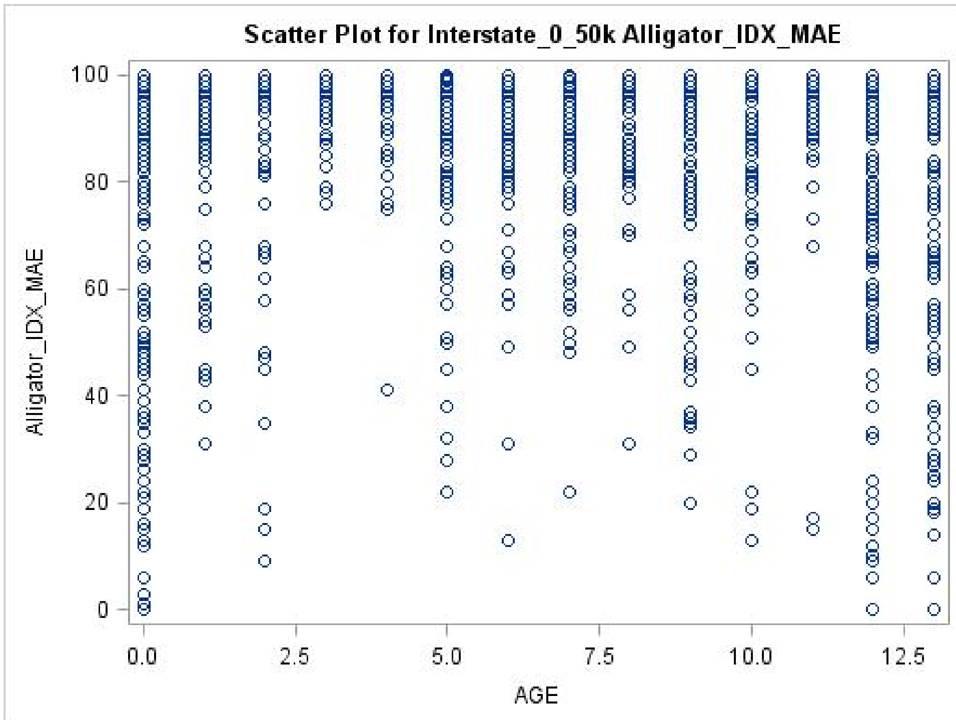

Figure 4: Scatter Plot of Alligator Cracking Index Values by Age (Interstate 0-50k)

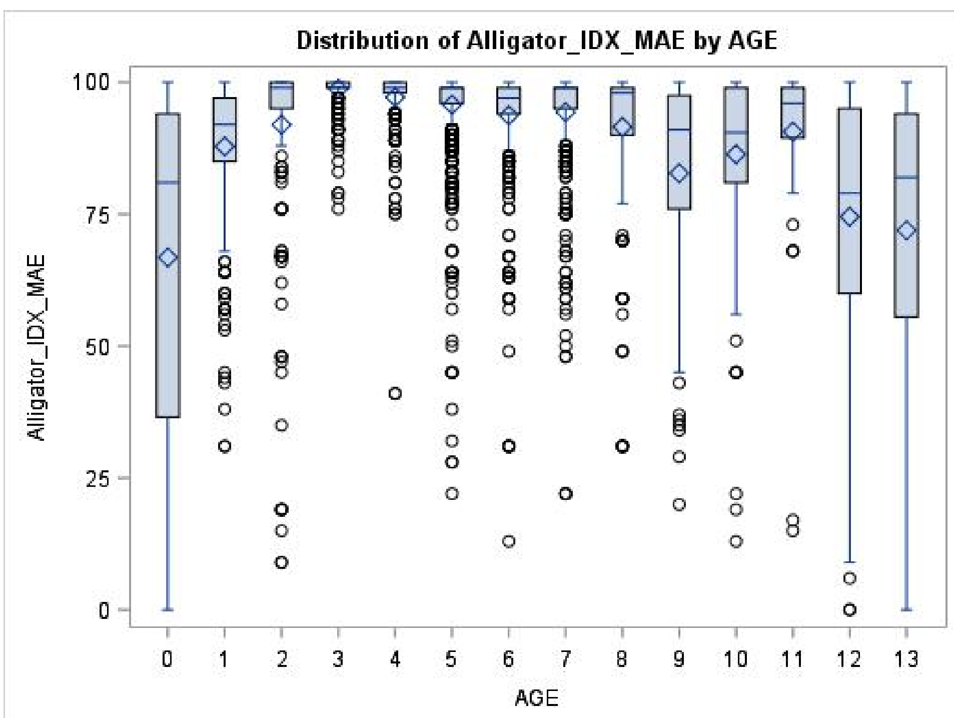

Figure 5: Box Plot of Alligator Cracking Index Values by Age (Interstate 0-50k)

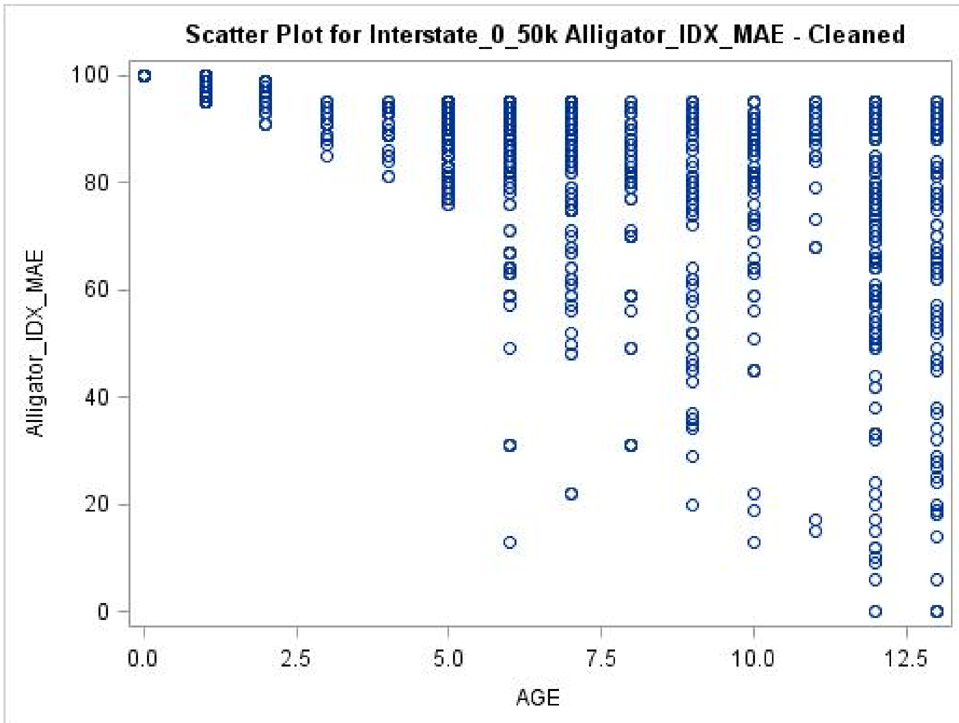

Figure 6: Scatter Plot of Alligator Cracking Index Values by Age (Interstate 0-50k, cleaned data)

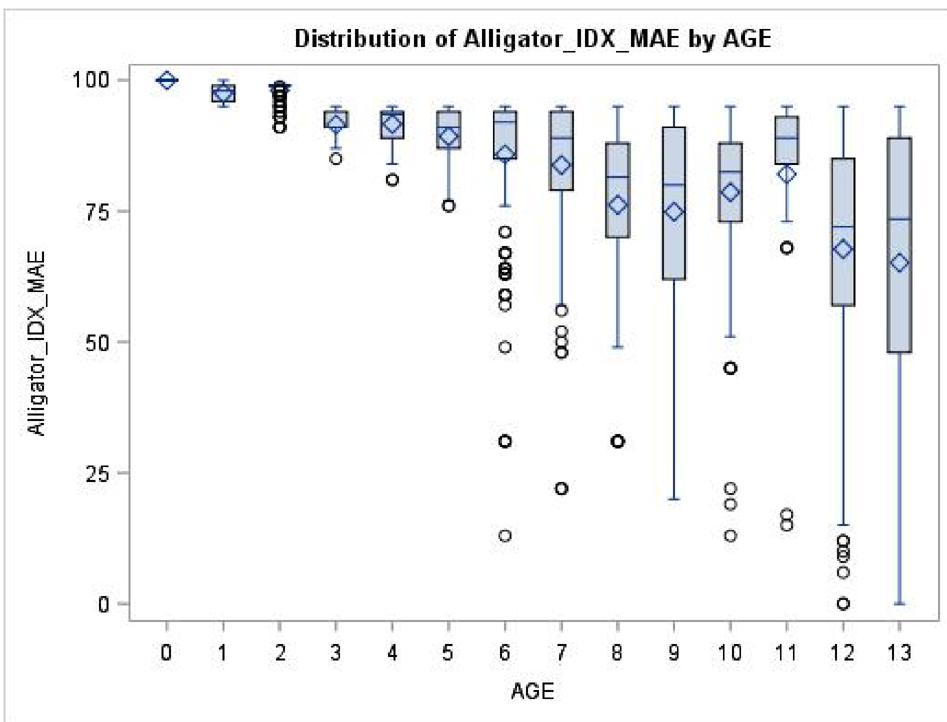

Figure 7: Box Plot of Alligator Cracking Index Values by Age (Interstate 0-50k, cleaned data)

3.2.5 Distress Models

To develop distress models, nonlinear statistical analysis was conducted to calculate model parameters for each roadway family. The results are included in Table 6 through Table 11. The model curves are included in Appendices C and D.

Table 6: Model Parameters for ASP Pavements (Transverse Cracking)

Distress	Family	a	b	c
Transverse Cracking	Interstate 0-50k	100.8147	15.80474	-3.285761408
	Interstate 50k plus	101.3702	17.86933	-4.165116791
	US 0-5k	102.0086	14.94777	-3.825190938
	US 5-15k	101.8342	16.01709	-4.005705009
	US 15-30k	101.4403	16.31155	-3.846757988
	US 30k plus	101.9367	15.82952	-4.013362823
	NC 0-1k	101.6832	14.94234	-3.658330125
	NC 1-5k	101.6212	14.51772	-3.522016684
	NC 5-15k	101.9818	15.05775	-3.840129722
	NC 15k plus	101.0899	16.97262	-3.755750195

Table 7: Model Parameters for ASP Pavements (Longitudinal Cracking)

Distress	Family	a	b	c
Longitudinal Cracking	Interstate 0-50k	101.2523	14.43773	-3.296115400
	Interstate 50k plus	102.3735	15.27120	-4.082350542
	US 0-5k	101.4953	15.03914	-3.578333280
	US 5-15k	102.0539	16.54969	-4.259420883
	US 15-30k	102.1256	16.16554	-4.197601546
	US 30k plus	103.9063	19.61783	-6.050062711
	NC 0-1k	101.8399	15.66223	-3.920022222
	NC 1-5k	101.5821	19.37947	-4.673782108
	NC 5-15k	101.6005	19.00372	-4.595986986
	NC 15k plus	101.5178	20.00996	-4.778030373

Table 8: Model Parameters for ASP Pavements (Alligator Cracking)

Distress	Family	a	b	c
Alligator Cracking	Interstate 0-50k	101.3308	12.11756	-2.805392996
	Interstate 50k plus	102.4110	10.75006	-2.885835012
	US 0-5k	101.6694	12.88757	-3.148894583
	US 5-15k	102.4353	13.34876	-3.593112121
	US 15-30k	101.8851	12.23358	-3.080601793
	US 30k plus*	101.8851	12.23358	-3.080601793
	NC 0-1k	101.4614	12.38892	-2.931764651
	NC 1-5k	101.3908	12.95698	-3.030686022

	NC 5-15k	101.8044	13.52898	-3.369648950
	NC 15k plus	101.7757	14.47723	-3.591491649

Table 9: Model Parameters for ASP Pavements (NWP)

Distress	Family	a	b	c
Patching Area - Non Wheel Path	Interstate 0-50k	100.2253	10.81332	-1.766728732
	Interstate 50k plus*	100.2253	10.81332	-1.766728732
	US 0-5k	100.2967	13.49311	-2.318319057
	US 5-15k	100.3455	13.04235	-2.301021834
	US 15-30k	100.5185	14.59624	-2.773855111
	US 30k plus	100.5258	11.84637	-2.257306752
	NC 0-1k	100.2544	14.05772	-2.353164043
	NC 1-5k	100.2634	12.71535	-2.140852782
	NC 5-15k	100.3998	13.34174	-2.416073386
	NC 15k plus	100.6519	14.97689	-2.975696396

Table 10: Model Parameters for ASP Pavements (WP)

Distress	Family	a	b	c
Patching Area - Wheel Path	Interstate 0-50k	100.2253	10.59640	-1.738431880
	Interstate 50k plus*	100.2253	10.59640	-1.738431880
	US 0-5k	100.2824	12.57584	-2.142545082
	US 5-15k	100.3257	12.78113	-2.232688451
	US 15-30k	100.4776	14.70451	-2.751539399
	US 30k plus	100.5628	12.67132	-2.446190787
	NC 0-1k	100.2887	13.21106	-2.259307864
	NC 1-5k	100.2561	12.08645	-2.025454459
	NC 5-15k	100.3324	12.95346	-2.269879374
	NC 15k plus	100.5152	12.79122	-2.427945541

Table 11: Model Parameters for ASP Pavements (Rutting)

Distress	Family	a	b	c
Rutting	Interstate 0-50k	101.0924	19.79958	-4.383509043
	Interstate 50k plus*	101.0924	19.79958	-4.383509043
	US 0-5k	101.3089	19.39526	-4.473069804
	US 5-15k	101.4052	20.24369	-4.746448979
	US 15-30k	101.3897	23.55509	-5.508613363
	US 30k plus*	101.3897	23.55509	-5.508613363
	NC 0-1k	101.2004	19.73971	-4.463448340
	NC 1-5k	101.3941	18.72931	-4.383285481
	NC 5-15k	101.6091	19.00475	-4.602202279

	NC 15k plus	102.5600	23.31479	-6.361170847

Some ASP distress curves are not reasonable because of small numbers of performance data that are available. After discussions with NCDOT engineers, it was decided to use the adjacent curves to replace these unreasonable curves. Adjacent curves are the ones that are in the same roadway family and have the closest AADT range. Unreasonable curves, marked with an asterisk in tables, are: Interstate 50k plus/Patching Area - Wheel Path, Interstate 50k plus/Patching Area – Non Wheel Path, US 30k plus/Alligator Cracking, Interstate 50k plus/Rutting, and US 30k plus/Rutting. Their replacement curves are: Interstate 0-50k /Patching Area - Wheel Path, Interstate 0-50k/Patching Area – Non Wheel Path, US 15-30k/ Alligator Cracking, Interstate 0-50k/Rutting, and US 15-30k/Rutting, respectively.

Since the total number of JCP pavements is small in North Carolina, it is not feasible to subdivide the JCP roadway classifications into families. Therefore, one distress model was developed for each type of JCP distress (Table 12). The model curves are included in Appendix F.

Table 12: Model Parameters for JCP Pavements

Distress	a	b	c
Corner Breaks	100.224	12.80209	-2.098300109
Transverse Joint Spalling	102.8947	23.97451	-6.768053097
Longitudinal Joint Spalling	102.765	17.22885	-4.801639756
Transverse Cracking	100.4431	13.37151	-2.467437768
Longitudinal Cracking	101.3737	13.09712	-3.054616335
Concrete Patching	100.0791	13.8810	-1.943347592
Asphalt Patching	100.0951	12.13975	-1.744709412
Joint Fault	101.1113	15.3520	-3.411814975

3.3 Pavement Performance Models

Pavement performance models were developed in a similar way that pavement distress models were developed. The same range of pavement age, less than or equal to 13 years, was used to develop pavement performance models. The sigmoidal model function used for performance models is:

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

where

y: PCR values

x: Age

a, *b*, *c*: Model parameters

3.3.1 ASP Pavements

To evaluate the overall performance of a roadway section, it is necessary to develop a composite performance index which combines the section's distress ratings into one single value. Analytical Hierarchy Process (AHP) was used to develop this composite index, Pavement Condition Rating (PCR), for ASP and JCP pavements.

3.3.1.1 Composite Performance Index Values for ASP Pavements

The NCDOT PMS has used a set of deduction values for PCR calculation for ASP pavements, which are included in Table 13. In the last column of this table, the average values of deduction points of each type of distress were calculated. These average values were used to calculate the individual weight factor for each distress. It should be noted that distress data of bleeding and oxidation were insufficient, and their models were not developed. The quality of raveling data was not satisfactory, thus raveling was not developed in this study.

Table 13: Deduction Values for ASP Pavements

Distress	Severity Level	Deduction	Average
Alligator Cracking	(L)ight	3.3 points - 10% to 90%; 1 point > 90% (3.3*9 + 1*0.1 = 29.8 points)	42
	(M)oderate	7.5 points - 10% to 40%; 2 points > 40% (7.5*4 + 2*6 = 42 points)	
	(S)evere	15 points - 10% to 20%; 3 points > 20% (15*2 + 3*8 = 54 points)	
Transverse Cracking	(L)ight	5 points	17
	(M)oderate	15 points	
	(S)evere	30 points	
Rutting	(L)ight	5 points	18
	(M)oderate	20 points	
	(S)evere	30 points	
Raveling	(L)ight	2 points	Models not developed
	(M)oderate	5 points	
	(S)evere	15 points	
Bleeding	(L)ight	10 points	Models not developed
	(M)oderate	20 points	
	(S)evere	30 points	
Patching	(L)ight	5 points	12
	(M)oderate	10 points	
	(S)evere	20 points	
Oxidation	(L)ight	0 points	Models not developed
	(S)evere	5 points	

Literature review indicates that distresses in ASP pavements can be categorized into load-related (LDR) and non-load related (NDR), and the PCR value is the smaller value of LDR an NDR values (McGhee 2004). This approach of calculating PCR values was used in this study.

LDR and NDR distresses and their corresponding average deduction values are presented in Table 14. Since Longitudinal Lane Joint and Patching Area - Non Wheel Path are non-loaded related distresses, they were assigned the smallest calculated value which was 7. Longitudinal Cracking was assigned a values of 9 because it is considered load related distress, but has less impact on the overall pavement condition than alligator cracking and patching, and rutting.

Table 14: Average Deduction Values for ASP Pavements

Distress	**Average**	**LDR/NDR**
Alligator Cracking	42	LDR
Patching Area - Wheel Path	12	LDR
Patching Area - Non Wheel Path	7	LDR
Rutting - Maximum Average Depth	18	LDR
Transverse/Reflective Transverse Cracking	17	NDR
Longitudinal Cracking	9	NDR
Longitudinal Lane Joint	7	NDR

These average deduction values were used to develop two comparison matrices, one for LDR distresses (Table 15) and the other one for NDR distresses (Table 16).Then AHP was used to calculate individual weight factors (Table 17).

Table 15: Comparison Matrix for LDR Distresses

Distress	ALGTR	WP	NWP	RUT
Alligator Cracking (ALGTR)	42/42 = 1.00	42/12 = 3.50	42/7 = 6.00	42/18 = 2.33
Patching Area - Wheel Path (WP)	12/42 = 0.29	12/12 = 1.00	12/7 = 1.71	12/18 = 0.67
Patching Area - Non Wheel Path (NWP)	7/42 = 0.17	7/12 = 0.58	7/7 = 1.00	7/18 = 0.39
Rutting - Maximum Average Depth (RUT)	18/42 = 0.43	18/12 = 1.50	18/7 = 2.57	18/18 = 1.00

Table 16: Comparison Matrix for NDR Distresses

Distress	TRA	LNG	LNG_JNT
Transverse/Reflective Transverse Cracking (TRA)	17/17 = 1.00	17/9 = 1.89	17/7 = 2.43
Longitudinal Cracking (LNG)	9/17 = 0.53	9/9 = 1.00	9/7 = 1.29
Longitudinal Lane Joint (LNG_JNT)	7/17 = 0.41	7/9 = 0.78	7/7 = 1.00

Table 17: Weight Factors of ASP Pavements

	Distress	Weight Factor
LDR	Alligator Cracking (ALGTR)	0.5316370
	Patching Area - Wheel Path (WP)	0.1520450
	Patching Area - Non Wheel Path (NWP)	0.0887566
	Rutting - Maximum Average Depth (RUT)	0.2275610
NDR	Transverse/Reflective Transverse Cracking (TRA)	0.5152640
	Longitudinal Cracking (LNG)	0.2729290
	Longitudinal Lane Joint (LNG_JNT)	0.2118080

Using these weight factors, PCR values of ASP pavements can be calculated as shown in equations below.

NDR = 0.5152640* TRA + 0.2729290* LNG + 0.2118080* LNG_JNT (2)

LDR = 0.5316370* ALGTR + 0.1520450* WP + 0.0887566* NWP + 0.2275610* RUT (3)

PCR = min (LDR, NDR) (4)

3.3.1.2 Pavement Performance Models for ASP Pavements

Using the calculated PCR values, pavement performance models (PCR vs. Age) can be developed. Nonlinear statistical analysis was conducted to calculate model parameters for each roadway family. The results are included in Table 18. The model curves are included in Appendix E.

Table 18: Model Parameters for PCR Curves (ASP Pavements)

Family	a	b	c
Interstate 0-50k	102.6845	12.8715	-3.557959102
Interstate 50k plus	105.6049	17.4871	-6.068686200
US 0-5k	103.3826	13.2481	-3.912000171
US 5-15k	103.3588	12.6774	-3.735687497
US 15-30k	103.2258	12.8860	-3.752472942
US 30k plus	105.5716	17.6787	-6.122522873
NC 0-1k	102.9406	12.1572	-3.447353301
NC 1-5k	102.4799	12.8117	-3.465468712
NC 5-15k	102.5865	13.0637	-3.574318553
NC 15k plus	102.4139	13.0419	-3.502193087

3.3.2 JCP Pavements

3.3.2.1 Composite Performance Index Values for JCP Pavements

Analytical Hierarchy Process (AHP) was also used to calculate the composite performance index values for JCP pavements. The NCDOT PMS has a set of deduction values for PCR calculation for JCP pavements. These existing JCP deduction values, however, were not used in this study. The reason was that new types of JCP distress (e.g., joint fault) were collected using the automated technique and corresponding deduction values for these new distresses are not available. A group of NCDOT engineers and researchers evaluated and scored the importance of each type of JCP distress. The results are included in Table 19. In this table, the least important JCP distress has a score of 1, the most important JCP distress has a score of 8. The average score of each distress is included in the last column. These average scores were used to develop a comparison matrix that presents relative importance among all JCP distresses (Table 20). The weight factors of JCP distresses were then calculated using AHP and are included in Table 21.

Table 19: Scores of Importance of JCP Distresses

Distress	Engineer #1	#2	#3	#4	#5	#6	#7	AVG
Transverse Cracking (TRNSVRS_CRK)	4	6	6	5	6	7	5	5.57
Longitudinal Cracking (LNGTDNL_CRK)	8	8	7	8	7	8	8	7.71
Concrete Patch (CON_PATCH)	1	1	3	4	1	3	3	2.29
Asphalt Patch (ASPHLT_PTCH)	6	7	8	7	7	5	7	6.71
Transverse Joint Spalled (TRNSVRS_SPLL)	3	3	2	2	3	1	2	2.29
Longitudinal Joint Spalled (LNGTDNL_JNT_SPLL)	2	2	1	1	1	2	1	1.43
Corner Break (CRNR)	7	5	4	6	5	6	6	5.57
Joint Fault (FAULT)	5	4	5	3	4	4	4	4.14

Table 20: Comparison Matrix for JCP Distresses

	Transverse Cracking (TRNSVRS_CRK)	Longitudinal Cracking (LNGTDNL_CRK)	Concrete Patch (CON_PATCH)	Asphalt Patch (ASPHLT_PTCH)	Transverse Joint Spalled (TRNSVRS_SPLL)	Longitudinal Joint Spalled (LNGTDNL_JNT_SPLL)	Corner Break (CRNR)	Joint Fault (FAULT)
Transverse Cracking (TRNSVRS_CRK)	5.57/5.57=1.00	5.57/7.71=0.72	5.57/2.29=2.43	5.57/6.71=0.83	5.57/2.29=2.43	5.57/1.43=3.90	5.57/5.57=1.0	5.57/4.14=1.53
Longitudinal Cracking (LNGTDNL_CRK)		7.71/7.71=1.00	7.71/2.29=3.37	7.71/6.71=1.15	7.71/2.29=3.37	7.71/1.43=5.39	7.71/5.57=1.38	7.71/4.14=1.86
Concrete Patch (CON_PATCH)			2.29/2.29=1.00	2.29/6.71=0.34	2.29/2.29=1.00	2.29/1.43=1.60	2.29/5.57=0.41	2.29/4.14=0.55
Asphalt Patch (ASPHLT_PTCH)				6.71/6.71=1.00	6.71/2.29=2.93	6.71/1.43=4.69	6.71/5.57=1.20	6.71/4.14=1.62
Transverse Joint Spalled (TRNSVRS_SPLL)					2.29/2.29=1.00	2.29/1.43=1.60	2.29/5.57=0.41	2.29/4.14=0.55
Longitudinal Joint Spalled (LNGTDNL_JNT_SPLL)						1.43/1.43=1.00	1.43/5.57=0.26	1.43/4.14=0.35
Corner Break (CRNR)							5.57/5.57=1.00	5.57/4.14=1.35
Joint Fault (FAULT)								4.14/4.14=1.00

Table 21: Weight Factors of JCP Pavements

Distress	Weight
Transverse Cracking (TRNSVRS_CRK)	0.1559790
Longitudinal Cracking (LNGTDNL_CRK)	0.2159680
Concrete Patch (CON_PATCH)	0.0640291

Asphalt Patch (ASPHLT_PTCH)	0.1878770
Transverse Joint Spalled (TRNSVRS_SPLL)	0.0640596
Longitudinal Joint Spalled (LNGTDNL_JNT_SPLL)	0.0401852
Corner Break (CRNR)	0.1560570
Joint Fault (FAULT)	0.1158460

Using these weight factors, PCR values of JCP pavements can be calculated as shown in the equation below.

PCR = 0.1559790* TRNSVRS_CRK + 0.2159680* LNGTDNL_CRK + 0.0640291* CON_PATCH + 0.1878770* ASPHLT_PTCH + 0.0640596* TRNSVRS_SPLL + 0.0401852* LNGTDNL_JNT_SPLL + 0.1560570* CRNR + 0.1158460* FAULT (6)

3.3.2.2 Pavement Performance Models for JCP Pavements

Using the calculated PCR values, pavement performance models (PCR vs. Age) for JCP pavements can be developed. Nonlinear statistical analysis was conducted to calculate model parameters for the entire JCP roadway family. For JCP pavements, no roadway families were developed because of the small sample sizes. Model parameters are included in Table 22. The model curve is included in Appendix G.

Table 22: Model Parameters for PCR Curves (JCP Pavements)

Family	**a**	**b**	**c**
Overall JCP	101.9740	13.8629	-3.531846494

CHAPTER 4 TRIGGER POINTS ON DECISION TREES

Trigger points are distress index values when reached can initiate or "trigger" certain types of treatments. This chapter describes detailed steps of deriving trigger points.

Step One: Define Treatment Strategy Zones

On a typical pavement performance curve, four treatment strategy zones can be defined. They are: preventive maintenance, light rehabilitation, heavy rehabilitation, and reconstruction. Based on input from NCDOT engineers, the corresponding PCR thresholds were determined to be 80, 60, and 40, respectively, as shown in Figure 8.

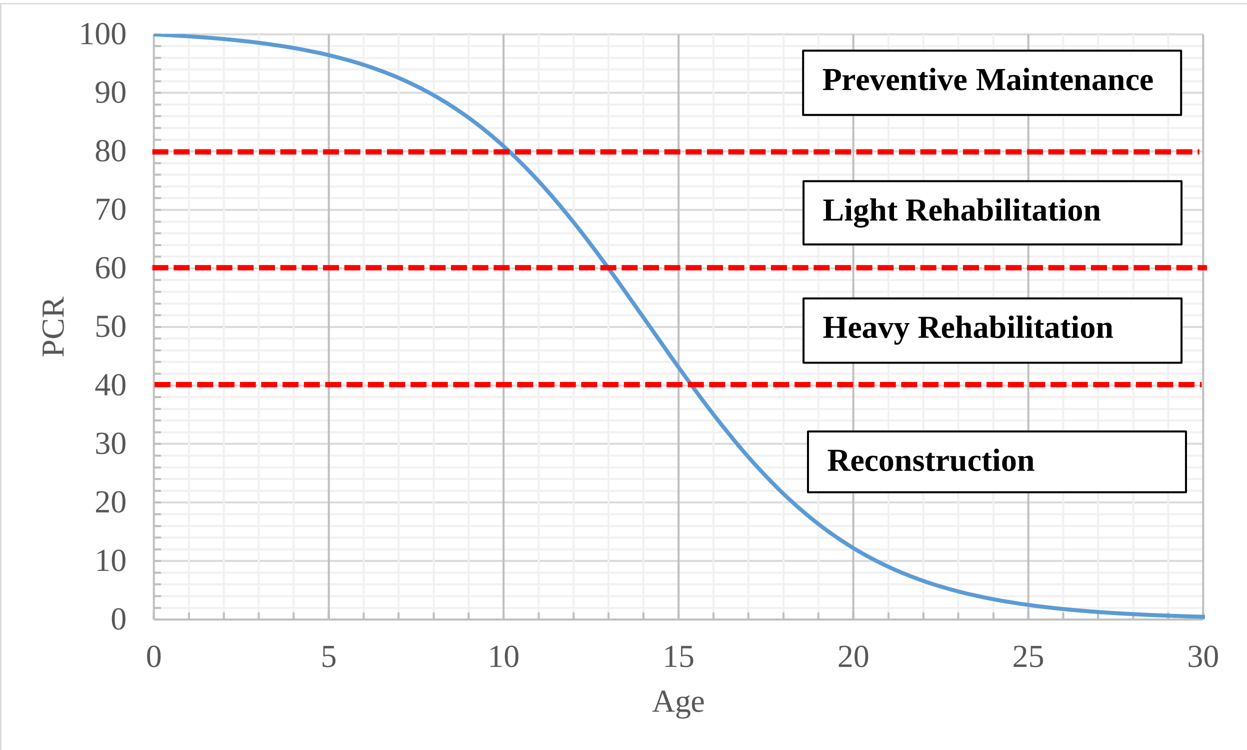

Figure 8: Treatment Strategy Zones (Performance Curve)

Step Two: Calculate Treatment Ages

For each roadway family, pavement ages when its PCR value reaches 80, 60, and 40 were calculated using performance model equations, denoted as Age_80, Age_60, and Age_40, respectively (Figure 9).

Step Three: Determine Trigger Point Values

For each type of distress of the same roadway family, the corresponding trigger point values, i.e., Trigger Point_80, Trigger Point_60, and Trigger Point_40 can be determined using the pavement ages obtained in Step 2 (Age_80, Age_60, and Age_40) (Figure 10). Then the final trigger point values of each type of distress are: (1) For ASP pavements, the median values of Trigger Point_80, Trigger Point_60, and Trigger Point_40 values across all roadway families; and (2) For JCP pavements, the calculated values of Trigger Point_80, Trigger Point_60, and Trigger Point_40 because there is only one overall JCP family.

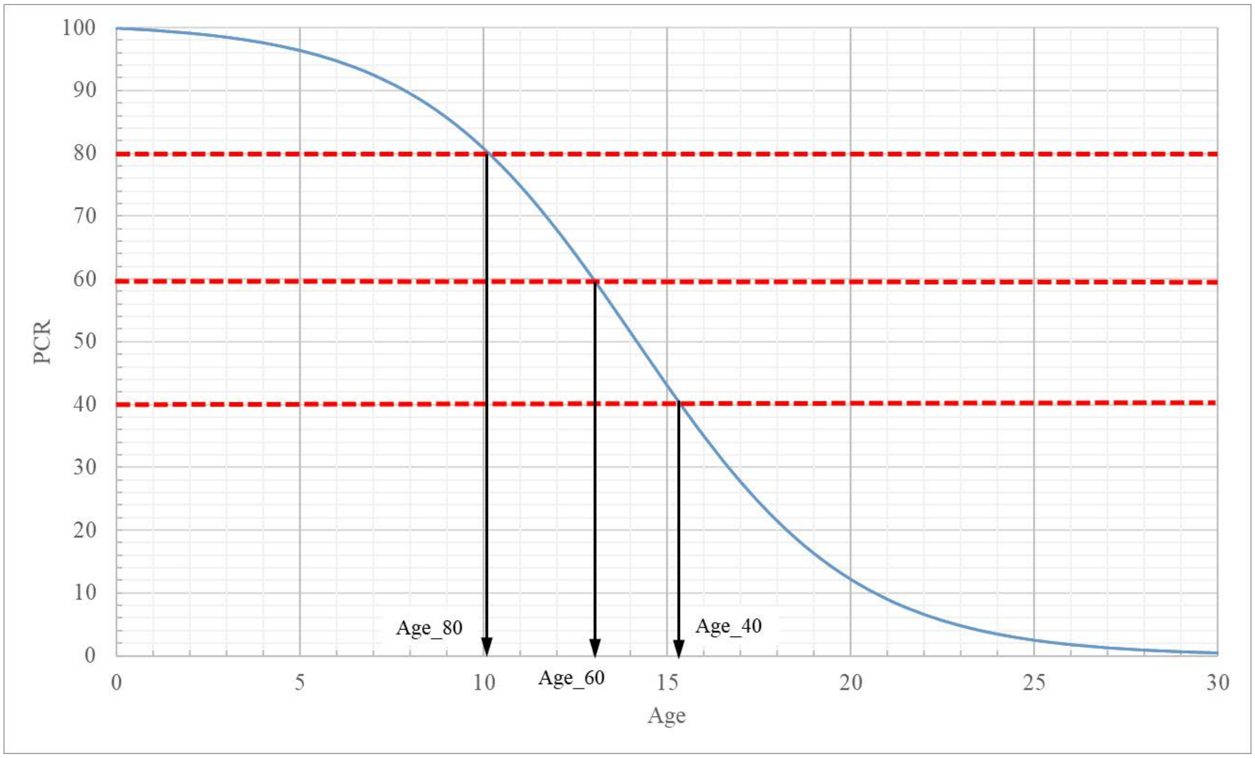

Figure 9: Treatment Ages (Performance Curve)

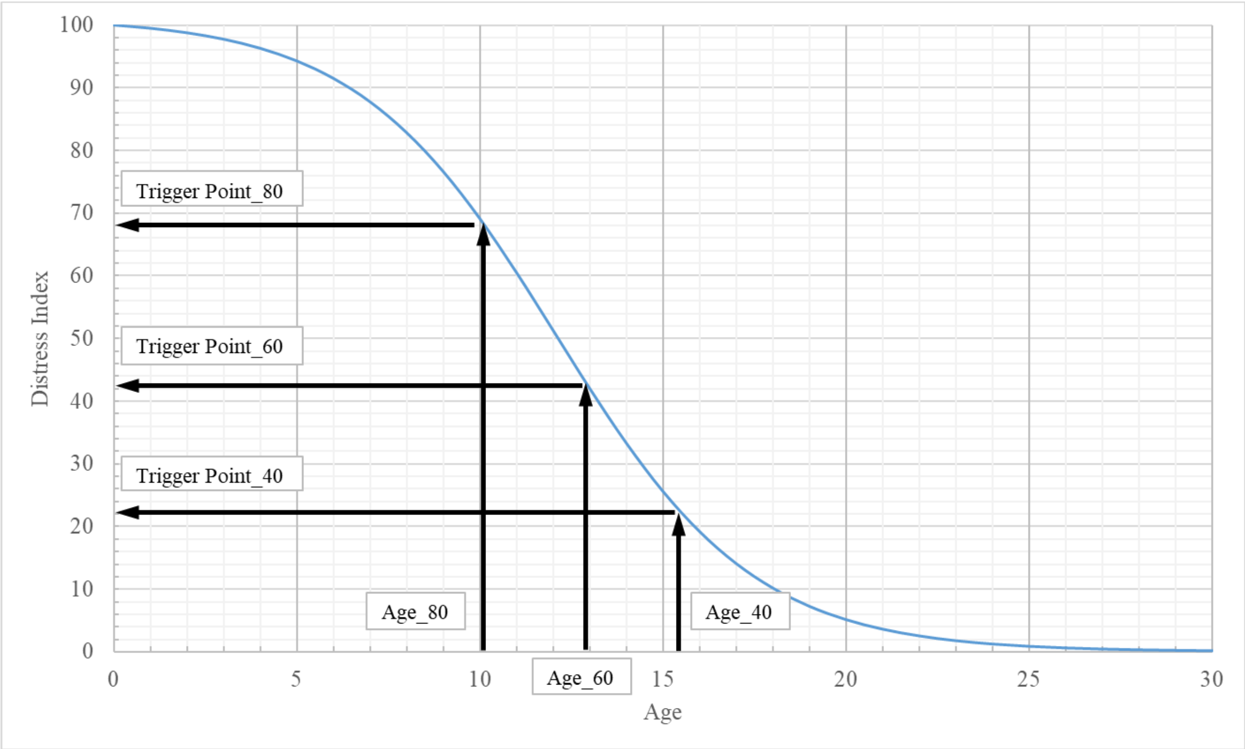

Figure 10: Trigger Point Values (Distress Curve)

From ASP and JCP performance curves, Age_80, Age_60, and Age_40 were calculated and are included in Table 23.

Table 23: Age_80, Age_60, and Age_40 for ASP and JCP pavements

	Family	Age_80	Age_60	Age_40
ASP	Interstate 0-50k	8.4	11.7	14.5
	Interstate 50k plus	10.6	15.8	20.5
	US 0-5k	8.4	12.0	15.0
	US 5-15k	8.1	11.5	14.4
	US 15-30k	8.2	11.7	14.6
	US 30k plus	10.7	16.0	20.7
	NC 0-1k	7.9	11.0	13.7
	NC 1-5k	8.4	11.6	14.4
	NC 5-15k	8.5	11.8	14.7
	NC 15k plus	8.6	11.8	14.6
JCP	Overall JCP	9.3	12.6	15.4

From ASP and JCP distress curves, Trigger Point_80, Trigger Point_60, and Trigger Point_40 were calculated and are included in Table 24 through Table 30. The median values were selected as the final trigger point values for ASP decision trees and the calculated values for JCP pavement decision trees (Table 31 and Table 32).

Table 24: Trigger Point Values (ASP Transverse Cracking)

Distress	Family	Trigger Point_80	Trigger Point_60	Trigger Point_40
Transverse	Interstate 0-50k	88.3	68.2	42.6
	Interstate 50k plus	80.6	44.6	16.0
	US 0-5k	81.4	56.3	31.4
	US 5-15k	82.4	56.3	30.1
	US 15-30k	84.2	59.1	32.3
	US 30k plus	84.5	63.7	40.5
	NC 0-1k	82.4	56.3	30.3
	NC 1-5k	79.5	52.2	27.4
	NC 5-15k	78.8	52.3	28.1
	NC 15k plus	87.5	69.2	46.5

Table 25: Trigger Point Values (ASP Longitudinal Cracking)

Distress	Family	Trigger Point_80	Trigger Point_60	Trigger Point_40
Longitudinal	Interstate 0-50k	87.3	70.8	50.4
	Interstate 50k plus	77.8	47.7	22.3
	US 0-5k	87.6	71.2	50.7
	US 5-15k	89.8	78.3	63.7
	US 15-30k	88.7	76.1	60.5
	US 30k plus	84.6	67.1	47.3
	NC 0-1k	89.6	78.1	63.3
	NC 1-5k	92.7	85.4	75.7
	NC 5-15k	92.1	83.9	73.1
	NC 15k plus	93.0	86.0	76.8

Table 26: Trigger Point Values (ASP Longitudinal Lane Joint Cracking)

Distress	Family	Trigger Point_80	Trigger Point_60	Trigger Point_40
Longitudinal Lane Joint	Interstate 0-50k	91.6	70.5	39.5
	Interstate 50k plus	86.7	62.6	34.0
	US 0-5k	95.5	80.5	50.2
	US 5-15k	95.2	80.7	52.3
	US 15-30k	92.8	68.3	31.6
	US 30k plus	70.6	12.4	1.1
	NC 0-1k	97.4	90.3	73.7
	NC 1-5k	97.8	92.3	80.3
	NC 5-15k	97.4	90.7	76.2

	NC 15k plus	96.1	87.9	72.0

Table 27: Trigger Point Values (ASP Alligator Cracking)

Distress	Family	Trigger Point_80	Trigger Point_60	Trigger Point_40
Alligator	Interstate 0-50k	80.1	54.8	30.6
	Interstate 50k plus	52.8	15.1	3.4
	US 0-5k	81.8	58.1	34.0
	US 5-15k	83.2	64.4	43.8
	US 15-30k	80.0	55.7	32.3
	US 30k plus	80.0	55.7	32.3
	NC 0-1k	83.7	62.5	39.4
	NC 1-5k	82.9	61.7	39.2
	NC 5-15k	82.9	63.4	42.4
	NC 15k plus	85.2	68.9	50.0

Table 28: Trigger Point Values (ASP NWP Patching)

Distress	Family	Trigger Point_80	Trigger Point_60	Trigger Point_40
Patching - Non Wheel Path	Interstate 0-50k	80.0	38.3	11.2
	Interstate 50k plus	80.0	38.3	11.2
	US 0-5k	90.1	66.0	33.9
	US 5-15k	89.9	66.7	35.8
	US 15-30k	91.3	74.7	50.2
	US 30k plus	62.8	13.8	1.9
	NC 0-1k	93.6	78.7	53.7
	NC 1-5k	88.4	62.7	31.8
	NC 5-15k	88.3	65.3	36.8
	NC 15k plus	90.1	74.7	53.5

Table 29: Trigger Point Values (ASP WP Patching)

Distress	Family	Trigger Point_80	Trigger Point_60	Trigger Point_40
Patching - Wheel Path	Interstate 0-50k	78.3	35.2	9.7
	Interstate 50k plus	78.3	35.2	9.7
	US 0-5k	87.6	57.1	24.0
	US 5-15k	89.4	64.5	32.8
	US 15-30k	91.7	75.5	51.2
	US 30k plus	69.5	20.6	3.6
	NC 0-1k	91.7	72.9	44.5
	NC 1-5k	86.2	55.9	24.6

	NC 5-15k	87.8	62.2	32.1
	NC 15k plus	85.4	60.1	32.4

Table 30: Trigger Point Values (ASP Rutting)

Distress	Family	Trigger Point_80	Trigger Point_60	Trigger Point_40
Rutting	Interstate 0-50k	94.1	87.4	78.0
	Interstate 50k plus	94.1	87.4	78.0
	US 0-5k	93.3	85.1	73.5
	US 5-15k	94.1	87.6	78.5
	US 15-30k	95.5	90.9	84.7
	US 30k plus	95.5	90.9	84.7
	NC 0-1k	94.6	88.7	80.3
	NC 1-5k	92.6	84.7	74.1
	NC 5-15k	92.1	83.9	73.1
	NC 15k plus	93.3	88.1	81.8

Table 31: Trigger Point Values (ASP Decision Trees)

Distress	Trigger Point_80	Trigger Point_60	Trigger Point_40
Transverse Cracking	82	56	31
Longitudinal Cracking	89	77	62
Longitudinal Lane Joint	95	81	51
Alligator Cracking	82	60	37
Patching Area - Non Wheel Path	89	66	35
Patching Area - Wheel Path	87	59	28
Rutting	94	88	78
Median	89	66	37

Table 32: Trigger Point Values (JCP Decision Trees)

Distress	Trigger Point_80	Trigger Point_60	Trigger Point_40
Corner Breaks	84	53	22
Transverse Joint Spalling	92	87	80
Longitudinal Joint Spalling	86	74	61
Transverse Cracking	84	58	31
Longitudinal Cracking	79	55	32
Concrete Patching	91	66	31
Asphalt Patching	84	43	13
Joint Fault	86	70	50
Median	85	62	32

In Table 31 and Table 32, some Trigger Point_80 values are greater than 90 which is not reasonable. This was probably because the corresponding distresses do not commonly exist in ASP/JCP pavements, and most of their distress ratings are equal to or close to zero, which can affect the way distress curves deteriorate over time. One example is Rutting in ASP pavements. In this case, it is suggested that the corresponding median value of 89 is used.

CHAPTER 5 WEIGHT FACTORS FOR COST-BENEFIT ANALYSIS

Cost-Benefit Analysis (CBA) has been used by NCDOT to select candidate roadways for maintenance. The analysis process ensures that the overall budget is minimized, and meanwhile the total benefit of treatments is maximized. Weight factors of roadway classifications play an essential role in CBA. Currently NCDOT uses 2.0 for Interstate, 1.66 for US routes, 1.33 for NC routes, and 1.0 for Secondary routes. After new distress and performance models are developed, the existing weight factors should be adjusted to reflect the new deterioration trends.

Windshield data and previously developed distress and performance models were used to determine benefit weight factors in this study. It was initially proposed that weight factors should be determined after the newly developed models are loaded into the NCDOT PMS. However, these models could not be loaded due to technical constraints. After discussions with NCDOT engineers, it was decided to use the existing windshield pavement performance data and models to determine these weight factors. The process of determining weight factors includes four steps.

Step One: Determine Possible Weight Factors.

The purpose of this step is to determine independent variables (weight factors) that can be used for regression analysis, in which dependent variable, NCDOT rating numbers, were regressed against independent variable, weight factors. According to a previous study (Chen et al. 2013), after eliminating the multicollinearity issue, a total of 33 sets of possible weight factors were obtained (Table 33).

Table 33: Possible Weight Factors

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

Step Two: Perform Cost-Benefit Analysis (CBA).

After discussions with NCDOT engineers, four divisions, two urban and two rural, were selected for CBA. These four divisions are: Division 3, Division 5, Division 10, and Division 13. The following conditions were applied to all CBA scenarios:

- Analysis period: 5 years;
- Cost constraints: $ 40 million per year for each division.

The CBA results are included in Appendix H.

Step Three: Investigate the relationship between NCDOT rating numbers and weight factors.

A simple linear regression analysis was conducted to regress NCDOT rating numbers against weight factors. The resulting regression equations are:

For Interstate:

$$\text{NCDOT Rating NUMBER} = 0.736145 + 0.00267 * \text{Weight Factor} \quad (7)$$

FOR US:

$$\text{NCDOT Rating Number} = 0.744448 - 0.00091 * \text{Weight Factor} \quad (8)$$

For NC:

$$\text{NCDOT Rating Number} = 0.745913 - 0.00225 * \text{Weight Factor} \quad (9)$$

These three regression lines are included in Figure 11. Based on the importance of roadway classifications, the weight factor of Interstate (w_1) should be greater than the weight factor of US (w_2), which should be greater than the weight factor of NC (w_3), with the weight factor of SR as the smallest value of 1.0. A horizontal line (dashed line in Figure 11) can be moved vertically between intersections A (1.0950338, 0.7434485). and B (2.3173589, 0.7423327), then the x ordinates of intersections C, D. and E are a set of possible weight factors for Interstate, US, and NC. A total of 9 sets of possible weight factors are obtained and included in Table 34.

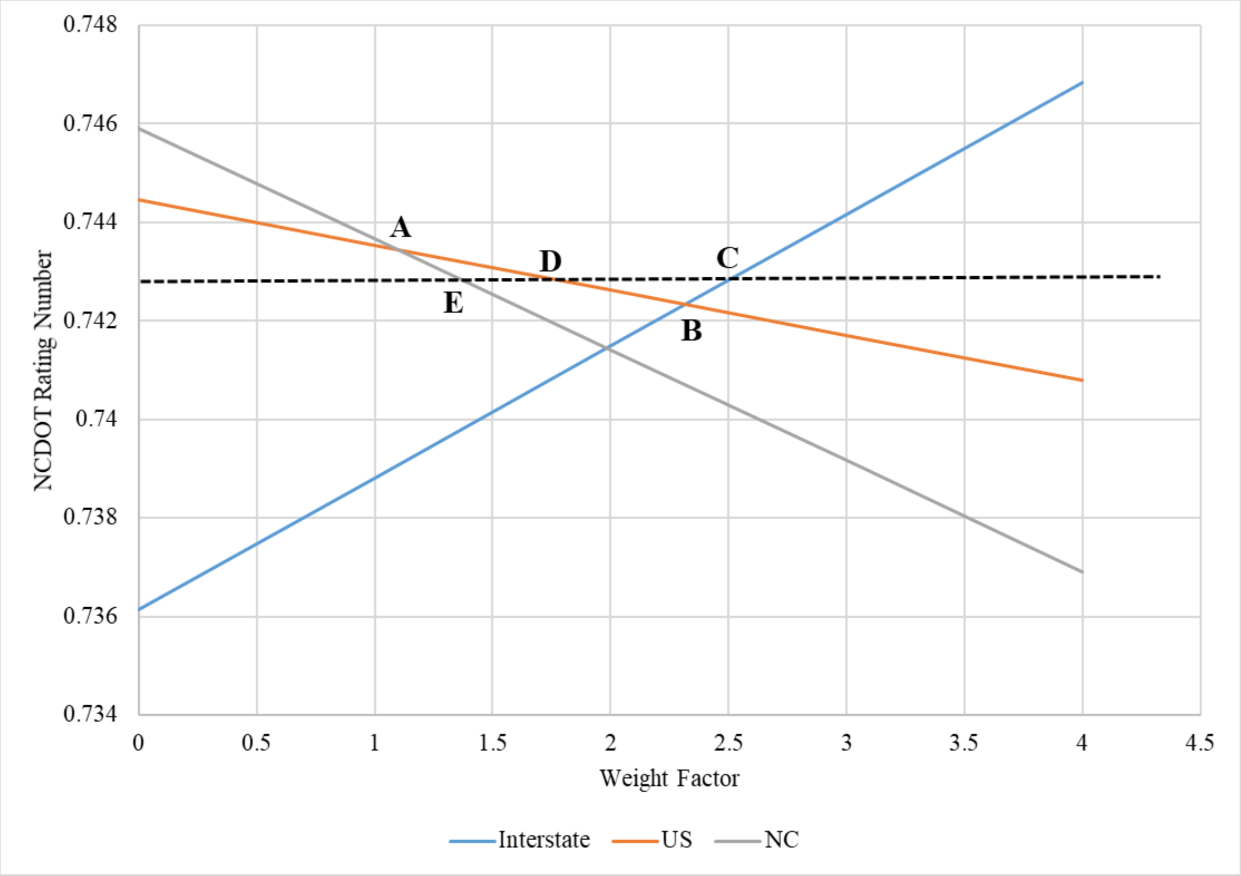

Figure 11: NCDOT Rating Number vs. Weight Factor

Table 34: Weight Factors for CBA

Weight Factor (Interstate)	Weight Factor (US)	Weight Factor (NC)	Weight Factor (SR)	Benefit	NCDOT rating number
2.38	2.13	1.51	1.00	378.848	0.742
2.42	2.02	1.47	1.00	378.970	0.744
2.45	1.92	1.43	1.00	379.042	0.744
2.49	1.81	1.38	1.00	378.926	0.744
2.53	1.74	1.34	1.00	378.582	0.744
2.57	1.59	1.29	1.00	378.972	0.746
2.60	1.74	1.25	1.00	375.860	0.746
2.64	1.45	1.21	1.00	378.294	0.746
2.68	1.26	1.16	1.00	379.320	0.746

Another round of CBA analysis was conducted using possible weight factors and results (Benefit and NCDOT rating number) are included in the last columns in Table 34 and Appendix I. Since the highest average NCDOT Rating Number and the largest average benefit value were produced by weight factors of 2.68 for Interstate, 1.26 for US, 1.16 for NC, and 1.0 for SR, this set of weight factors are selected as the final weight factors.

CHAPTER 6 FINDINGS AND CONCLUSIONS

Findings and conclusions of this study are as follows:

- The newly developed distress models can be implemented into the NCDOT PMS with preliminary trigger points determined in this study.
- MAE input values are essential in obtaining correct distress index values. Percentiles of distress index values and input from NCDOT engineers are the key information to derive appropriate MAE input values.
- Collecting importance scores of JCP distresses from NCDOT engineers and researchers is an imperative step in calculating PCR values of JCP pavements. The scores are accurate as attested by the robustness of JCP models.
- For ASP pavements, newly developed PCR curves are visually comparable to PCR curves developed using manual data. The comparison curves are included in Appendix D.
- A new set of Weight factors were determined by performing CBA analysis and statistical regression. Conditions for CBA analysis are: a 5-year analysis period, two urban divisions (Divisions 5 and 10) and two rural divisions (Divisions 3 and 13), and a $ 40 million budget each year for each division.
- Automated pavement performance data still need to be cleaned. Outliers are observed in the lower left region and the top region of distress scatter plots. Minimal number of outliers in these two regions were removed in order to save more data that can be used to develop the distress and performance models.
- A significant number of performance data was not used due to the short data history. Pavement age was not reset in this study. The reason was that only three years of performance data have been collected, which does not satisfy the minimal data requirement of the three-point method (Chen et al. 2013) – more than three consecutive performance ratings for each roadway section. Performance data collected from pavement sections whose age is greater than 13 were not used. This can negatively impact the prediction of future pavement performance, especially when treatment effectiveness is the focus of study.
- Family curves of some distresses are close to each other, indicating there is a need to combine these families into one family. This probably means that AADT breakpoints for subdividing families should be adjusted.

CHAPTER 7 RECOMMENDATIONS

Recommendations for further avenues of research are:

- Pretreatment condition can have significantly impact on treatment performance. It is recommended to include pretreatment condition as a grouping factor when develop performance models. For example, the Interstate 0-50k family can be divided into three sub-families based on Good/Fair/Poor pretreatment condition: Interstate 0-50k/Good, Interstate 0-50k/Fair, and Interstate 0-50k/Poor, and three family models can be developed to more accurately predict pavement performance.
- More advanced image recognition techniques are recommended to be used to improve the quality of raw performance data. One such technique is deep learning, which has proven to be superior to traditional computer vision algorithms and if trained appropriately can improve the quality over time.
- To transition the NCDOT PMS to full-use of automated data, the following tasks are recommended:

  Step 1. Redefining roadway families by adjusting AADT breakpoints for more consistent performance within families.

  Step 2. Developing new distress and performance models once more automated data become available.

  Step 3. Loading automated data and newly developed models (Step 2) into the NCDOT PMS.

  Step 4. Determining a new set of benefit weight factors using cost-benefit analysis (CBA).

CHAPTER 8 IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

The outcomes of this study will be disseminated through the following venues:

- Implement the distress models into the PMS with preliminary trigger point values determined in this study.
- Providing project deliverables. Project deliverables, in both hard copy and digital format, as described in the “Anticipated Research Products” section of this proposal, will be provided to NCDOT.
- Generating research publications. Research findings will be published in peer reviewed journals, such as Transportation Research Record (TRR) and ASCE journals.
- Presenting at national/international professional conferences, for example, TRB annual conference and ASCE conferences.
- Transferring the technology to NCDOT. Short course or demonstrations can be provided to NCDOT personnel regarding approaches of developing models, deriving trigger points, and calculating weight factors.
- Integrating research findings into engineering courses at UNC Charlotte. In the past three years, the PI has integrated the methodologies and findings of previous NCDOT studies into a senior level undergraduate course entitled “Highway Design and Construction”. This integration resulted in increased interest in working in the transportation industry, and increased participation in transportation related research among undergraduate students. The PI will continue this holistic approach in this study.

CITED REFERENCES

American Association of State Highway and Transportation Officials (AASHTO). (2001). Pavement Management Guide. Washington, D.C.

Chen, D., Cavalline, T., Ogunro, V., Thompson, D. (2013). *Development and Validation of Pavement Deterioration Models and Analysis Weight Factors for the NCDOT Pavement Management System: Phase 1,* North Carolina Department of Transportation, Raliegh, NC

Forman, E. H., and Gass, S. I. (2001). "The analytical hierarchy process-An exposition."

Ganesan, V. P. K., Stoffels, S.M., Arellano, J., and Morian, D.A. (2006). "Improving Pavements with Long-Term Pavement Performance: Products for Today and Tomorrow", *Use of LTPP Data to Verify the Acceptance Limits Developed for PennDOT Pavement Distress Data*. No. 01036914. Federal Highway Administration, Washington, DC.

Groeger, J.L., P. Stephanos, P. Dorsey, and M. Chapman (2003). *Implementation of Automated Network Level Crack Detection Processes in the State of Maryland*, Transportation Research Board.

MacLeod, D. (2008). "Establishment of Network Trigger Values for Pavement Management Rehabilitation", *7th International Conference on Managing Pavement Assets,* June 23-28, 2008, in Calgary, Alberta, Canada.

Mastin, N. (2011). *NCDOT Digital Imagery Distress Evaluation Handbook,* North Carolina Department of Transportation, Raleigh, North Carolina.

McGhee, K. (2004). "NCHRP Synthesis 334: Automated Pavement Distress Collection Techniques" National Cooperative Highway Research Program, Transportation Research Board.

North Carolina Department of Transportation (2010). "Performance Dashboard Documentation", *Definitions, Rationale and Supporting Information for the Performance Dashboard,* www.ncdot.gov/performance.

Saaty, T. (1977). "A Scaling Method for Priorities in Hierarchical Structures", Journal of Mathematical Psychology 15 (3), 234-281

Sun, L. and Gu, W. (2011). *Pavement Condition Assessment Using Fuzzy Logic Theory and Analytic Hierarchy Process,* American Society of Civil Engineers, DOI: 10.1061/(ASCE)

Sun, L., and Greenberg, B. S. (2006). "Multicriteria group decision making: Optimal priority synthesis from pairwise comparisons." J. Optim.Theory Appl., 130(2).

Timm, D. and McQueen, J. (2004). *A Study of Manual vs. Automated Pavement Condition Surveys,* Highway Research Center, Harbert Engineering Center, Auburn University, Alabama.

Transportation Research Board Pavement Management Section (2007). “Transportation Research Circular”, *Pavement Lesons Learned from the AASHO Road Test and Performance of the Interstate Highway System.* No. E-C118. Transportation Research Board, TRB, Washington, DC.

Triantaphyllou, E., and Mann, S. (1995). “Using the Analytic Hierarchy Process for Decision Making in Engineering Applications: Some Challenges”, *International Journal of Industrial Engineering Applications and Practice*, 2(1), 35-44.

Wang, K.C.P., Nunn, C., Mackey, C., Gong, W., Wilson, D., Evans, M., and Daleiden, J. (2003). *Network Level Crack Survey with the Automated Real-Time Distress Analyzer*, Transportation Research Board.

Appendix A – Scatter Plots and Box Plots of Raw Data

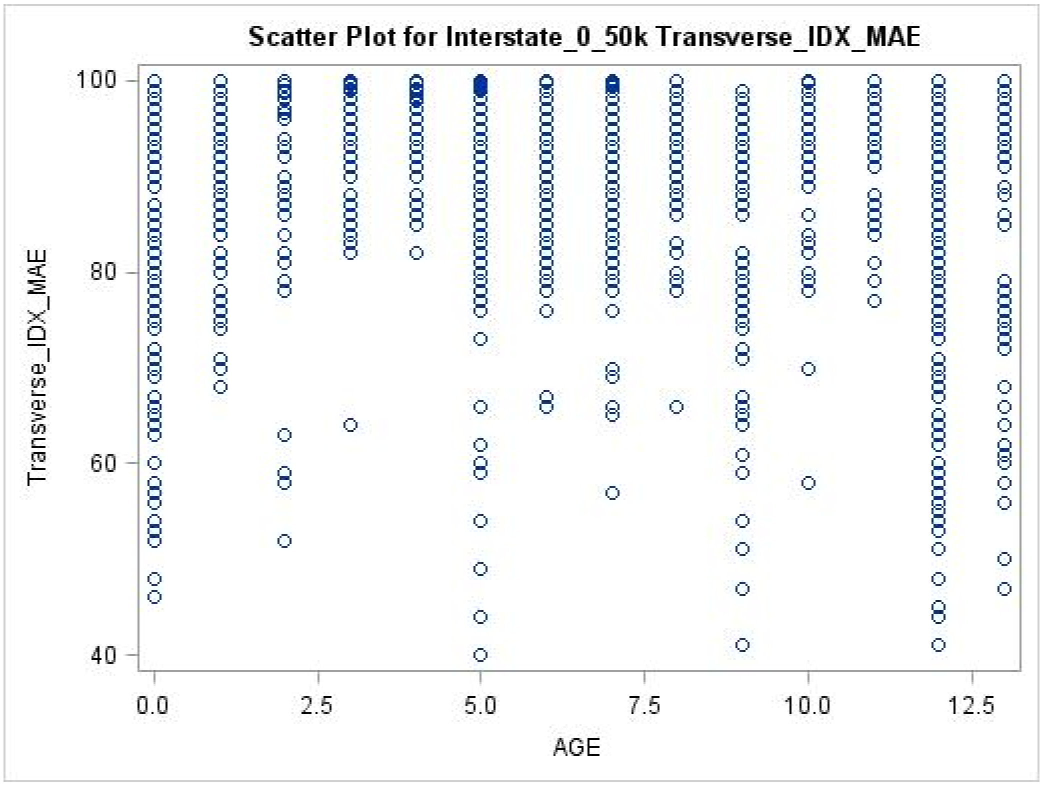

Figure 1: Scatter Plot for Interstate_0_50k Transverse_IDX_MAE

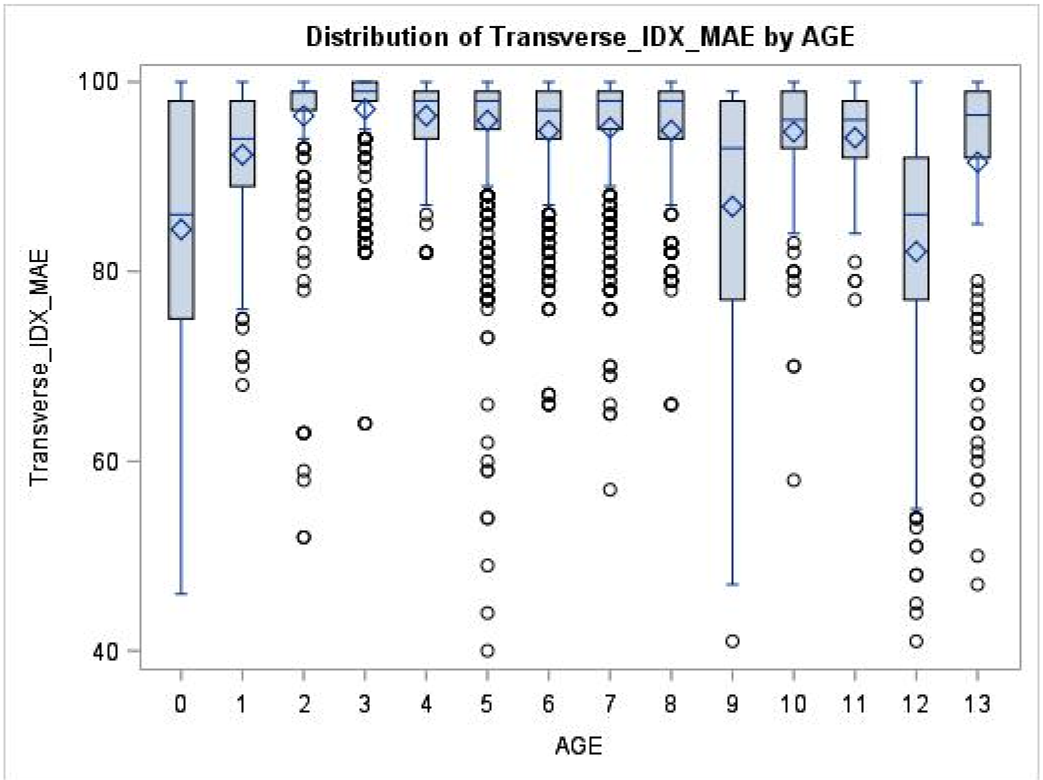

Figure 2: Schematic Box Plot for Interstate_0_50k Transverse_IDX_MAE

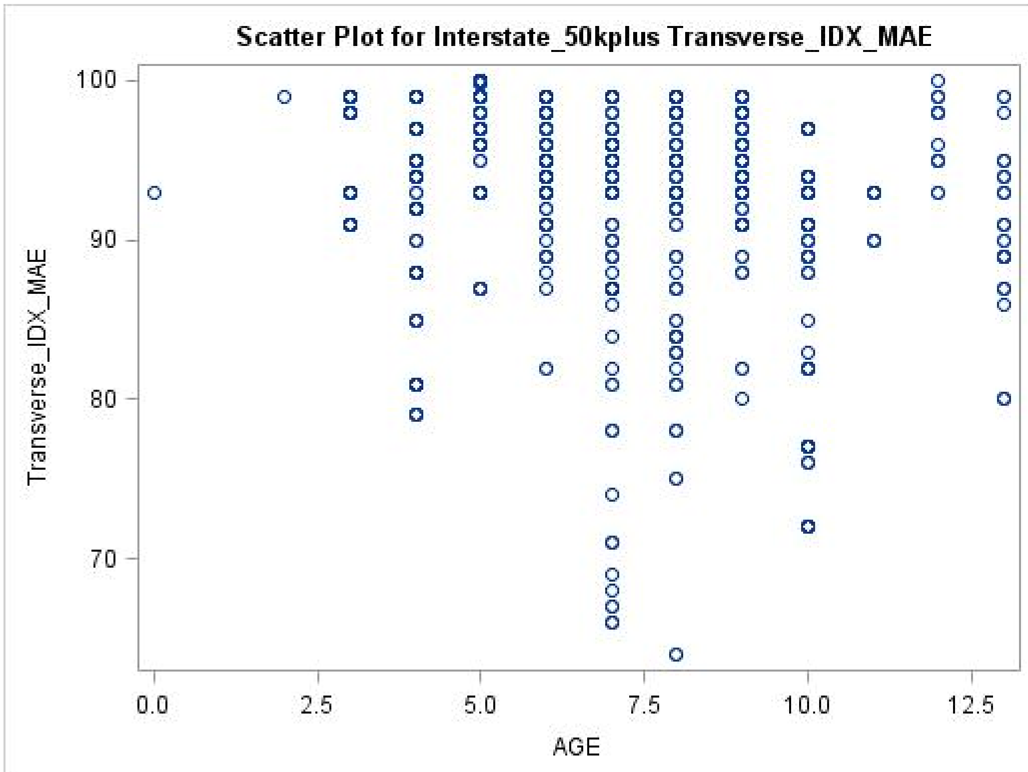

Figure 3: Scatter Plot for Interstate_0_50k Transverse_IDX_MAE

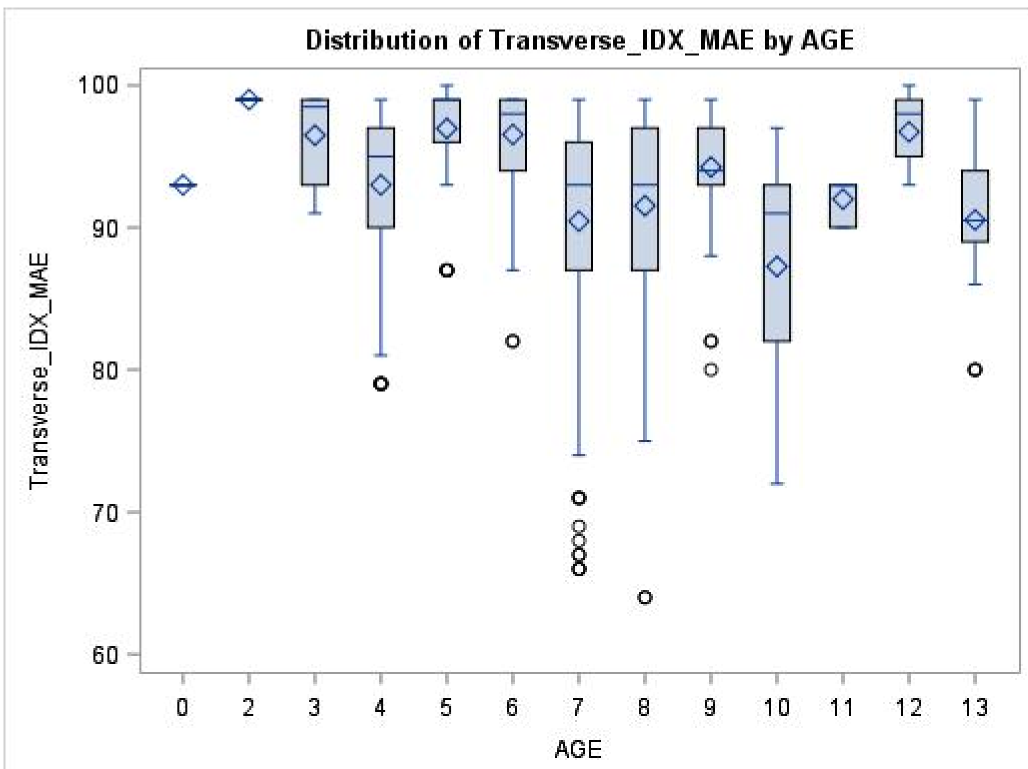

Figure 4: Schematic Box Plot for Interstate_50kplus Transverse_IDX_MAE

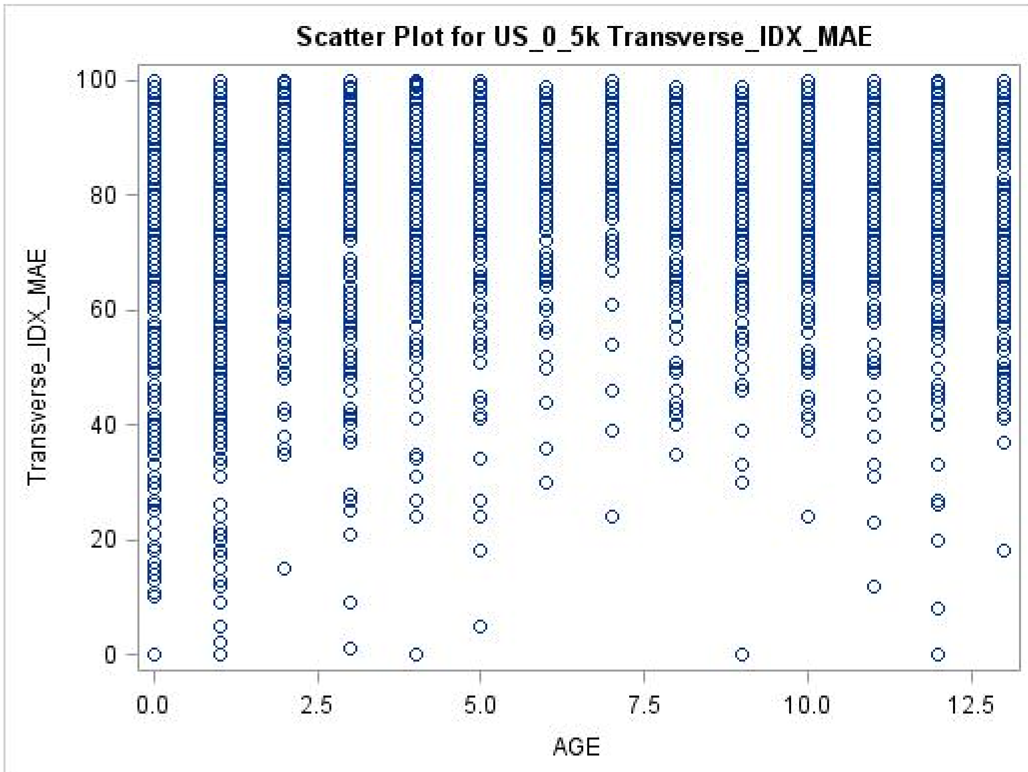

Figure 5: Scatter Plot for US _0_5k Transverse_IDX_MAE

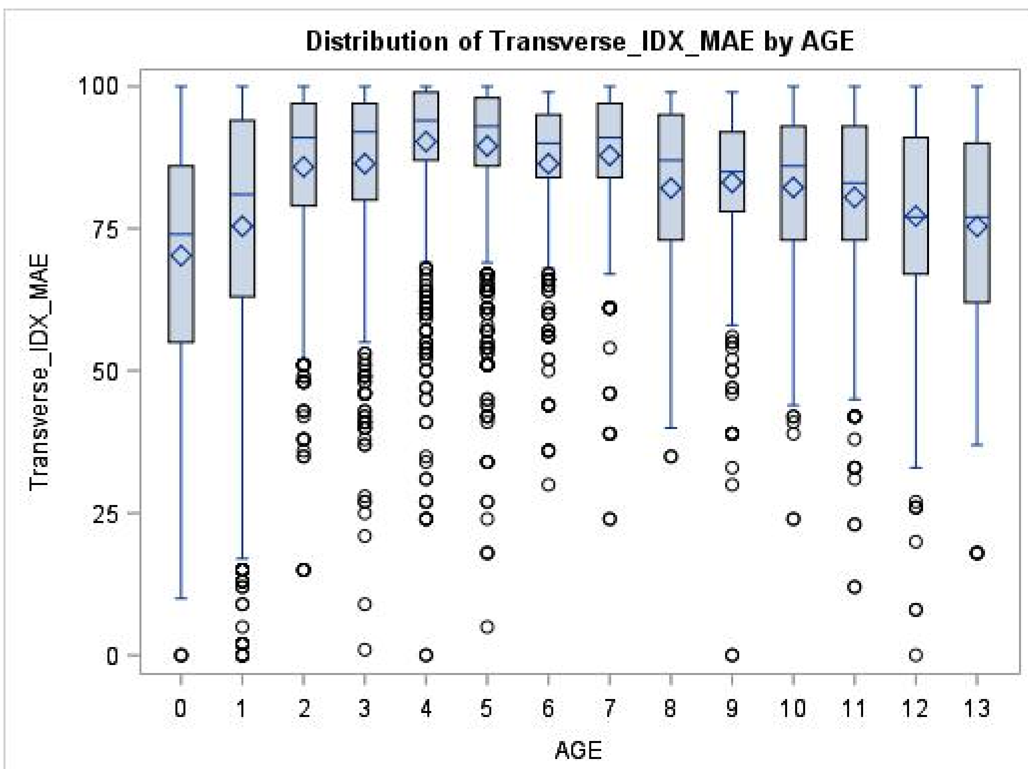

Figure 6: Schematic Box Plot for US_0_5k Transverse_IDX_MAE

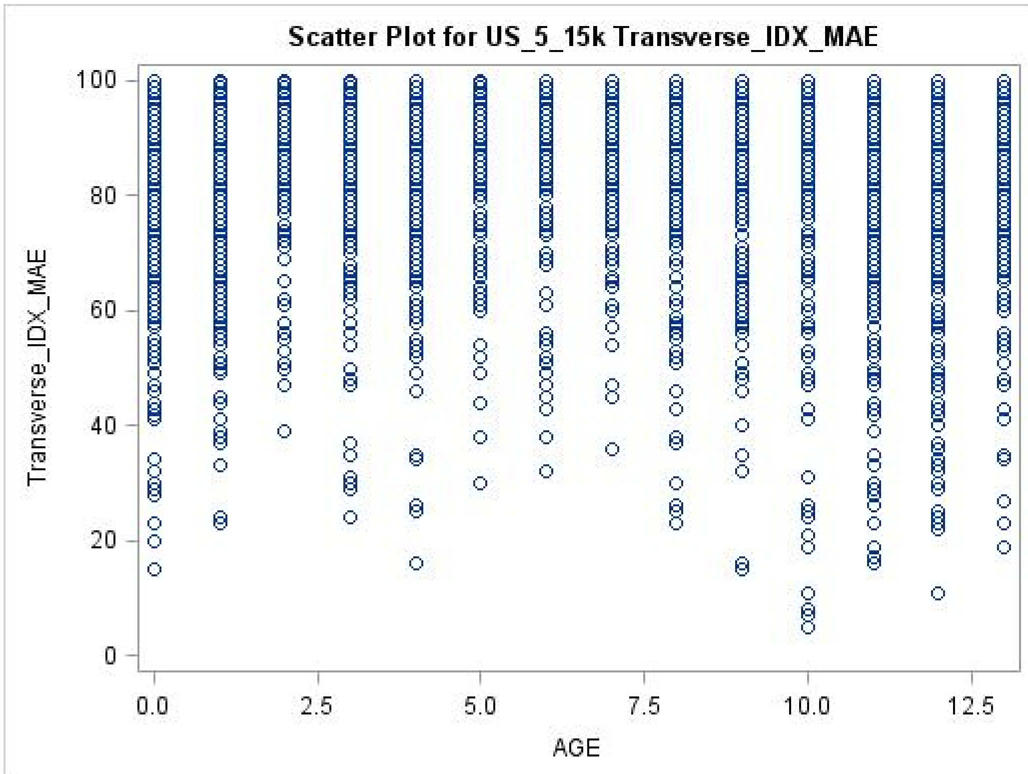

Figure 7: Scatter Plot for US _5_15k Transverse_IDX_MAE

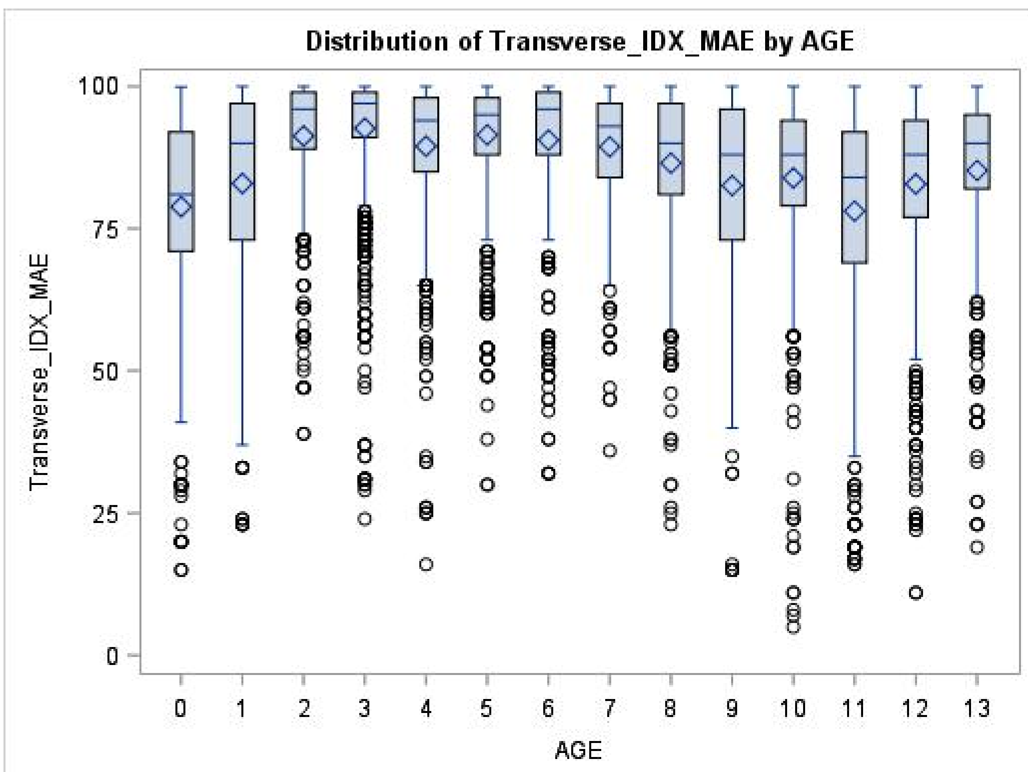

Figure 8: Schematic Box Plot for US_5_15k Transverse_IDX_MAE

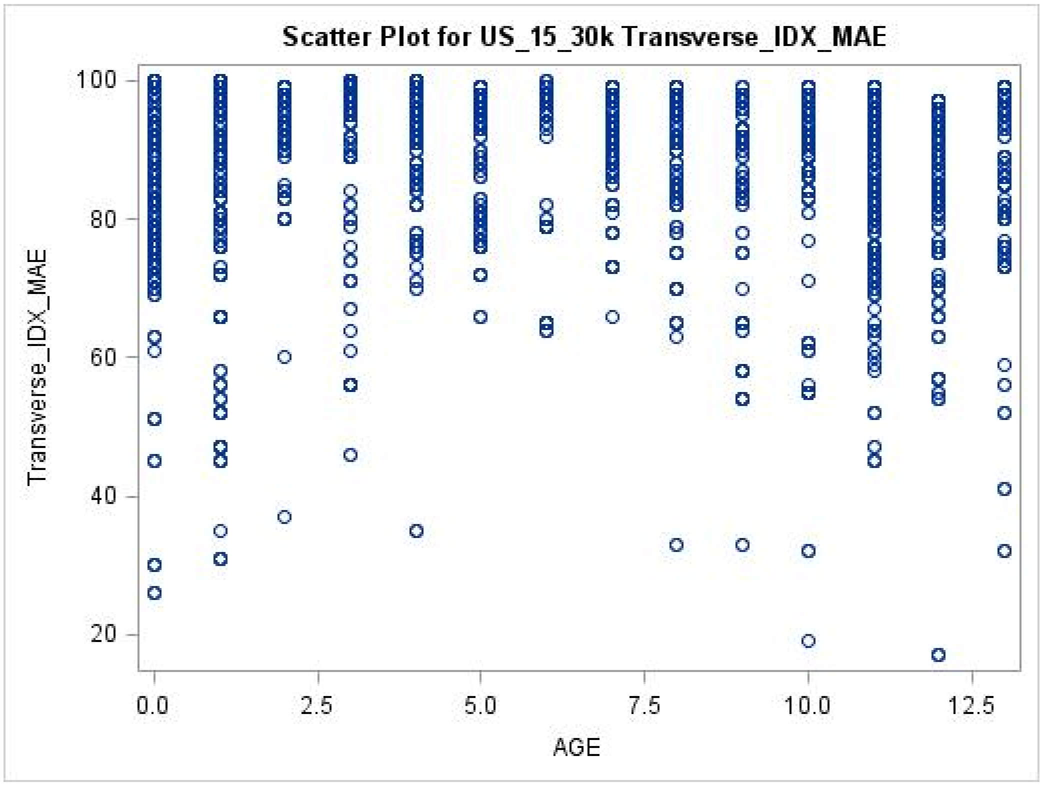

Figure 9: Scatter Plot for US_15_30k Transverse_IDX_MAE

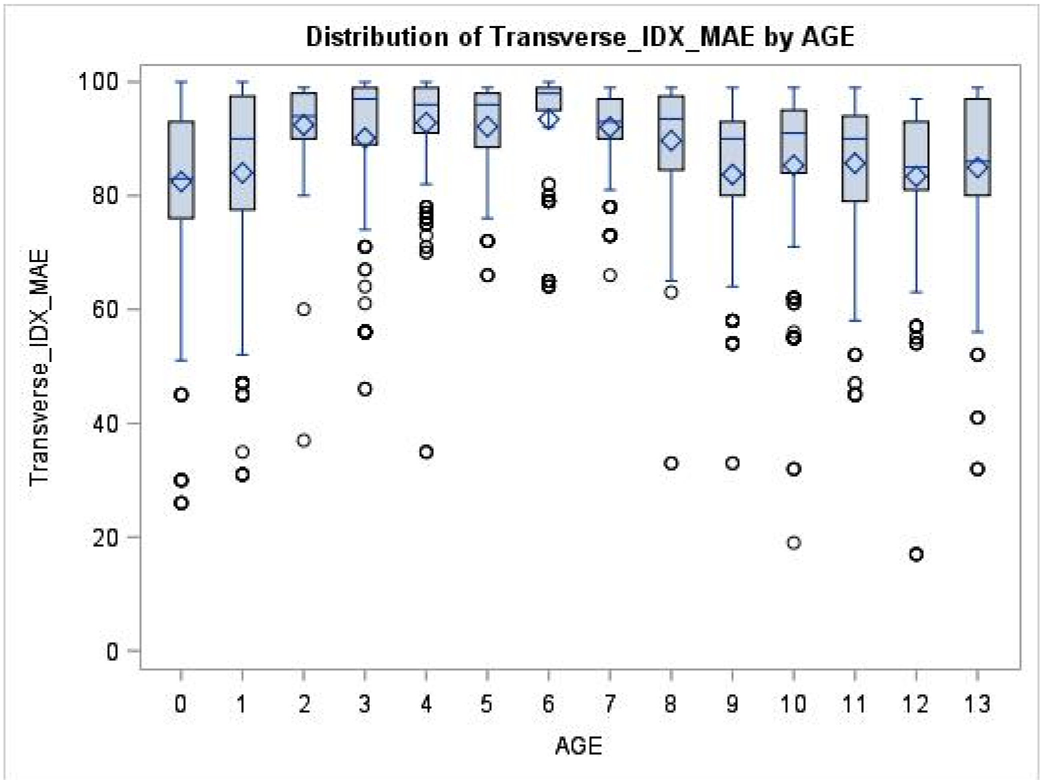

Figure 10: Schematic Box Plot for US_15_30k Transverse_IDX_MAE

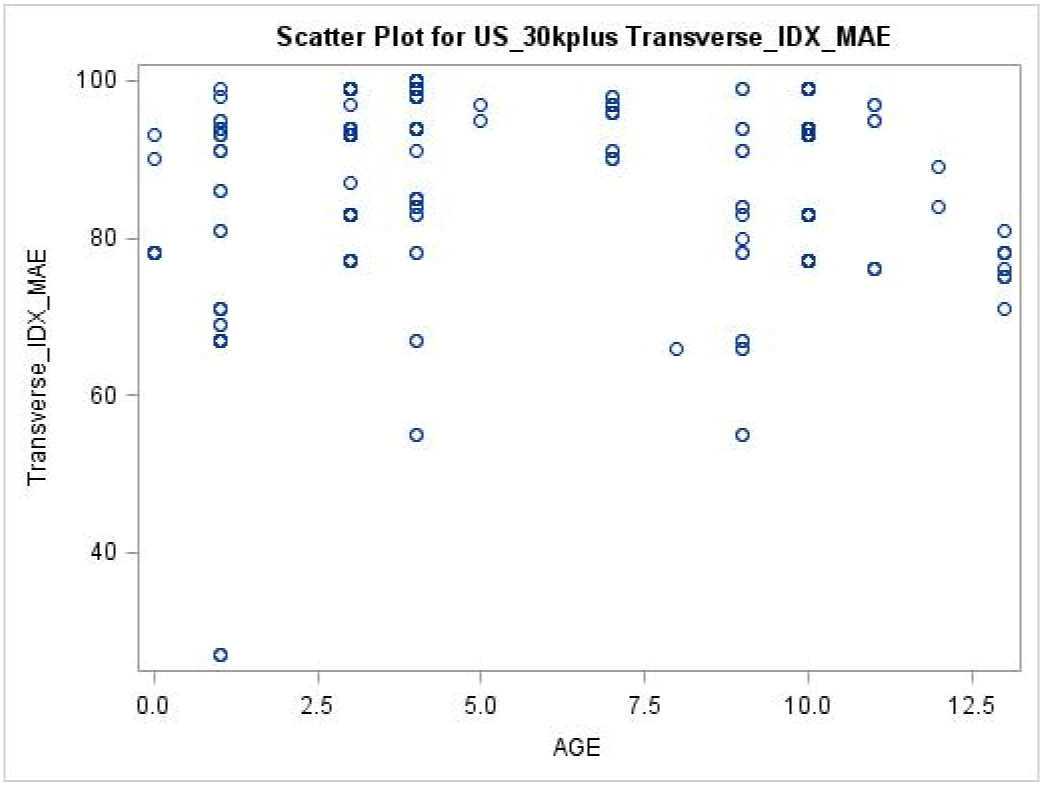

Figure 11: Scatter Plot for US_30kplus Transverse_IDX_MAE

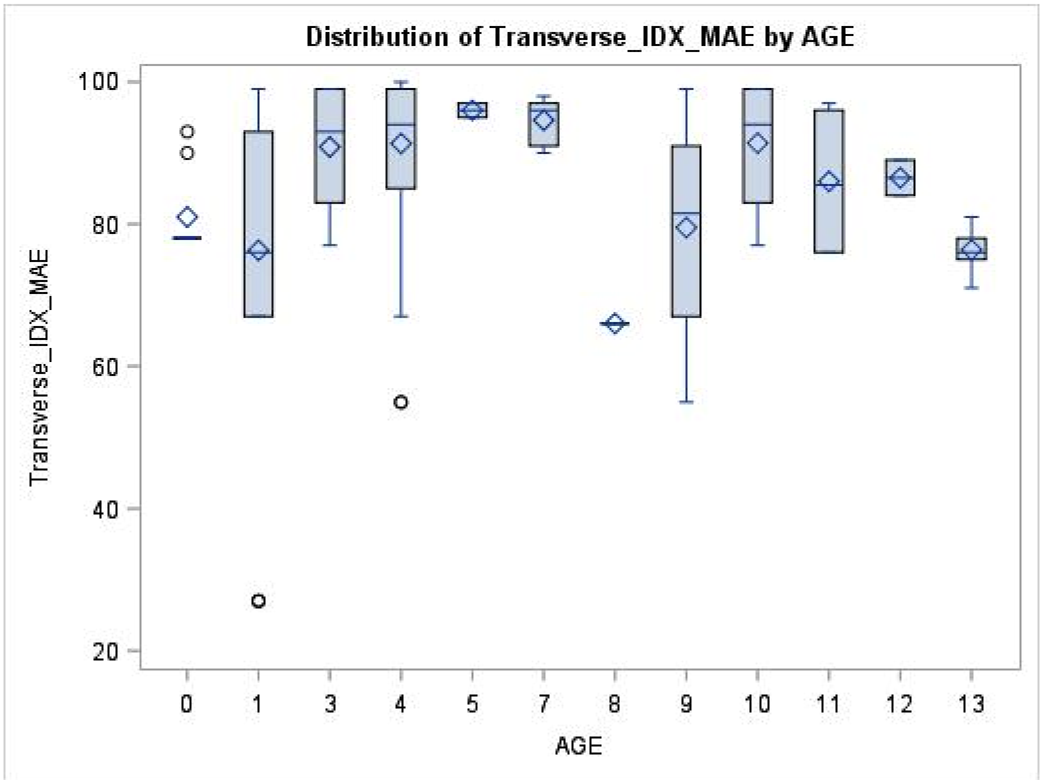

Figure 12: Schematic Box Plot for US_30kplus Transverse_IDX_MAE

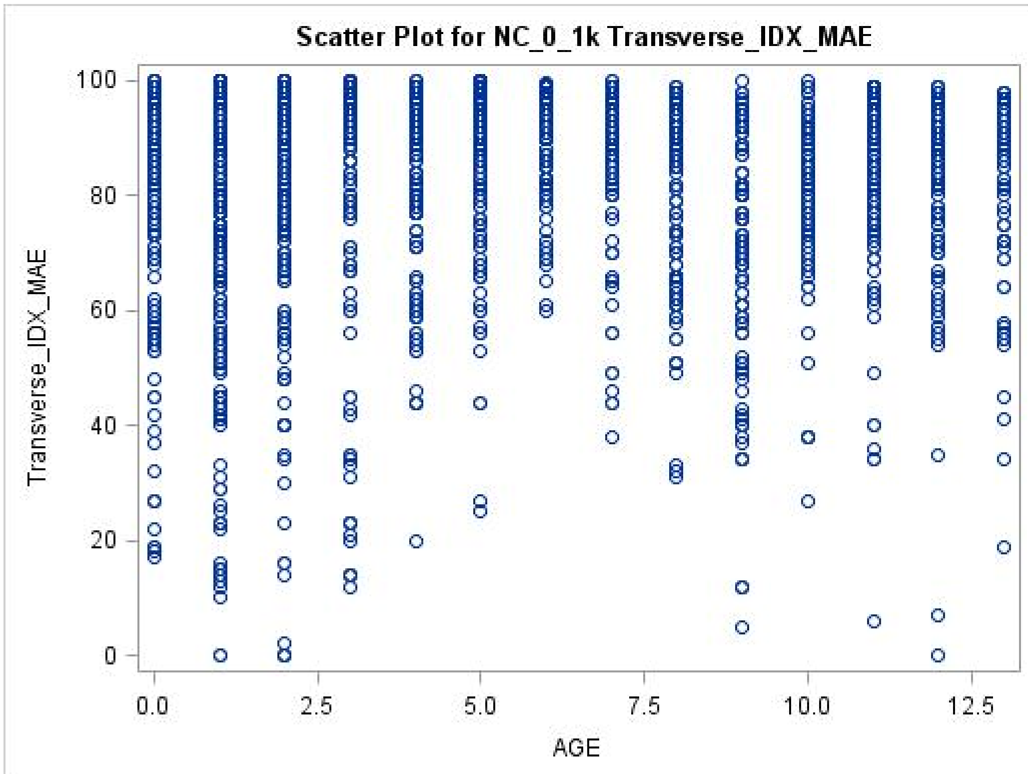

Figure 13: Scatter Plot for NC_0_1k Transverse_IDX_MAE

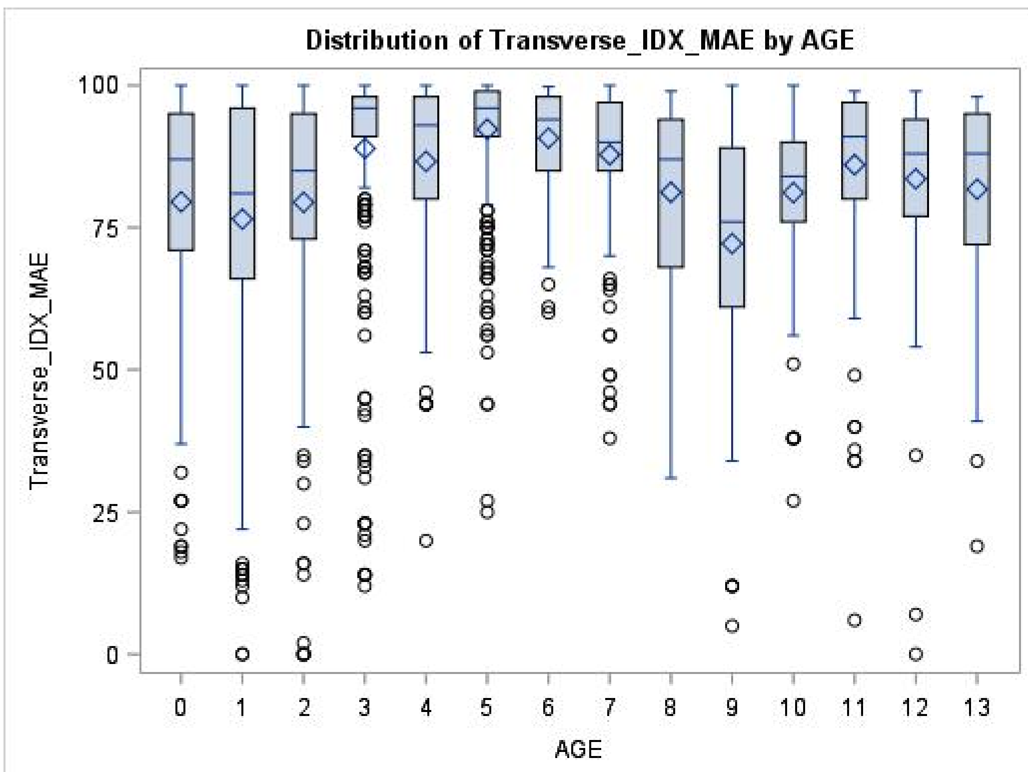

Figure 14: Schematic Box Plot for NC_0_1k Transverse_IDX_MAE

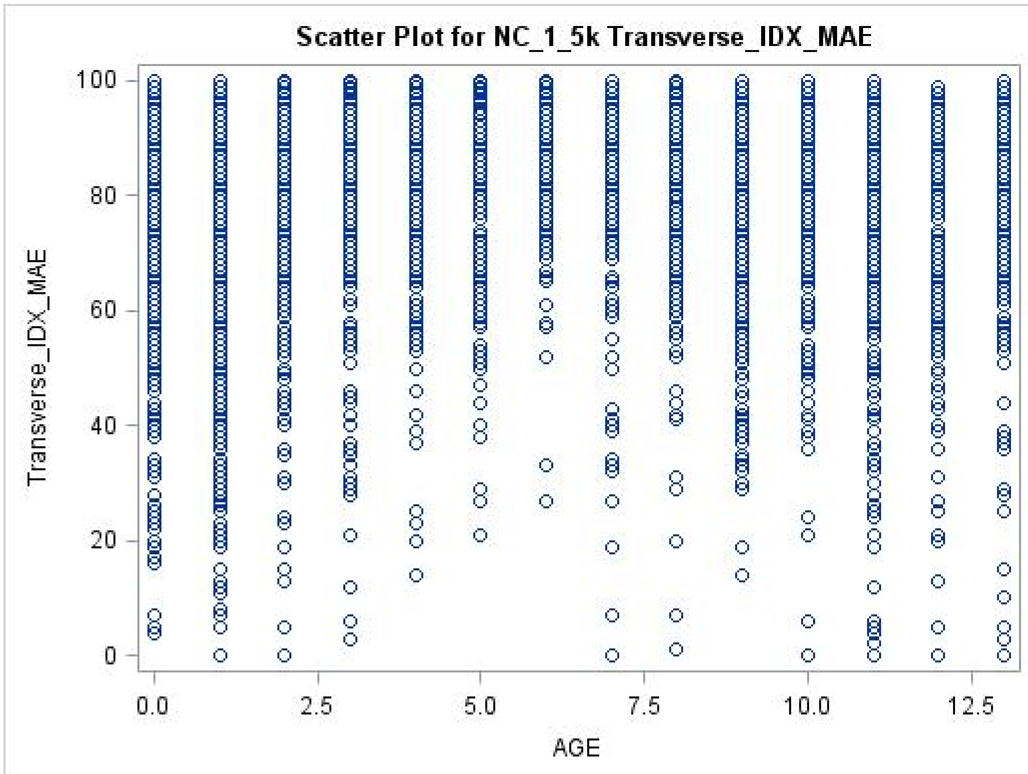

Figure 15: Scatter Plot for NC_1_5k Transverse_IDX_MAE

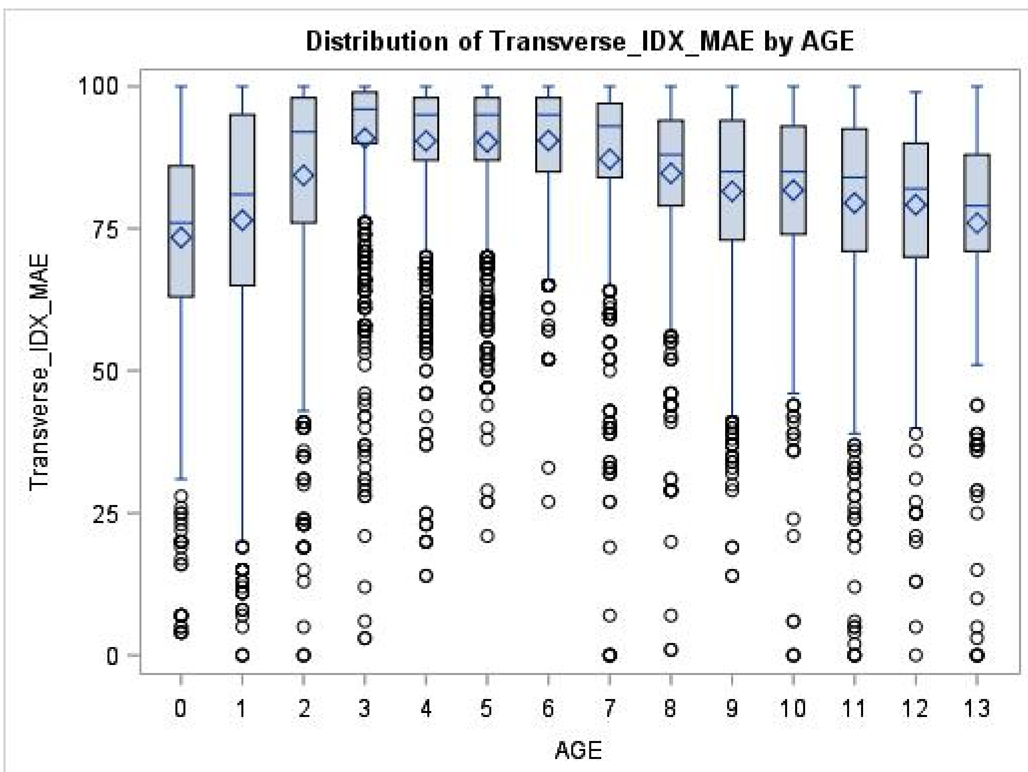

Figure 16: Schematic Box Plot for NC_1_5k Transverse_IDX_MAE

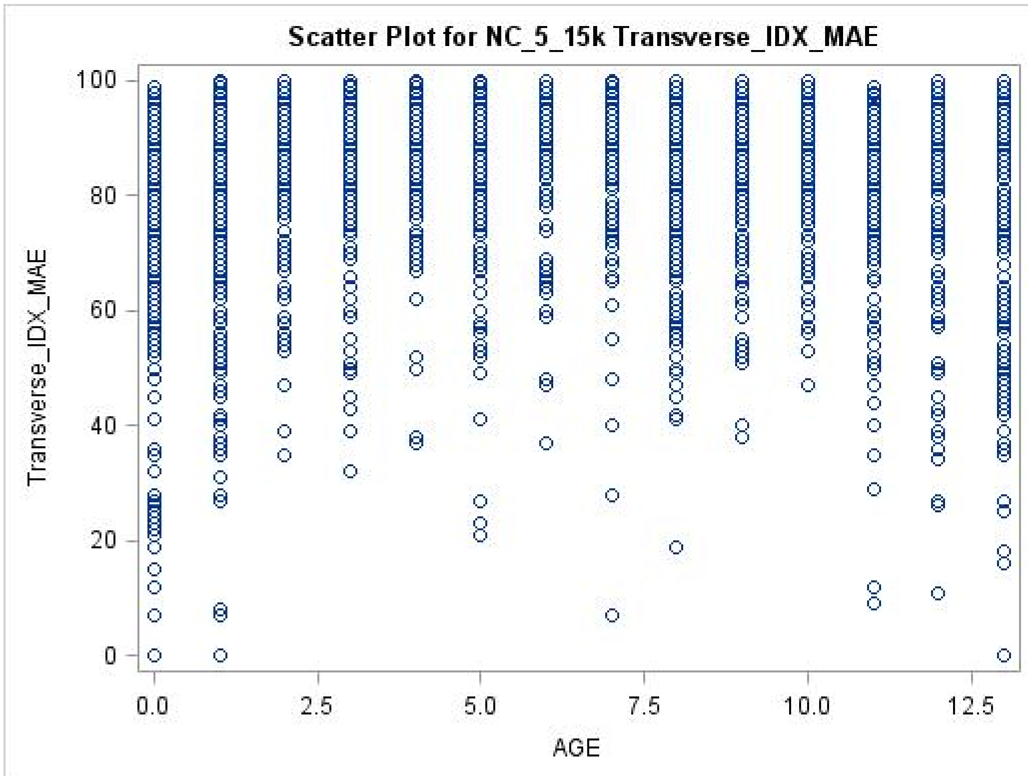

Figure 17: Scatter Plot for NC_5_15k Transverse_IDX_MAE

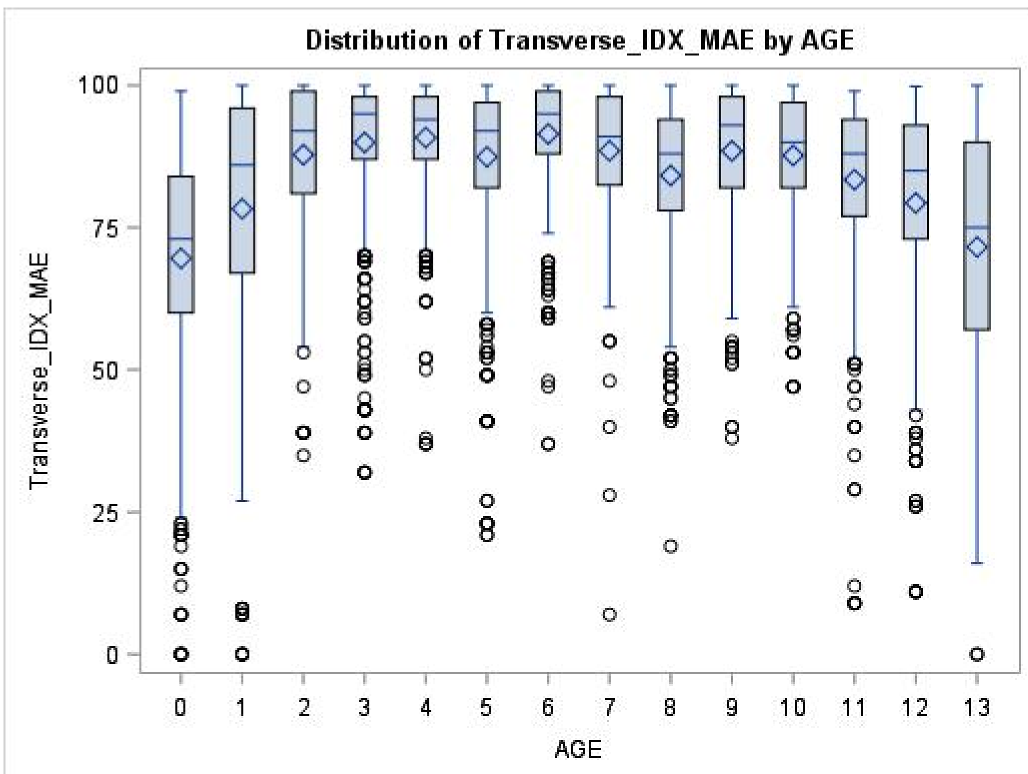

Figure 18: Schematic Box Plot for NC_5_15k Transverse_IDX_MAE

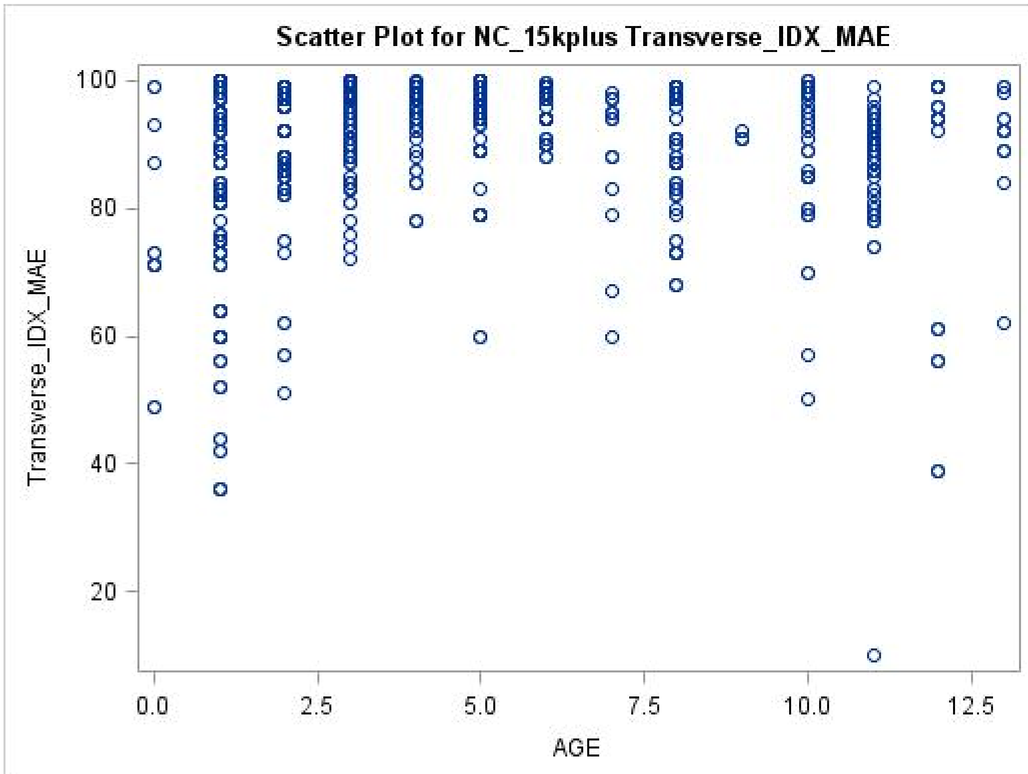

Figure 19: Scatter Plot for NC_15kplus Transverse_IDX_MAE

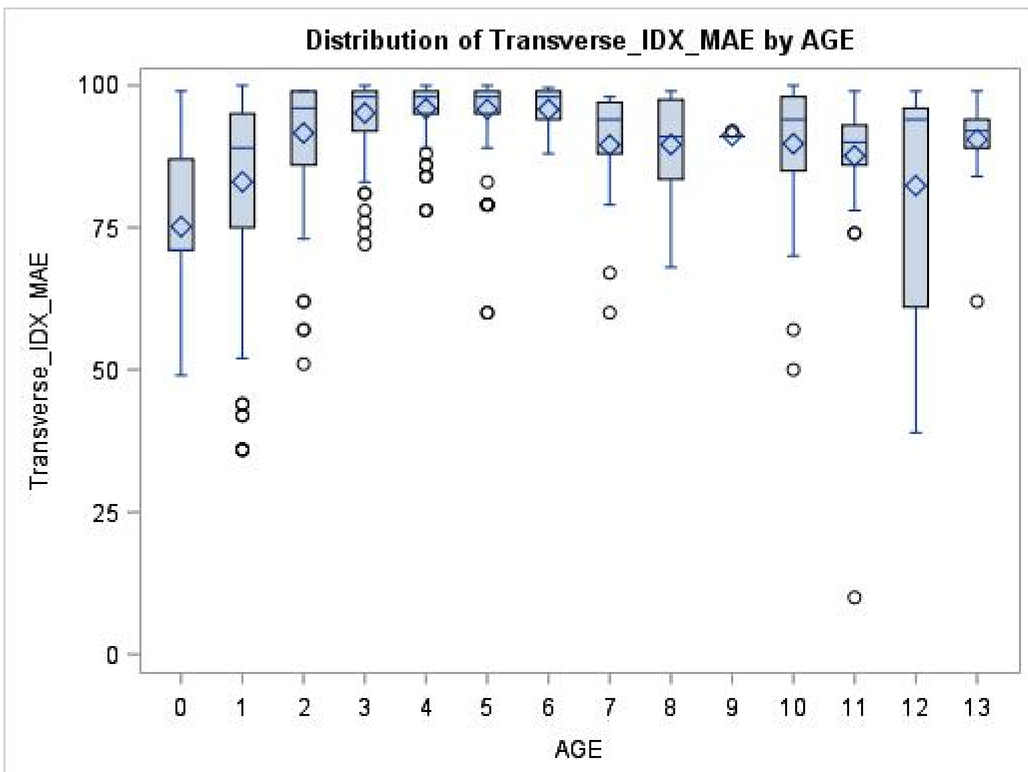

Figure 20: Schematic Box Plot for NC_15kplus Transverse_IDX_MAE

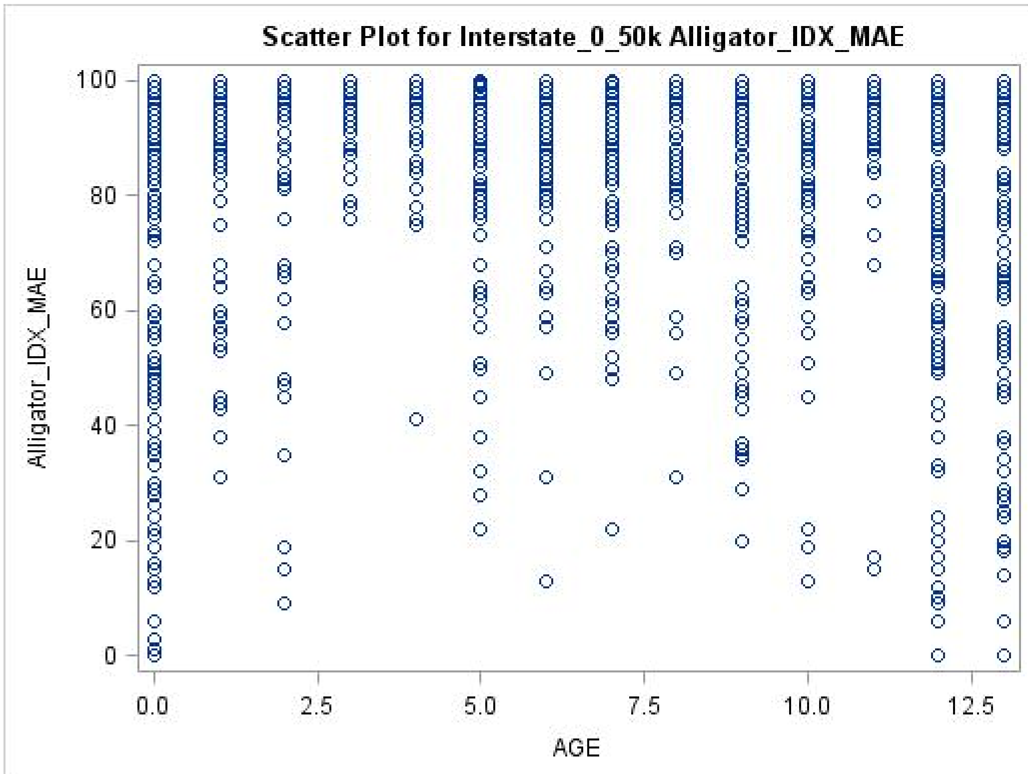

Figure 21: Scatter Plot for Interstate_0_50k Alligator_IDX_MAE

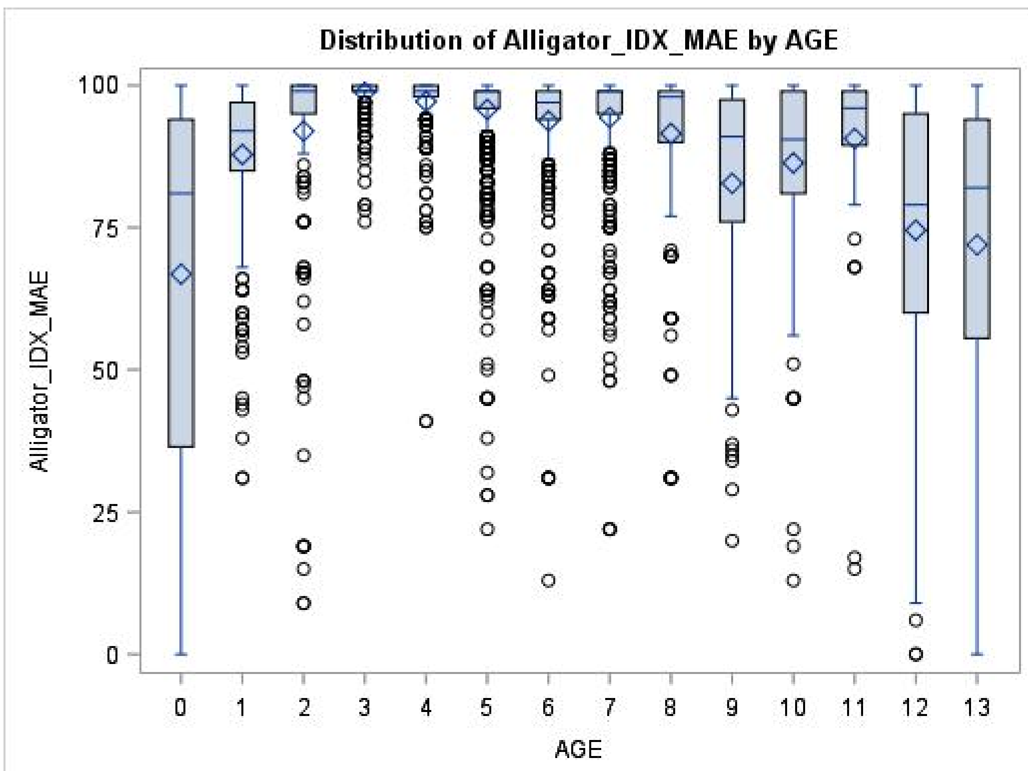

Figure 22: Schematic Box Plot for Interstate_0_50k Alligator_IDX_MAE

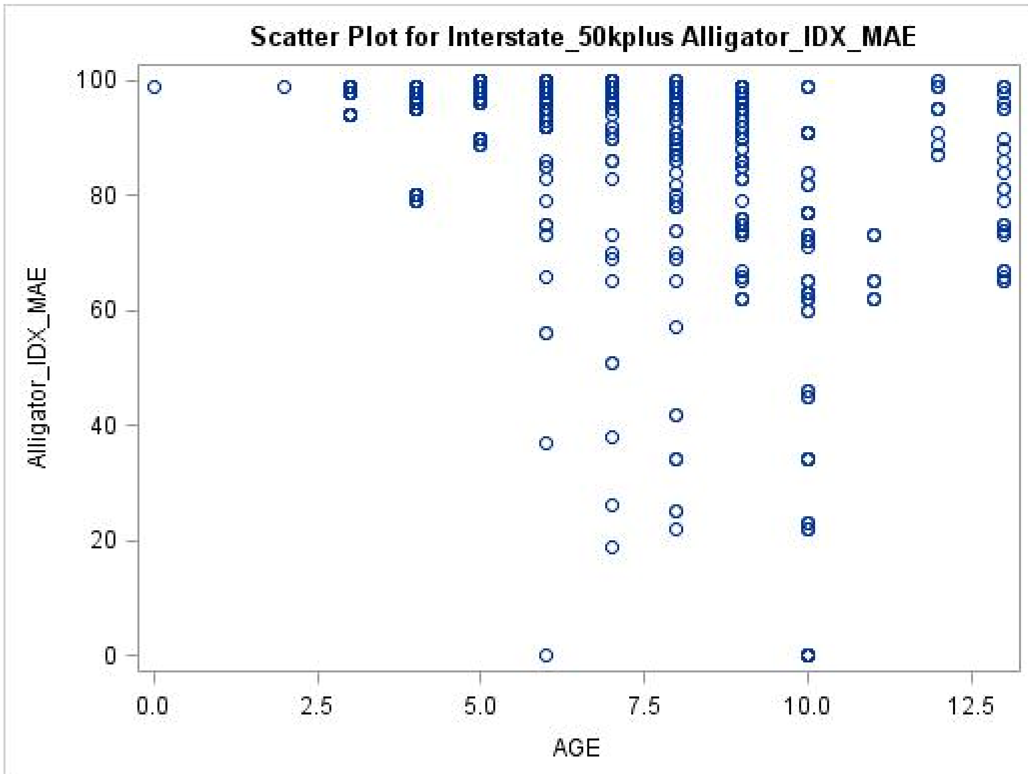

Figure 23: Scatter Plot for Interstate_50kplus Alligator_IDX_MAE

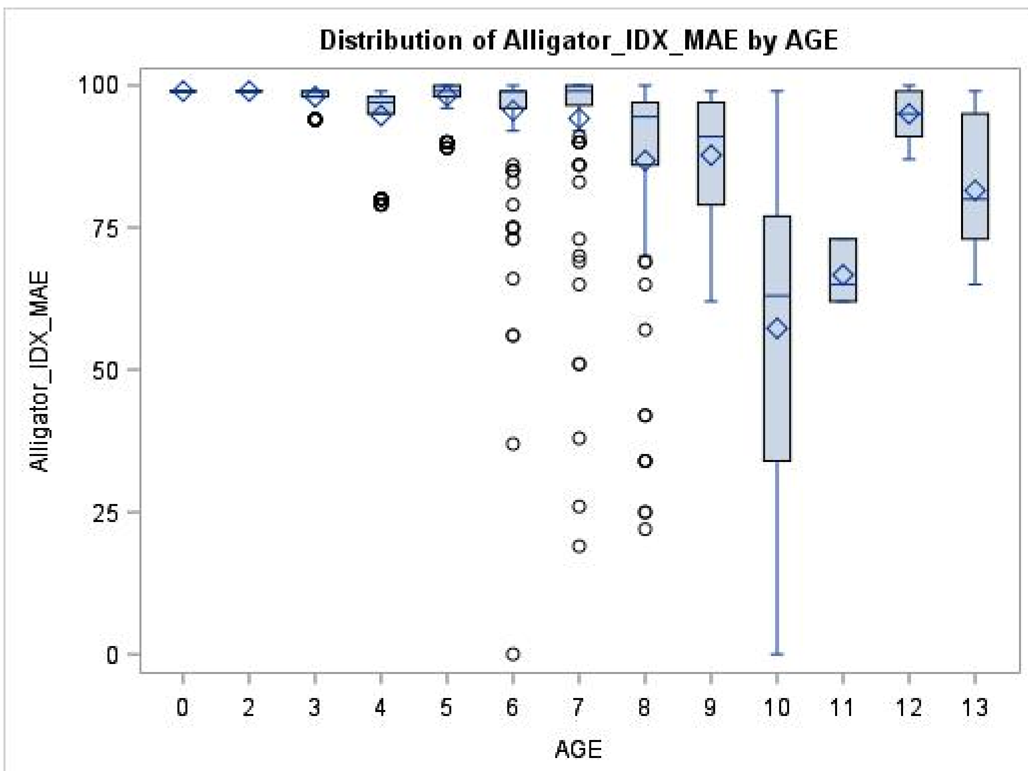

Figure 24: Schematic Box Plot for Interstate_50kplus Alligator_IDX_MAE

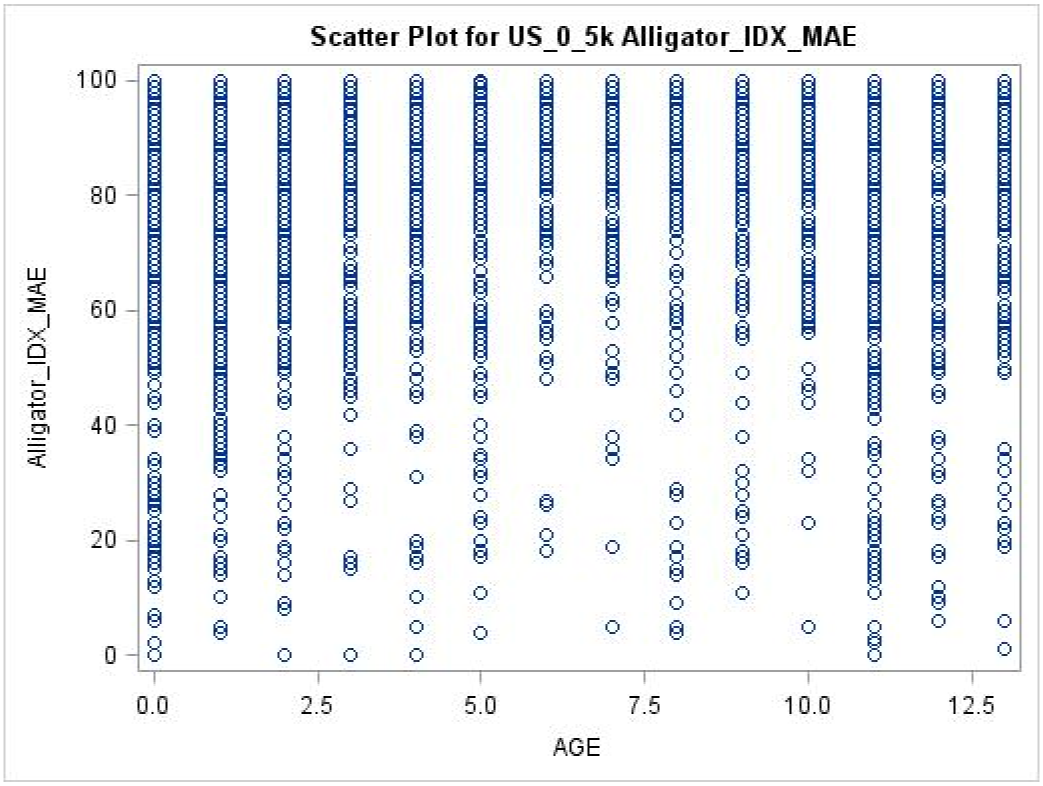

Figure 25: Scatter Plot for US_0_5k Alligator_IDX_MAE

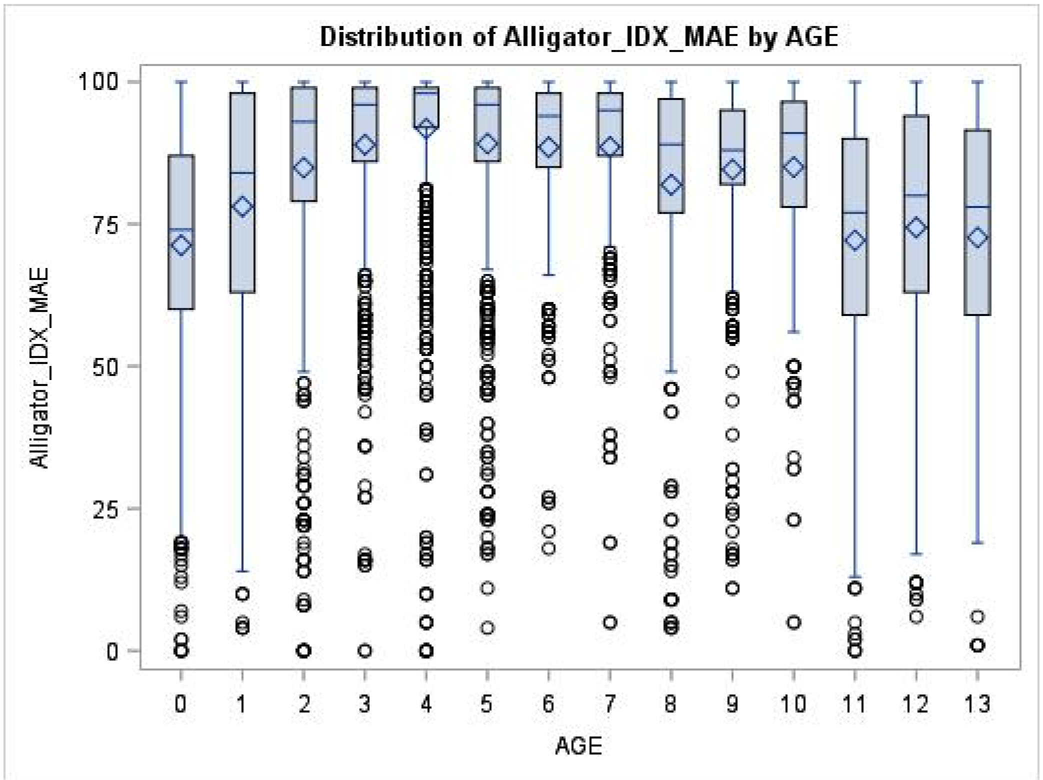

Figure 26: Schematic Box Plot for US_0_5k Alligator_IDX_MAE

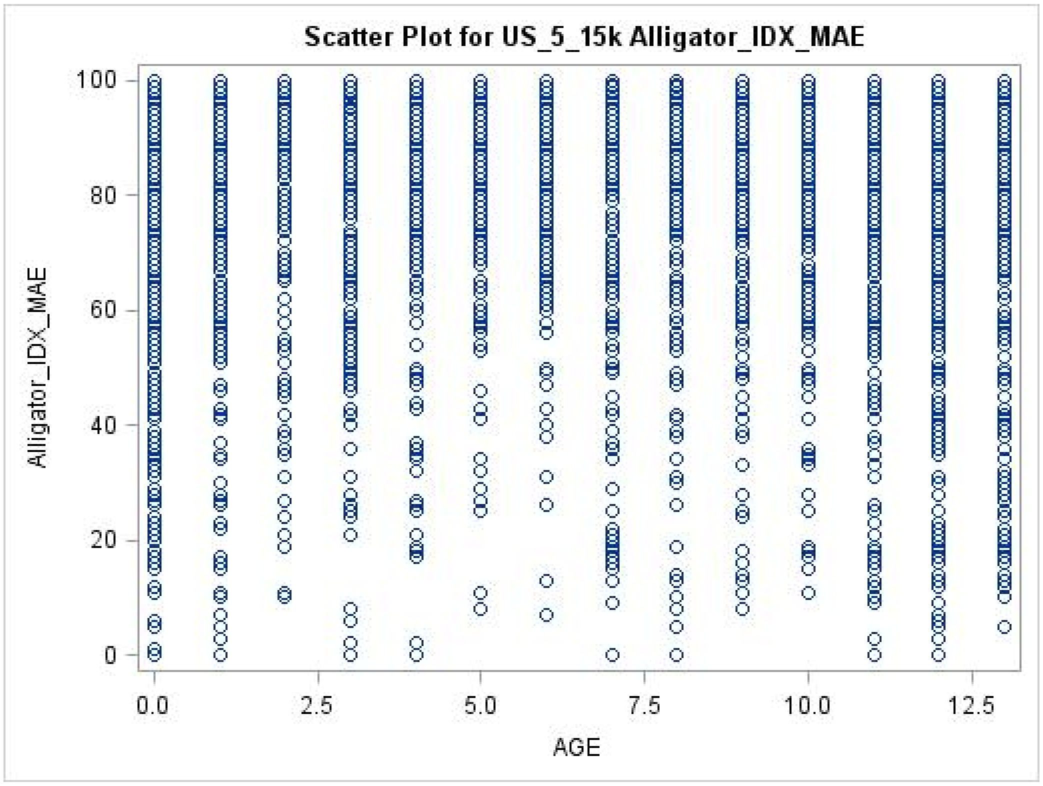

Figure 27: Scatter Plot for US_5_15k Alligator_IDX_MAE

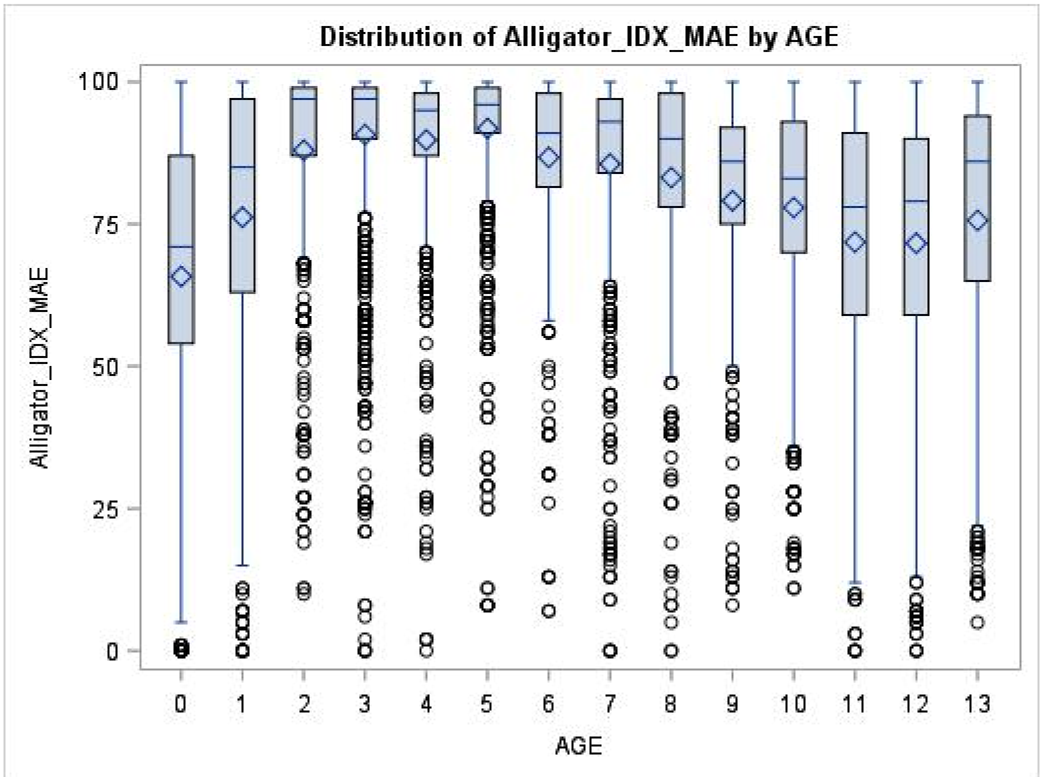

Figure 28: Schematic Box Plot for US_5_15k Alligator_IDX_MAE

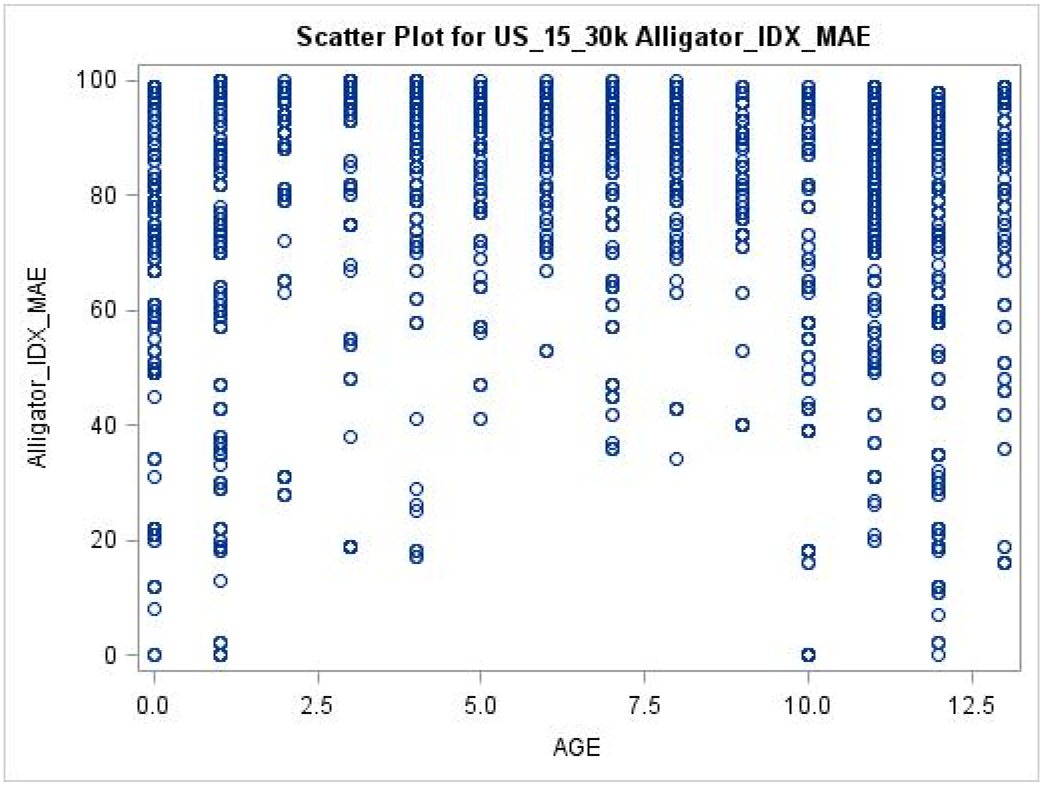

Figure 29: Scatter Plot for US_15_30k Alligator_IDX_MAE

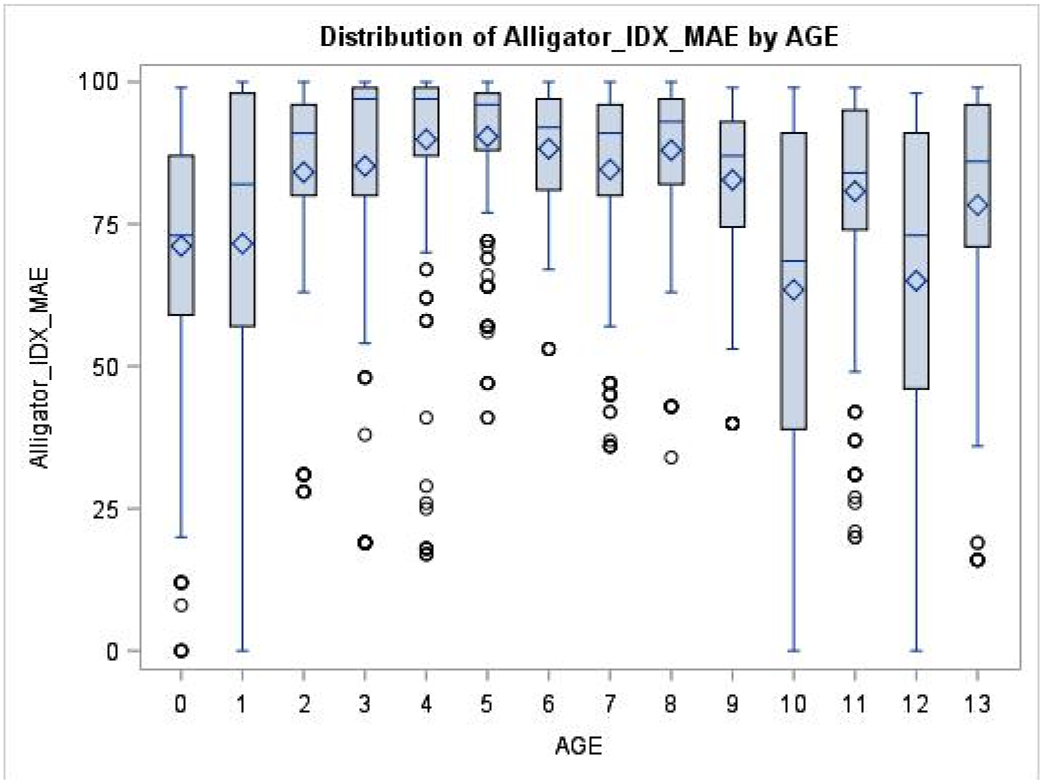

Figure 30: Schematic Box Plot for US_15_30k Alligator_IDX_MAE

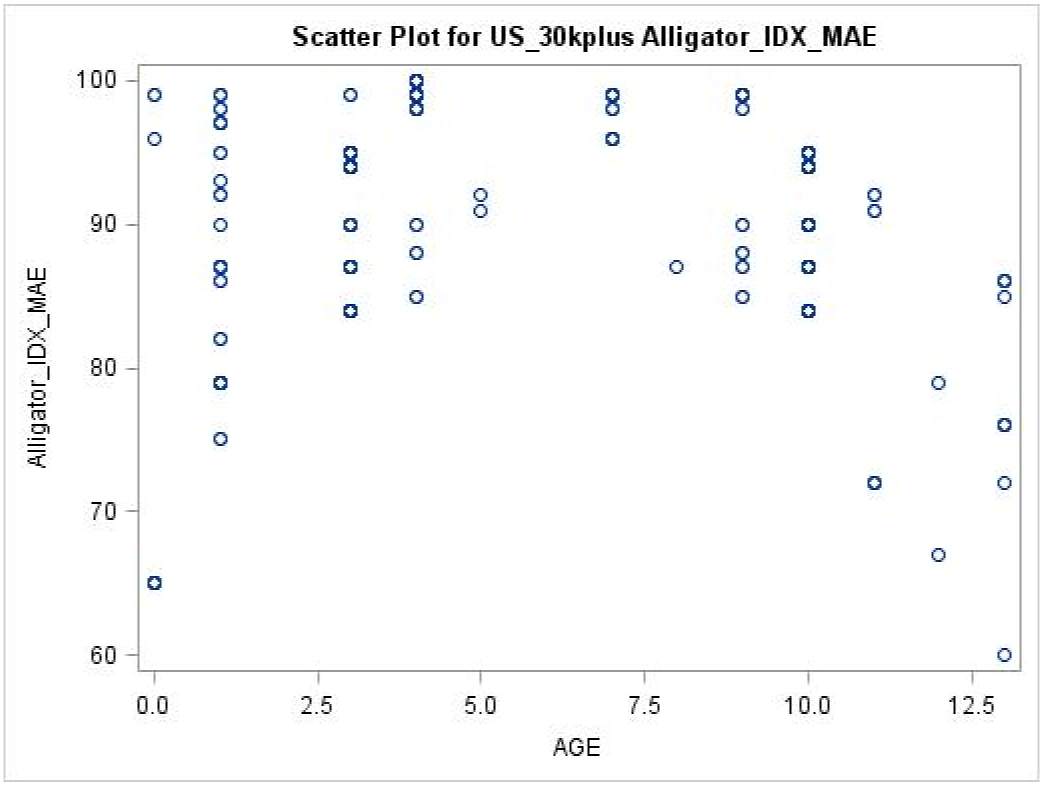

Figure 31: Scatter Plot for US_30kplus Alligator_IDX_MAE

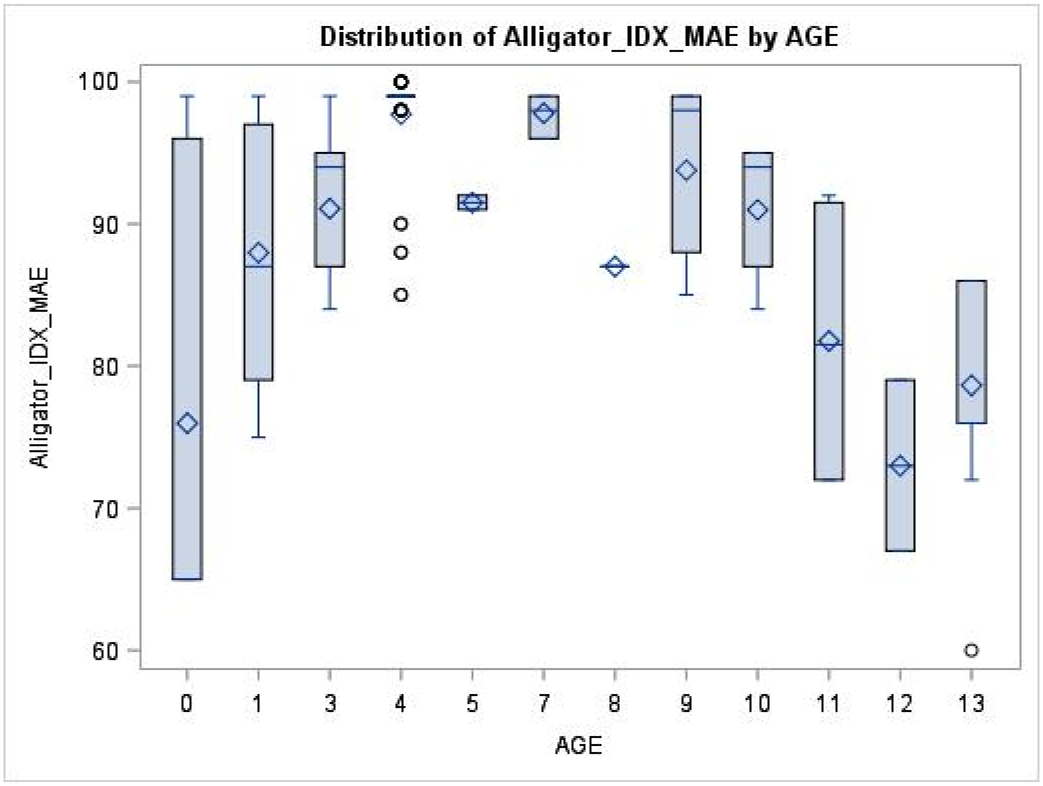

Figure 32: Schematic Box Plot for US_30kplus Alligator_IDX_MAE

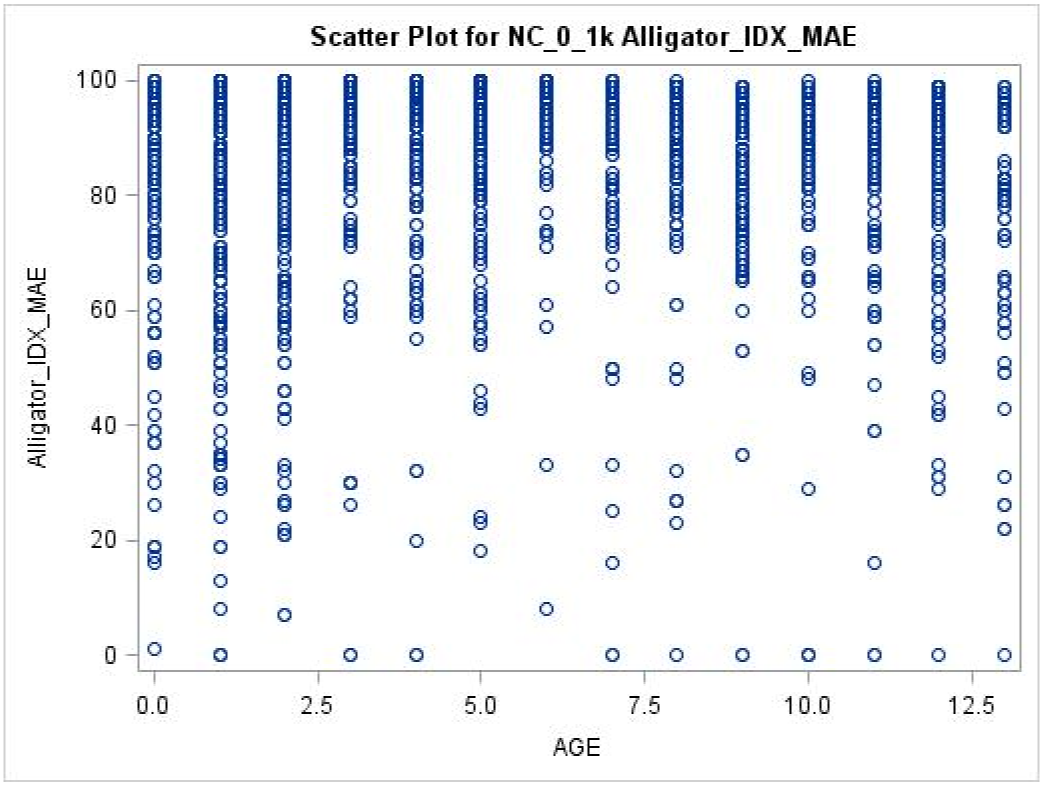

Figure 33: Scatter Plot for NC_0_1k Alligator_IDX_MAE

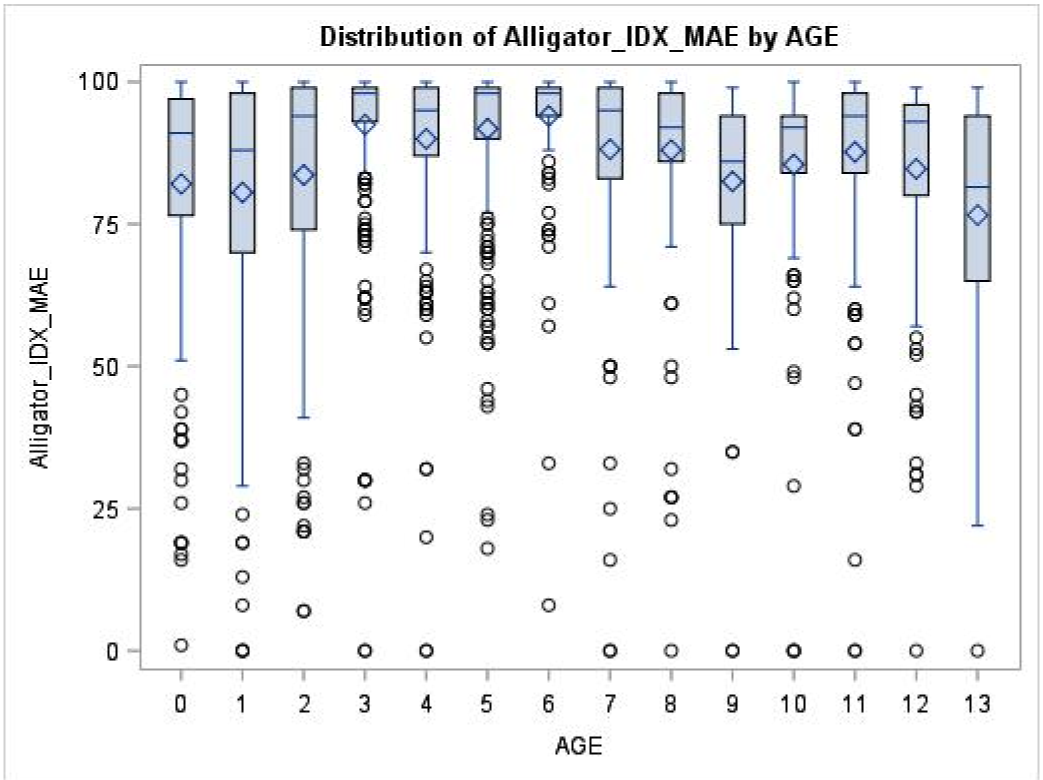

Figure 34: Schematic Box Plot for NC_0_1k Alligator_IDX_MAE

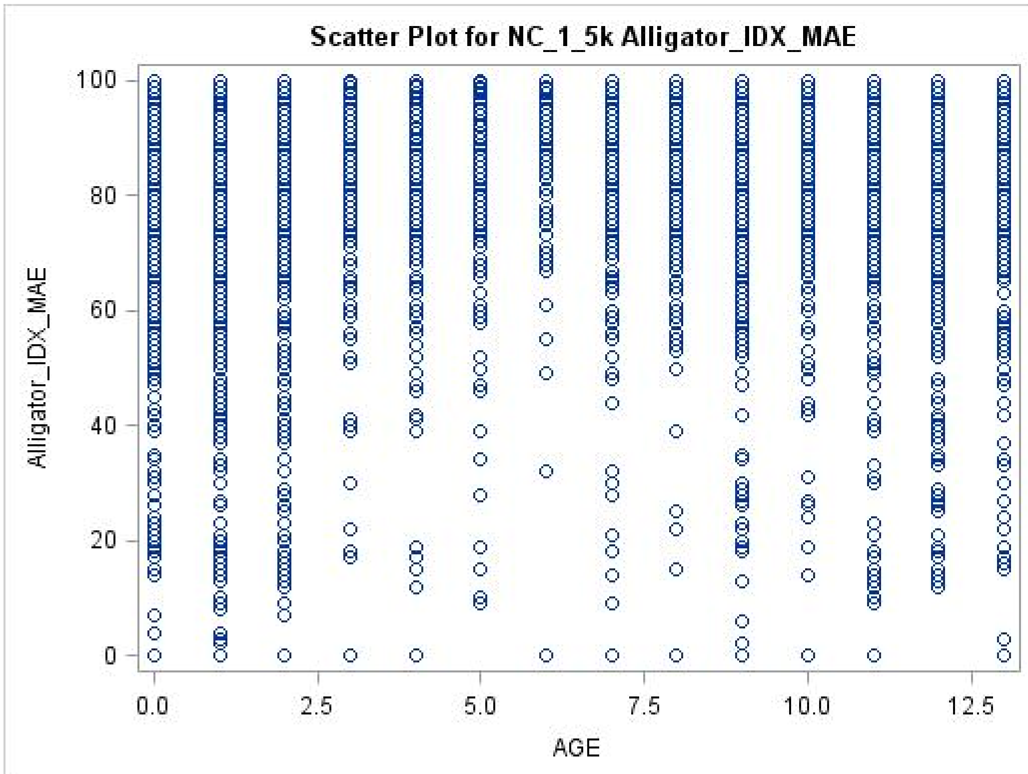

Figure 35: Scatter Plot for NC_1_5k Alligator_IDX_MAE

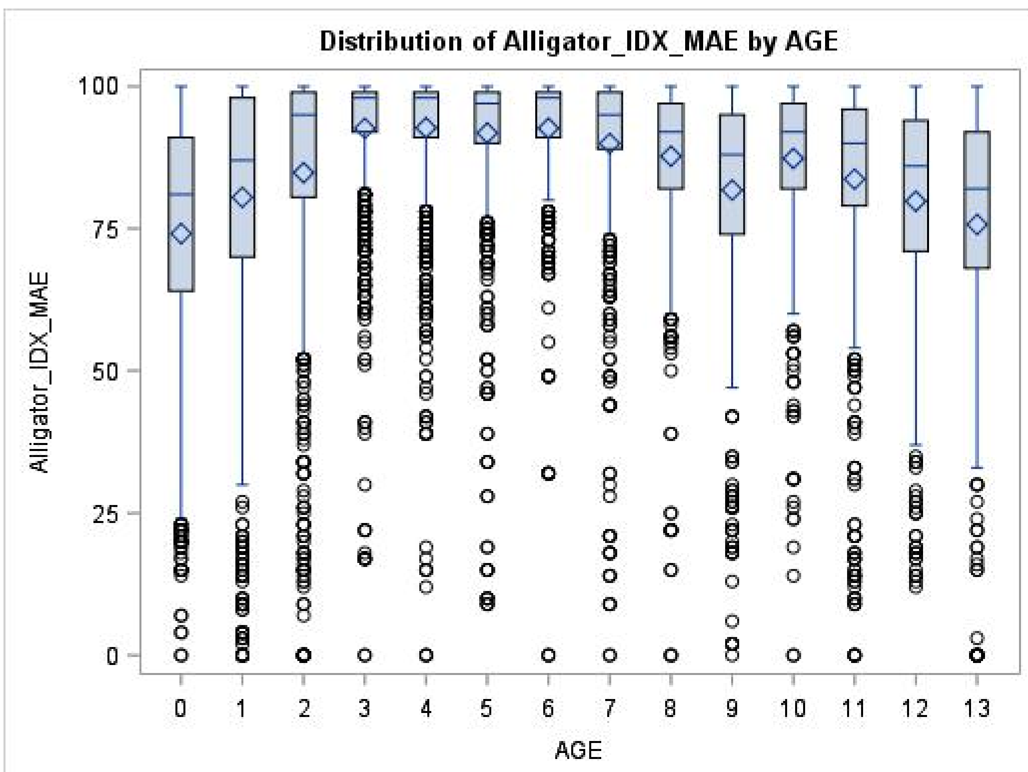

Figure 36: Schematic Box Plot for NC_1_5k Alligator_IDX_MAE

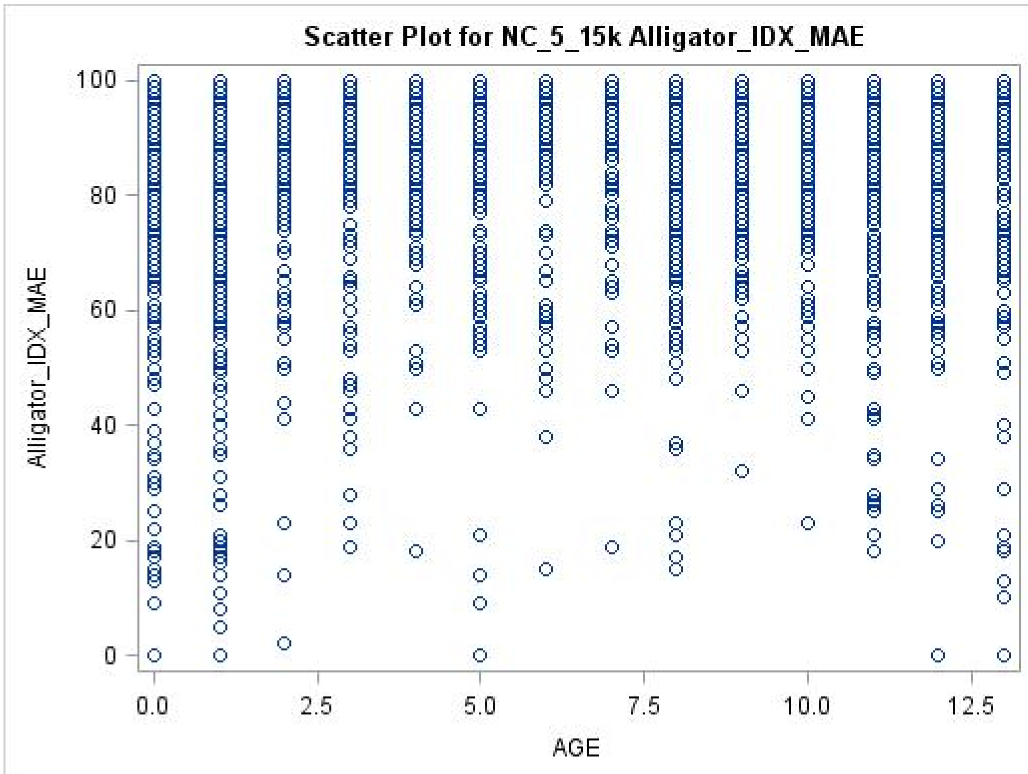

Figure 37: Scatter Plot for NC_5_15k Alligator_IDX_MAE

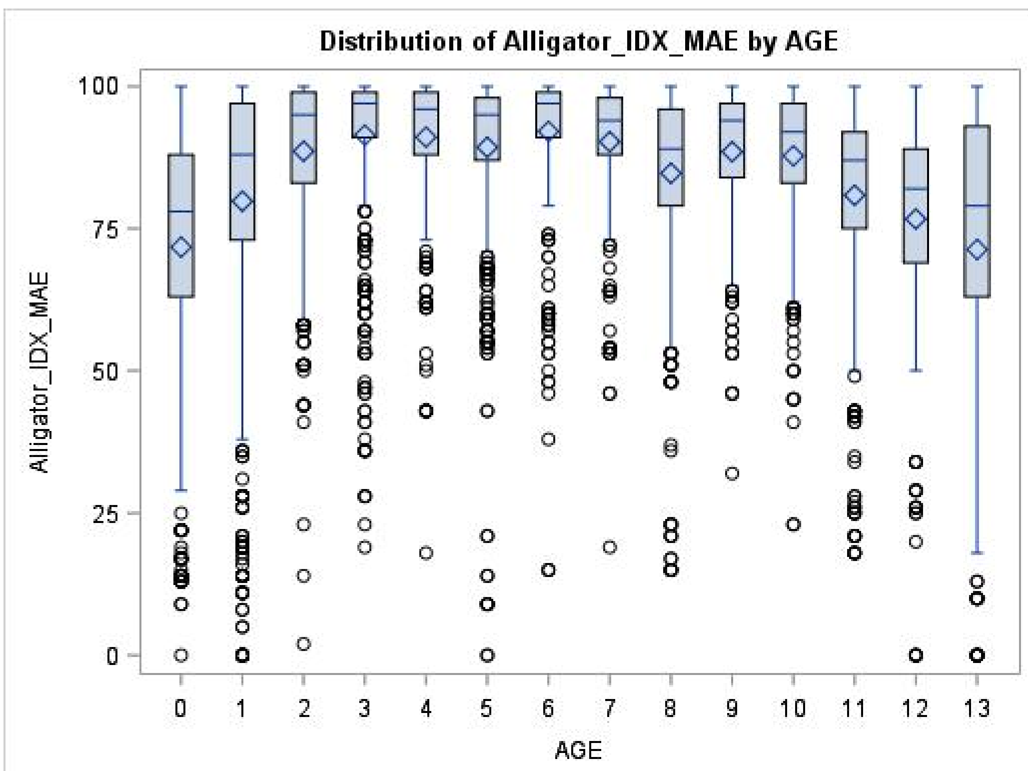

Figure 38: Schematic Box Plot for NC_5_15k Alligator_IDX_MAE

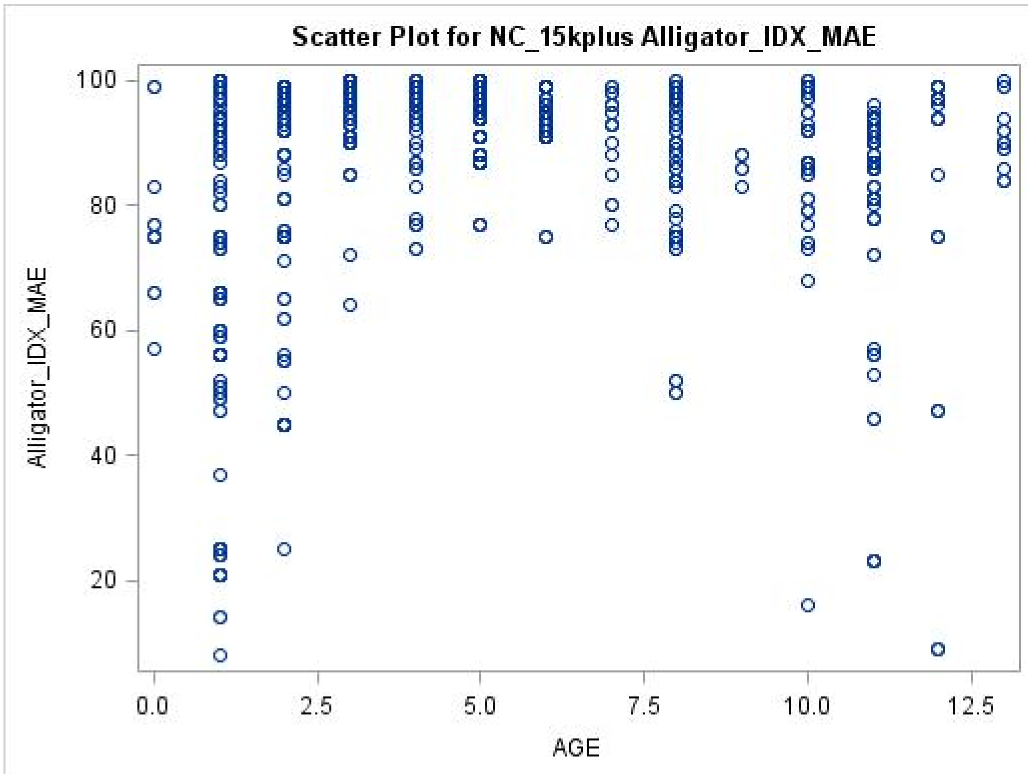

Figure 39: Scatter Plot for NC_15kplus Alligator_IDX_MAE

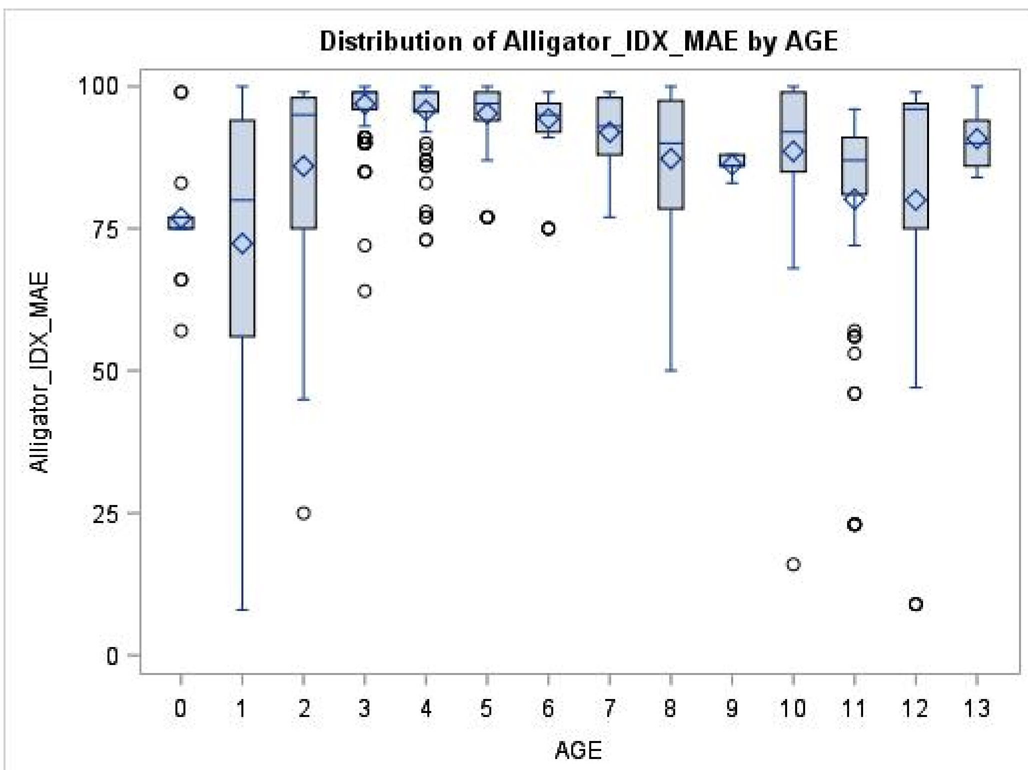

Figure 40: Schematic Box Plot for NC_15kplus Alligator_IDX_MAE

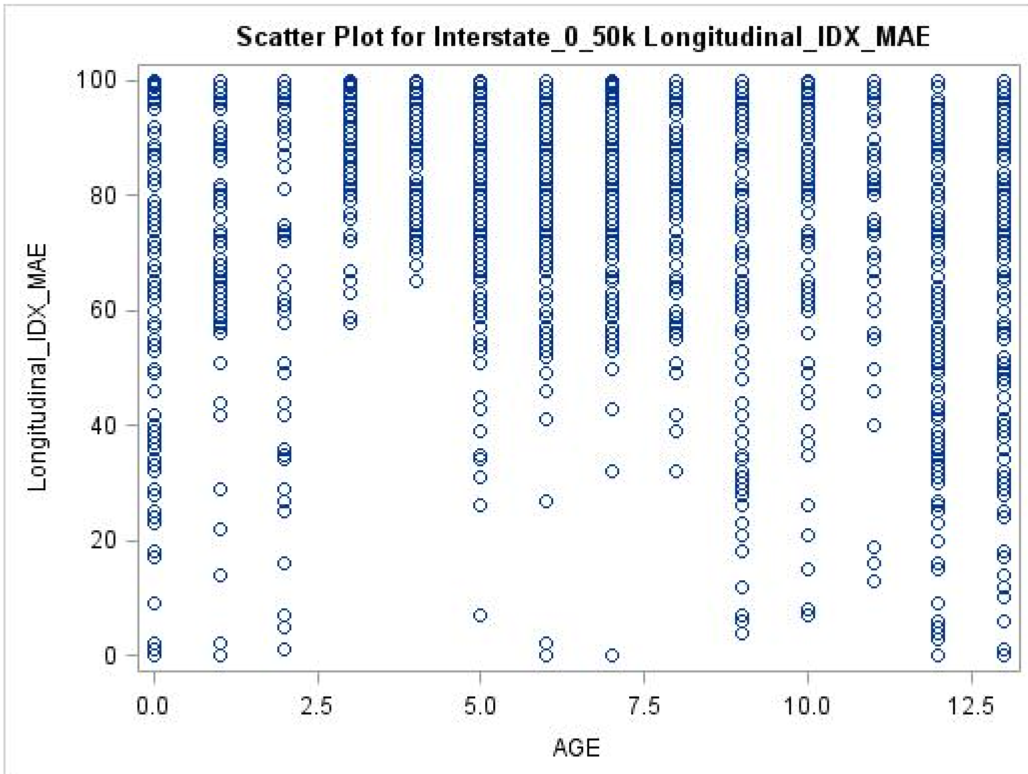

Figure 41: Scatter Plot for Interstate_0_50k Longitudinal_IDX_MAE

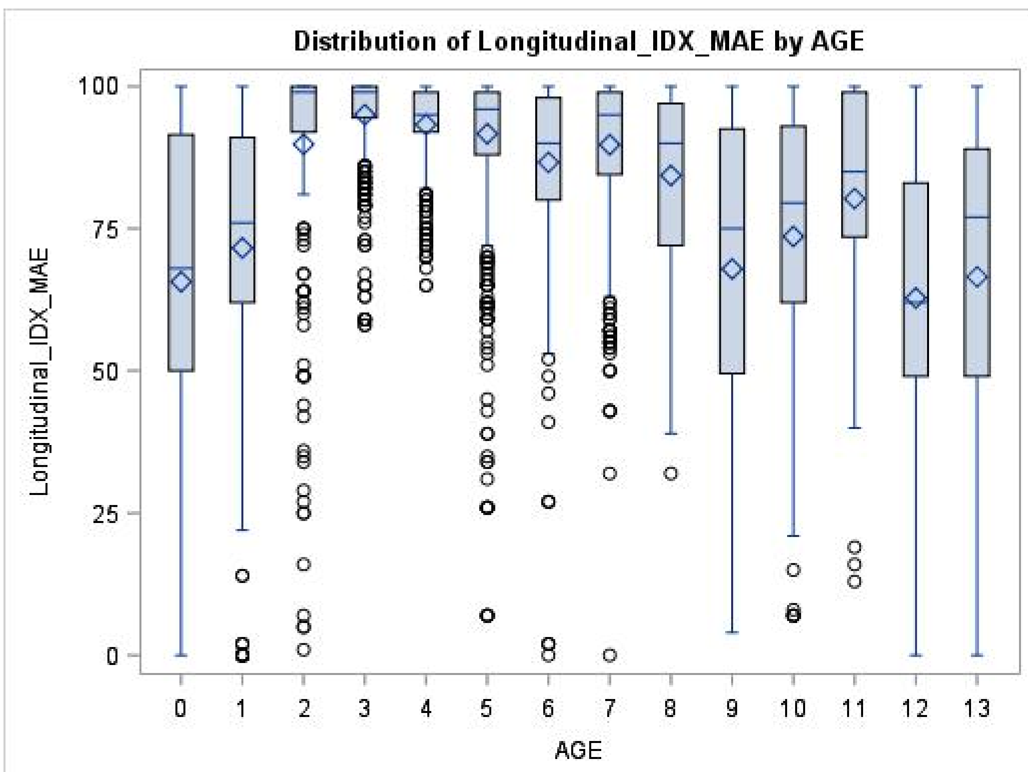

Figure 42: Schematic Box Plot for Interstate_0_50k Longitudinal_IDX_MAE

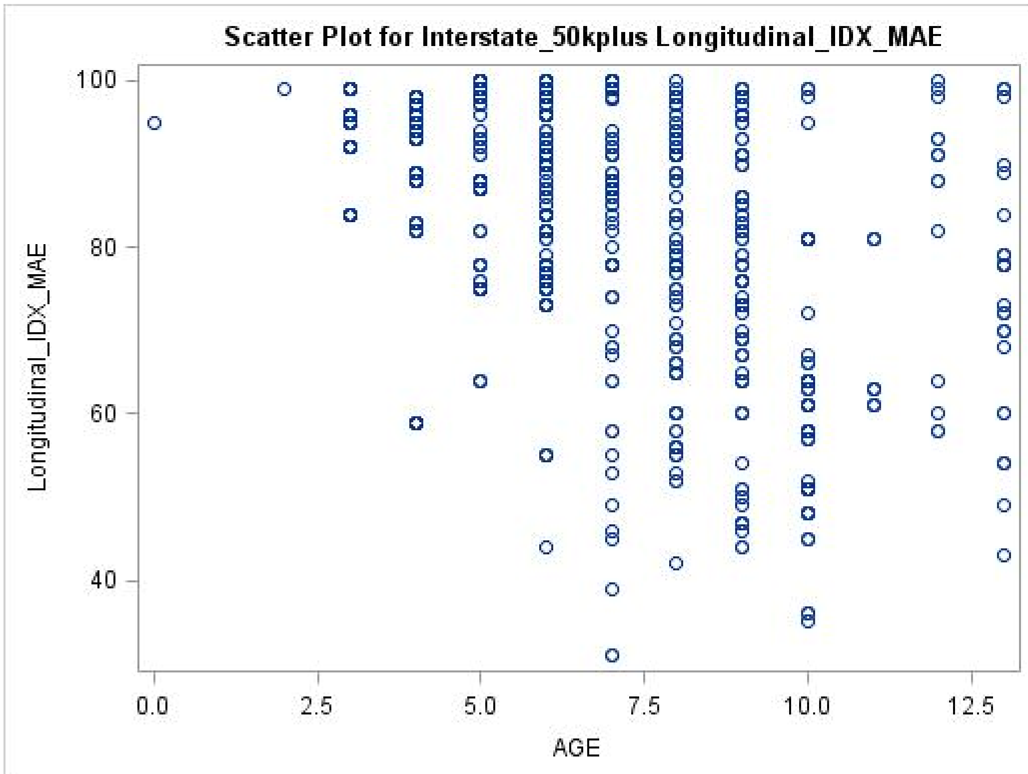

Figure 43: Scatter Plot for Interstate_50kplus Longitudinal_IDX_MAE

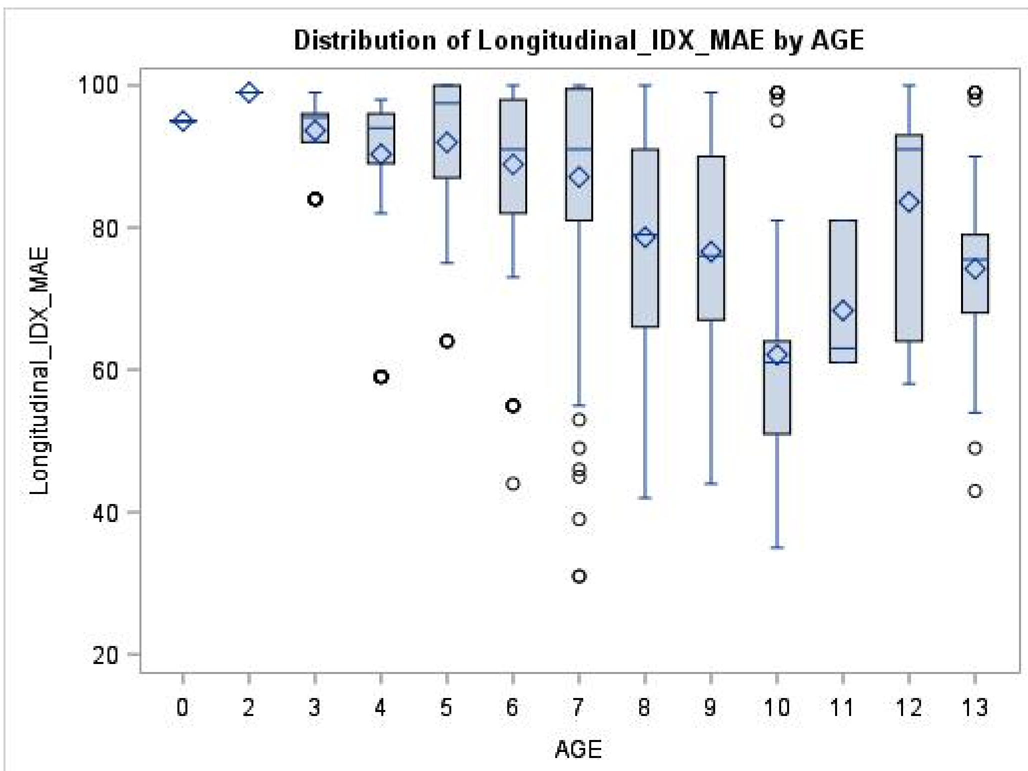

Figure 44: Schematic Box Plot for Interstate_50kplus Longitudinal_IDX_MAE

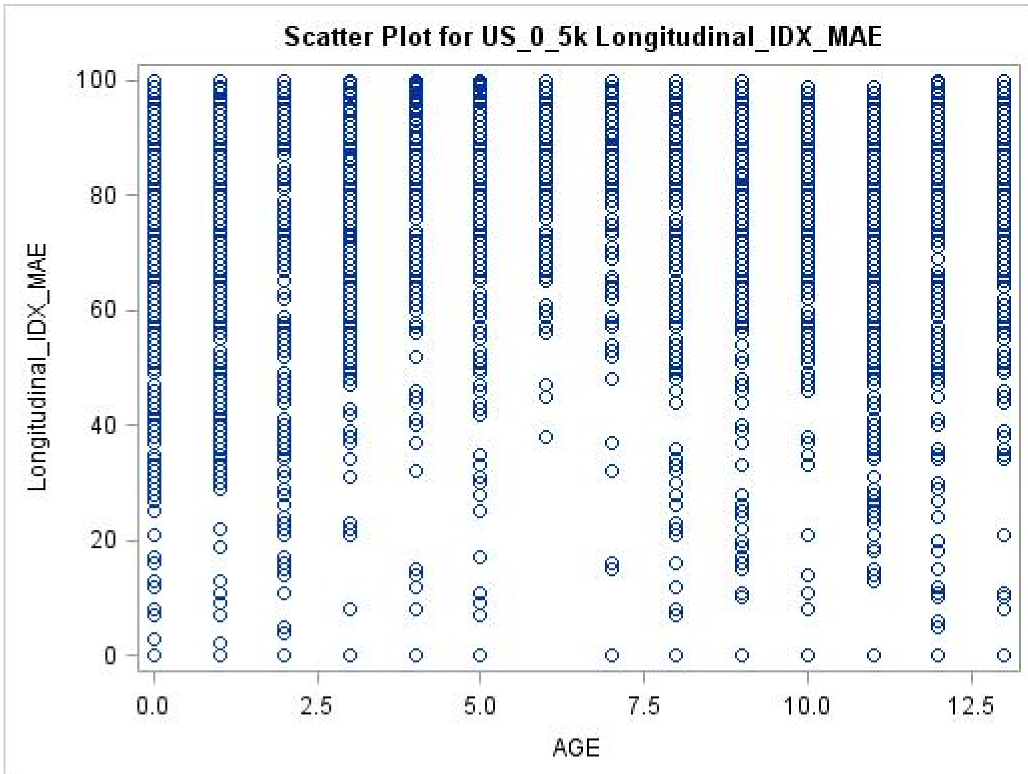

Figure 45: Scatter Plot for US_0_5k Longitudinal_IDX_MAE

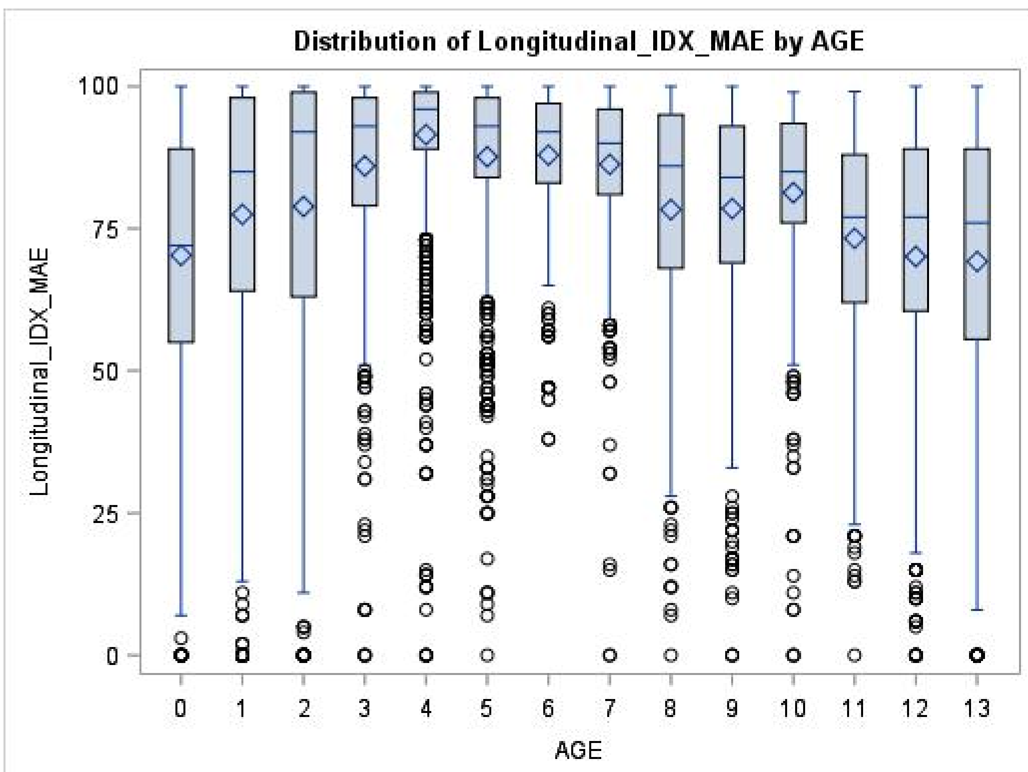

Figure 46: Schematic Box Plot for US_0_5k Longitudinal_IDX_MAE

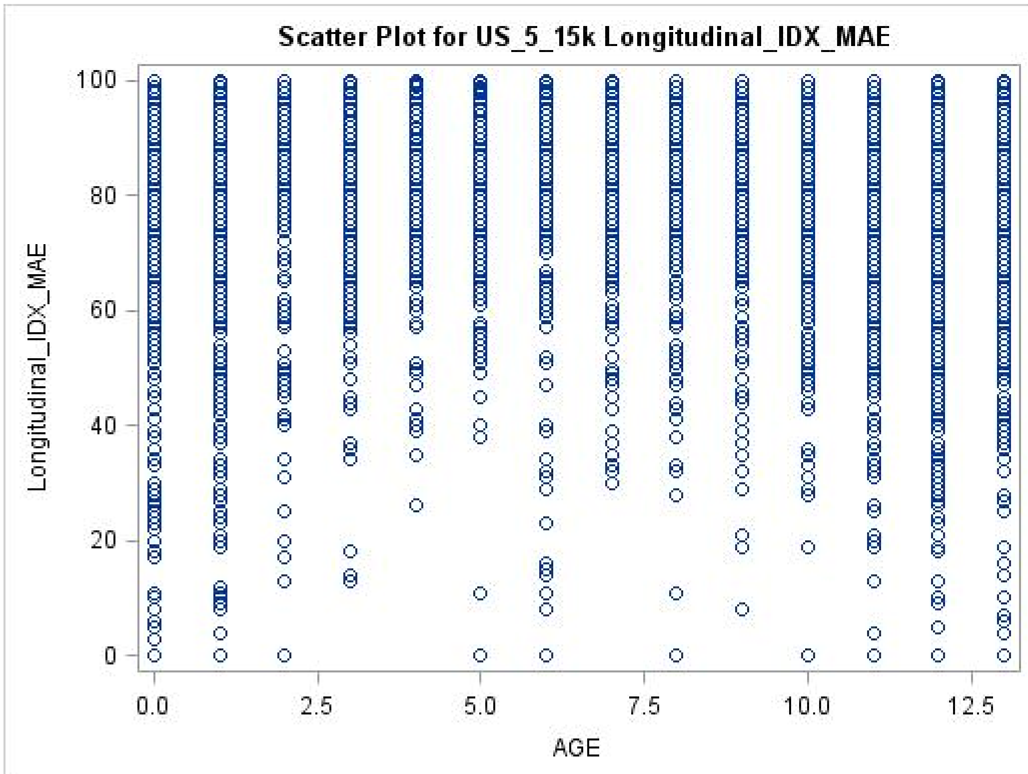

Figure 47: Scatter Plot for US_5_15k Longitudinal_IDX_MAE

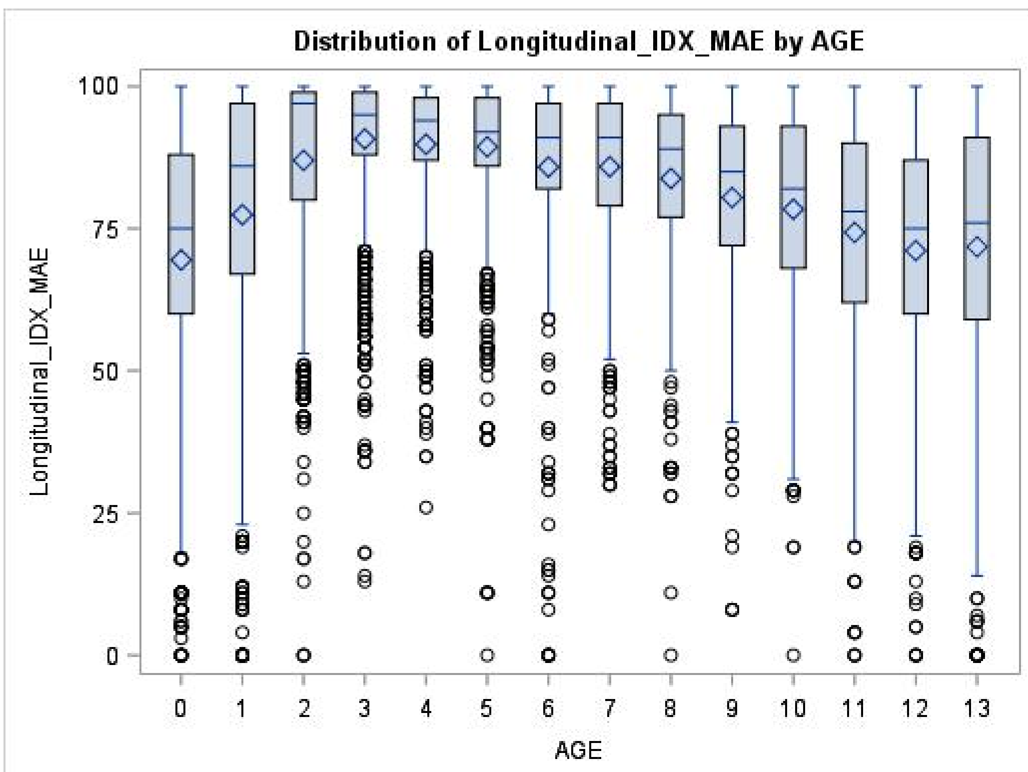

Figure 48: Schematic Box Plot for US_5_15k Longitudinal_IDX_MAE

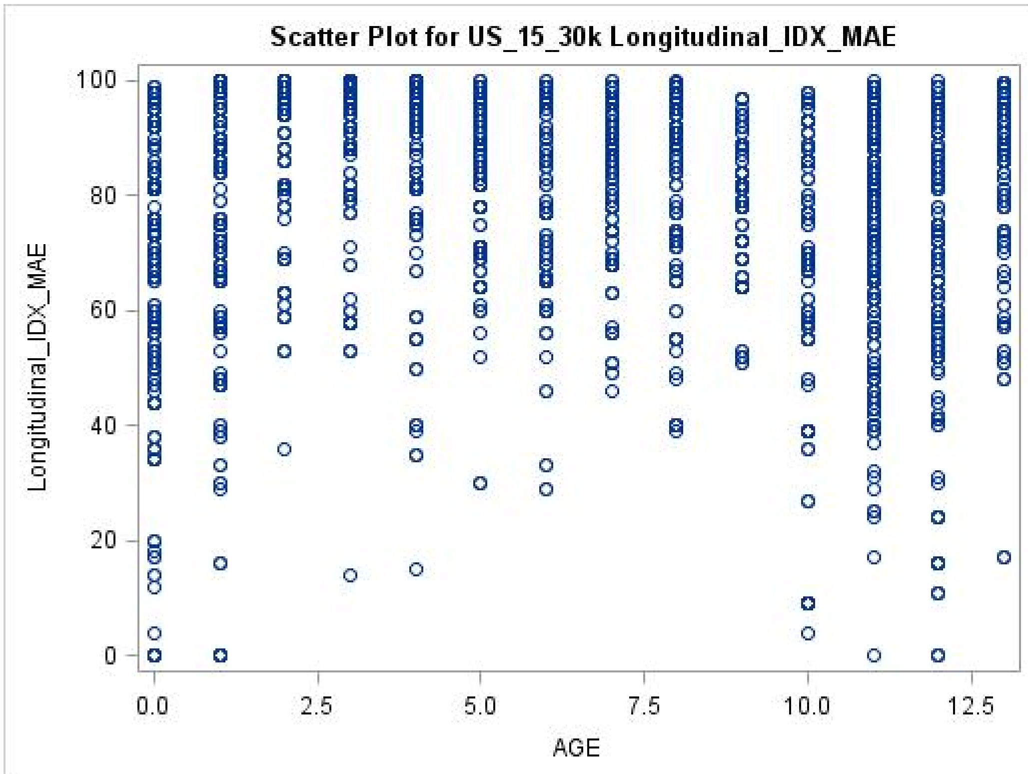

Figure 49: Scatter Plot for US_15_30k Longitudinal_IDX_MAE

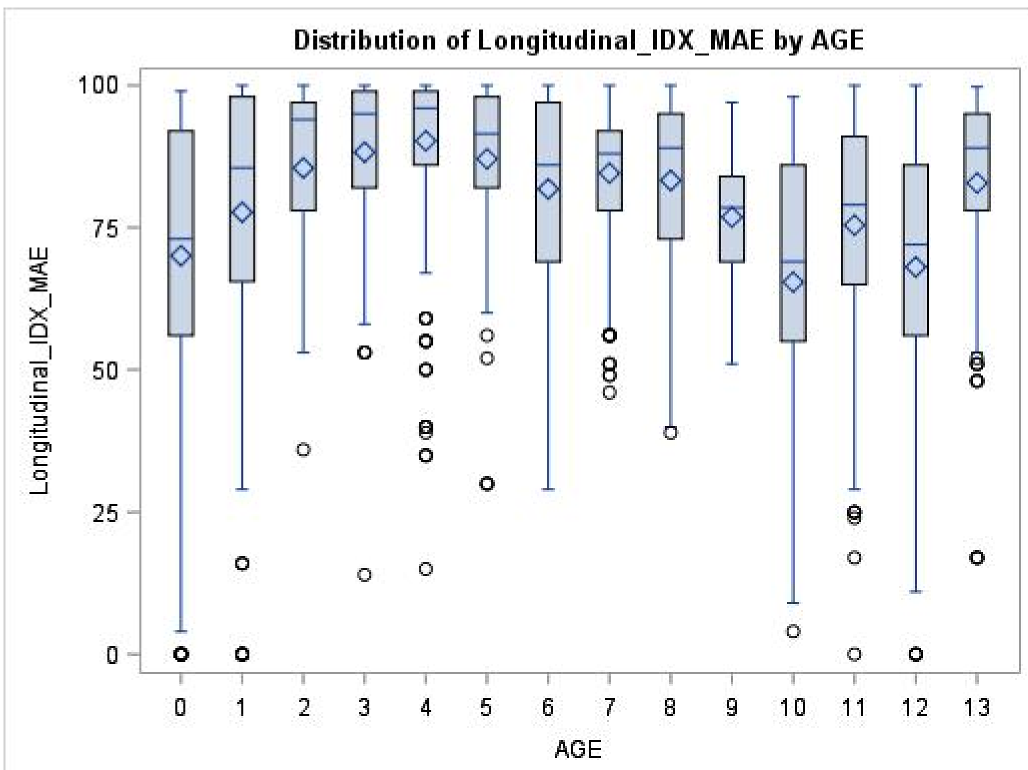

Figure 50: Schematic Box Plot for US_15_30k Longitudinal_IDX_MAE

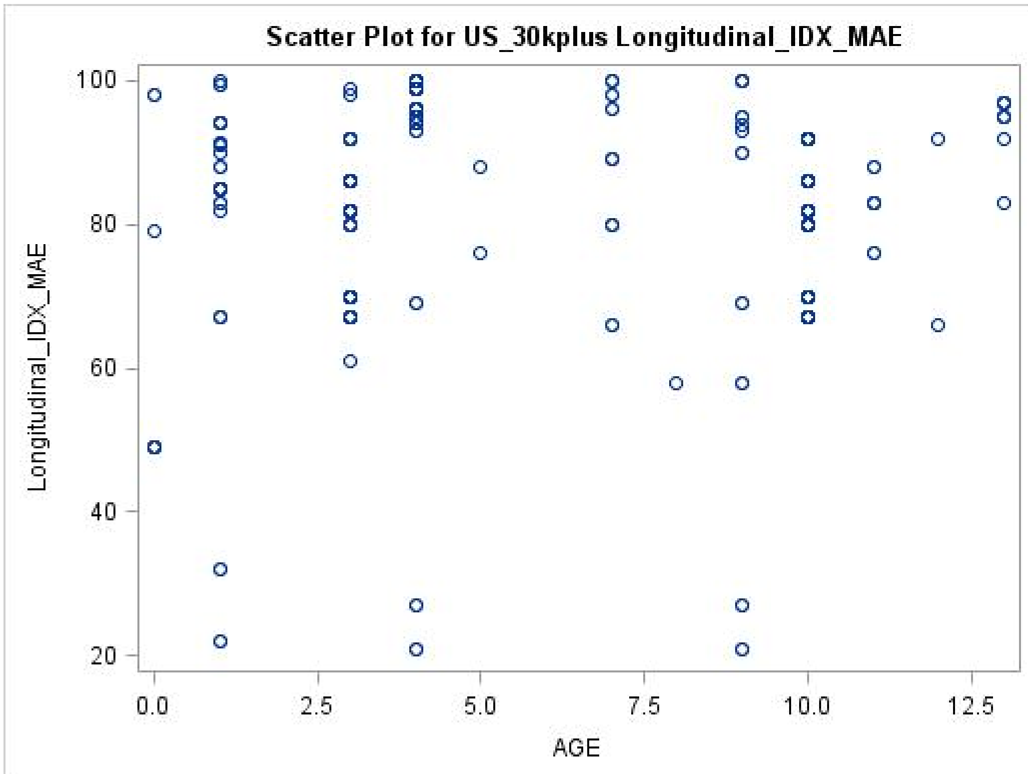

Figure 51: Scatter Plot for US_30kplus Longitudinal_IDX_MAE

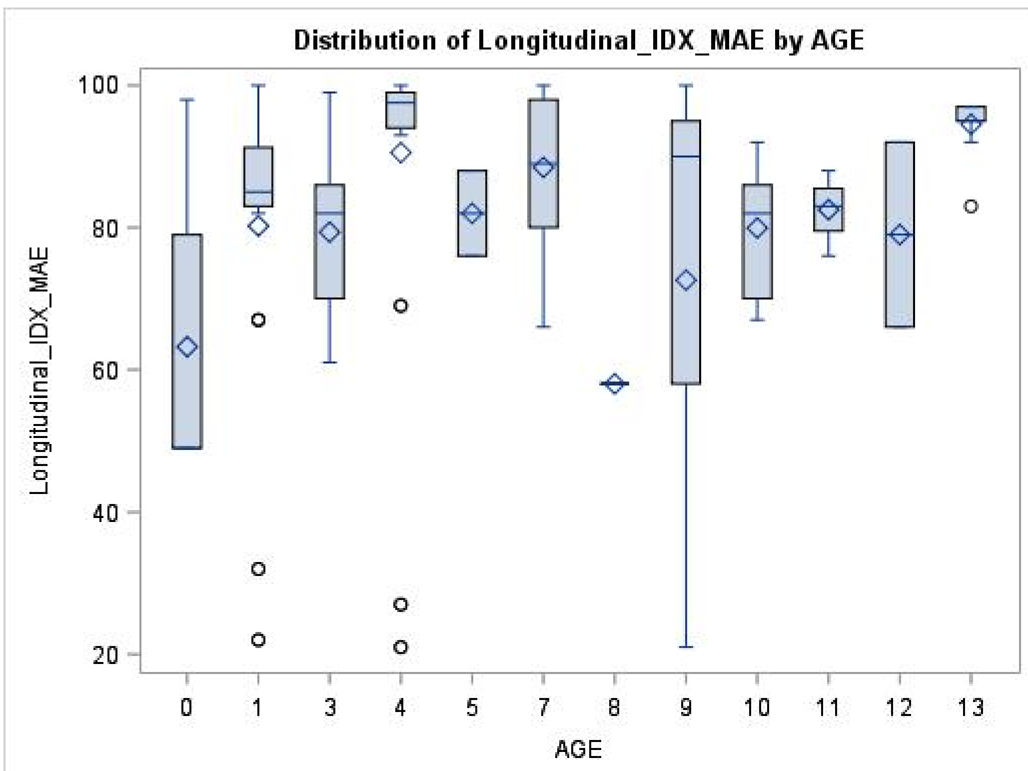

Figure 52: Schematic Box Plot for US_30kplus Longitudinal_IDX_MAE

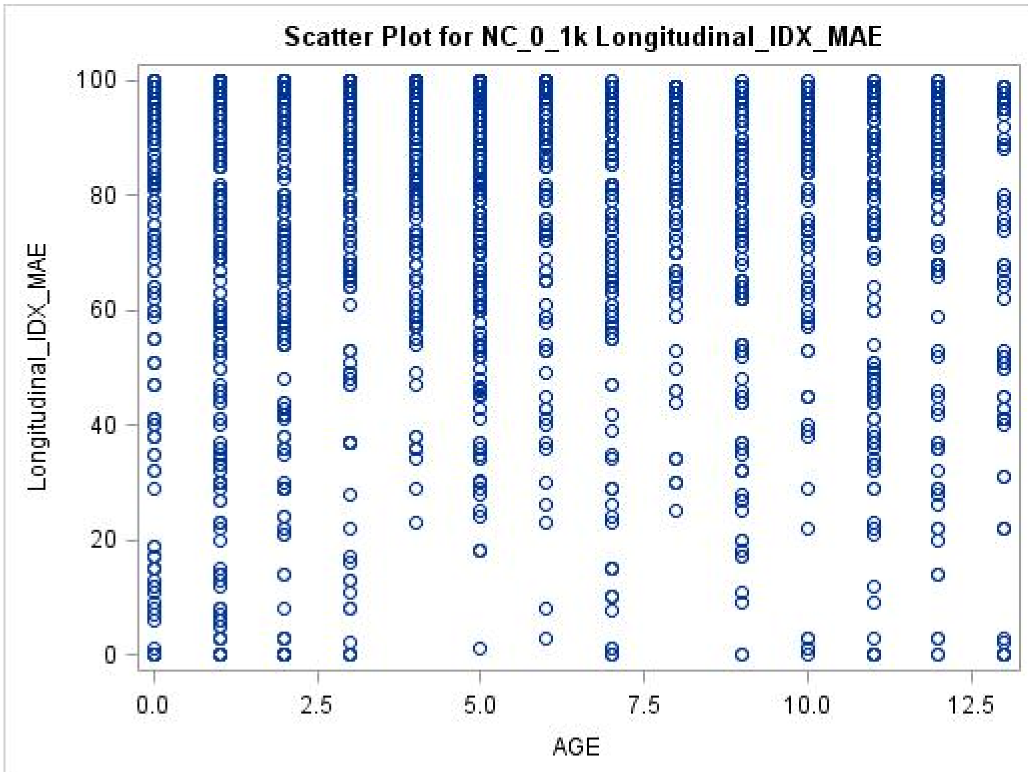

Figure 53: Scatter Plot for NC_0_1k Longitudinal_IDX_MAE

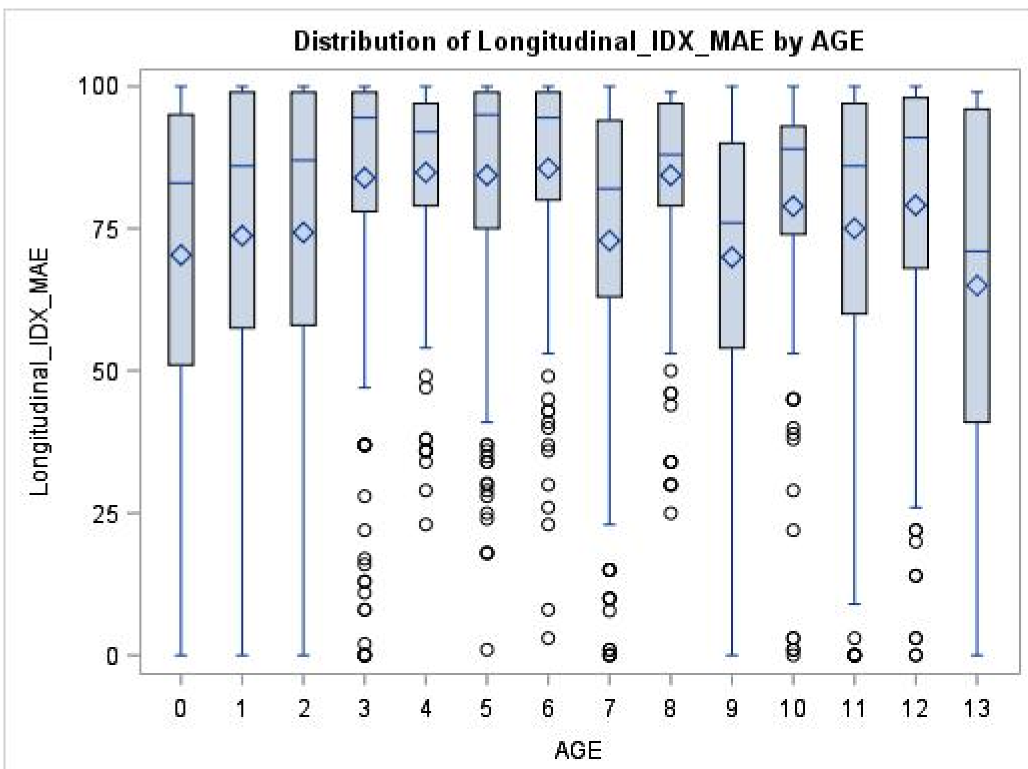

Figure 54: Schematic Box Plot for NC_0_1k Longitudinal_IDX_MAE

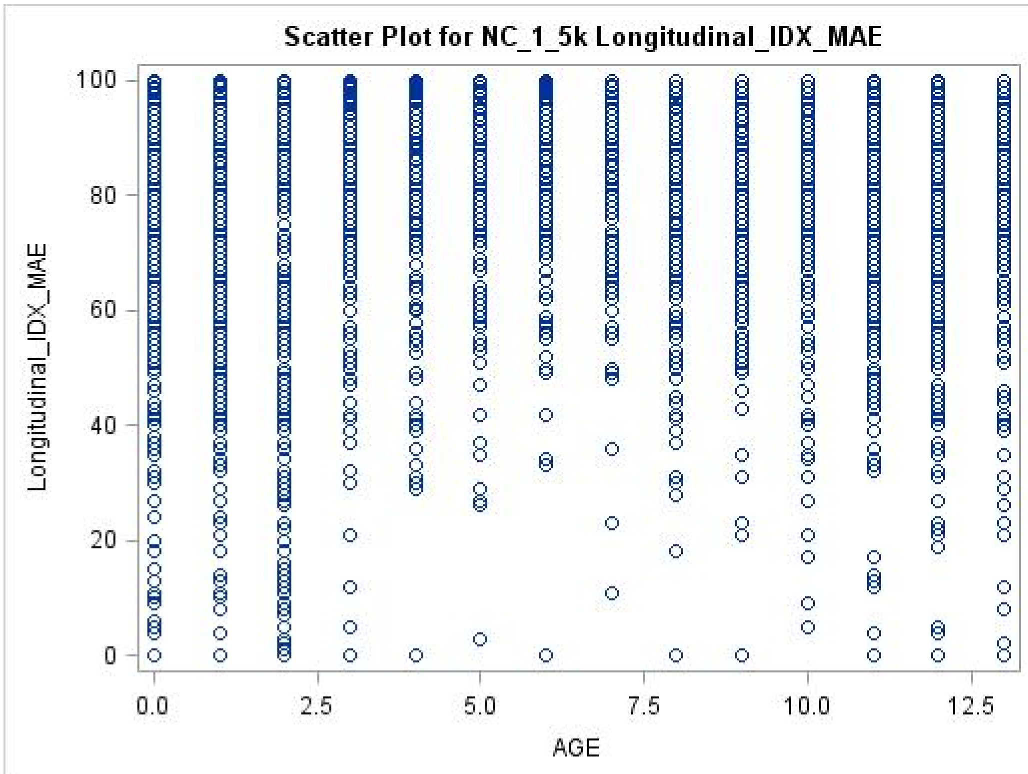

Figure 55: Scatter Plot for NC_1_5k Longitudinal_IDX_MAE

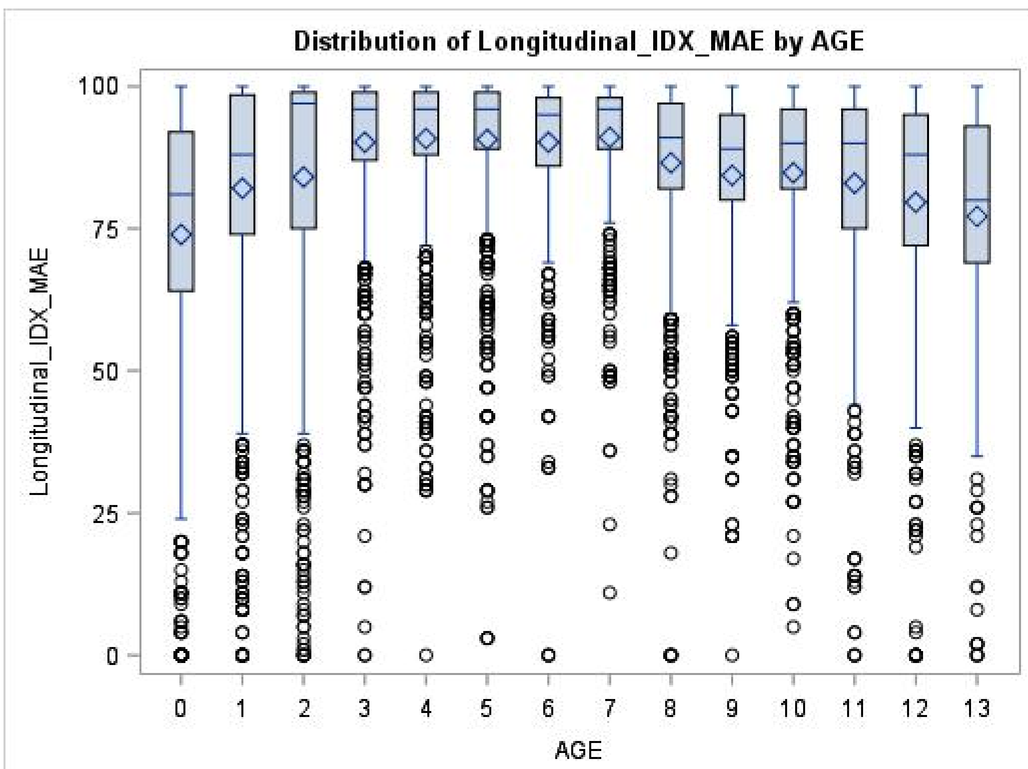

Figure 56: Schematic Box Plot for NC_1_5k Longitudinal_IDX_MAE

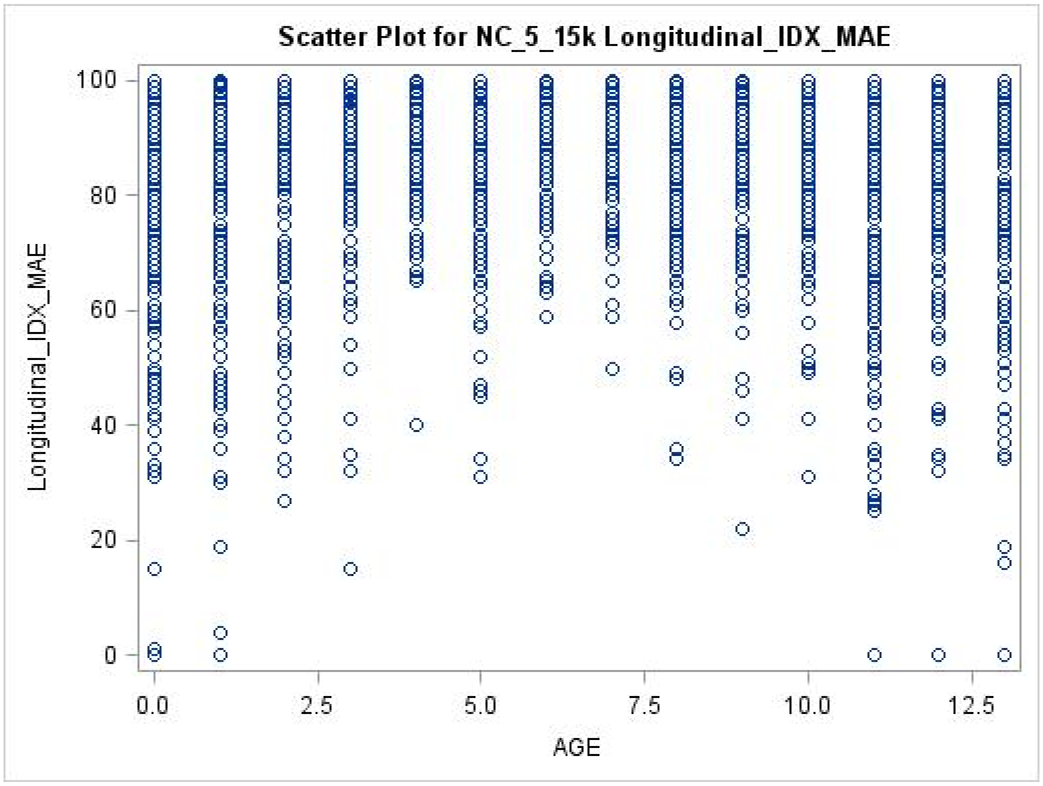

Figure 57: Scatter Plot for NC_5_15k Longitudinal_IDX_MAE

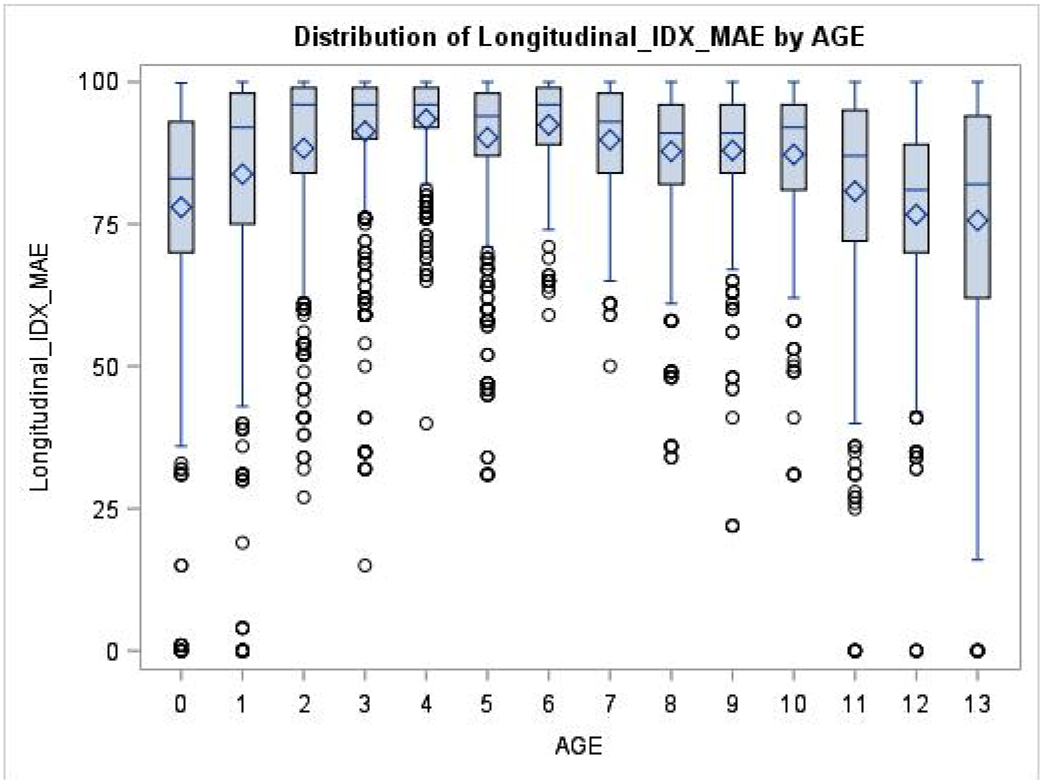

Figure 58: Schematic Box Plot for NC_5_15k Longitudinal_IDX_MAE

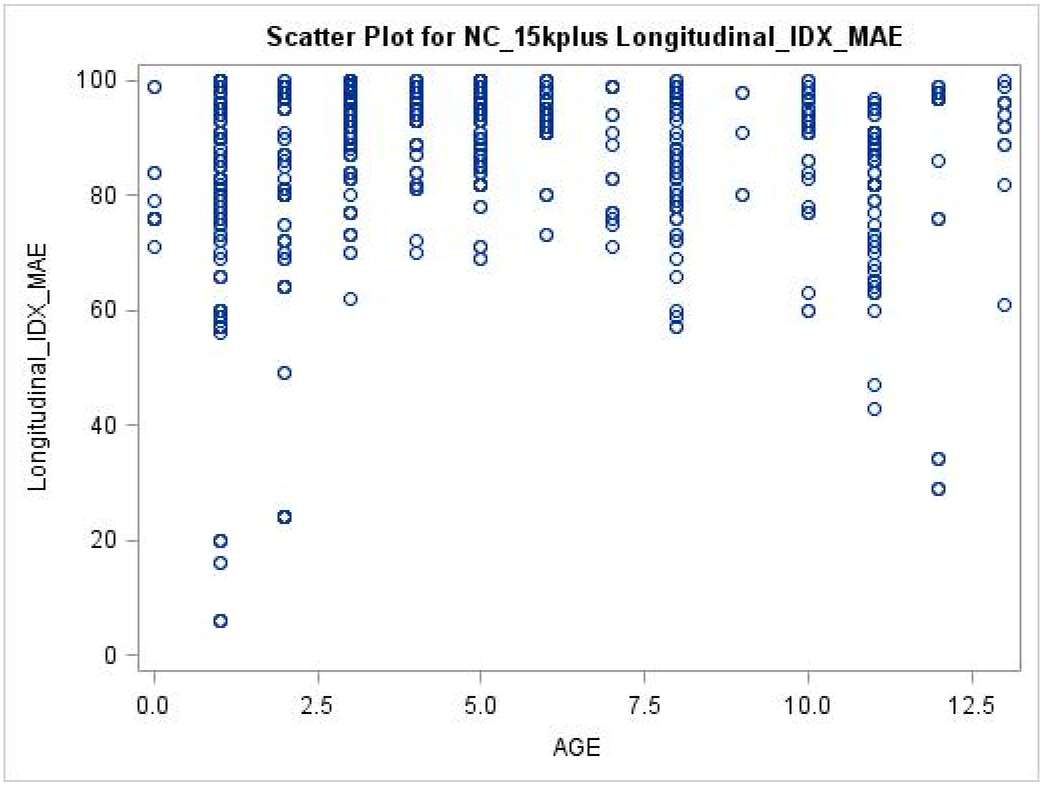

Figure 59: Scatter Plot for NC_15kplus Longitudinal_IDX_MAE

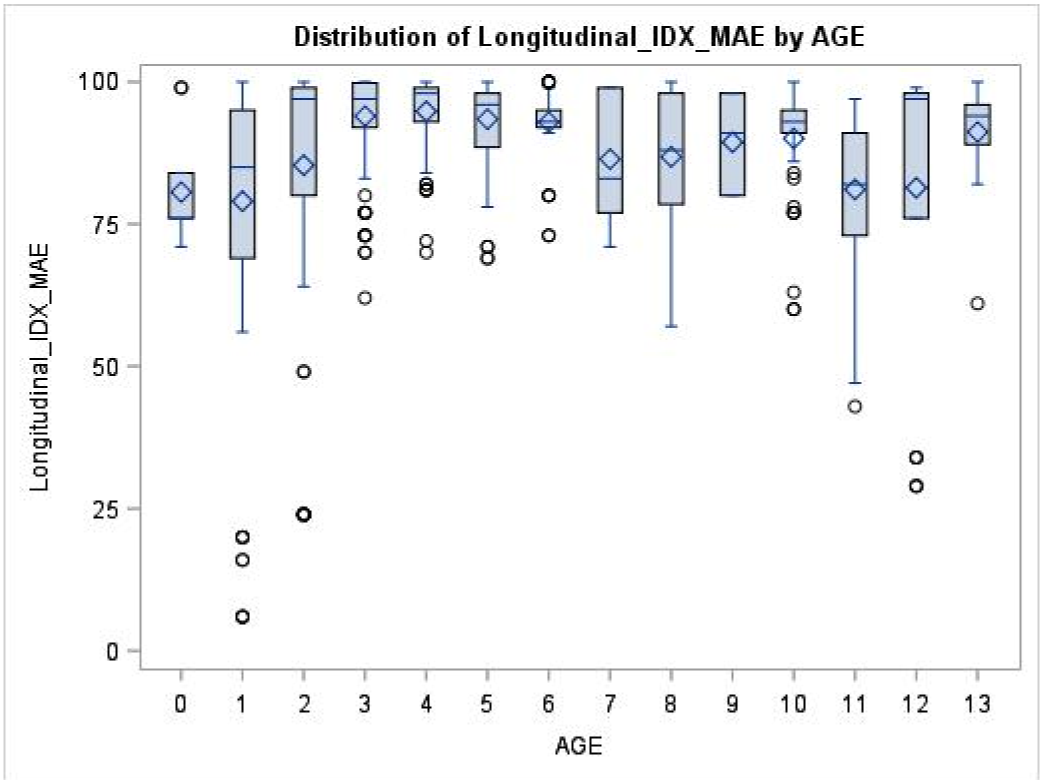

Figure 60: Schematic Box Plot for NC_15kplus Longitudinal_IDX_MAE

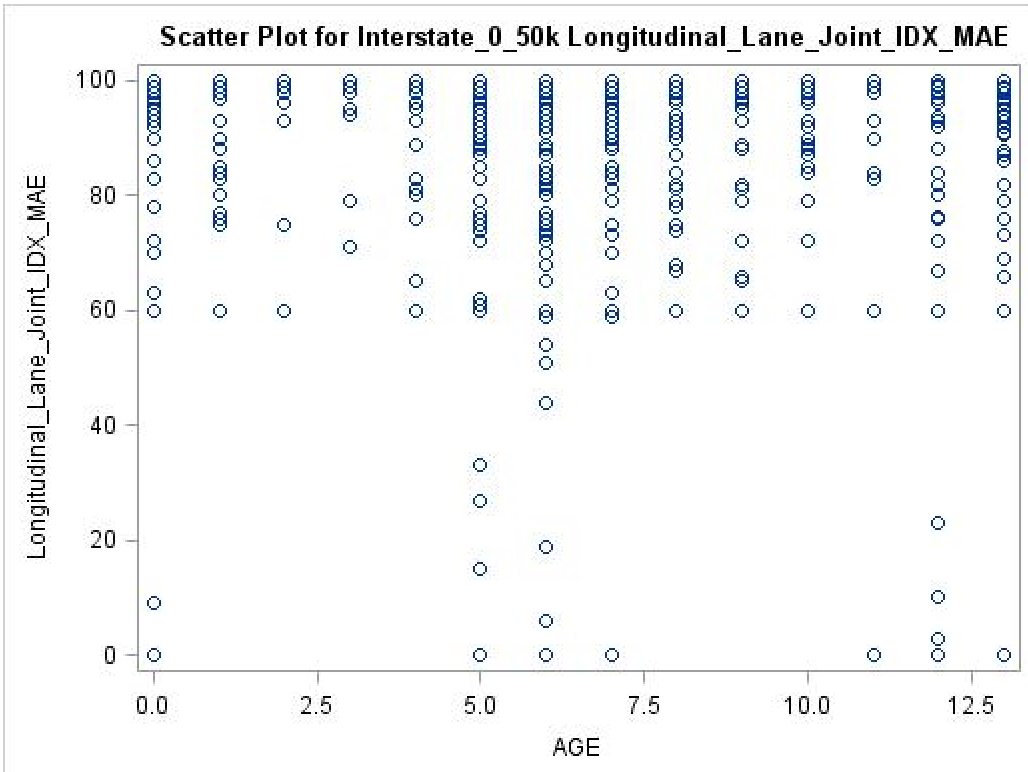

Figure 61: Scatter Plot for Interstate_0_50k Longitudinal_Lane_Joint_IDX_MAE

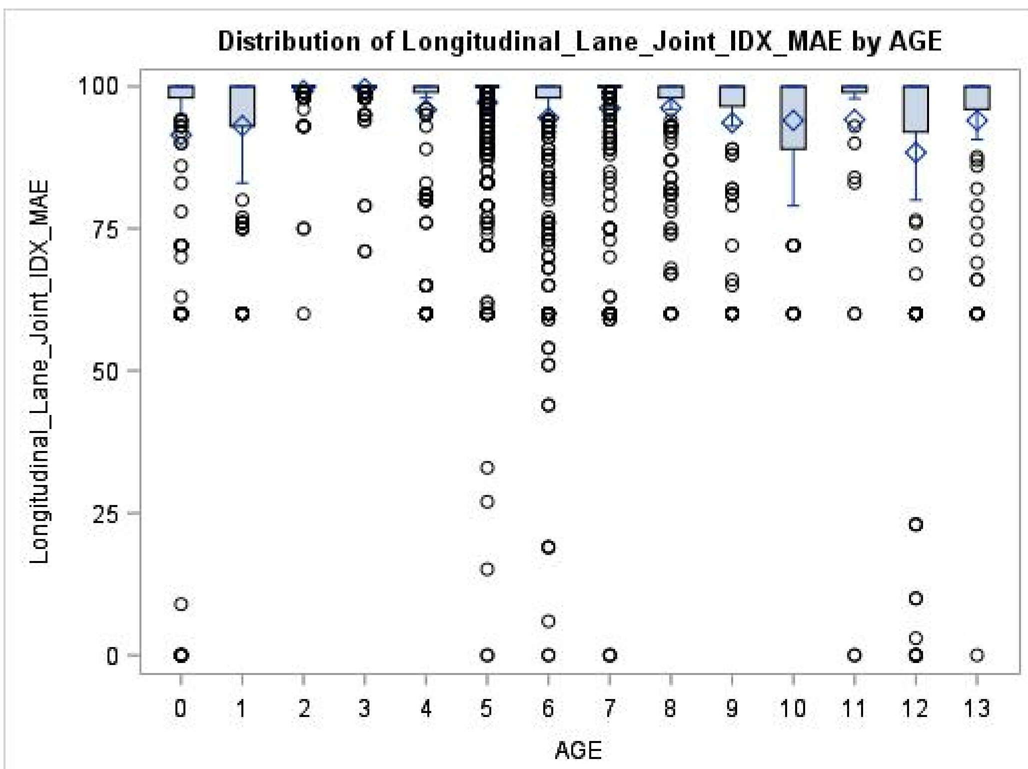

Figure 62: Schematic Box Plot for Interstate_0_50k Longitudinal_Lane_Joint_IDX_MAE

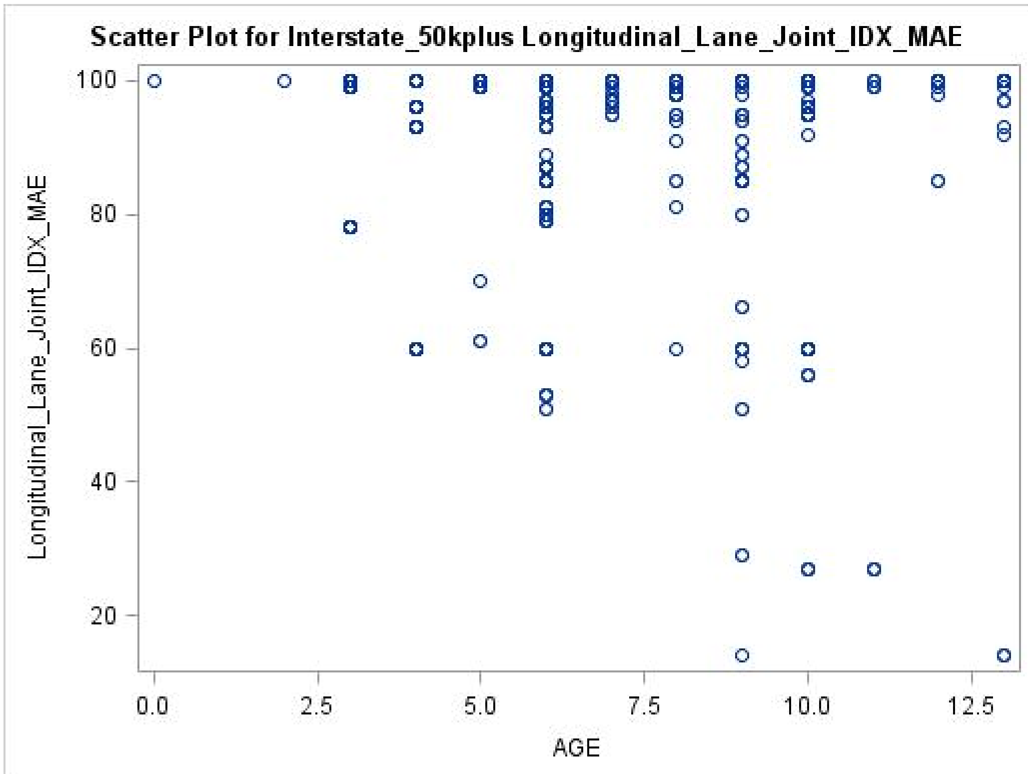

Figure 63: Scatter Plot for Interstate_50kplus Longitudinal_Lane_Joint_IDX_MAE

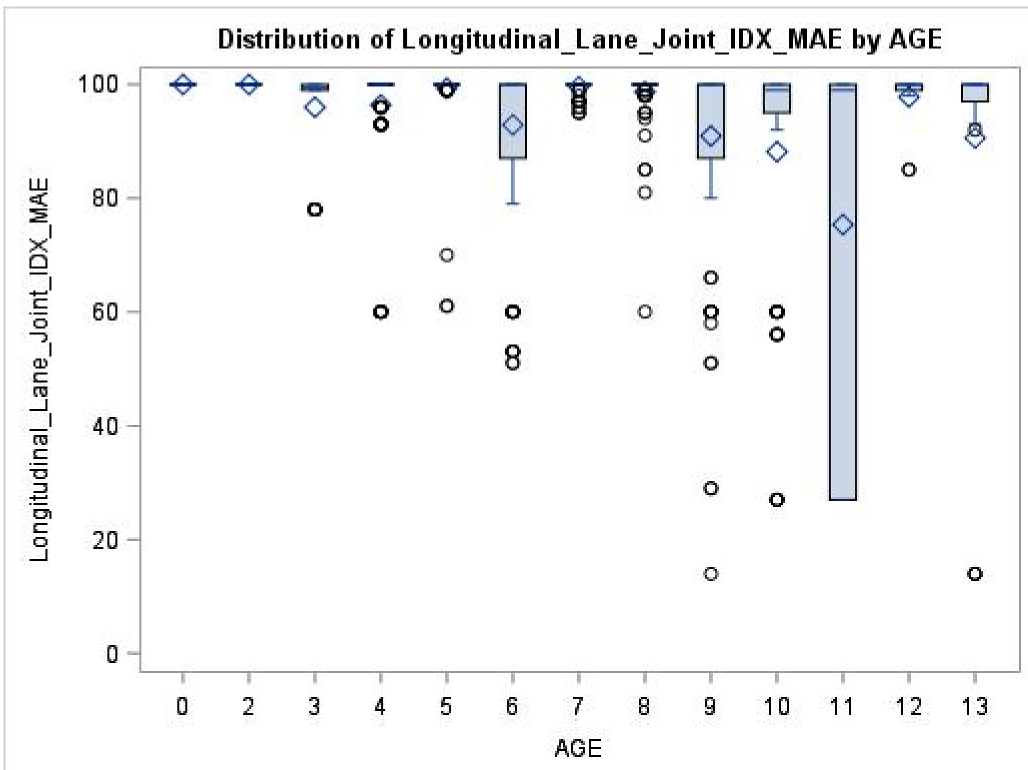

Figure 64: Schematic Box Plot for Interstate_50kplus Longitudinal_Lane_Joint_IDX_MAE

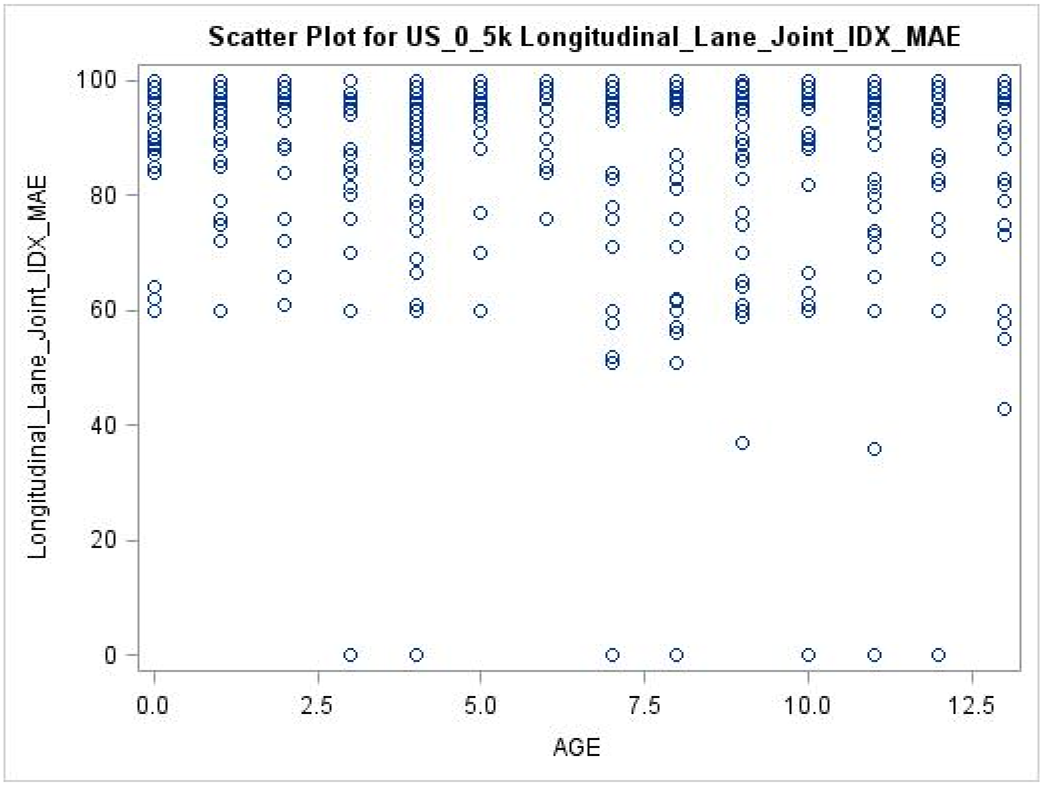

Figure 65: Scatter Plot for US_0_5k Longitudinal_Lane_Joint_IDX_MAE

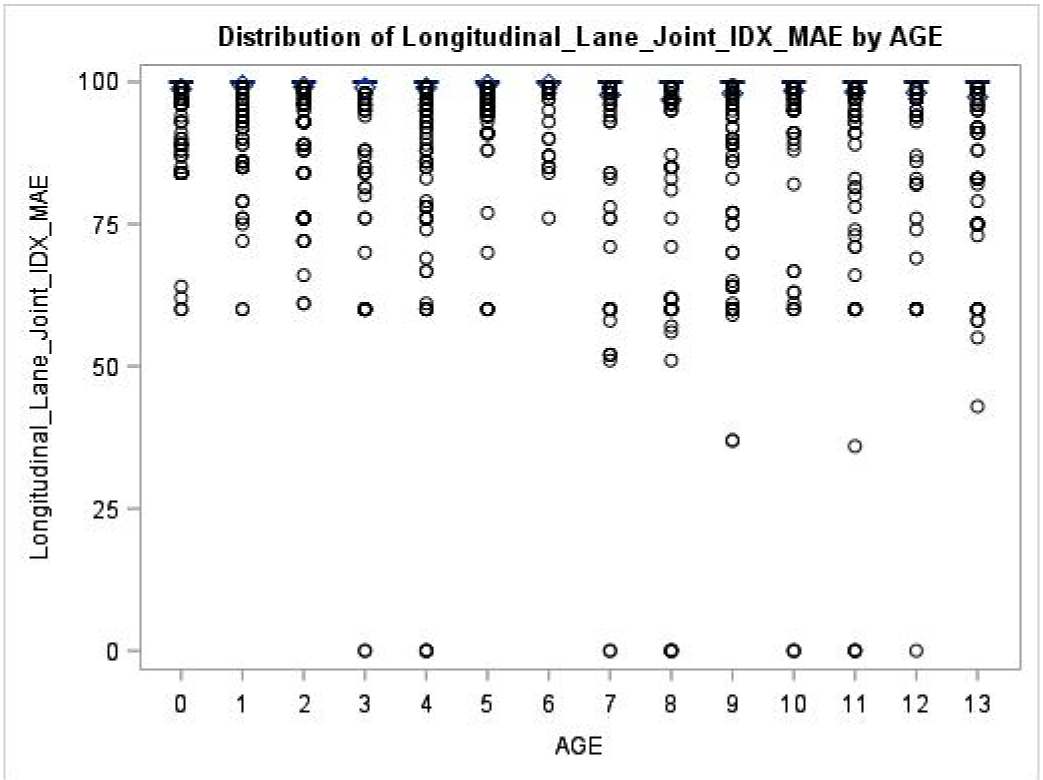

Figure 66: Schematic Box Plot for US_0_5k Longitudinal_Lane_Joint_IDX_MAE

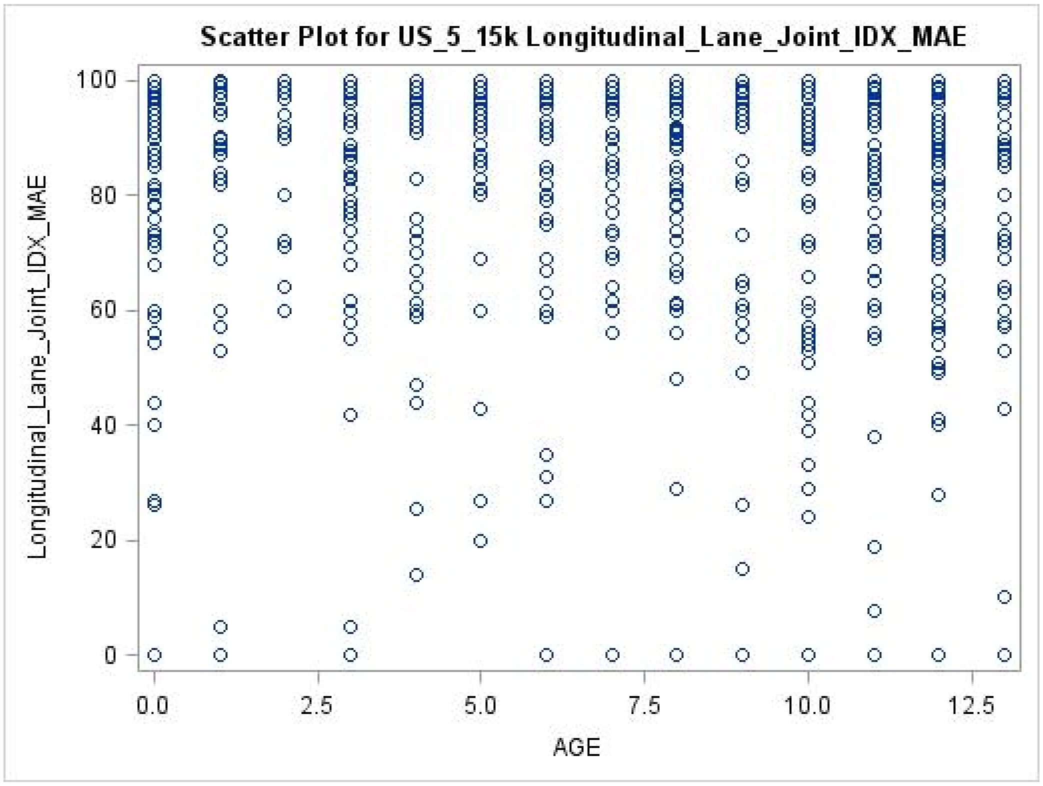

Figure 67: Scatter Plot for US_5_15k Longitudinal_Lane_Joint_IDX_MAE

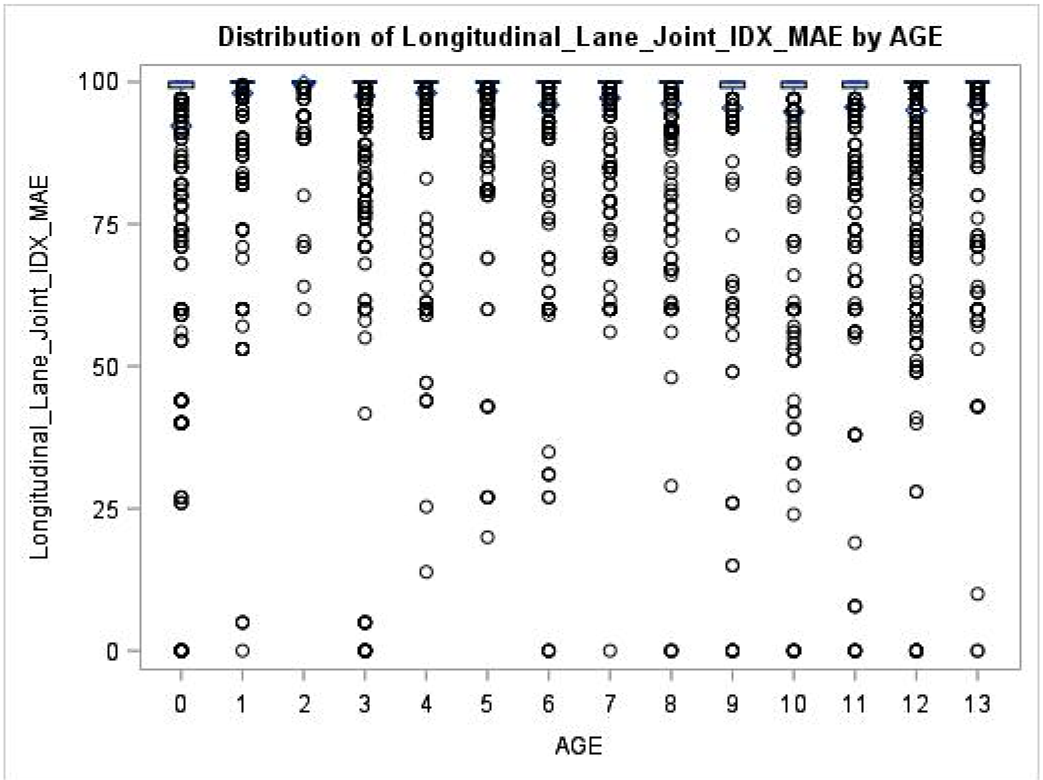

Figure 68: Schematic Box Plot for US_5_15k Longitudinal_Lane_Joint_IDX_MAE

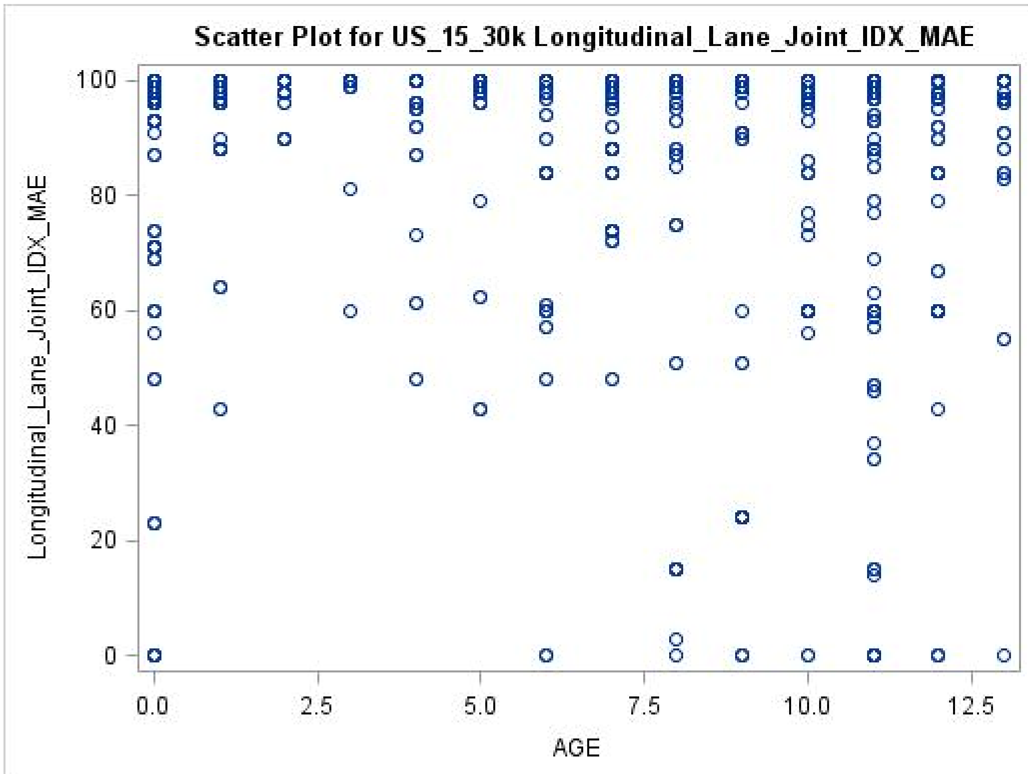

Figure 69: Scatter Plot for US_15_30k Longitudinal_Lane_Joint_IDX_MAE

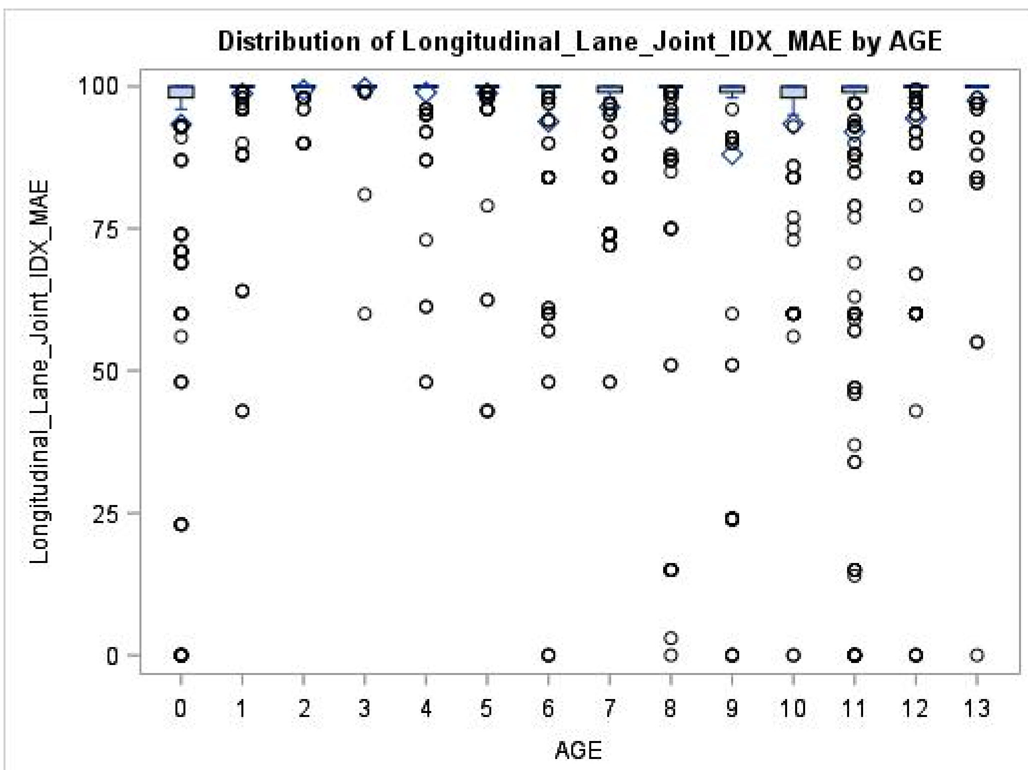

Figure 70: Schematic Box Plot for US_15_30k Longitudinal_Lane_Joint_IDX_MAE

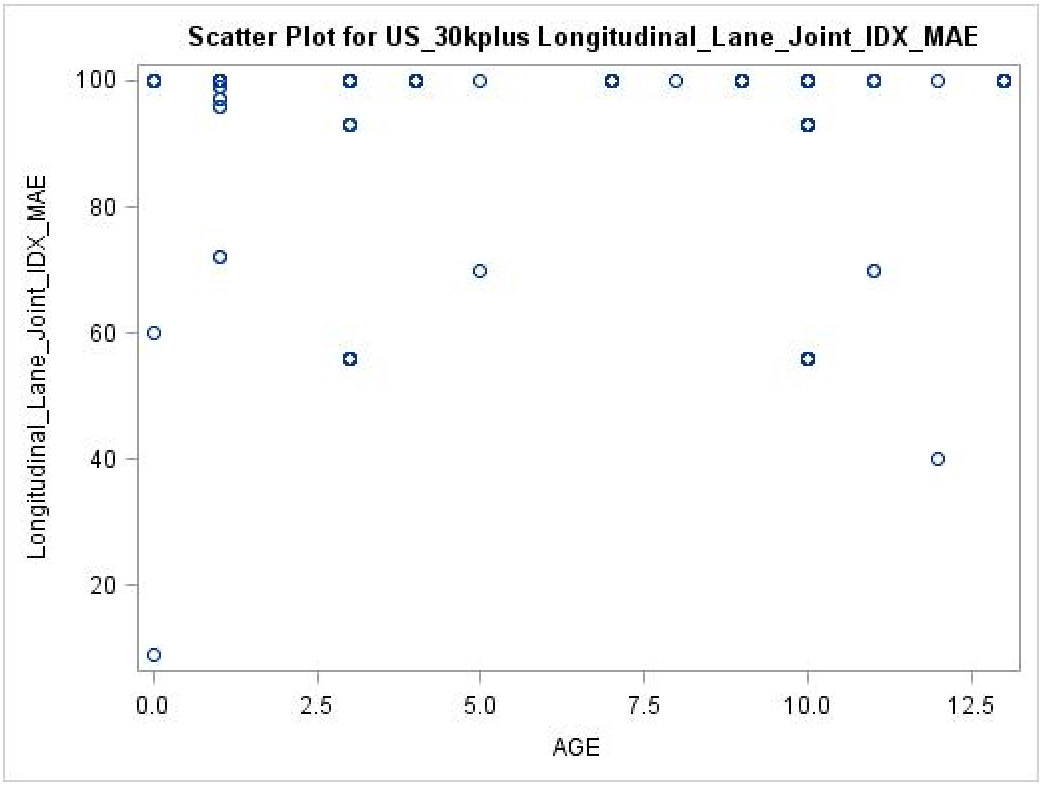

Figure 71: Scatter Plot for US_30kplus Longitudinal_Lane_Joint_IDX_MAE

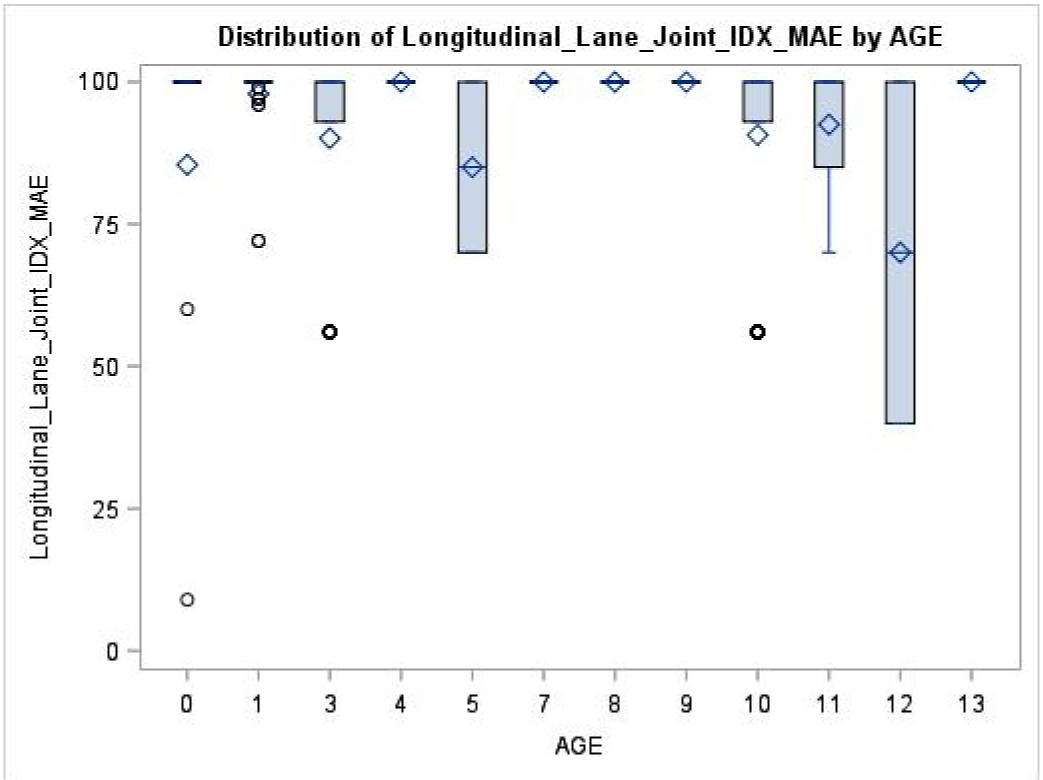

Figure 72: Schematic Box Plot for US_30kplus Longitudinal_Lane_Joint_IDX_MAE

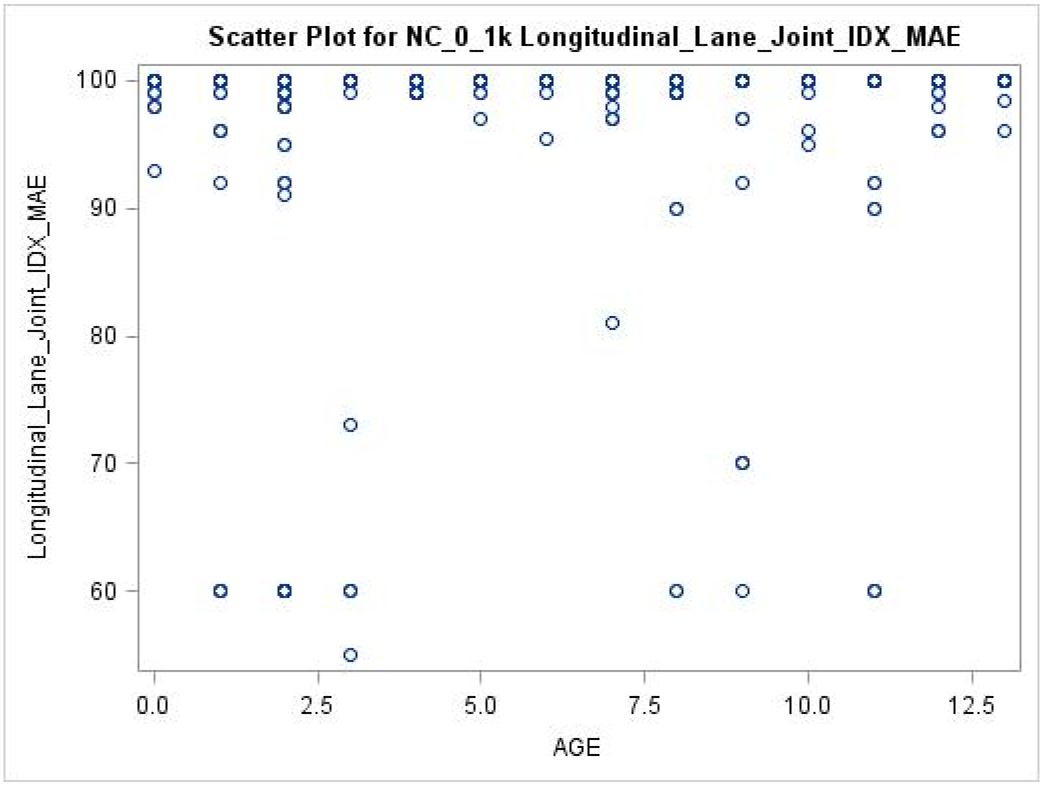

Figure 73: Scatter Plot for NC_0_1k Longitudinal_Lane_Joint_IDX_MAE

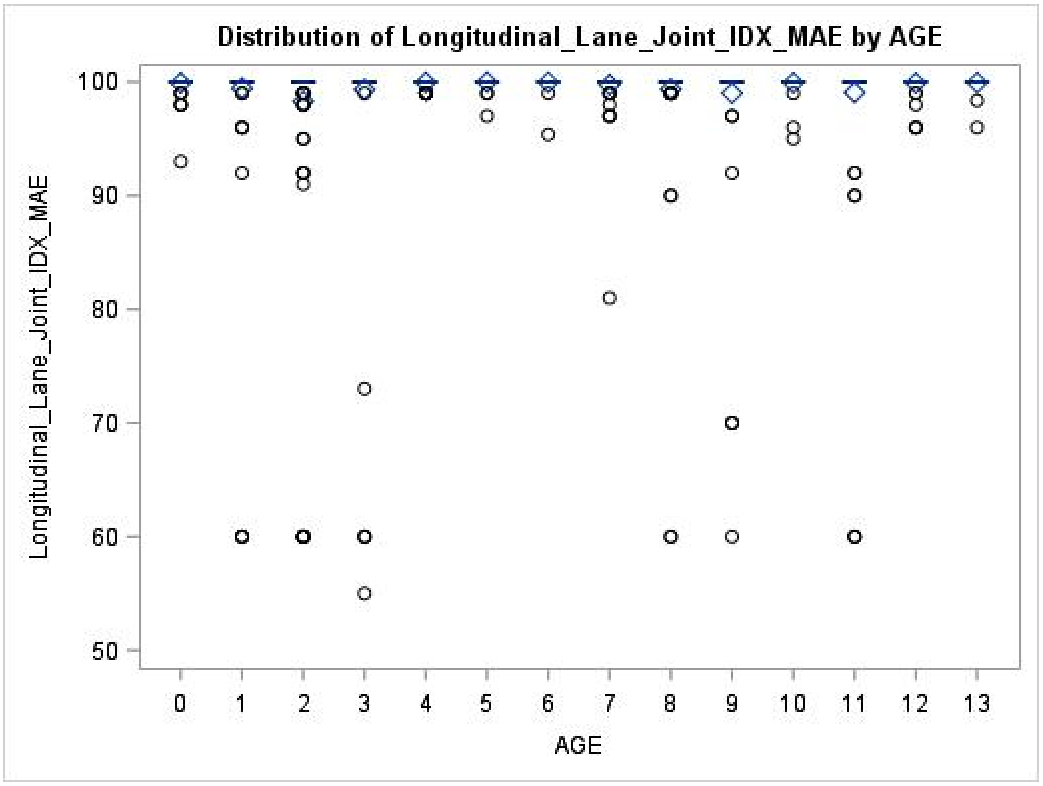

Figure 74: Schematic Box Plot for NC_0_1k Longitudinal_Lane_Joint_IDX_MAE

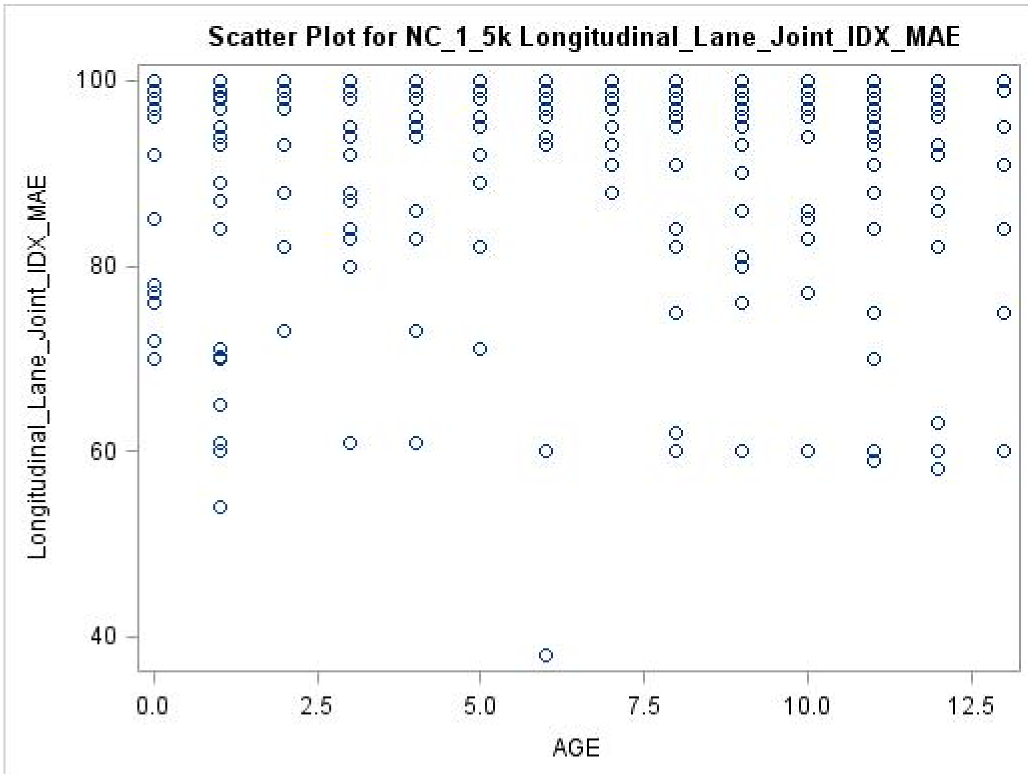

Figure 75: Scatter Plot for NC_1_5k Longitudinal_Lane_Joint_IDX_MAE

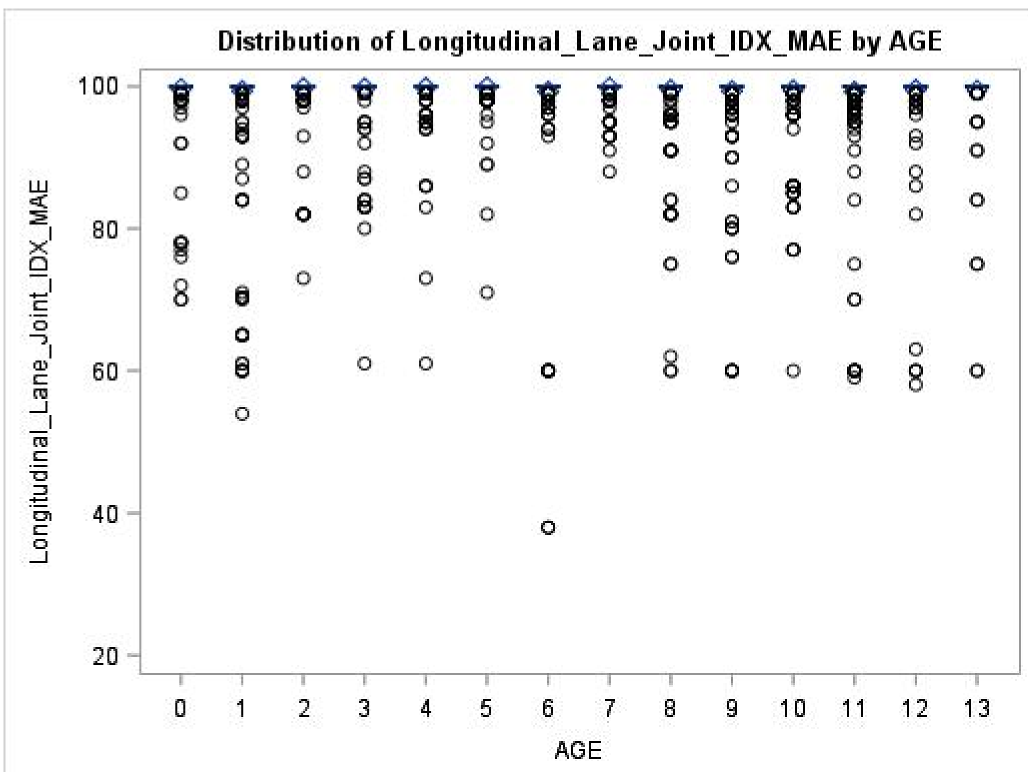

Figure 76: Schematic Box Plot for NC_1_5k Longitudinal_Lane_Joint_IDX_MAE

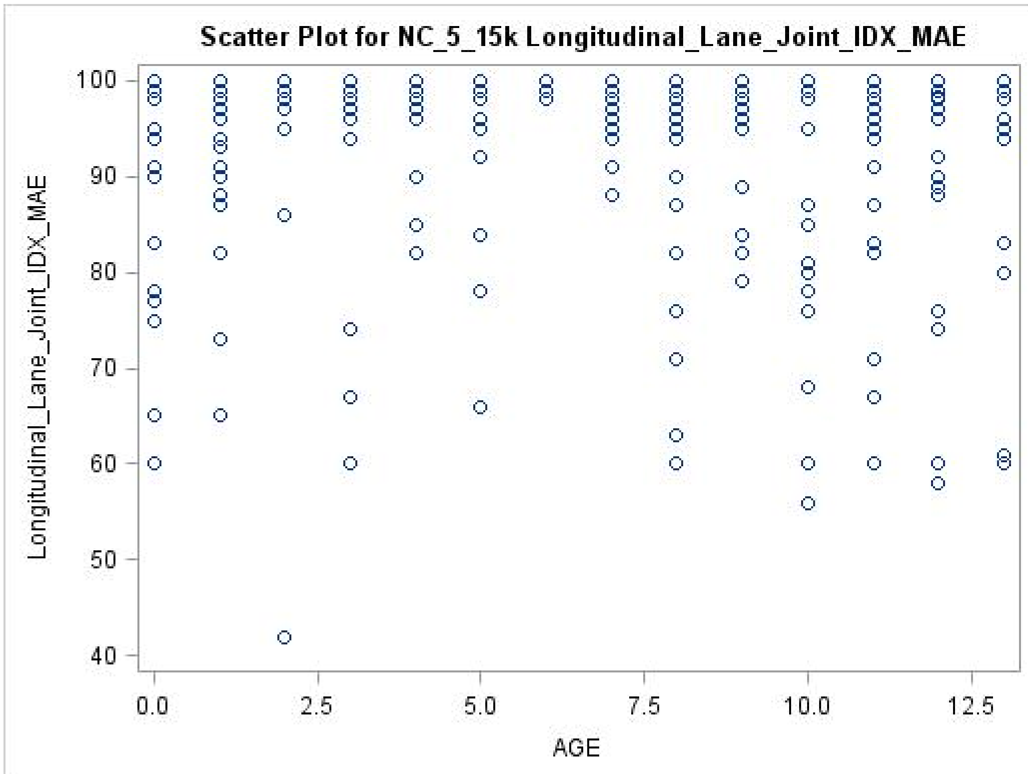

Figure 77: Scatter Plot for NC_5_15k Longitudinal_Lane_Joint_IDX_MAE

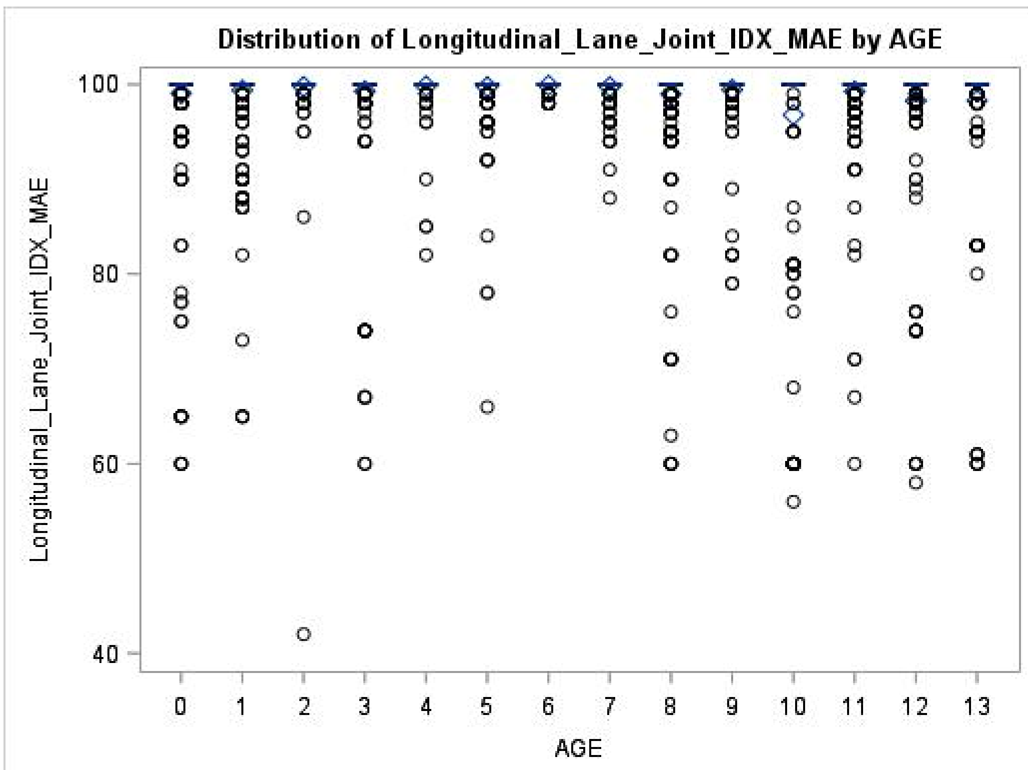

Figure 78: Schematic Box Plot for NC_5_15k Longitudinal_Lane_Joint_IDX_MAE

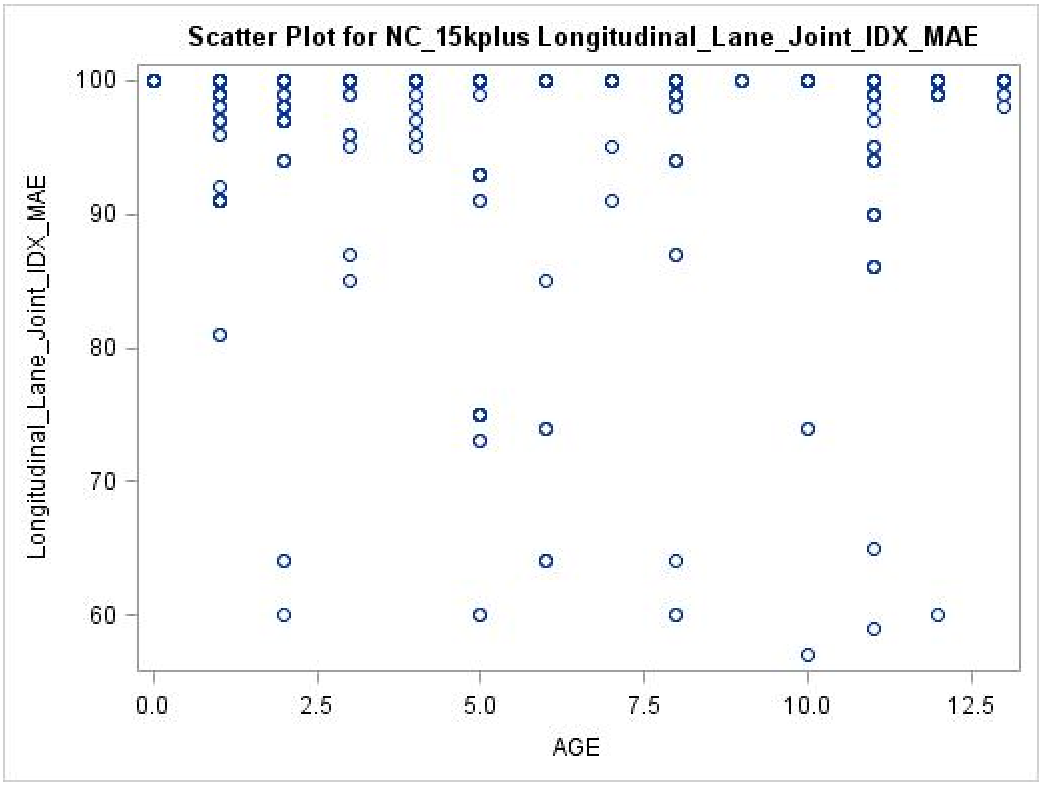

Figure 79: Scatter Plot for NC_15kplus Longitudinal_Lane_Joint_IDX_MAE

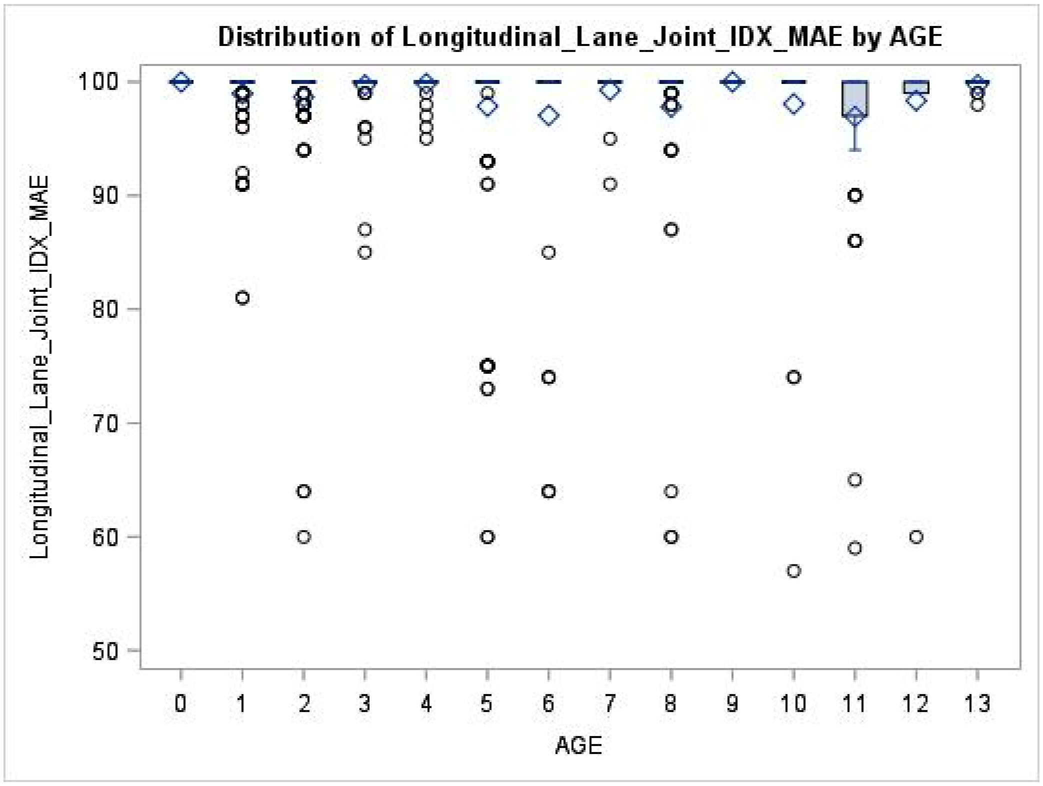

Figure 80: Schematic Box Plot for NC_15kplus Longitudinal_Lane_Joint_IDX_MAE

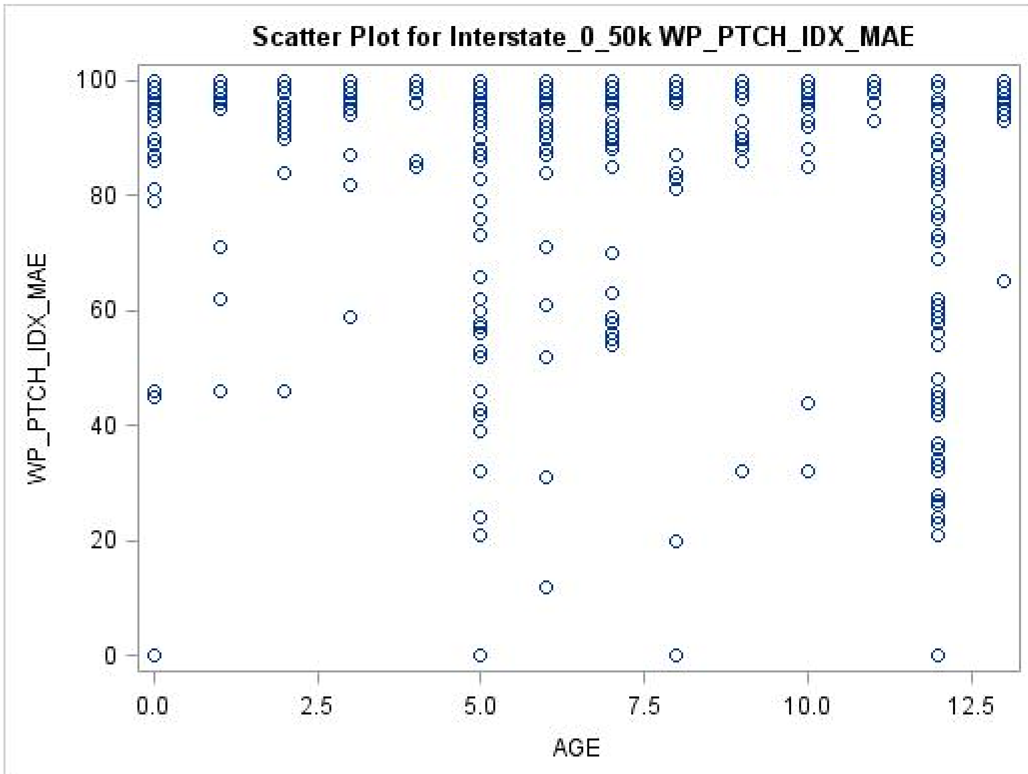

Figure 81: Scatter Plot for Interstate_0_50k WP_PTCH_IDX_MAE

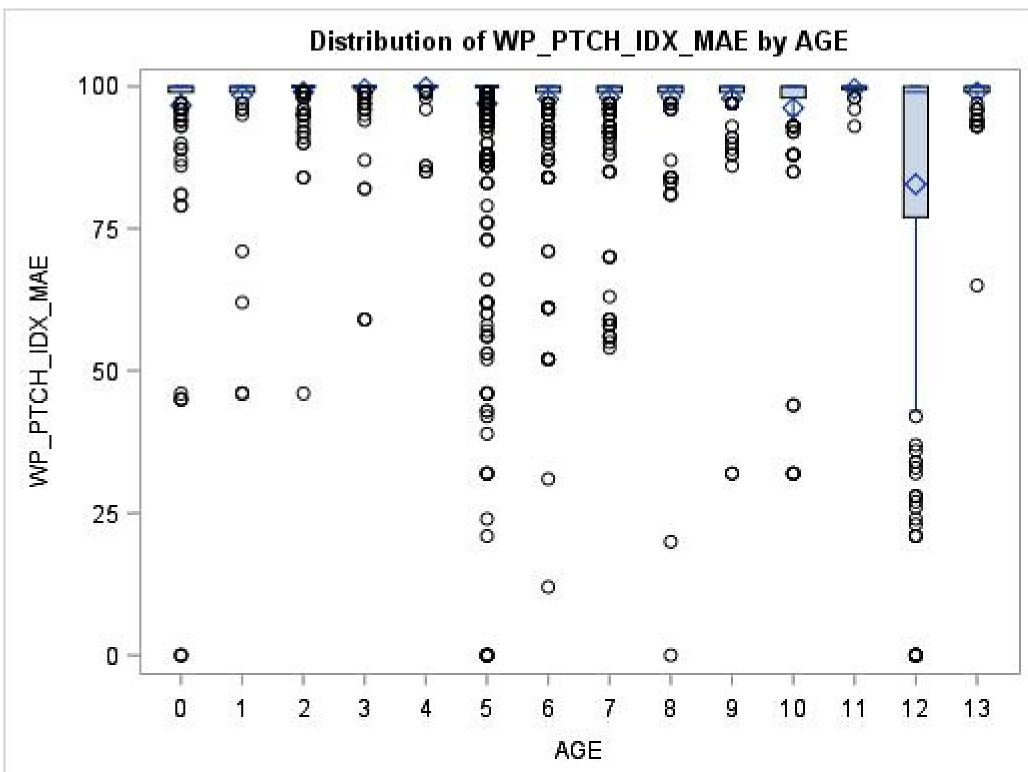

Figure 82: Schematic Box Plot for Interstate_0_50k WP_PTCH_IDX_MAE

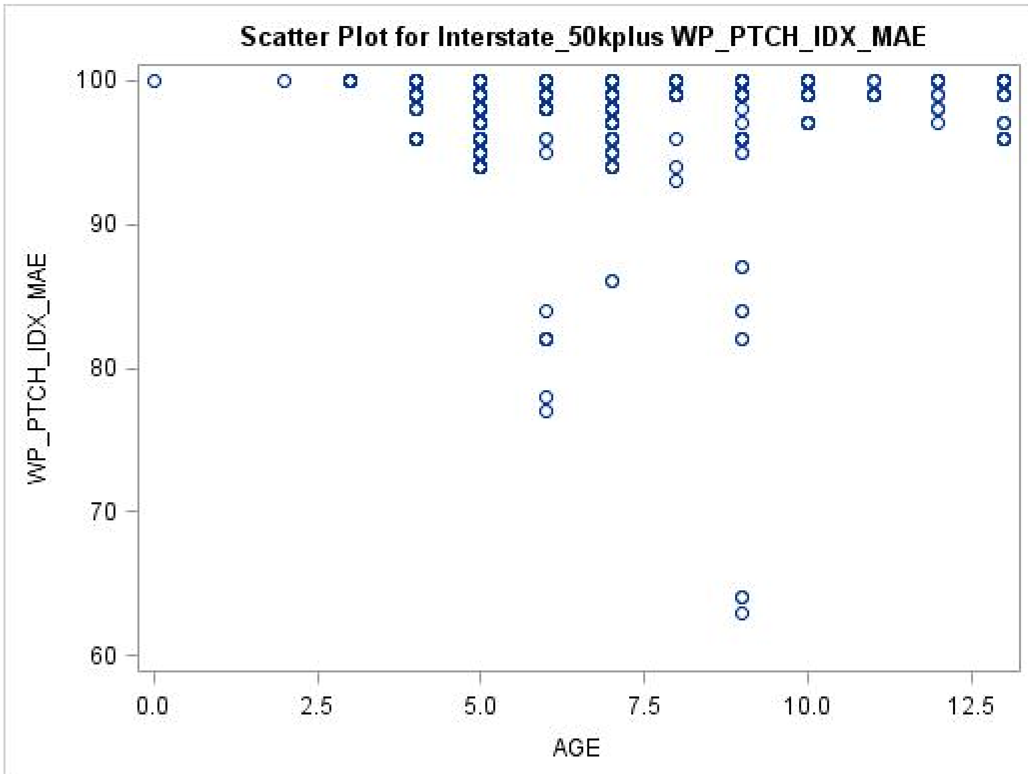

Figure 83: Scatter Plot for Interstate_50kplus WP_PTCH_IDX_MAE

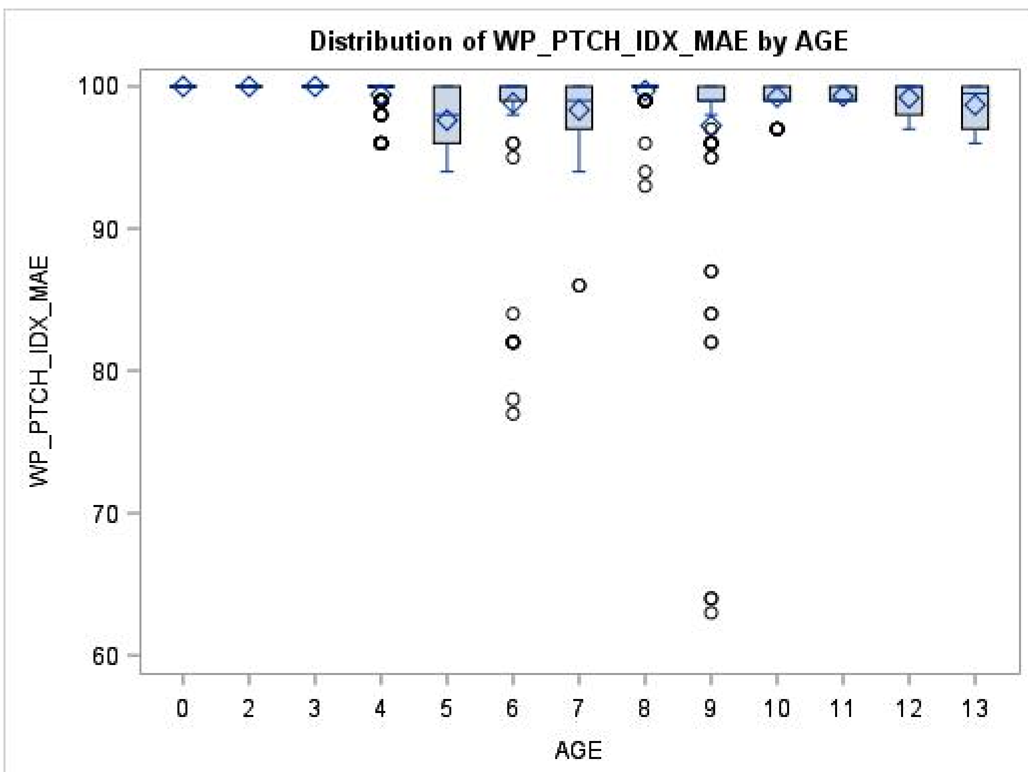

Figure 84: Schematic Box Plot for Interstate_50kplus WP_PTCH_IDX_MAE

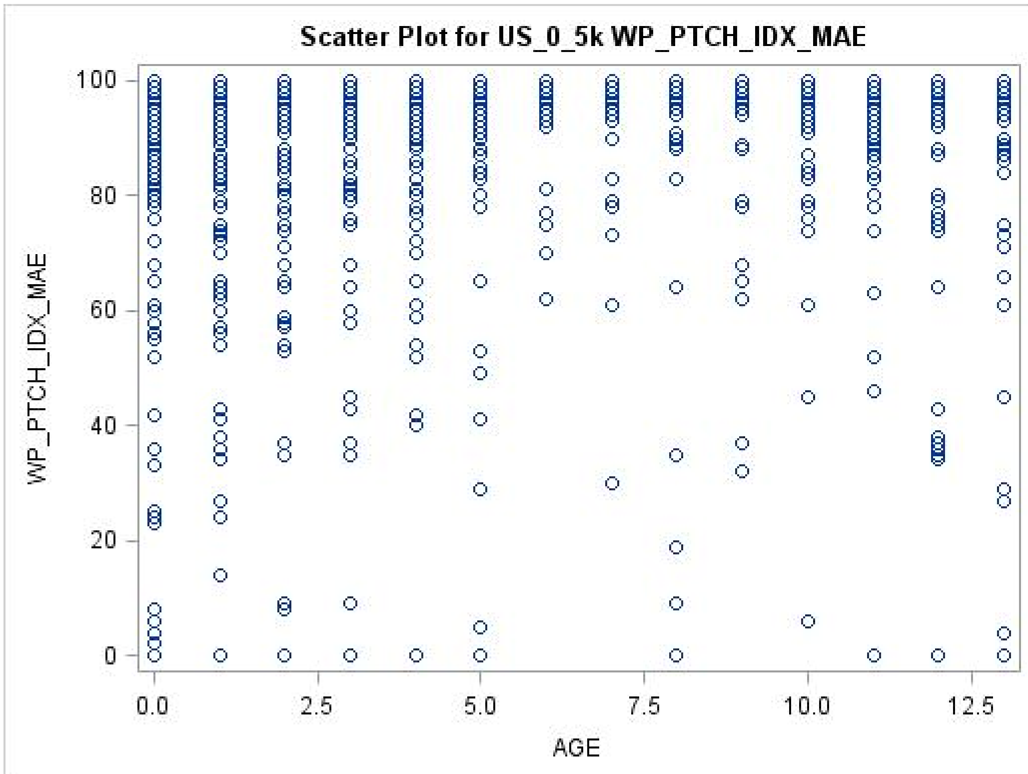

Figure 85: Scatter Plot for US_0_5k WP_PTCH_IDX_MAE

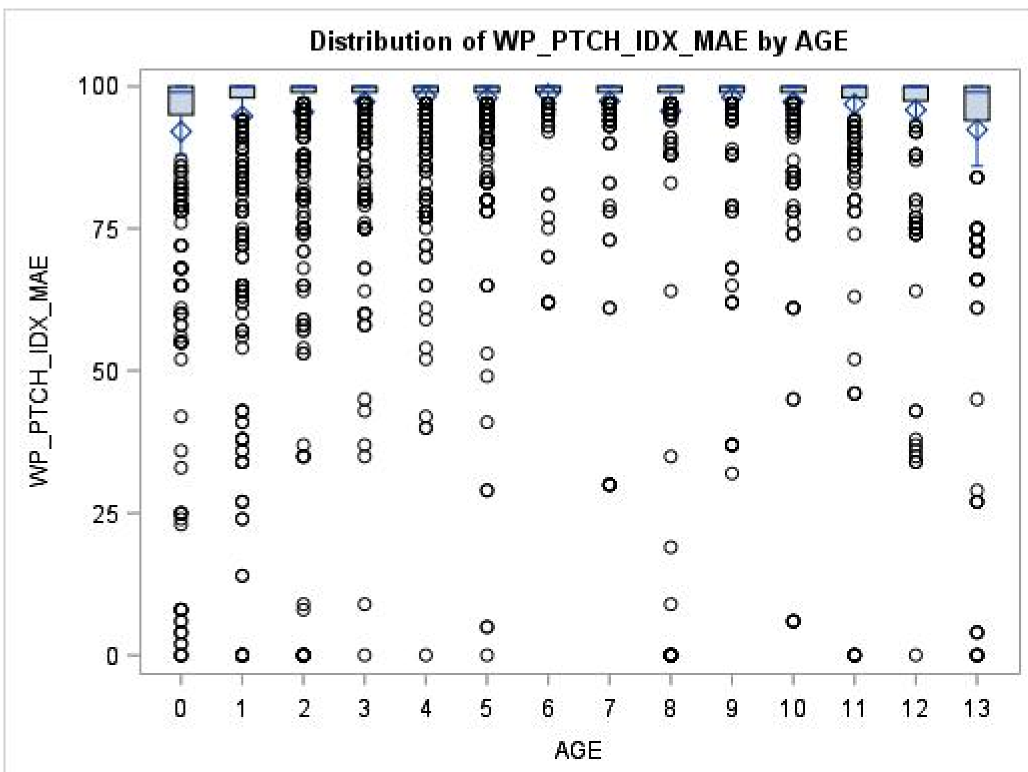

Figure 86: Schematic Box Plot for US_0_5k WP_PTCH_IDX_MAE

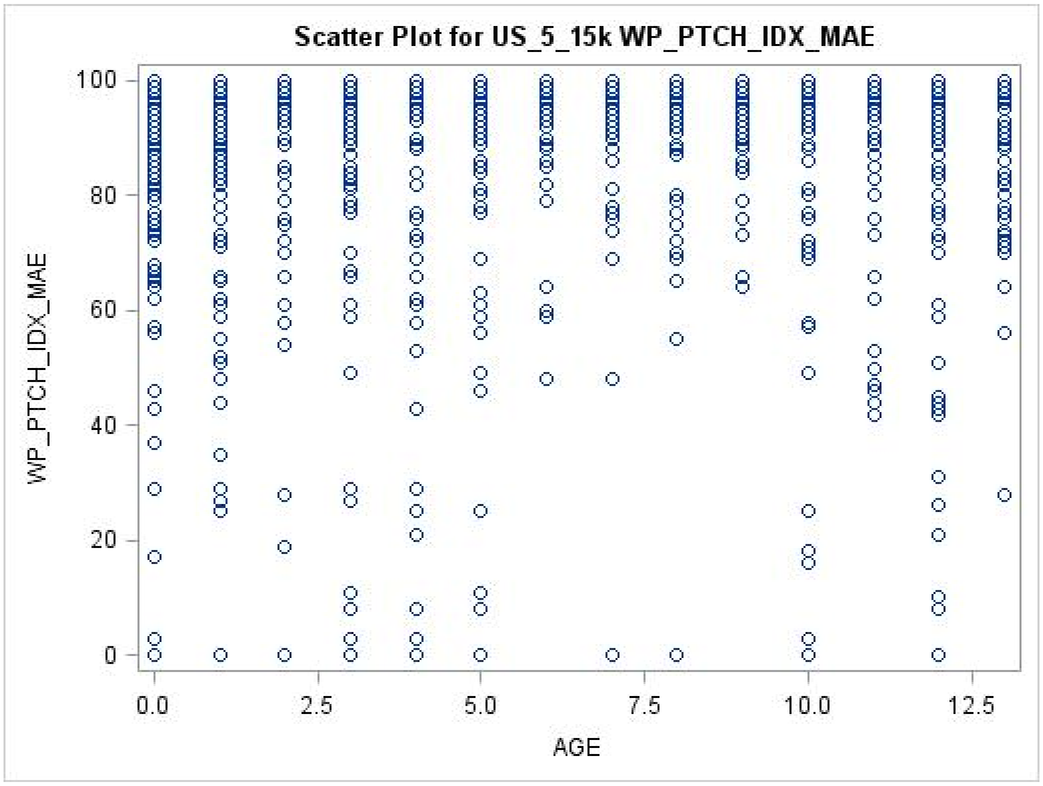

Figure 87: Scatter Plot for US_5_15k WP_PTCH_IDX_MAE

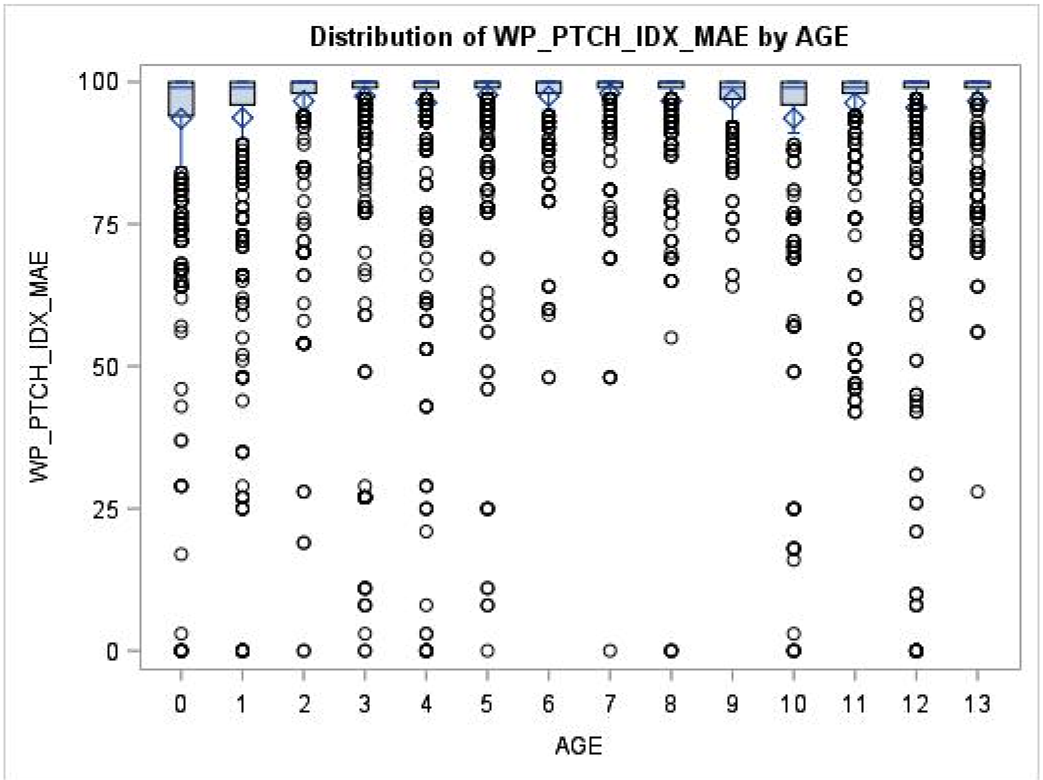

Figure 88: Schematic Box Plot for US_5_15k WP_PTCH_IDX_MAE

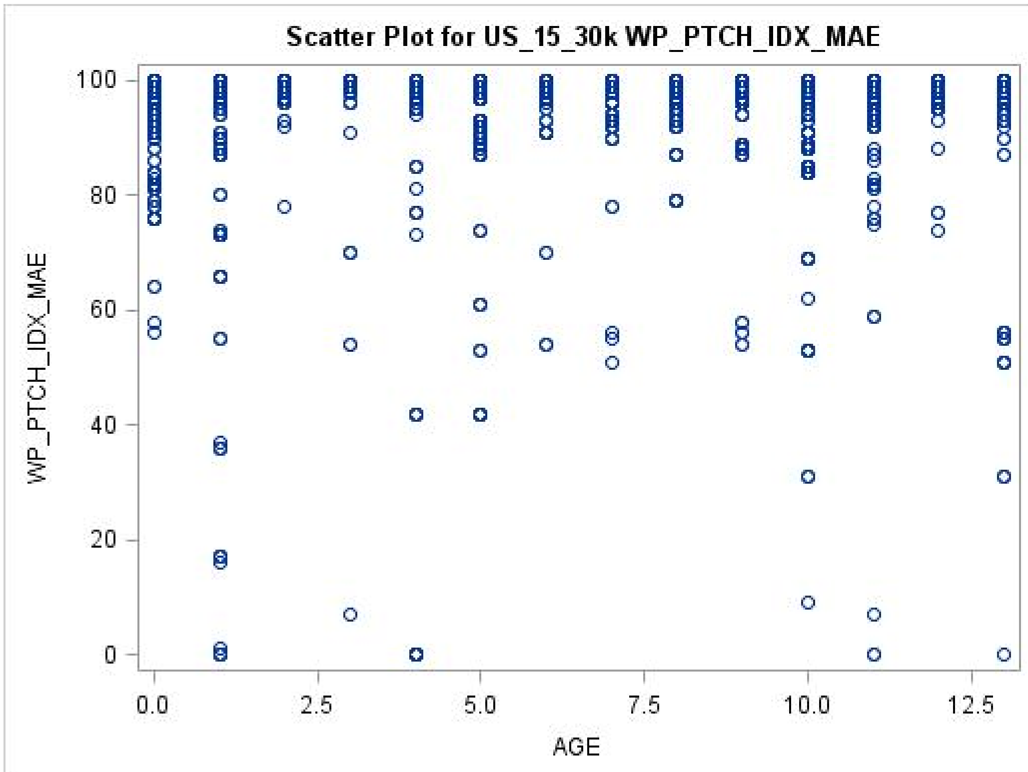

Figure 89: Scatter Plot for US_15_30k WP_PTCH_IDX_MAE

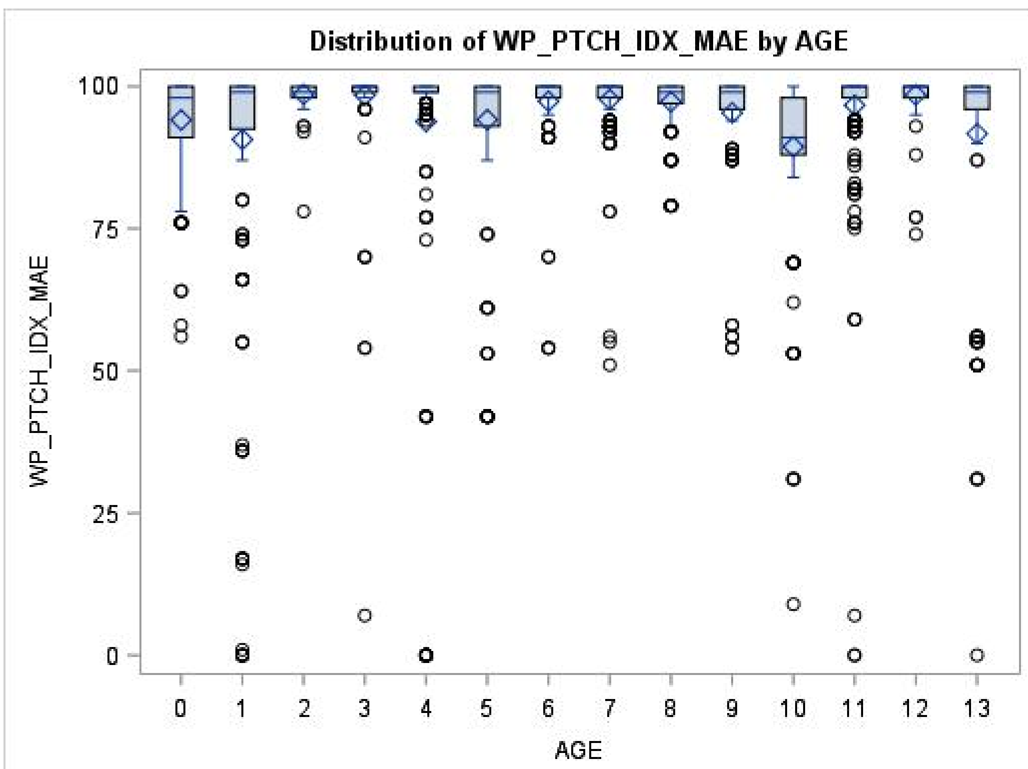

Figure 90: Schematic Box Plot for US_15_30k WP_PTCH_IDX_MAE

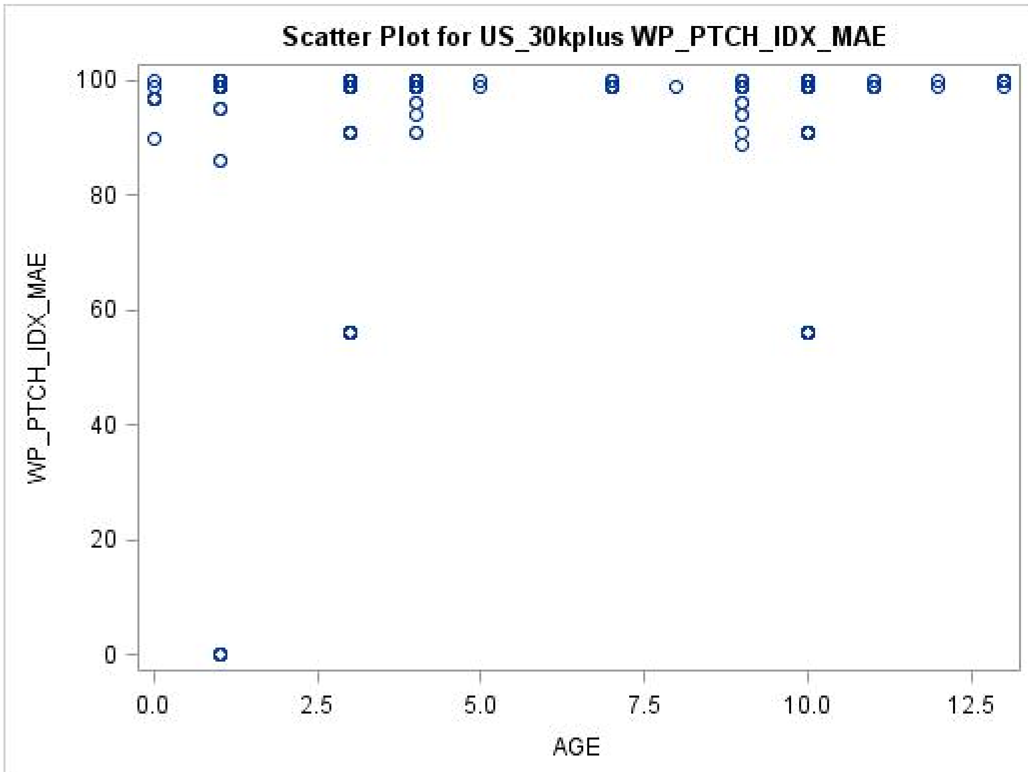

Figure 91: Scatter Plot for US_30kplus WP_PTCH_IDX_MAE

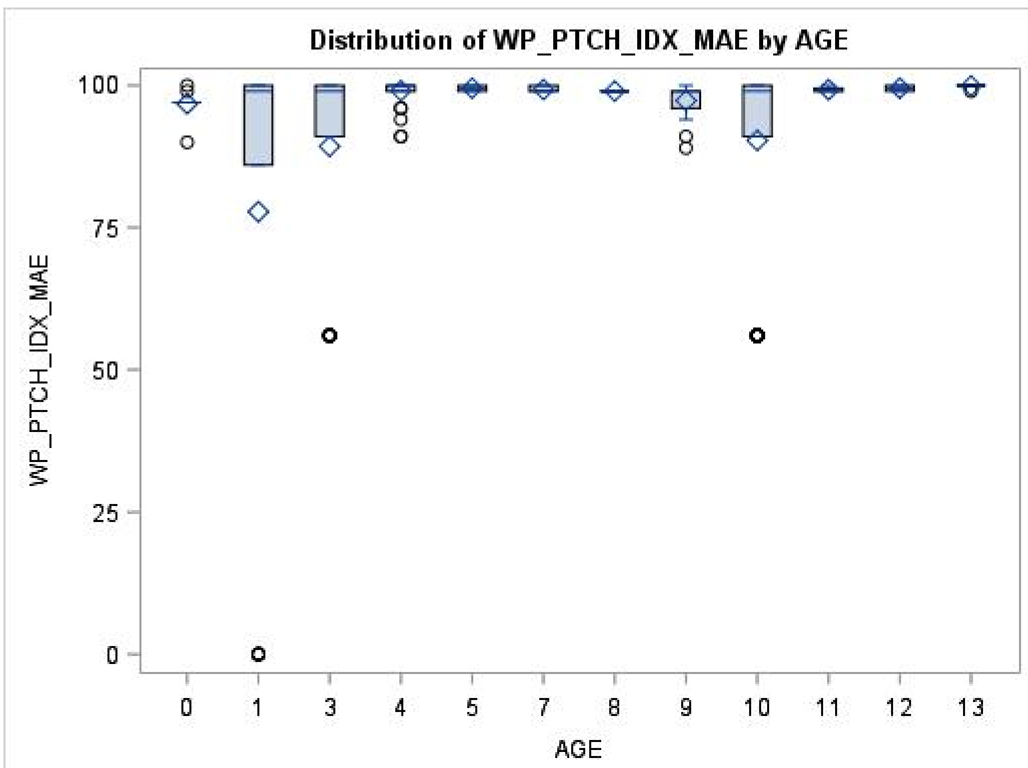

Figure 92: Schematic Box Plot for US_30kplus WP_PTCH_IDX_MAE

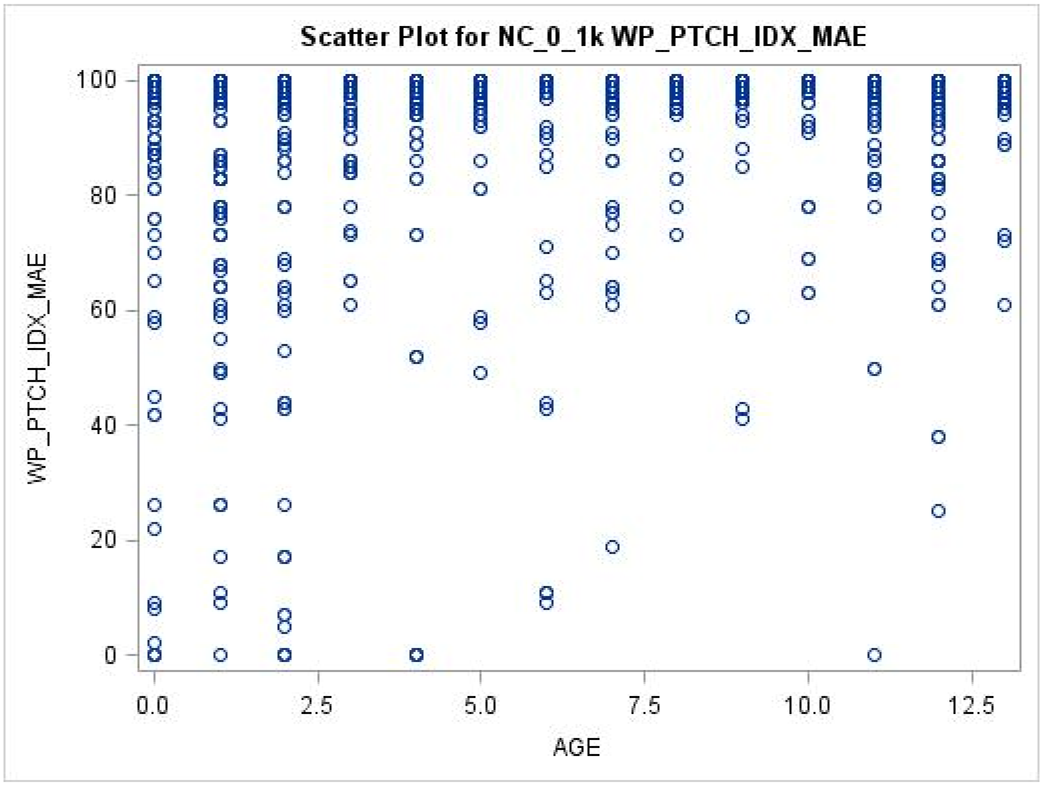

Figure 93: Scatter Plot for NC_0_1k WP_PTCH_IDX_MAE

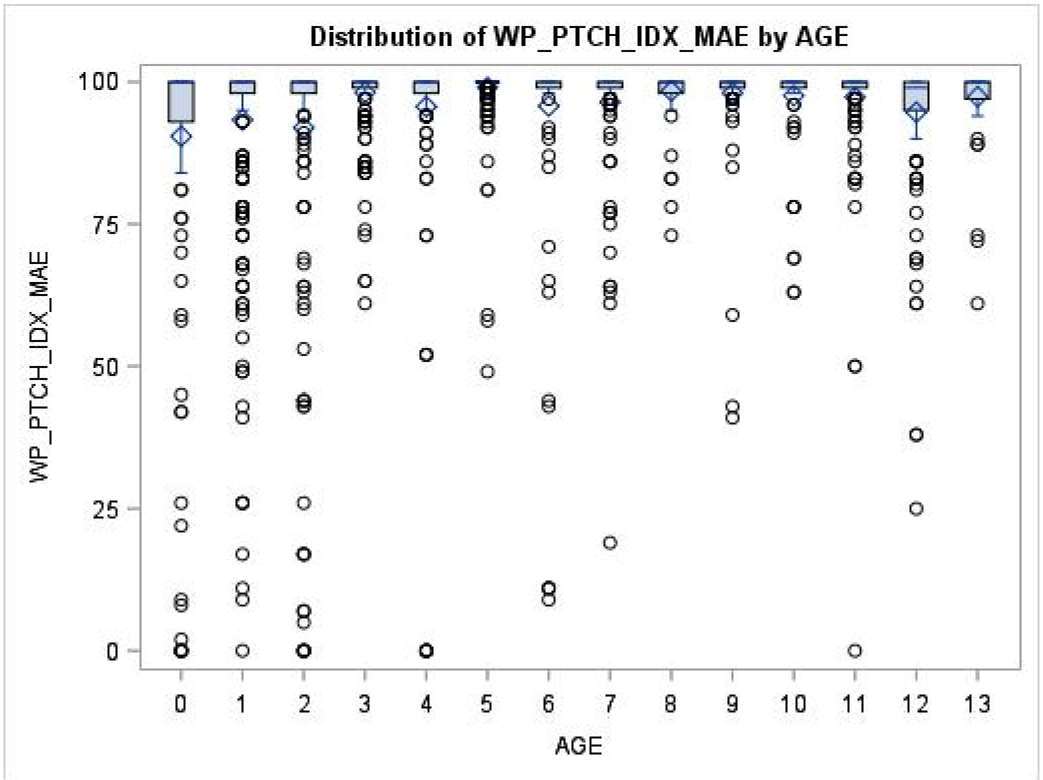

Figure 94: Schematic Box Plot for NC_0_1k WP_PTCH_IDX_MAE

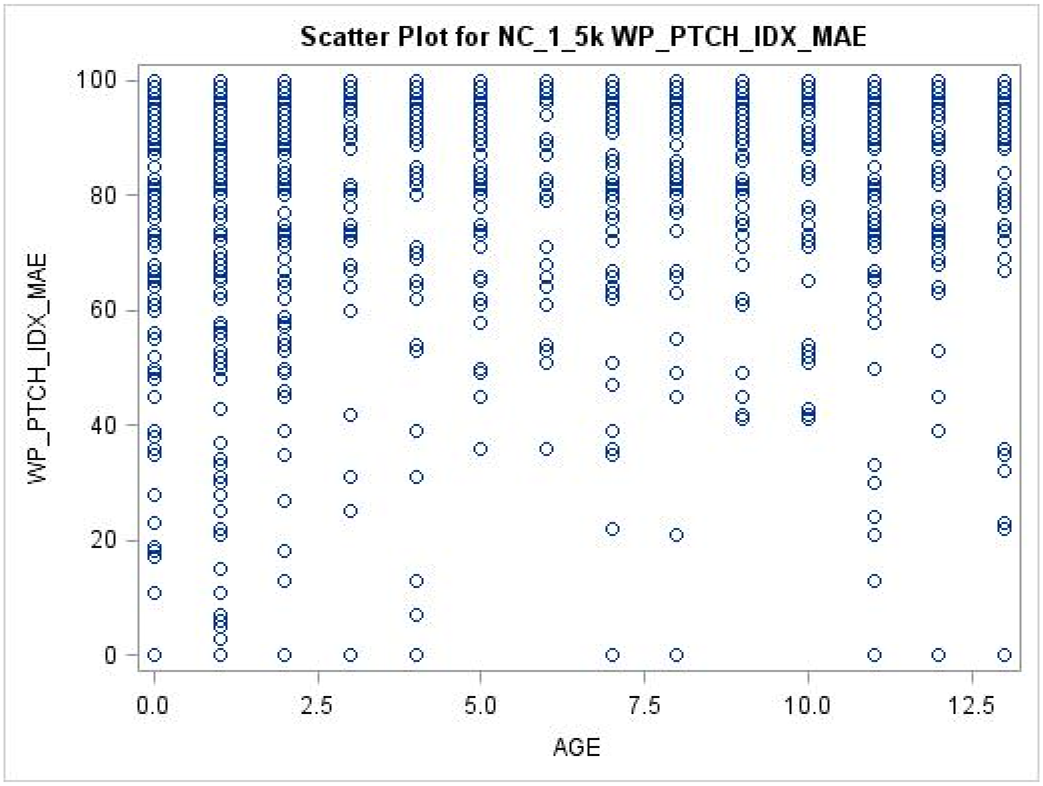

Figure 95: Scatter Plot for NC_1_5k WP_PTCH_IDX_MAE

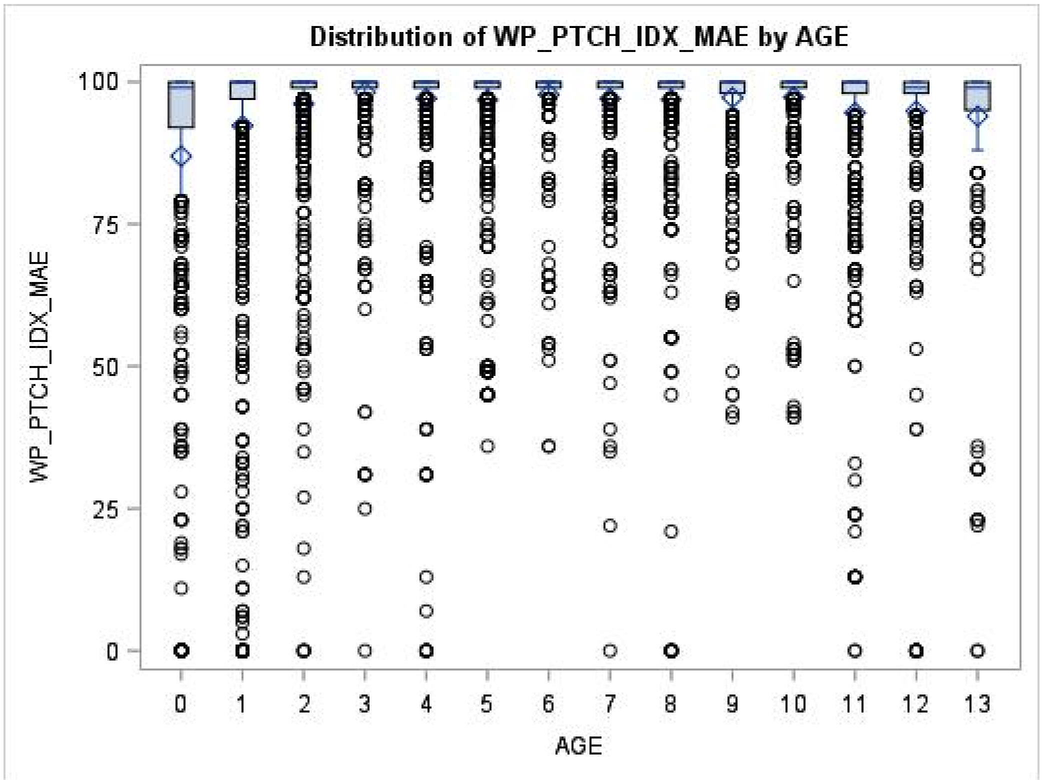

Figure 96: Schematic Box Plot for NC_1_5k WP_PTCH_IDX_MAE

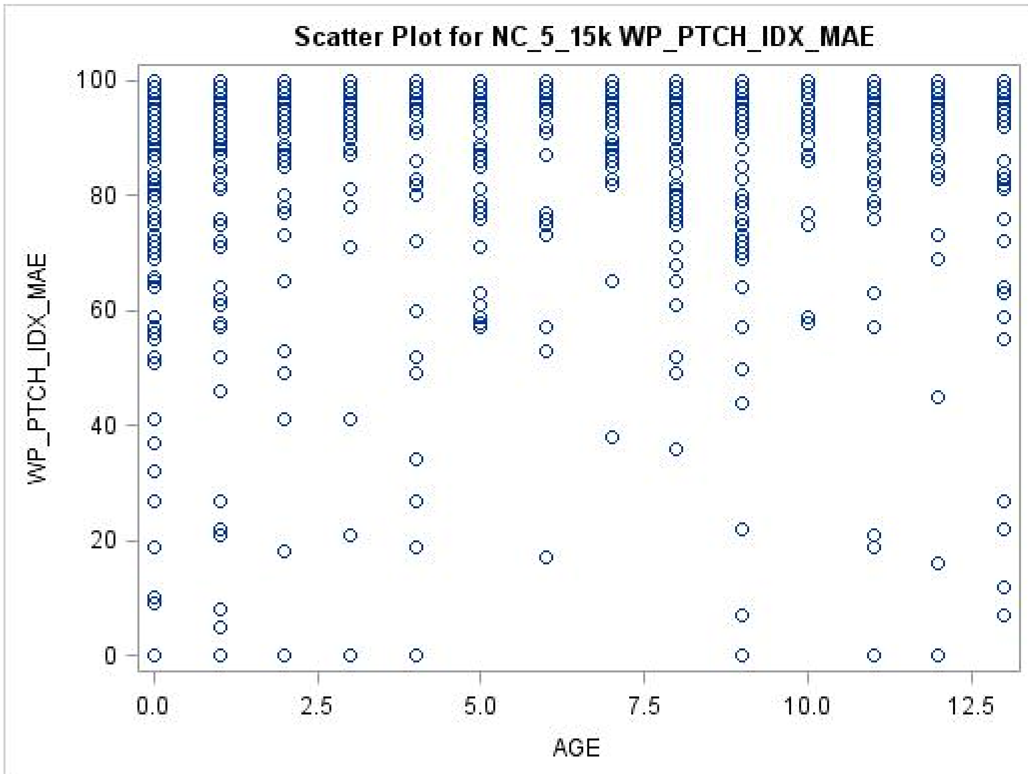

Figure 97: Scatter Plot for NC_5_15k WP_PTCH_IDX_MAE

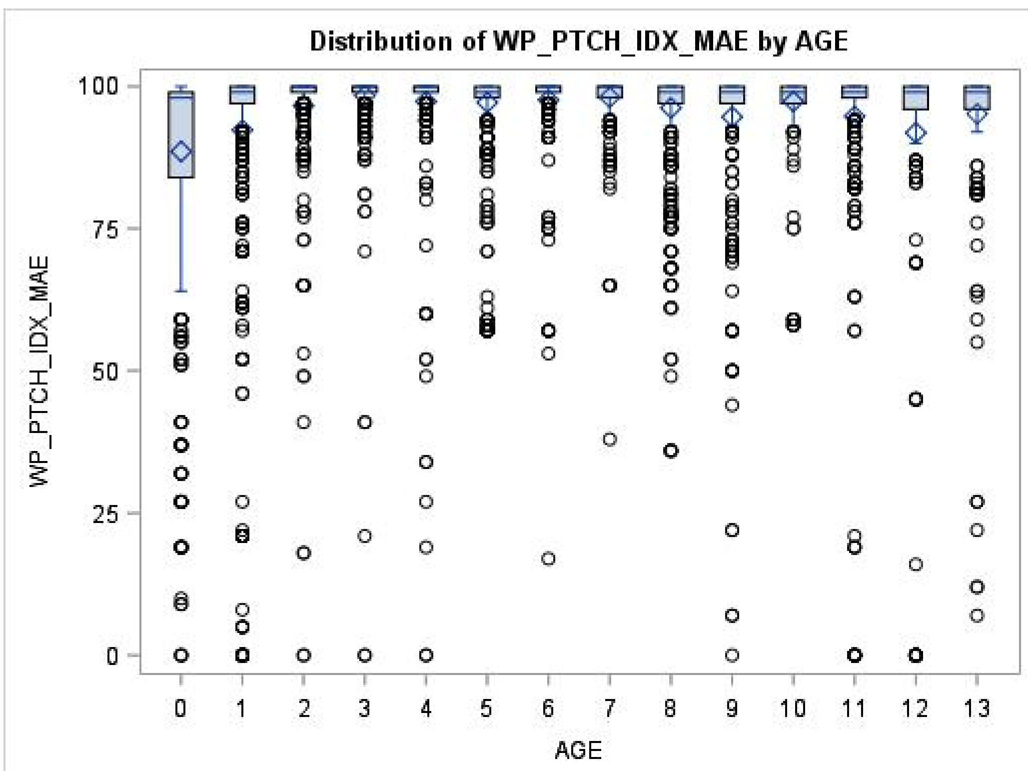

Figure 98: Schematic Box Plot for NC_5_15k WP_PTCH_IDX_MAE

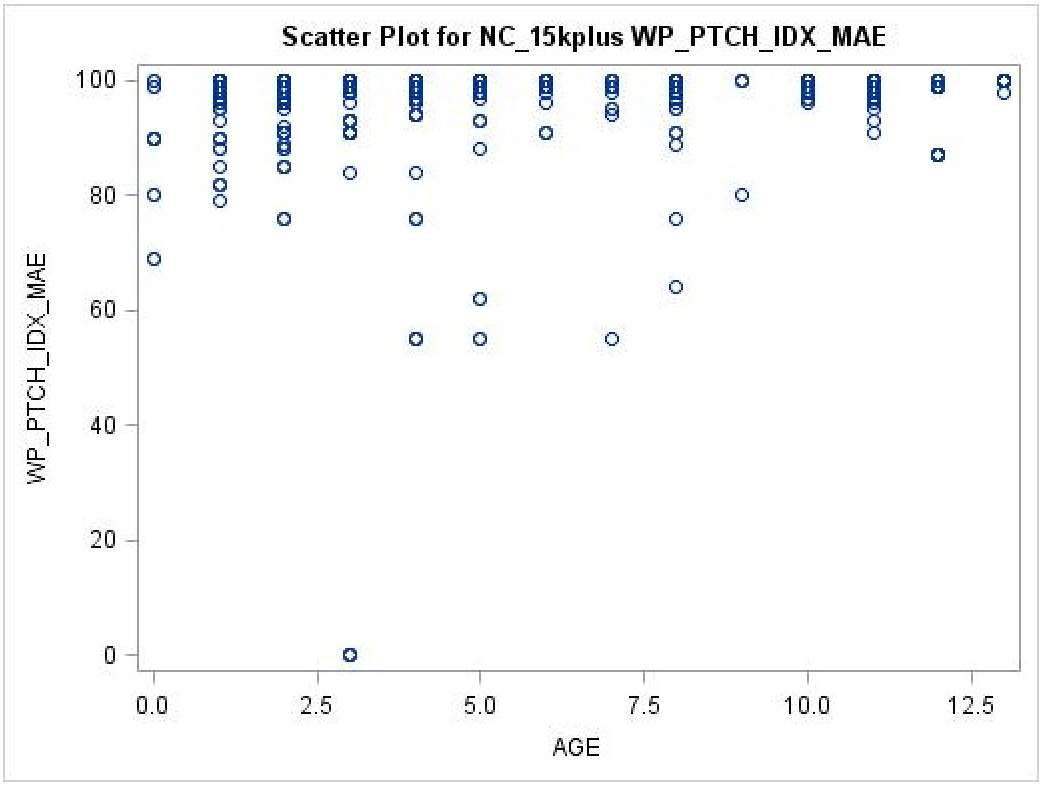

Figure 99: Scatter Plot for NC_15kplus WP_PTCH_IDX_MAE

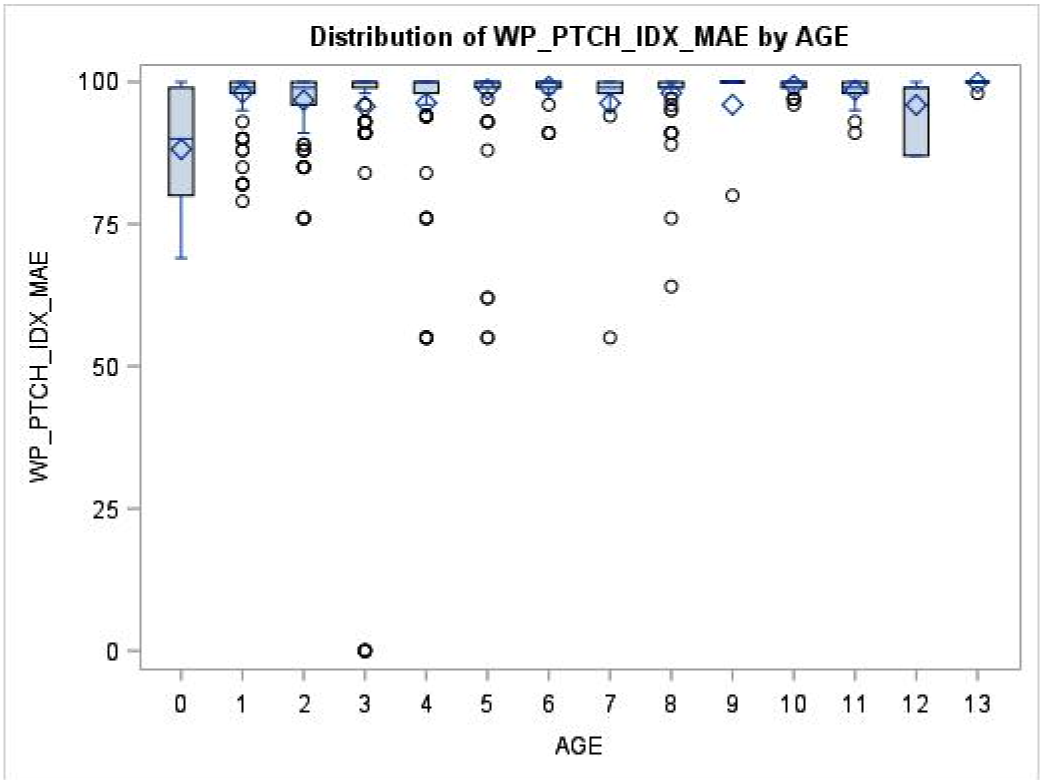

Figure 100: Schematic Box Plot for NC_15kplus WP_PTCH_IDX_MAE

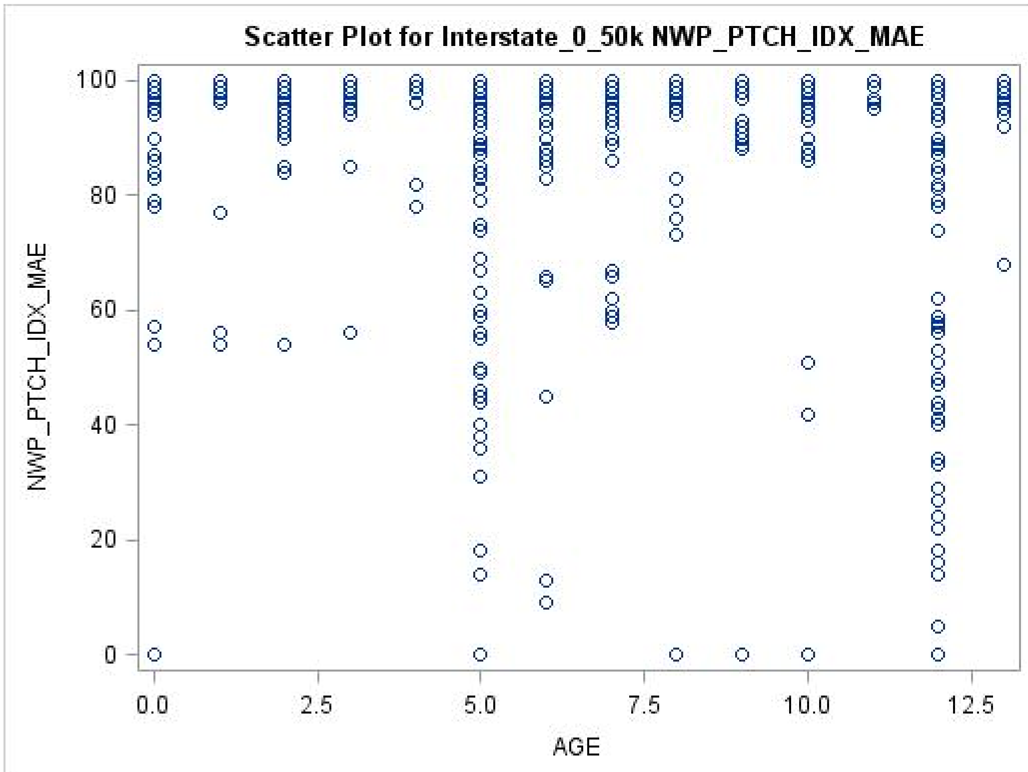

Figure 101: Scatter Plot for Interstate_0_50k NWP_PTCH_IDX_MAE

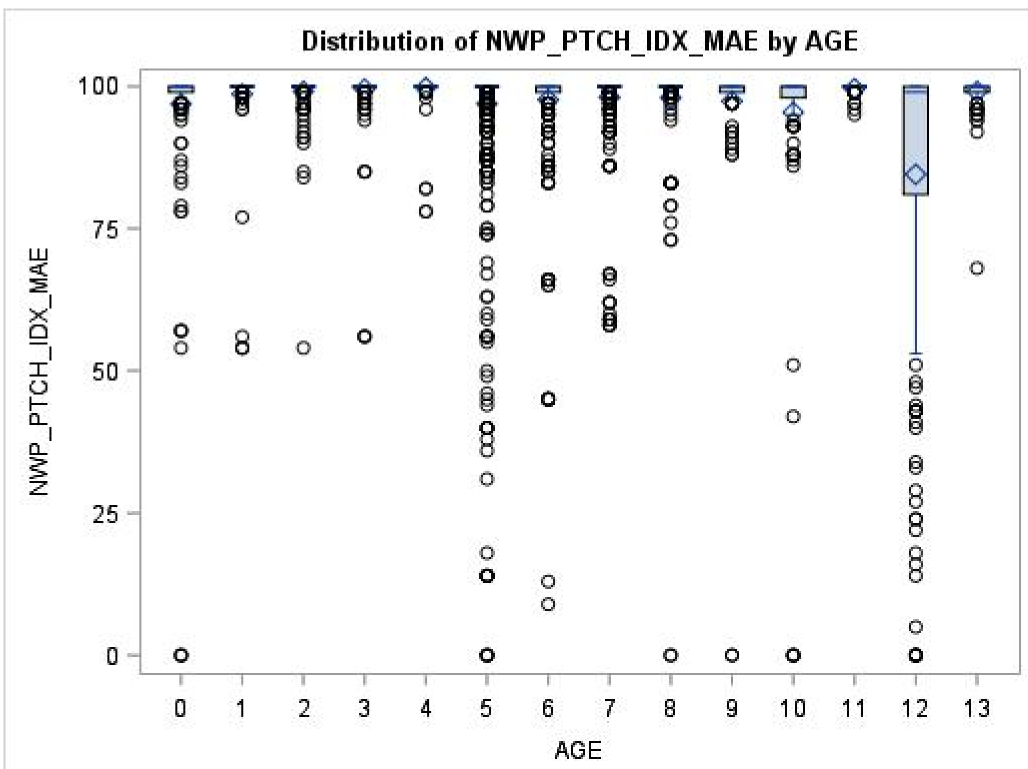

Figure 102: Schematic Box Plot for Interstate_0_50k NWP_PTCH_IDX_MAE

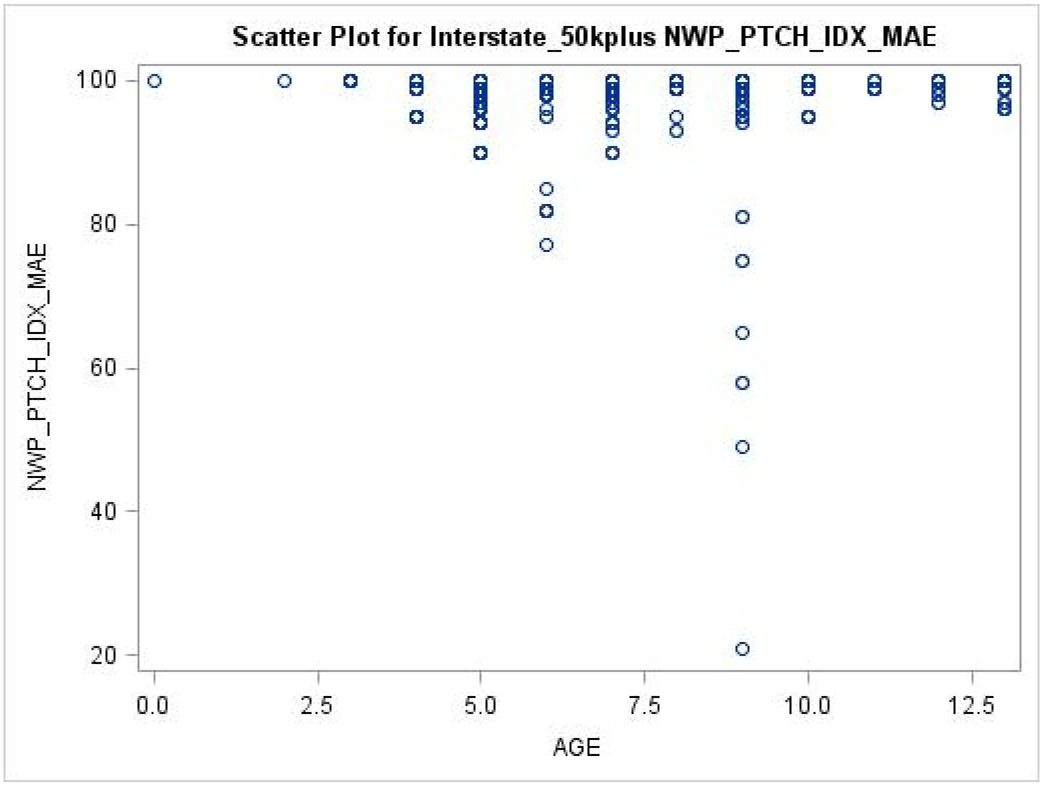

Figure 103: Scatter Plot for Interstate_50kplus NWP_PTCH_IDX_MAE

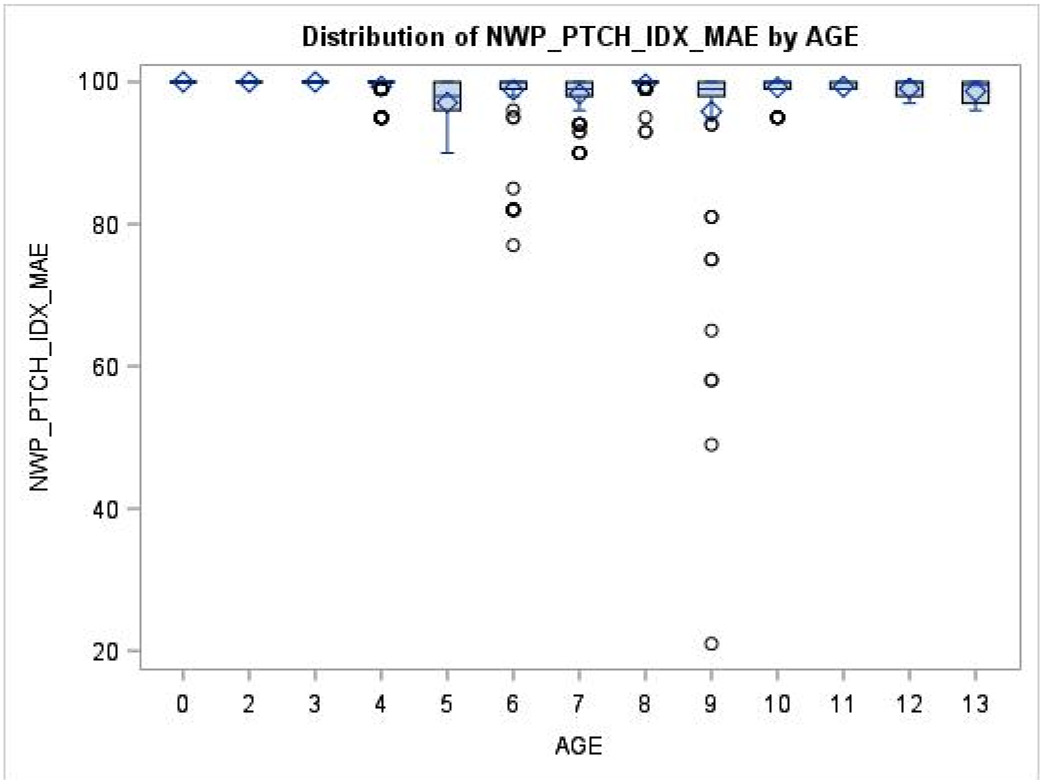

Figure 104: Schematic Box Plot for Interstate_50kplus NWP_PTCH_IDX_MAE

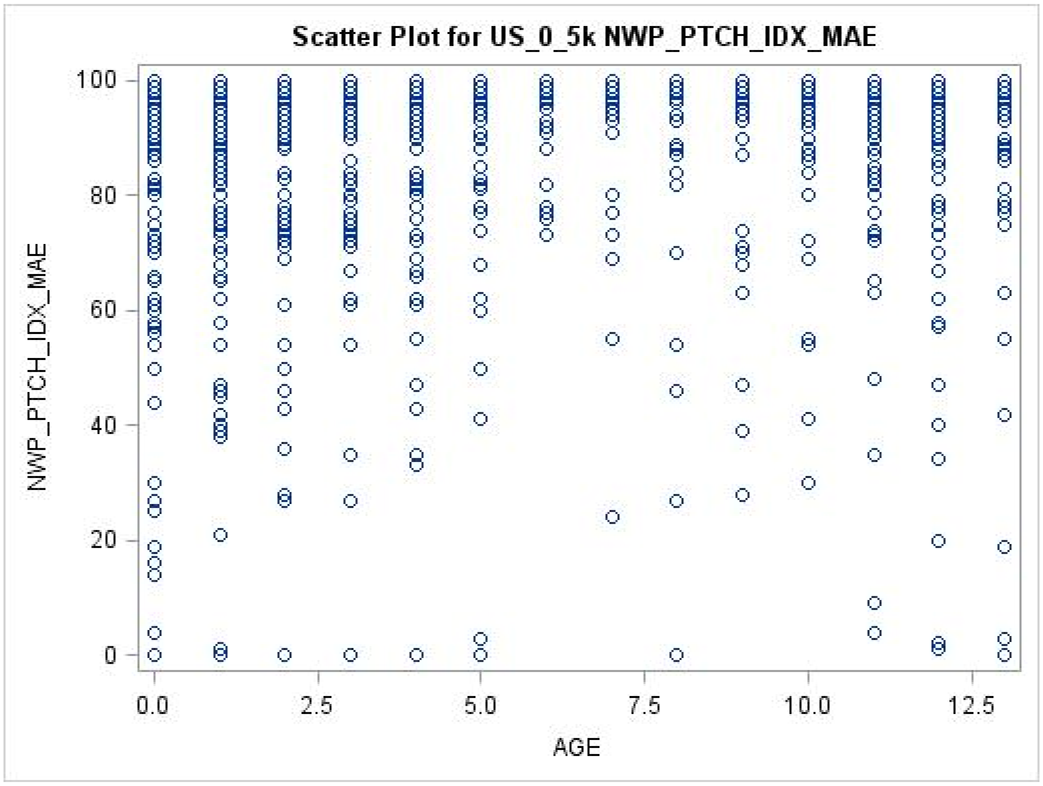

Figure 105: Scatter Plot for US_0_5k NWP_PTCH_IDX_MAE

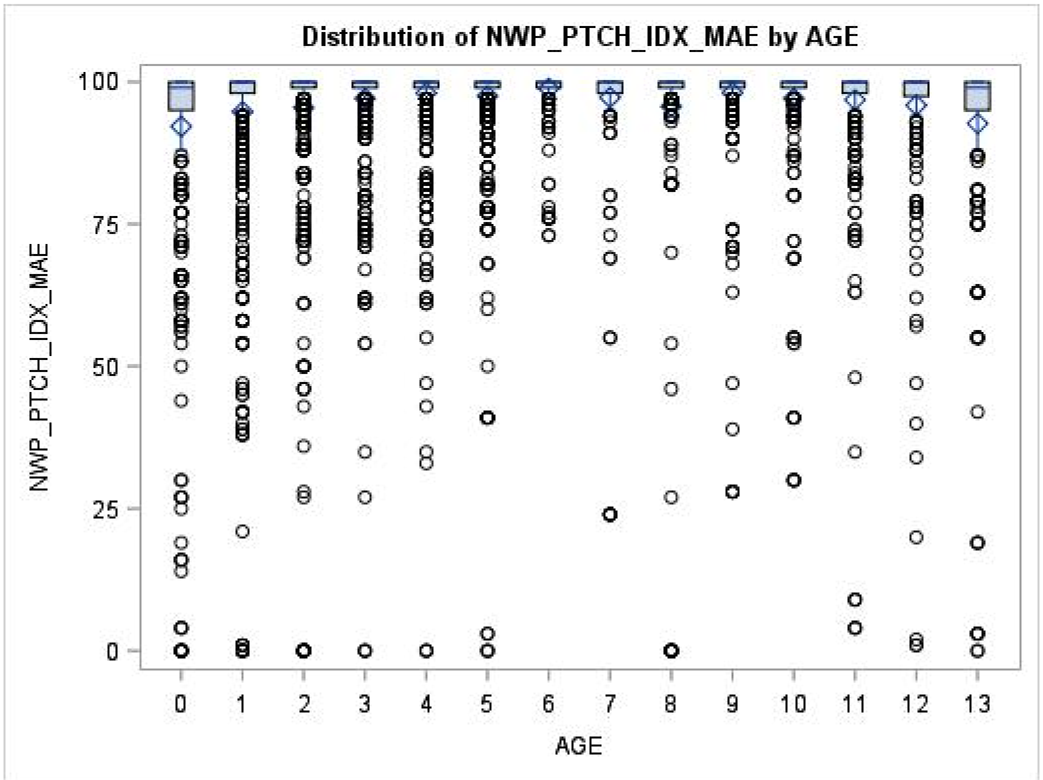

Figure 106: Schematic Box Plot for US_0_5k NWP_PTCH_IDX_MAE

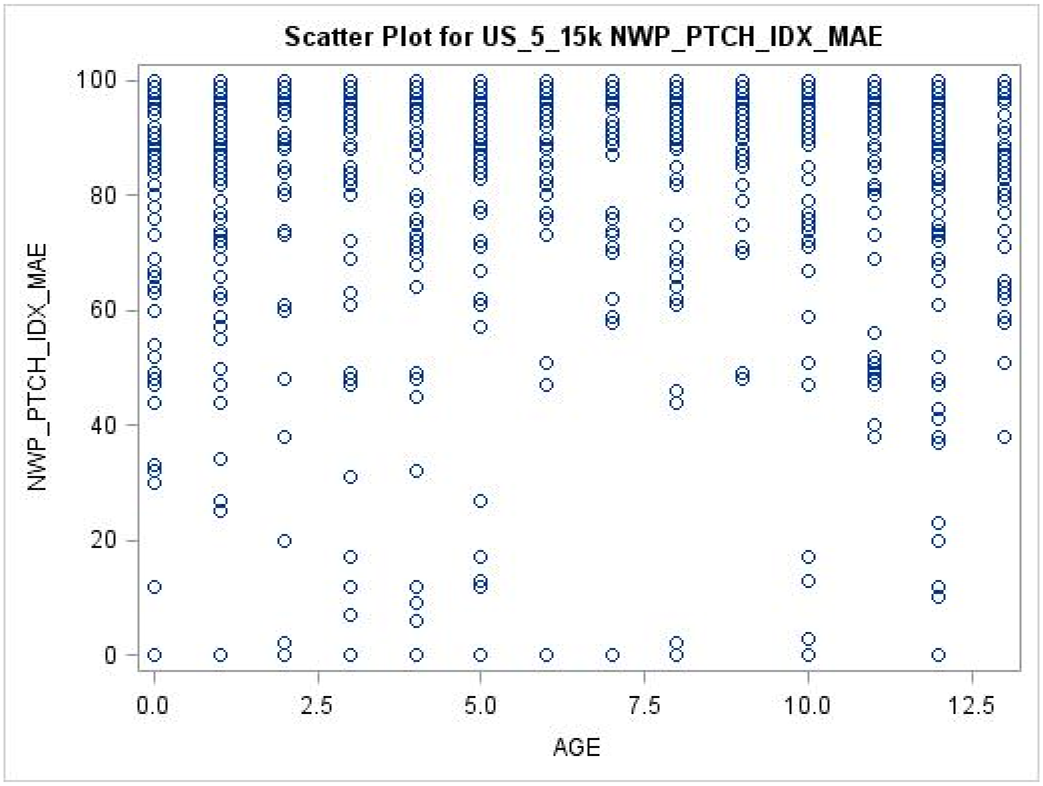

Figure 107: Scatter Plot for US_5_15k NWP_PTCH_IDX_MAE

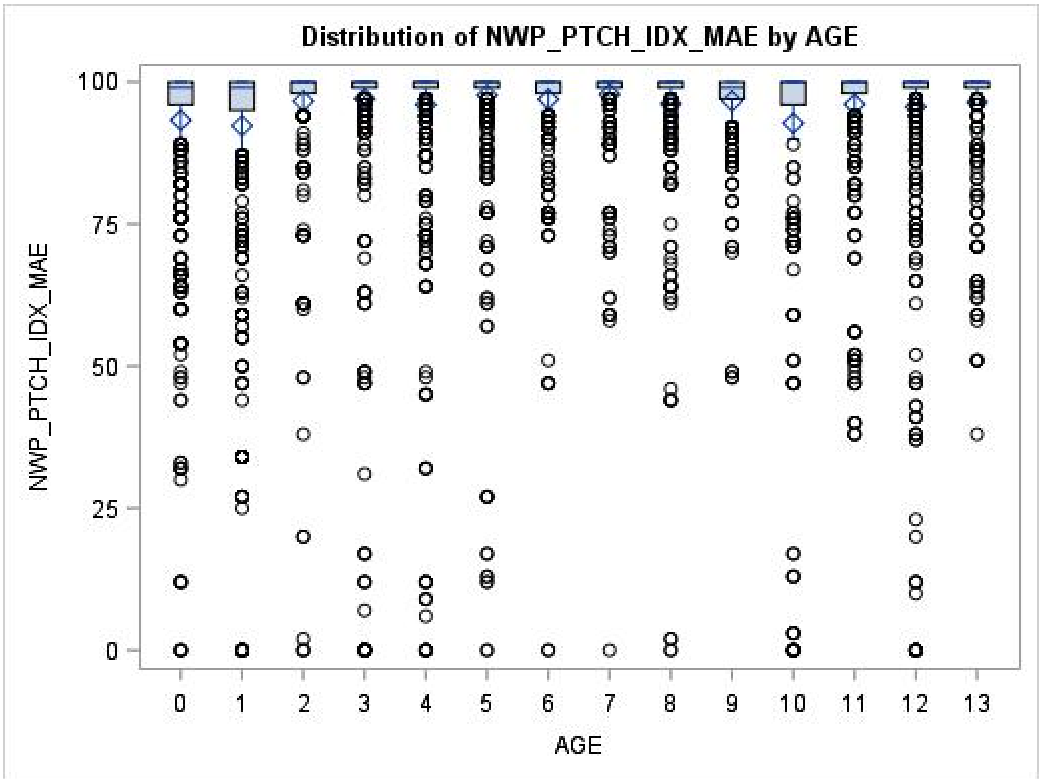

Figure 108: Schematic Box Plot for US_5_15k NWP_PTCH_IDX_MAE

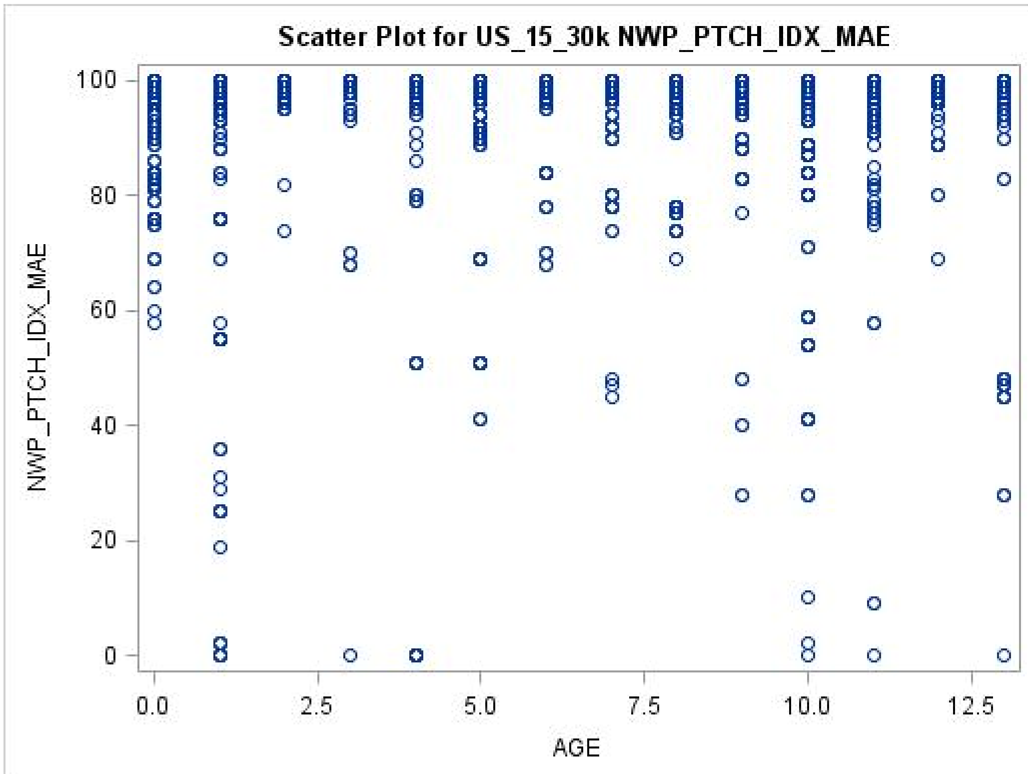

Figure 109: Scatter Plot for US_15_30k NWP_PTCH_IDX_MAE

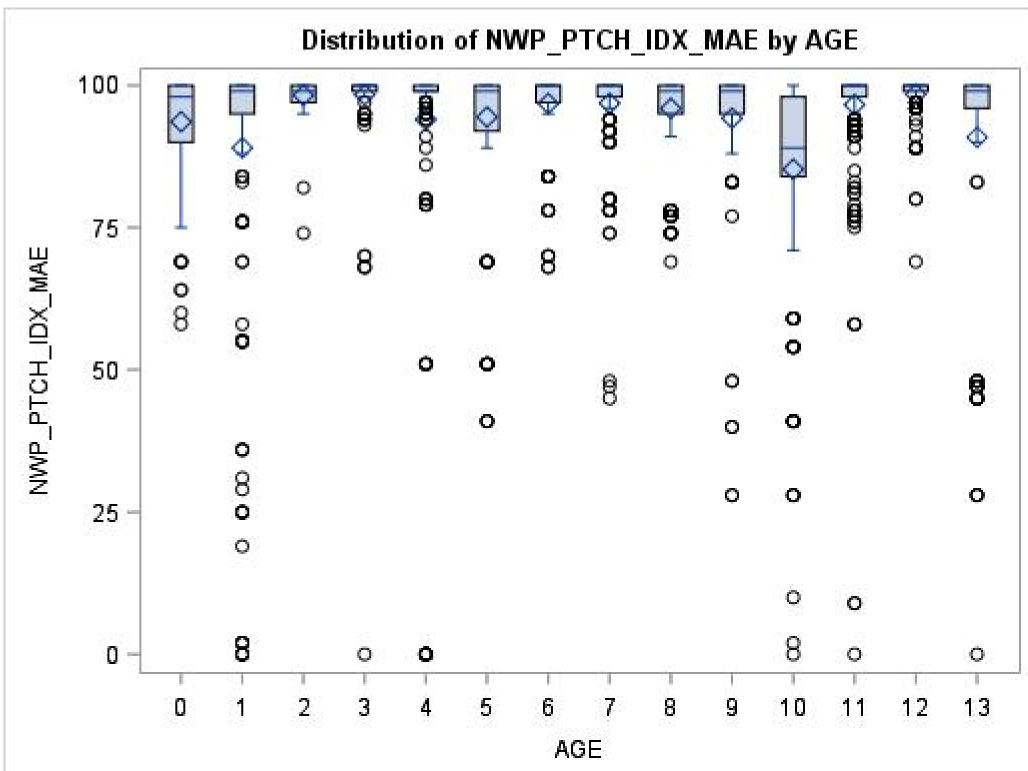

Figure 110: Schematic Box Plot for US_15_30k NWP_PTCH_IDX_MAE

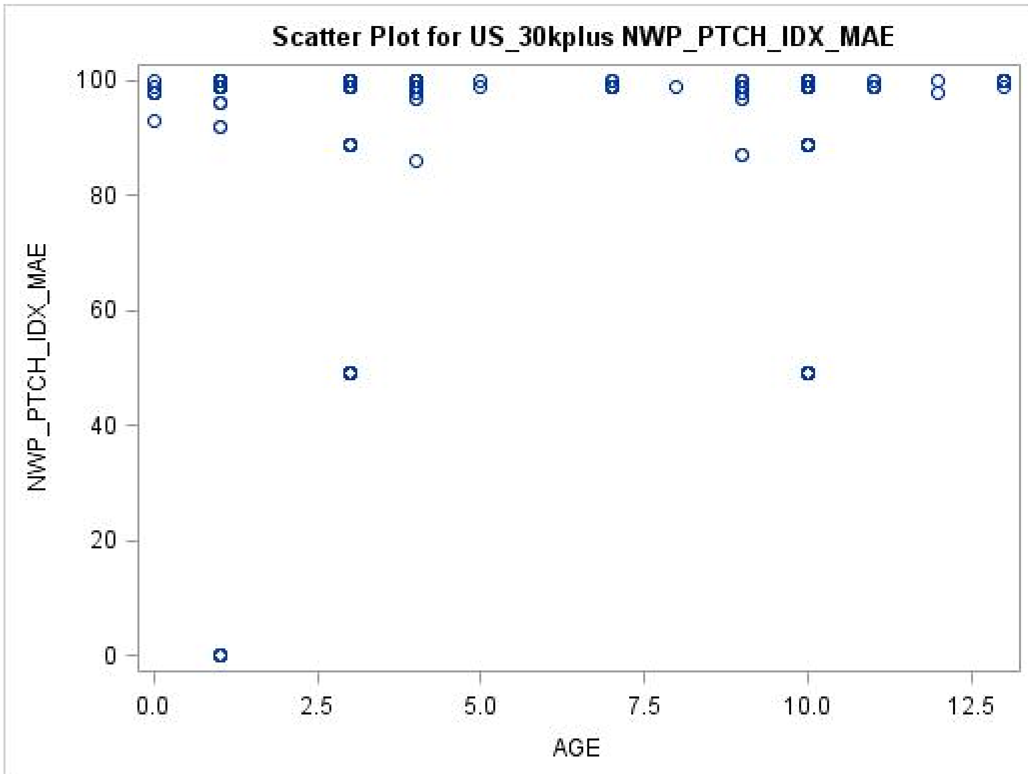

Figure 111: Scatter Plot for US_30kplus NWP_PTCH_IDX_MAE

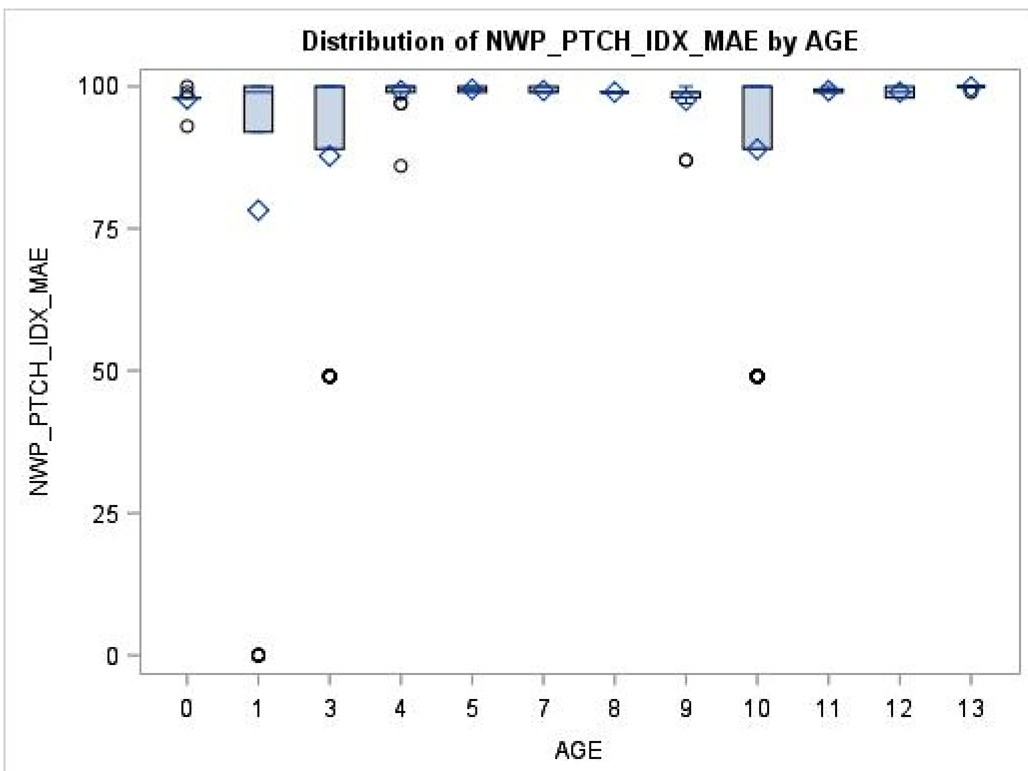

Figure 112: Schematic Box Plot for US_30kplus NWP_PTCH_IDX_MAE

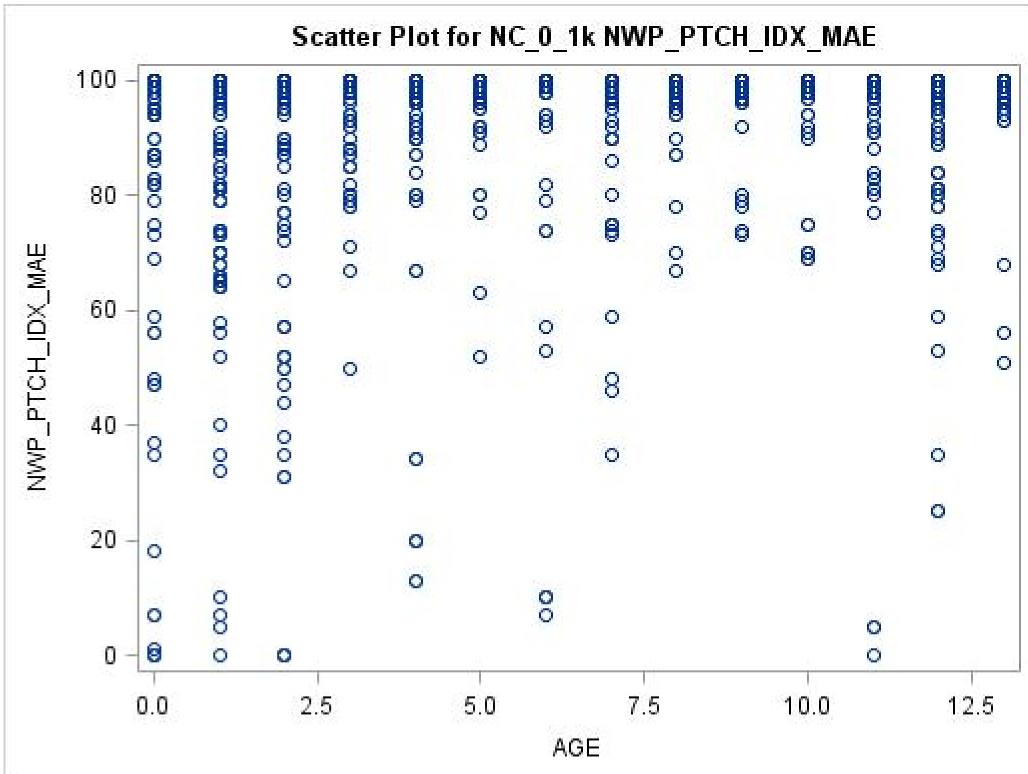

Figure 113: Scatter Plot for NC_0_1k NWP_PTCH_IDX_MAE

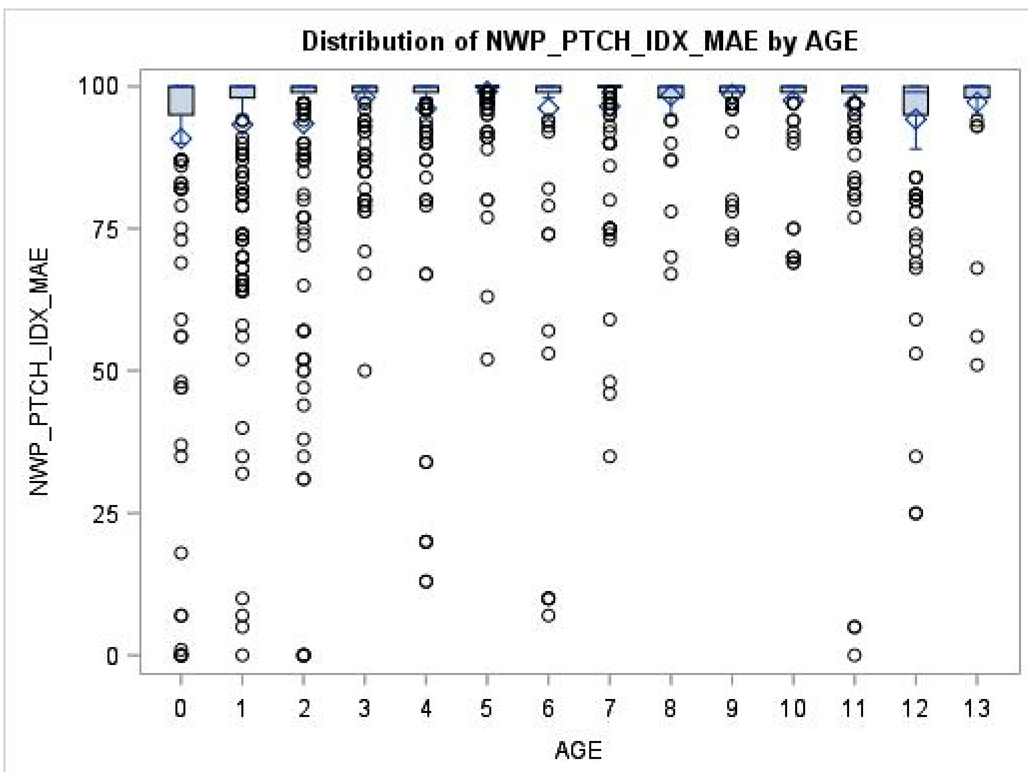

Figure 114: Schematic Box Plot for NC_0_1k NWP_PTCH_IDX_MAE

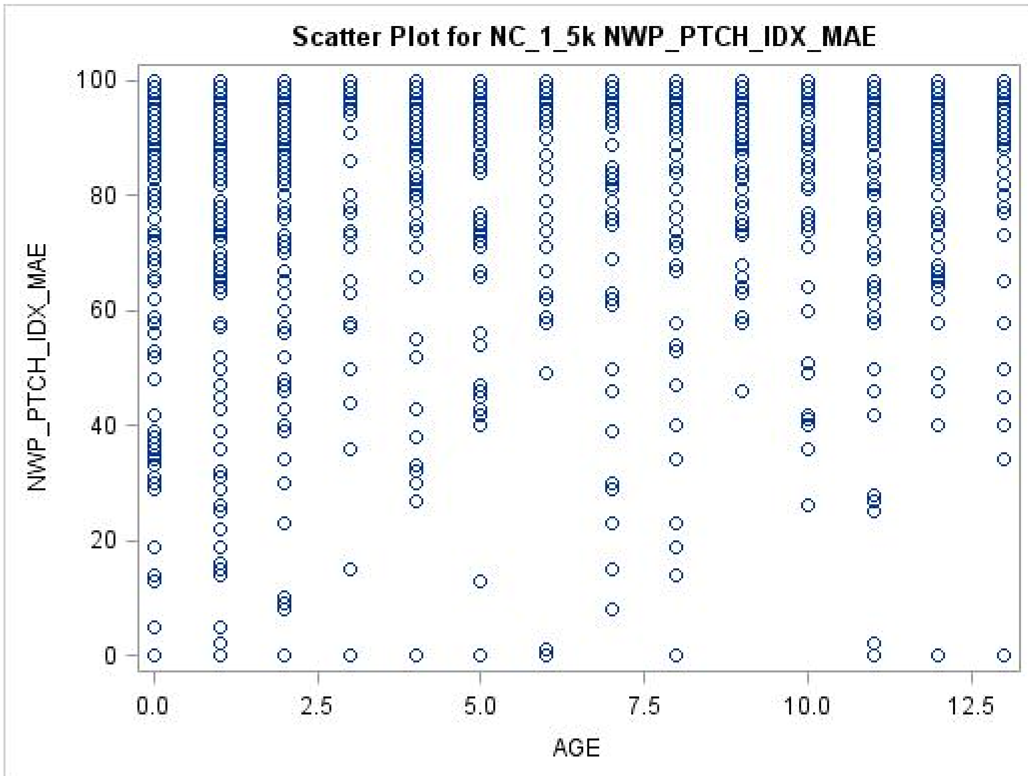

Figure 115: Scatter Plot for NC_1_5k NWP_PTCH_IDX_MAE

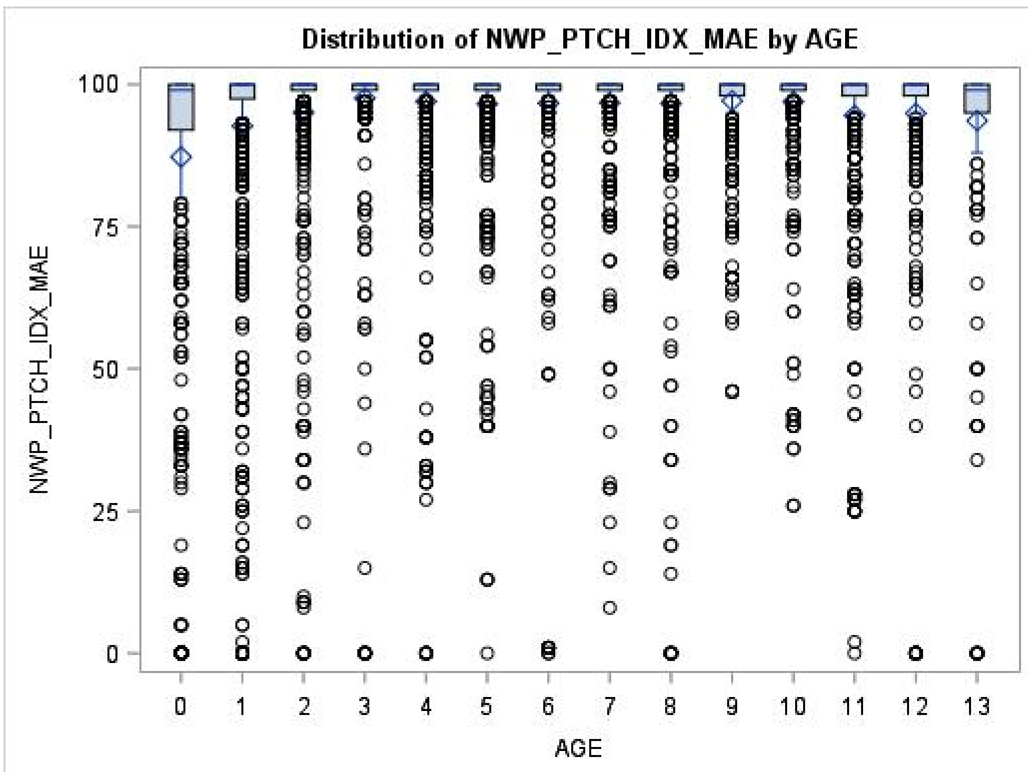

Figure 116: Schematic Box Plot for NC_1_5k NWP_PTCH_IDX_MAE

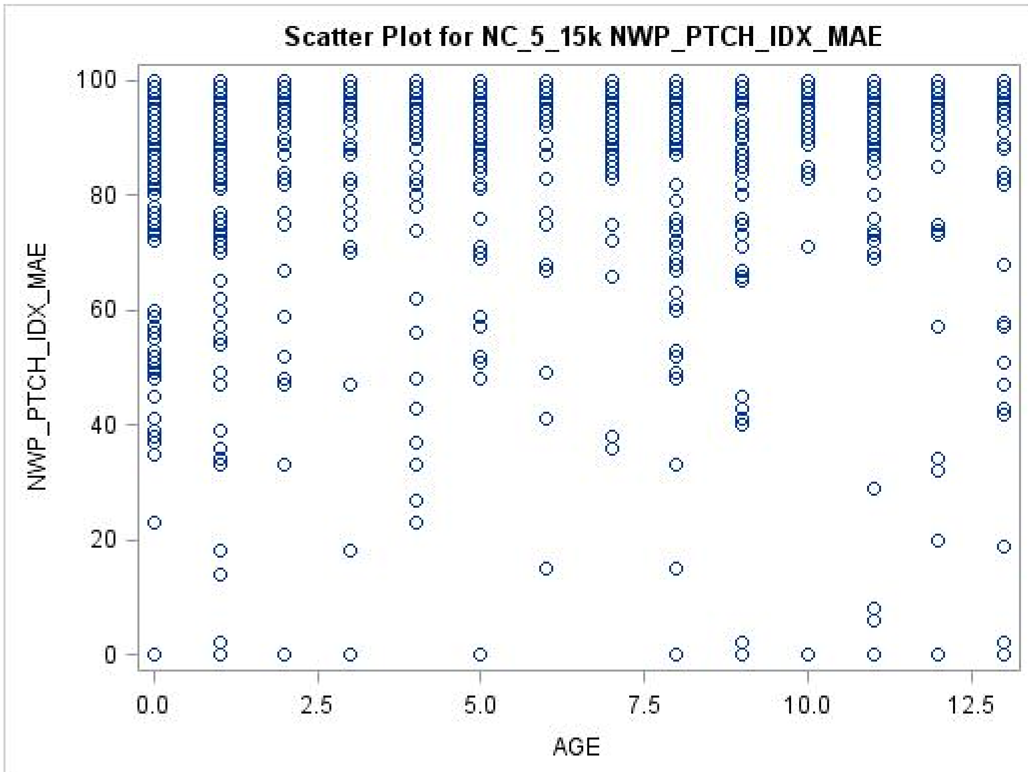

Figure 117: Scatter Plot for NC_5_15k NWP_PTCH_IDX_MAE

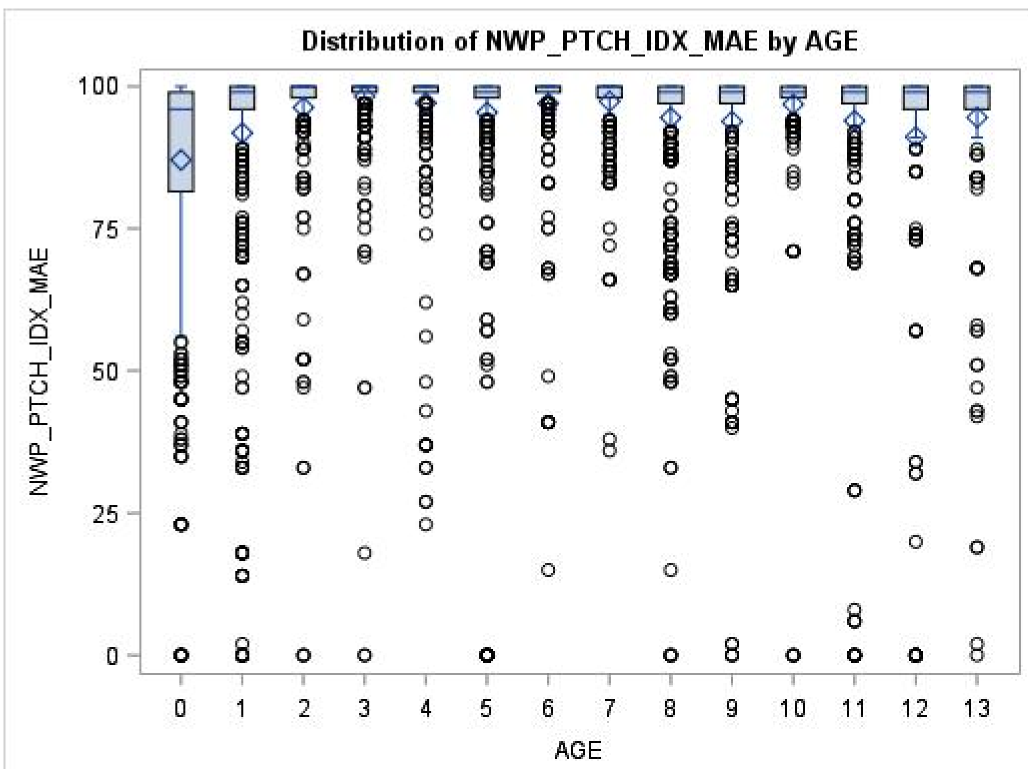

Figure 118: Schematic Box Plot for NC_5_15k NWP_PTCH_IDX_MAE

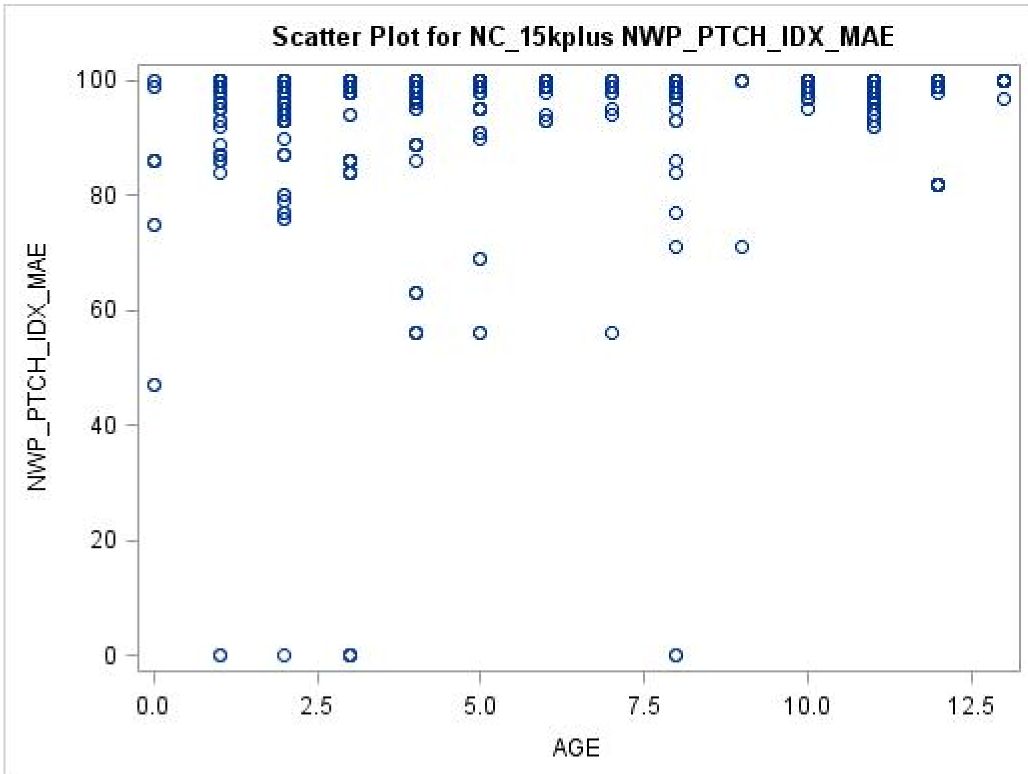

Figure 119: Scatter Plot for NC_15kplus NWP_PTCH_IDX_MAE

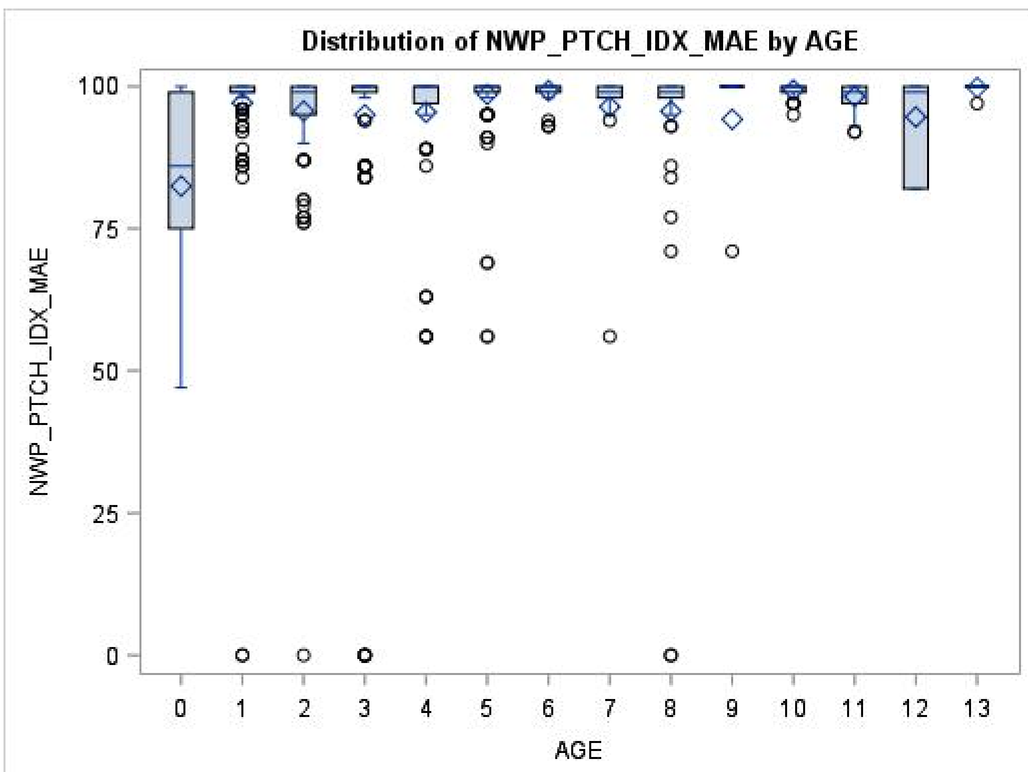

Figure 120: Schematic Box Plot for NC_15kplus NWP_PTCH_IDX_MAE

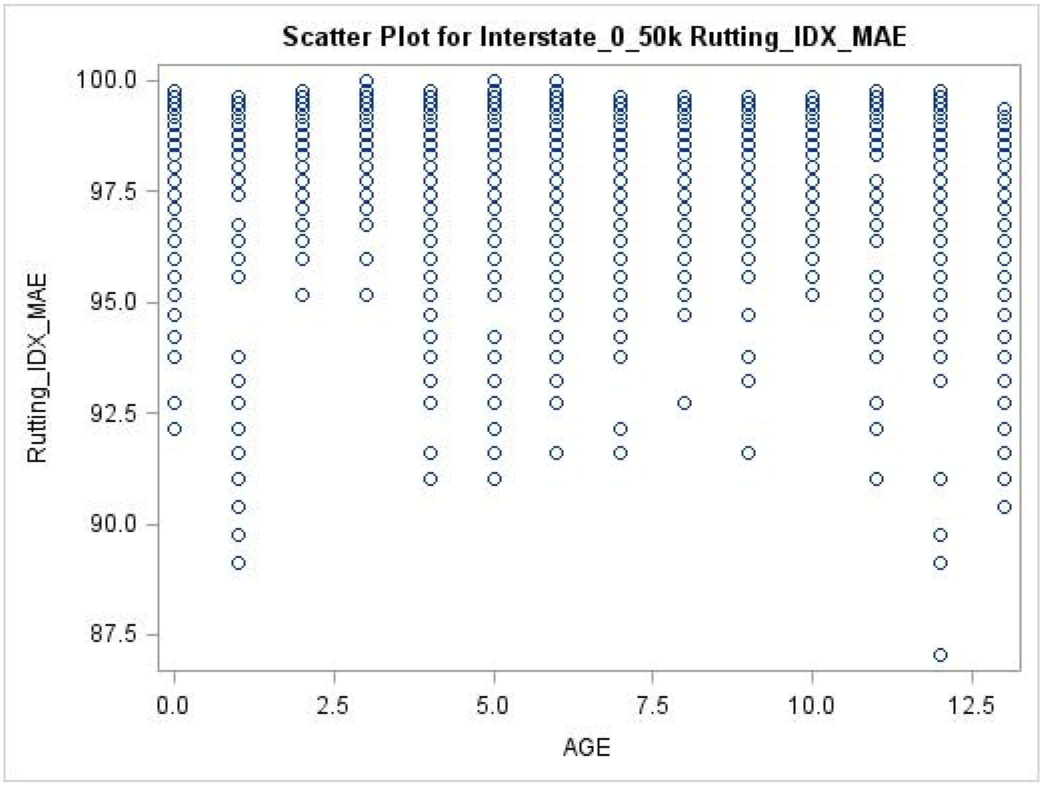

Figure 121: Scatter Plot for Interstate_0_50k Rutting_IDX_MAE

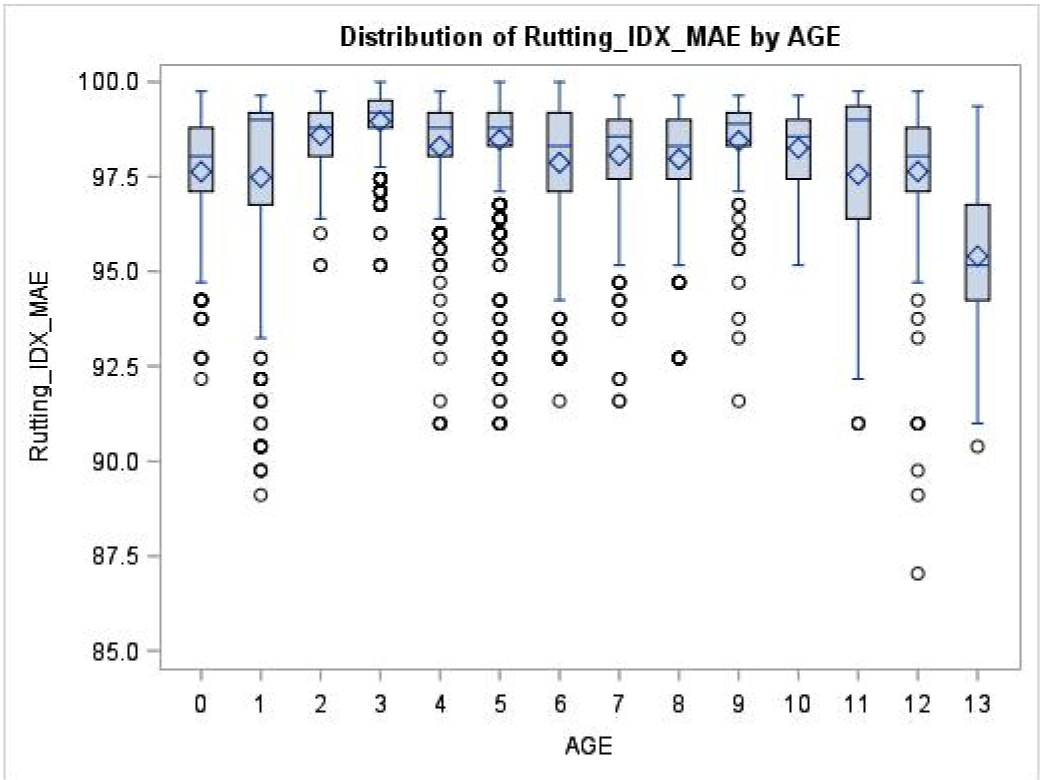

Figure 122: Schematic Box Plot for Interstate_0_50k Rutting_IDX_MAE

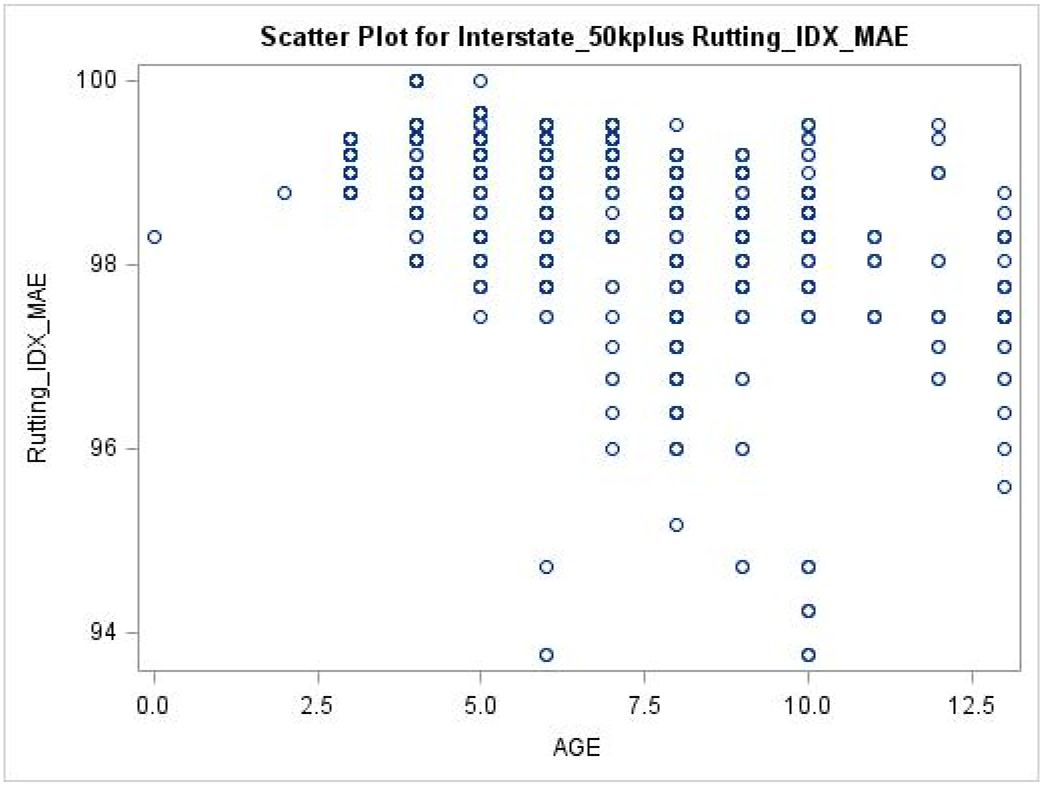

Figure 123: Scatter Plot for Interstate_50kplus Rutting_IDX_MAE

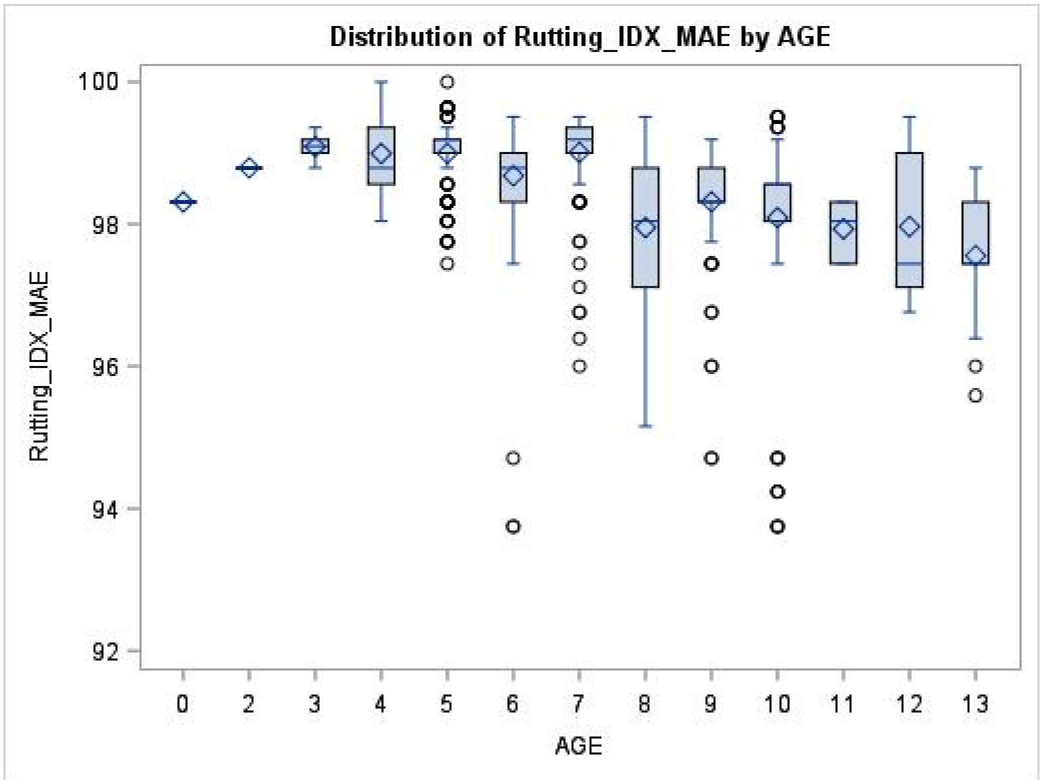

Figure 124: Schematic Box Plot for Interstate_50kplus Rutting_IDX_MAE

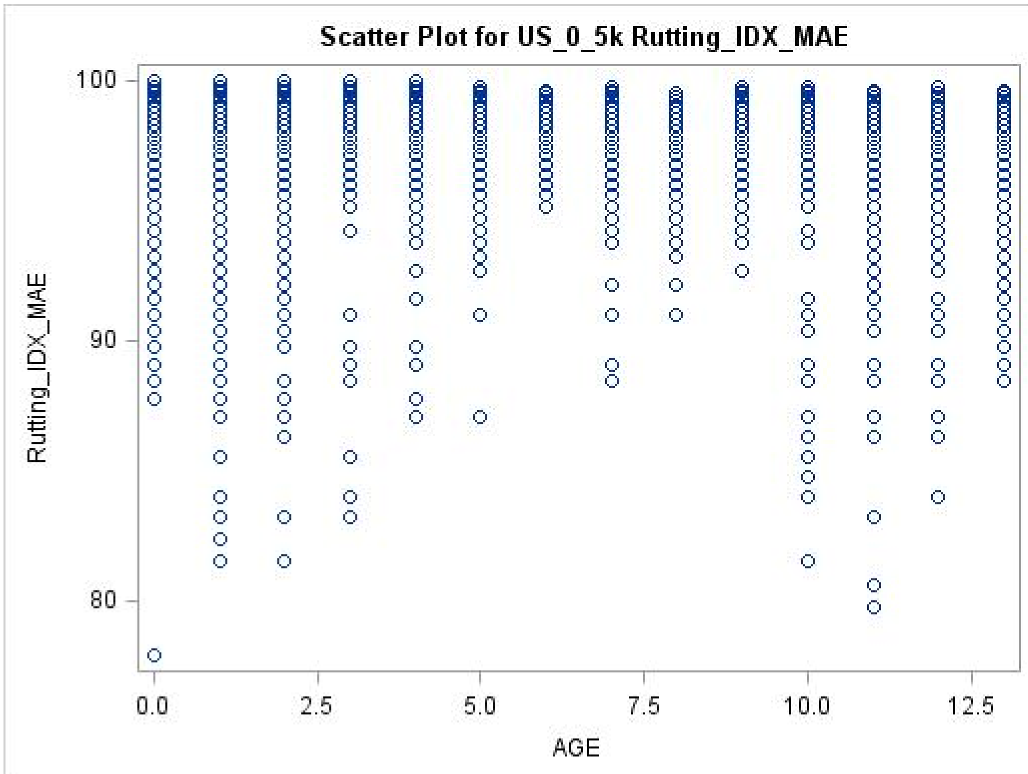

Figure 125: Scatter Plot for US_0_5k Rutting_IDX_MAE

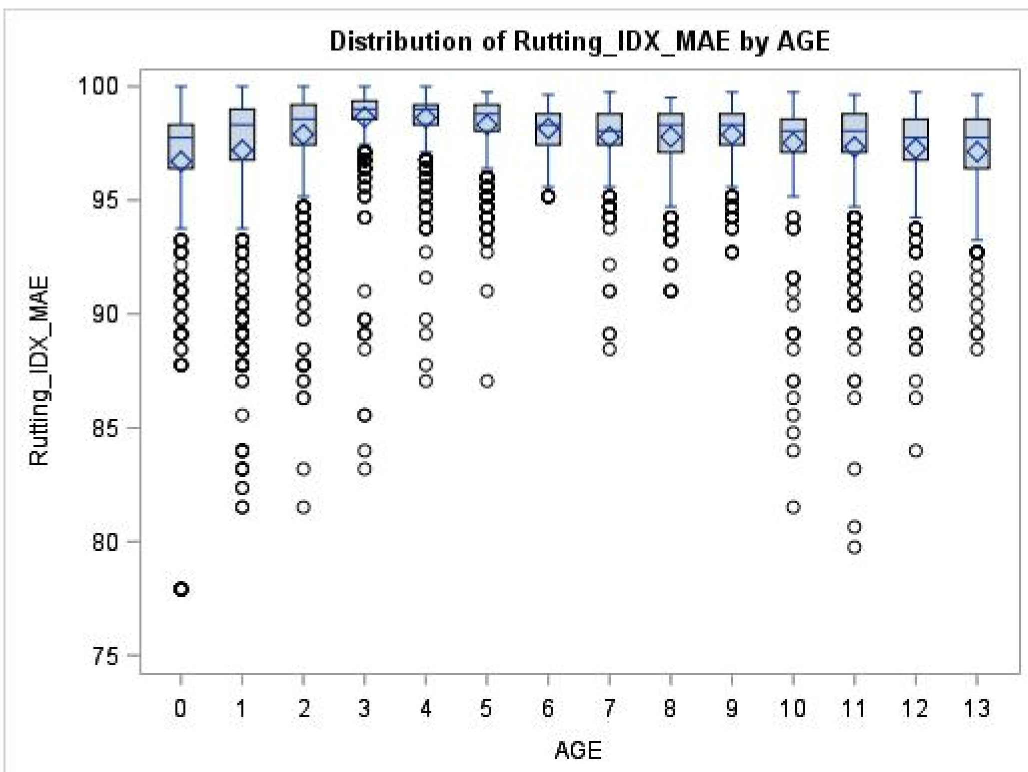

Figure 126: Schematic Box Plot for US_0_5k Rutting_IDX_MAE

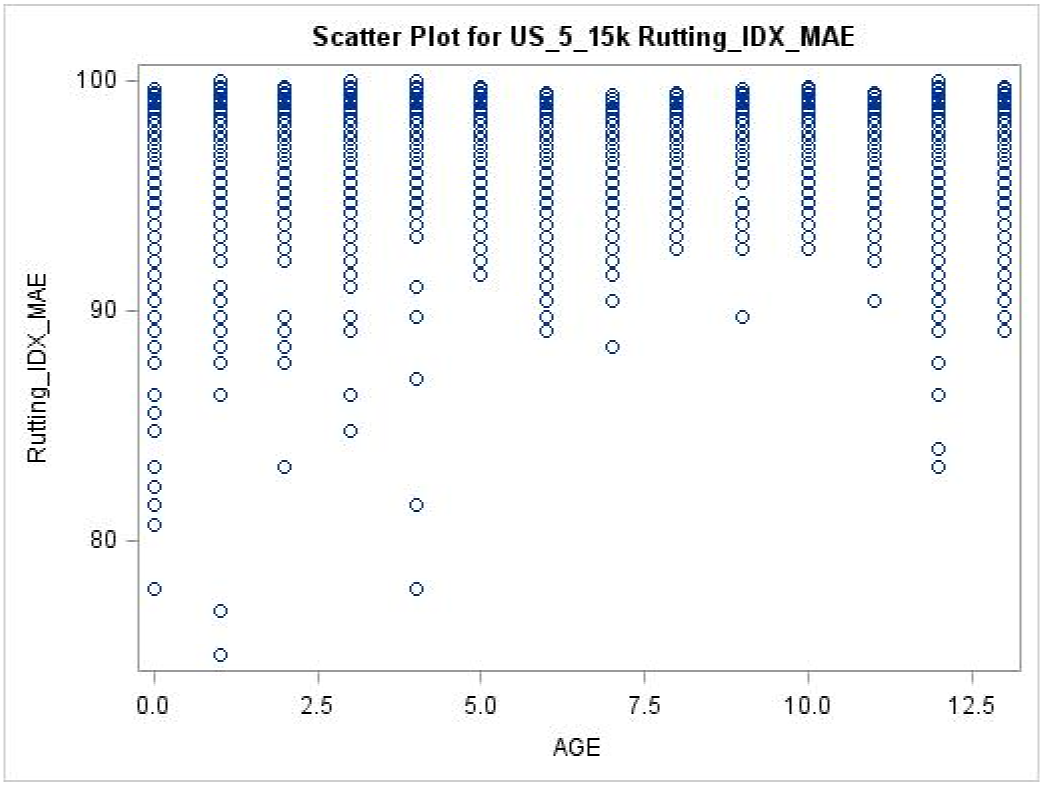

Figure 127: Scatter Plot for US_5_15k Rutting_IDX_MAE

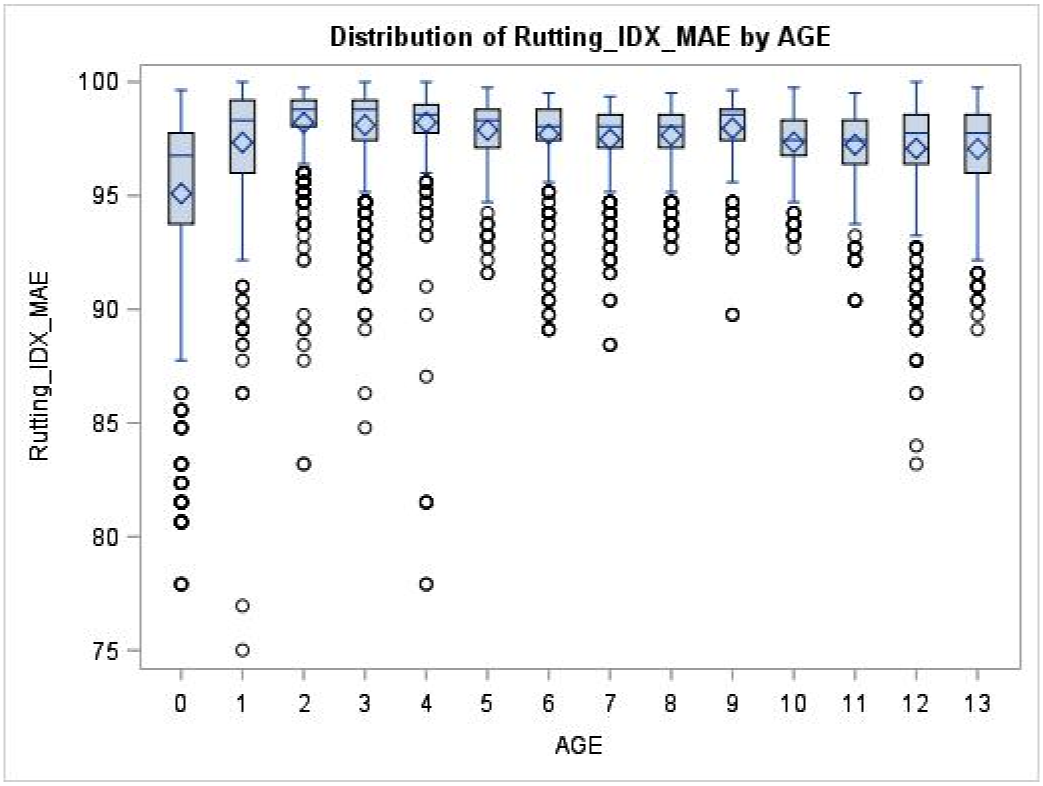

Figure 128: Schematic Box Plot for US_5_15k Rutting_IDX_MAE

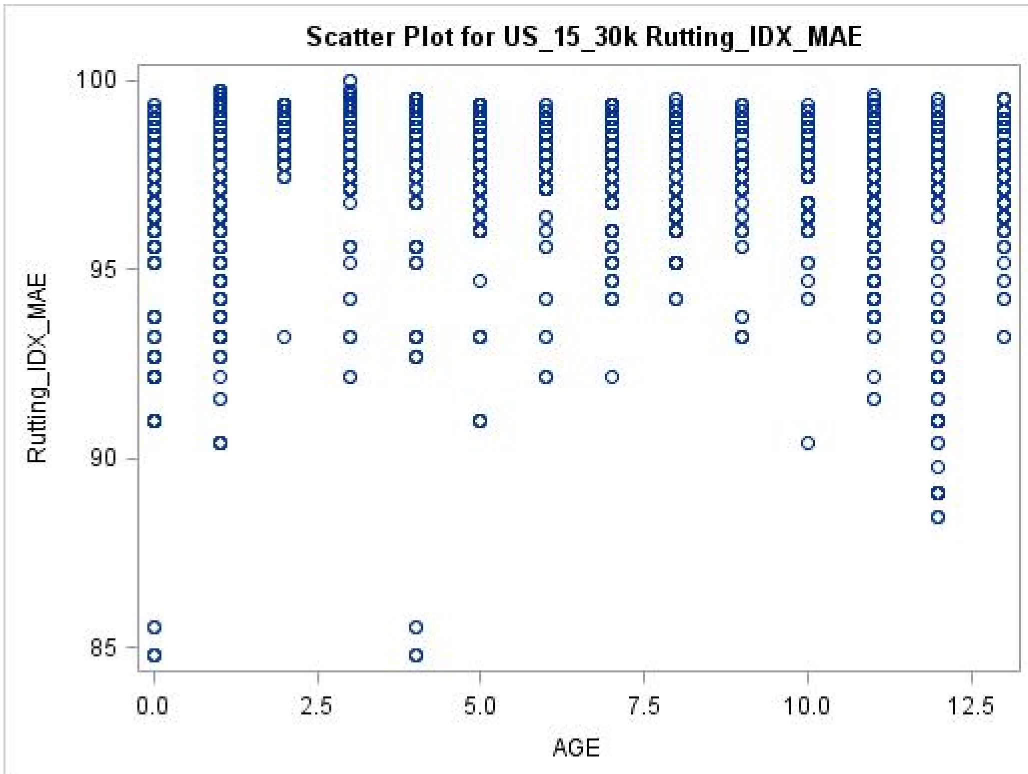

Figure 129: Scatter Plot for US_15_30k Rutting_IDX_MAE

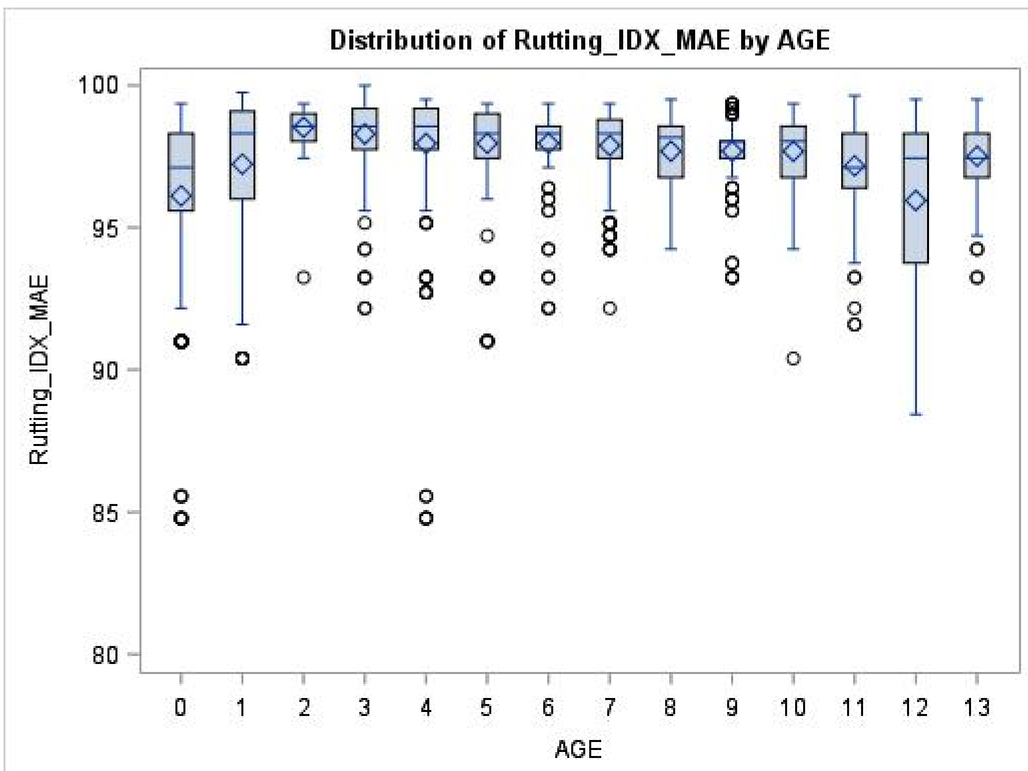

Figure 130: Schematic Box Plot for US_15_30k Rutting_IDX_MAE

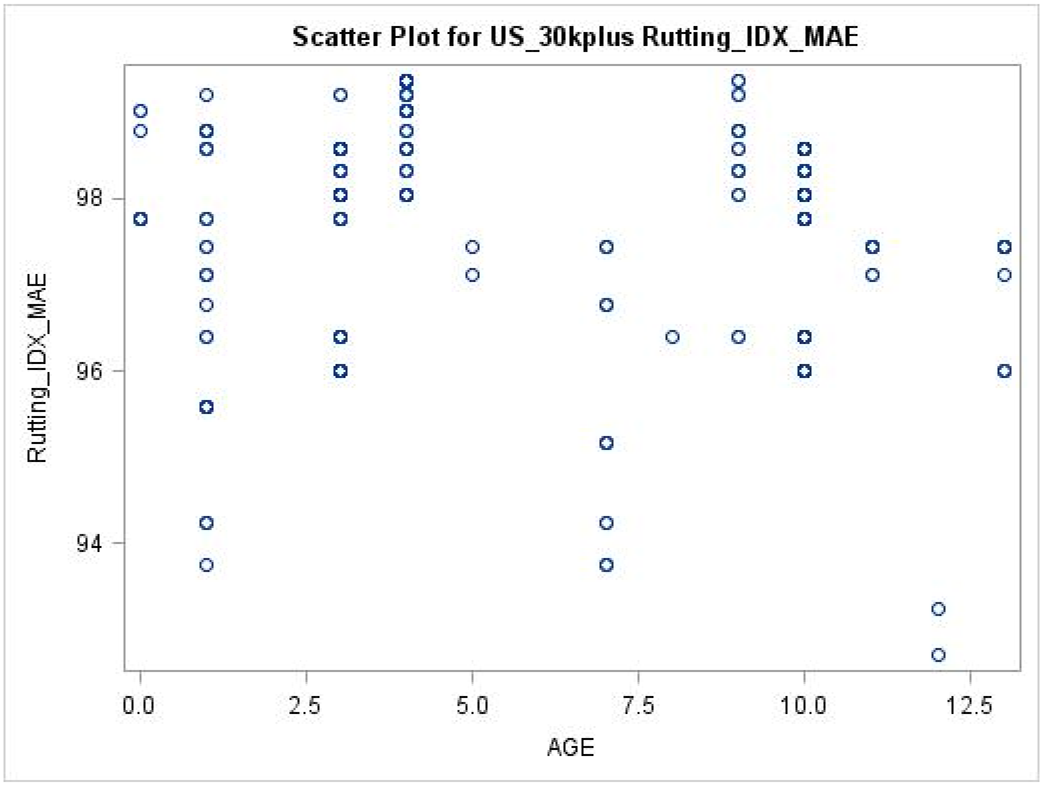

Figure 131: Scatter Plot for US_30kplus Rutting_IDX_MAE

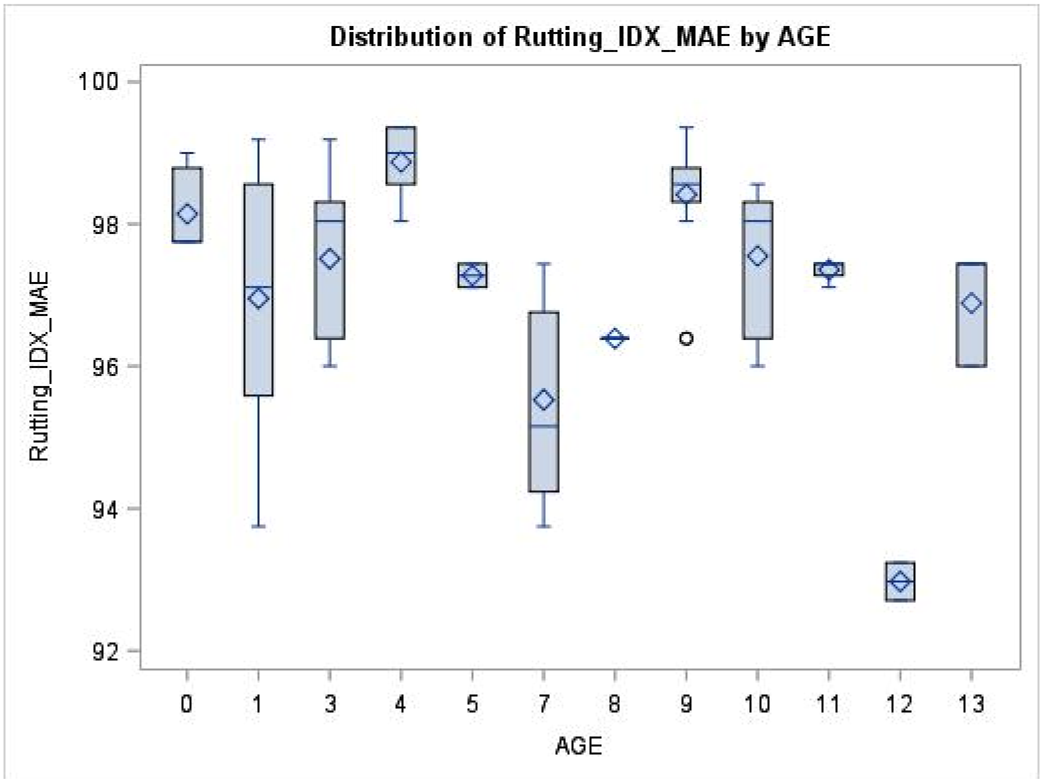

Figure 132: Schematic Box Plot for US_30kplus Rutting_IDX_MAE

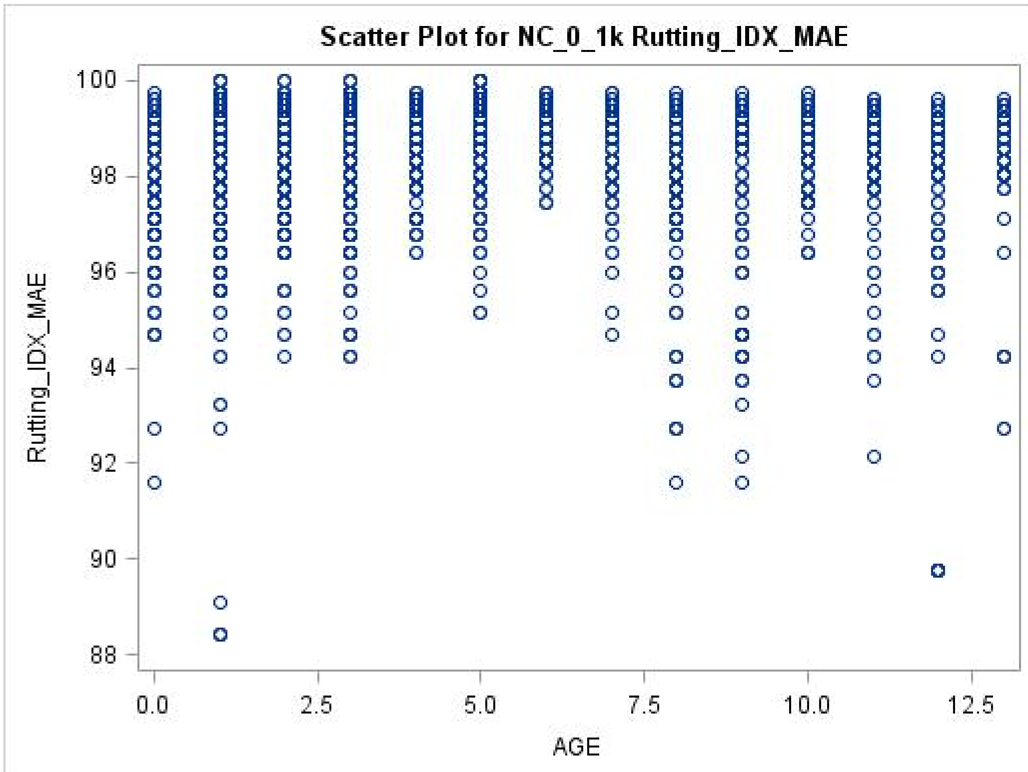

Figure 133: Scatter Plot for NC_0_1k Rutting_IDX_MAE

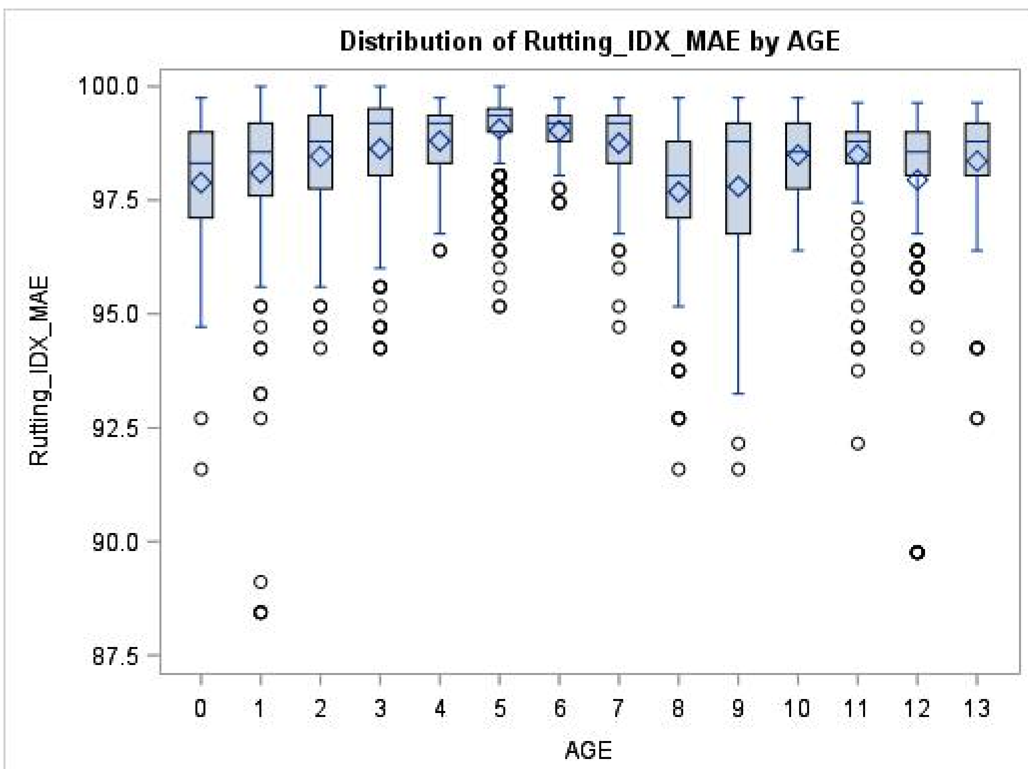

Figure 134: Schematic Box Plot for NC_0_1k Rutting_IDX_MAE

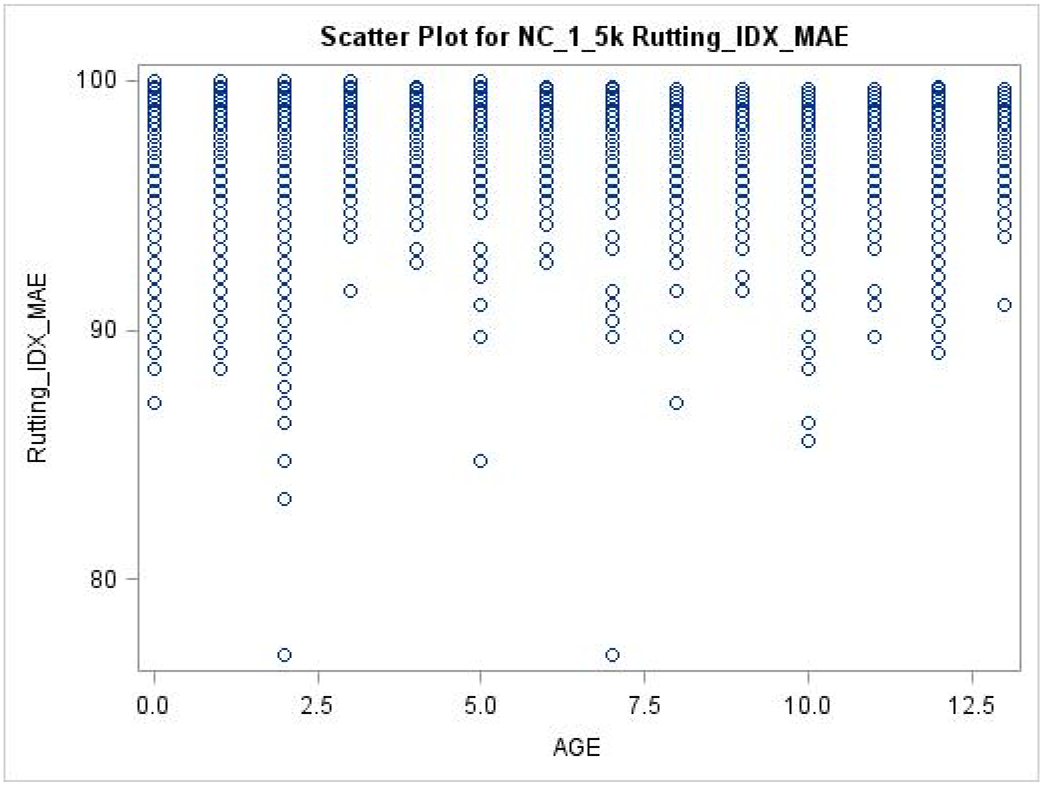

Figure 135: Scatter Plot for NC_1_5k Rutting_IDX_MAE

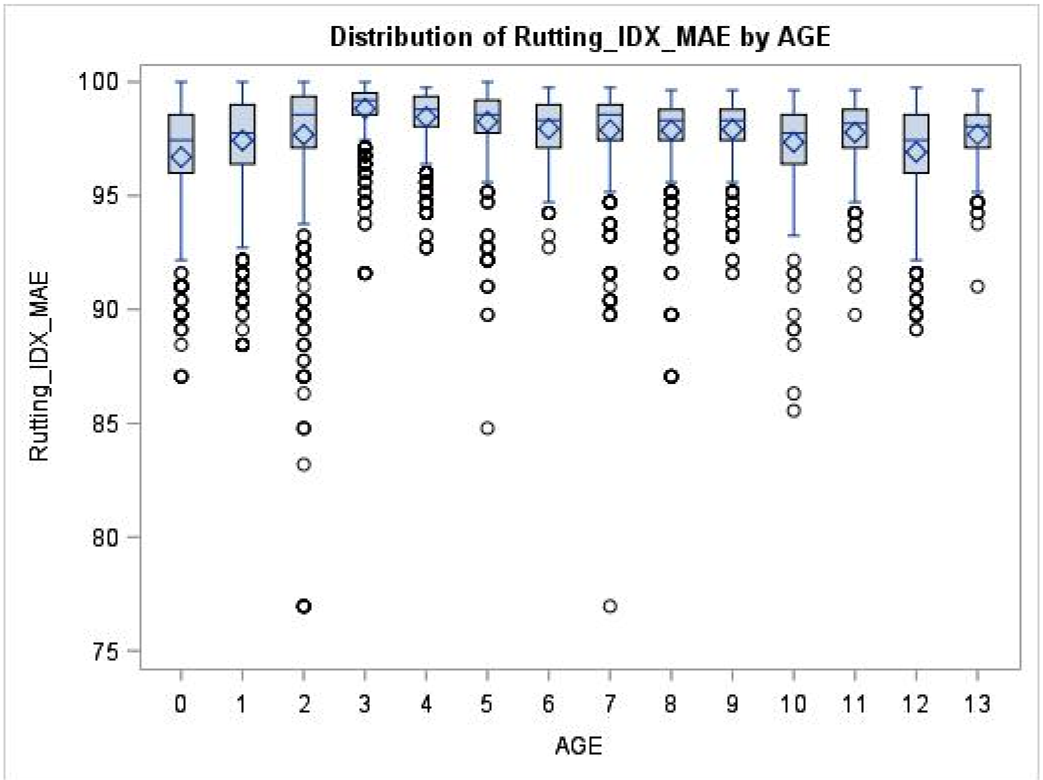

Figure 136: Schematic Box Plot for NC_1_5k Rutting_IDX_MAE

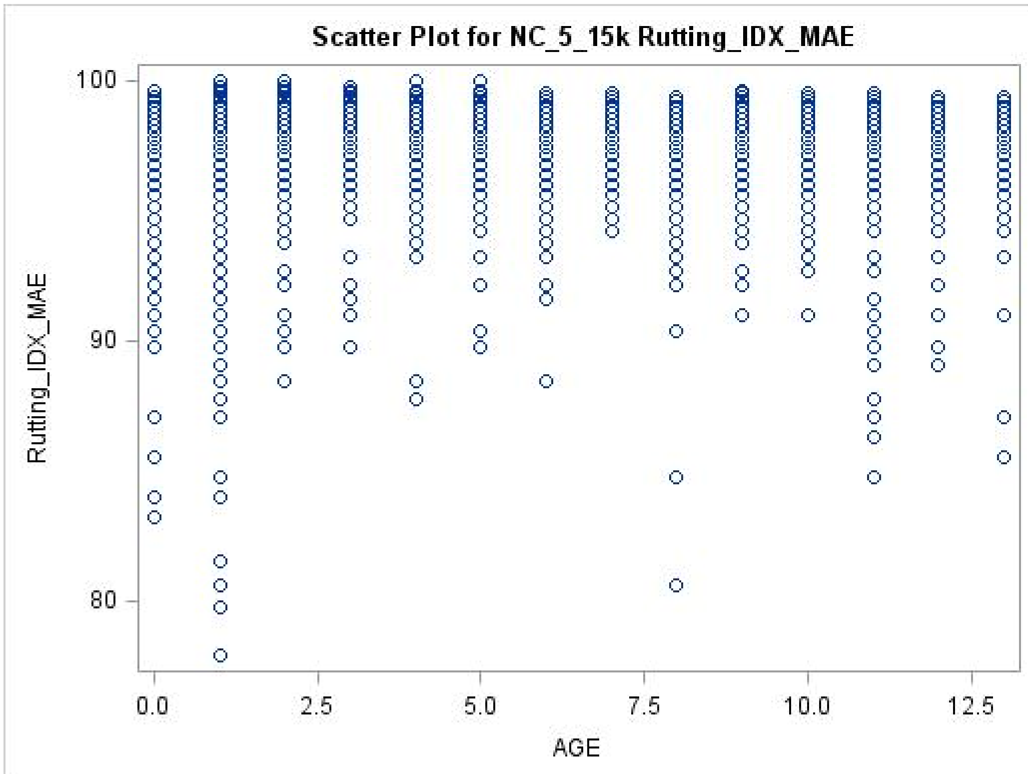

Figure 137: Scatter Plot for NC_5_15k Rutting_IDX_MAE

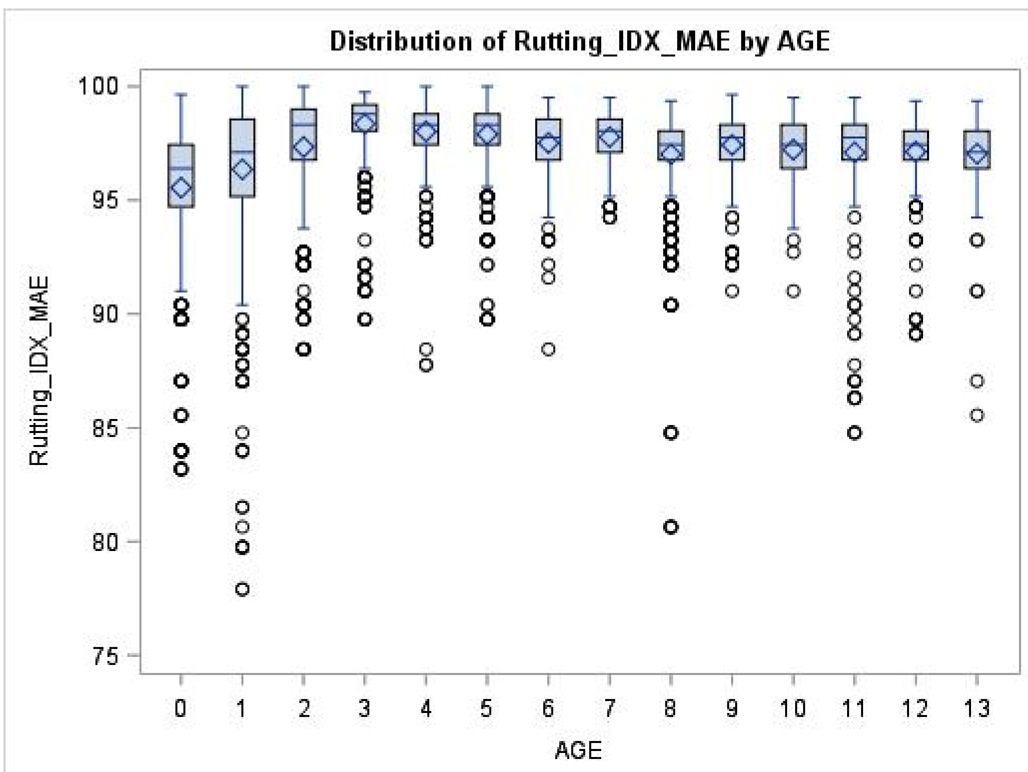

Figure 138: Schematic Box Plot for NC_5_15k Rutting_IDX_MAE

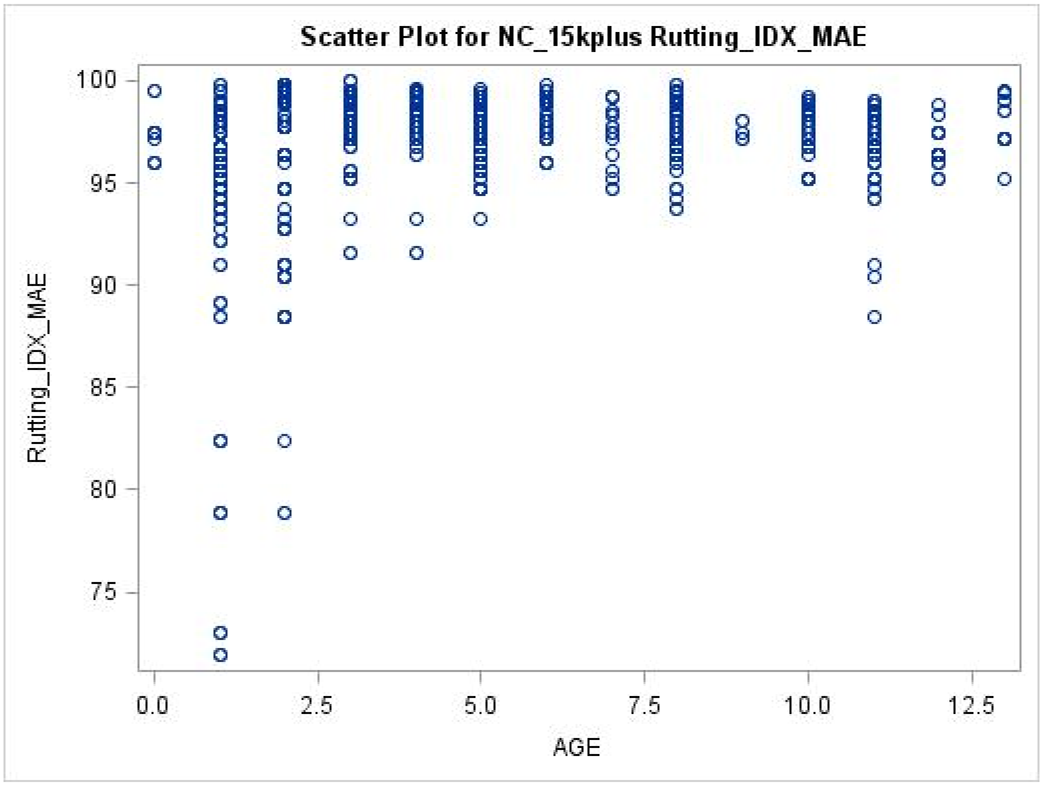

Figure 139: Scatter Plot for NC_15kplus Rutting_IDX_MAE

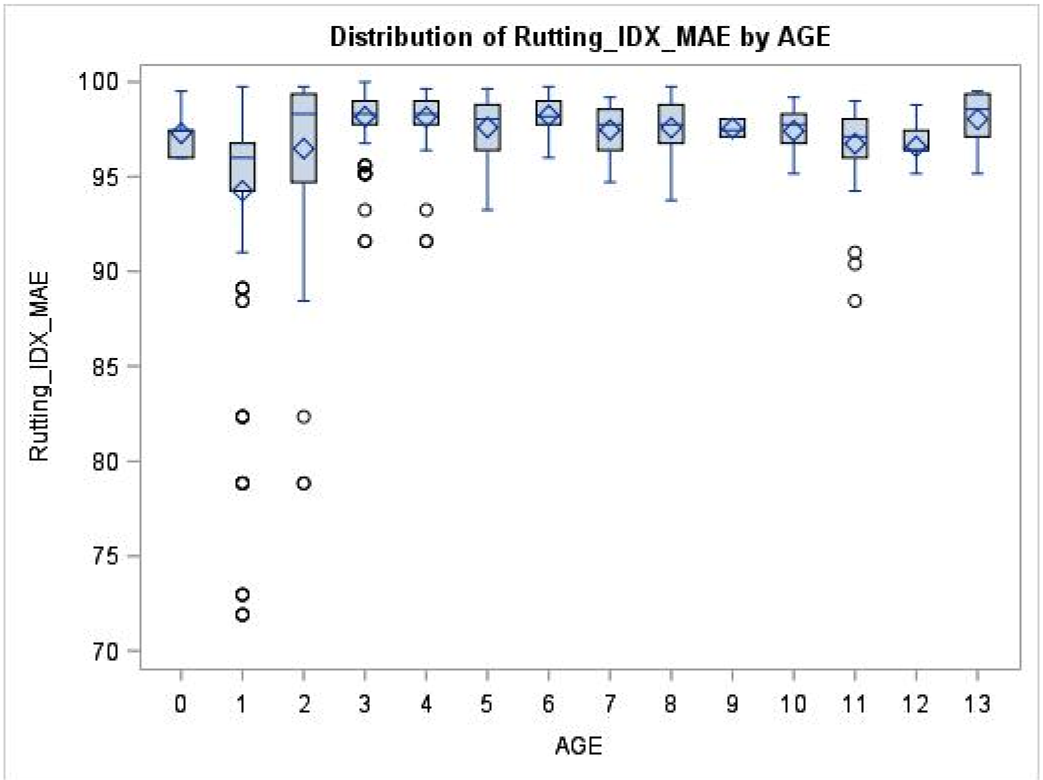

Figure 140: Schematic Box Plot for NC_15kplus Rutting_IDX_MAE

Appendix B – Scatter Plots and Box Plots of Cleaned Data

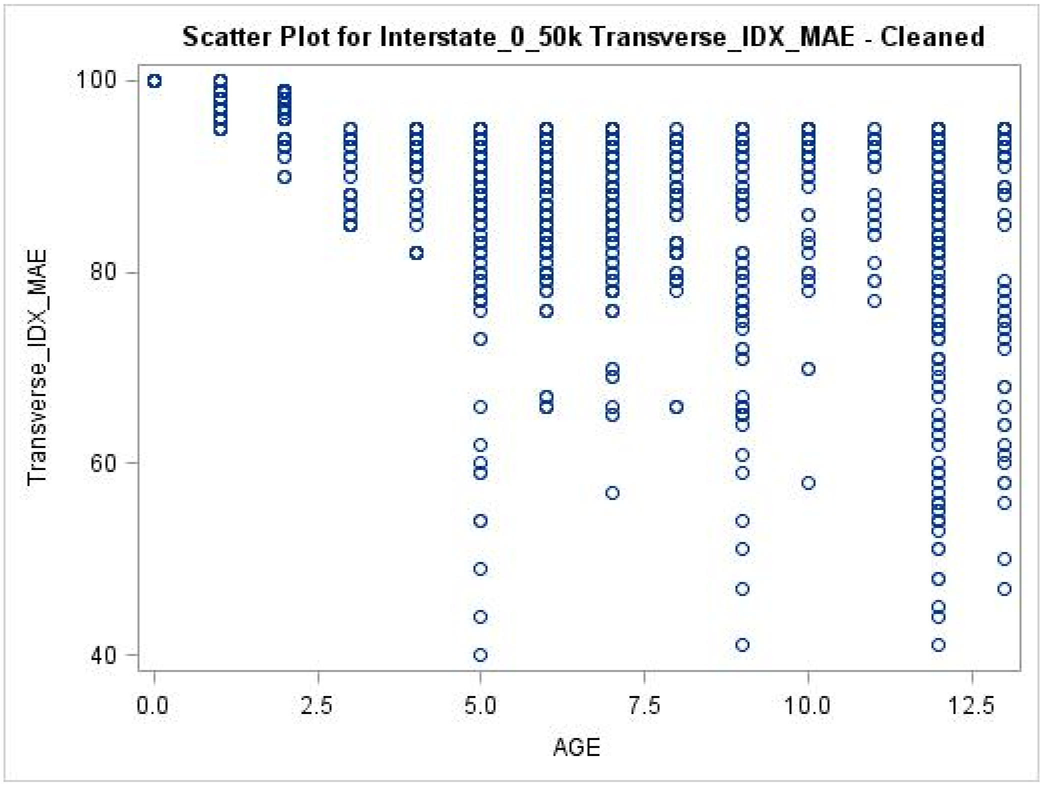

Figure 1: Schematic Scatter Plot for Interstate_0_50k Transverse_IDX_MAE - Cleaned

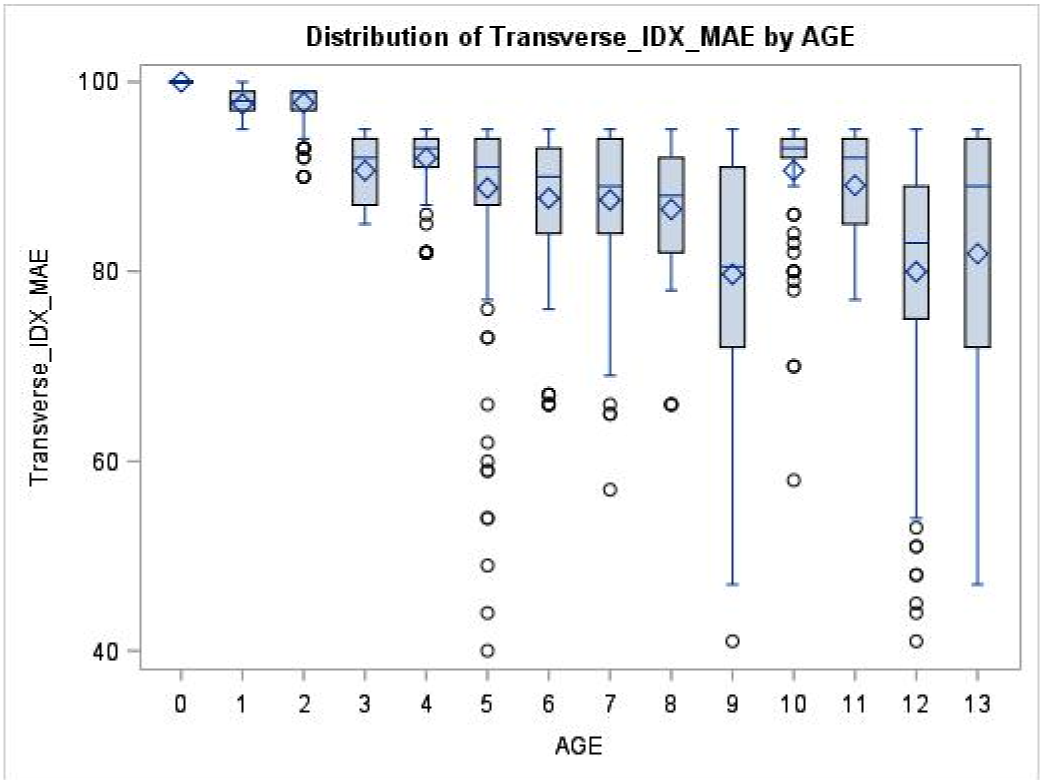

Figure 2: Schematic Box Plot for Interstate_0_50k Transverse_IDX_MAE - Cleaned

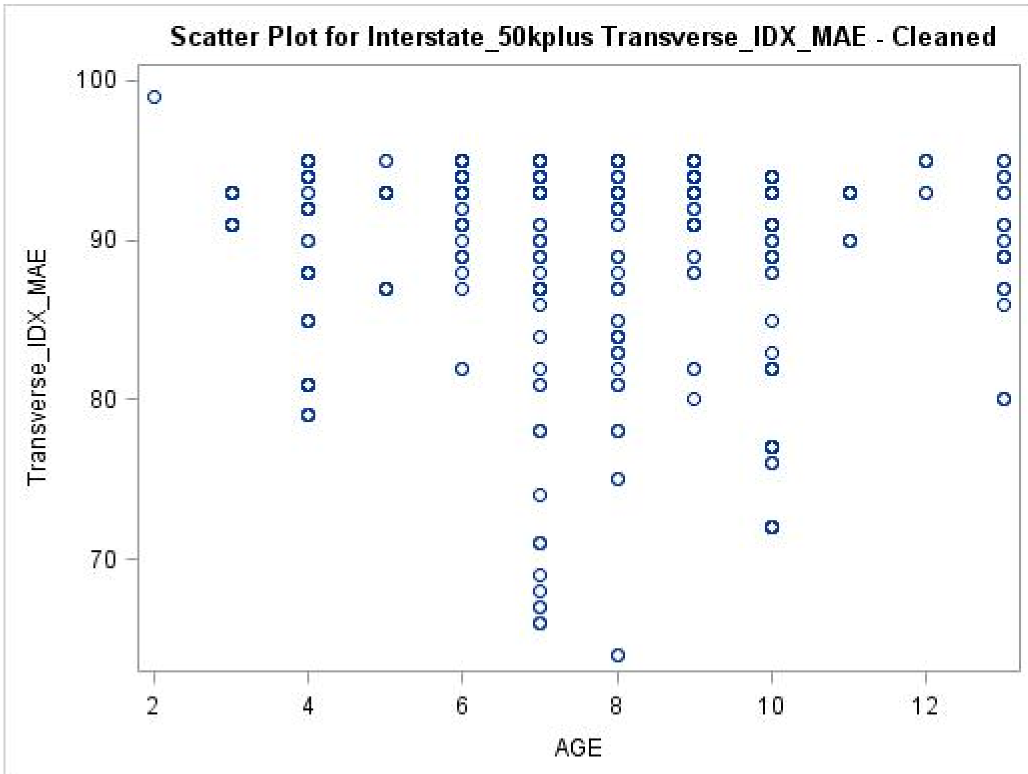

Figure 3: Schematic Scatter Plot for Interstate_50kplus Transverse_IDX_MAE - Cleaned

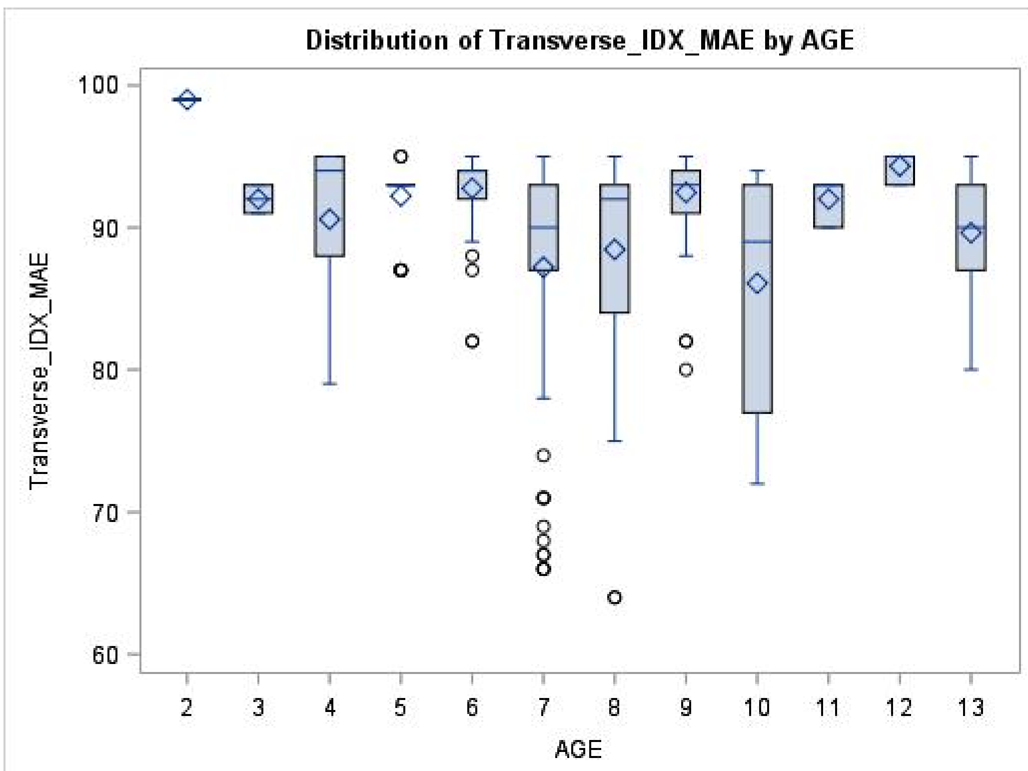

Figure 4: Schematic Box Plot for Interstate_50kplus Transverse_IDX_MAE - Cleaned

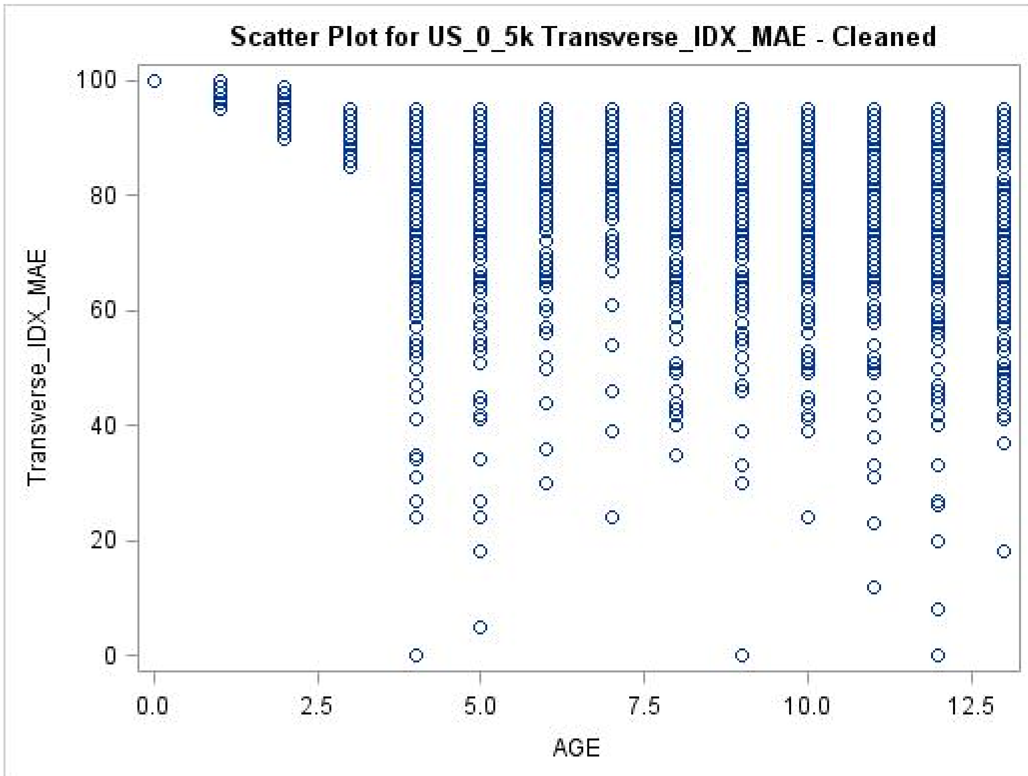

Figure 5: Schematic Scatter Plot for US_0_5k Transverse_IDX_MAE - Cleaned

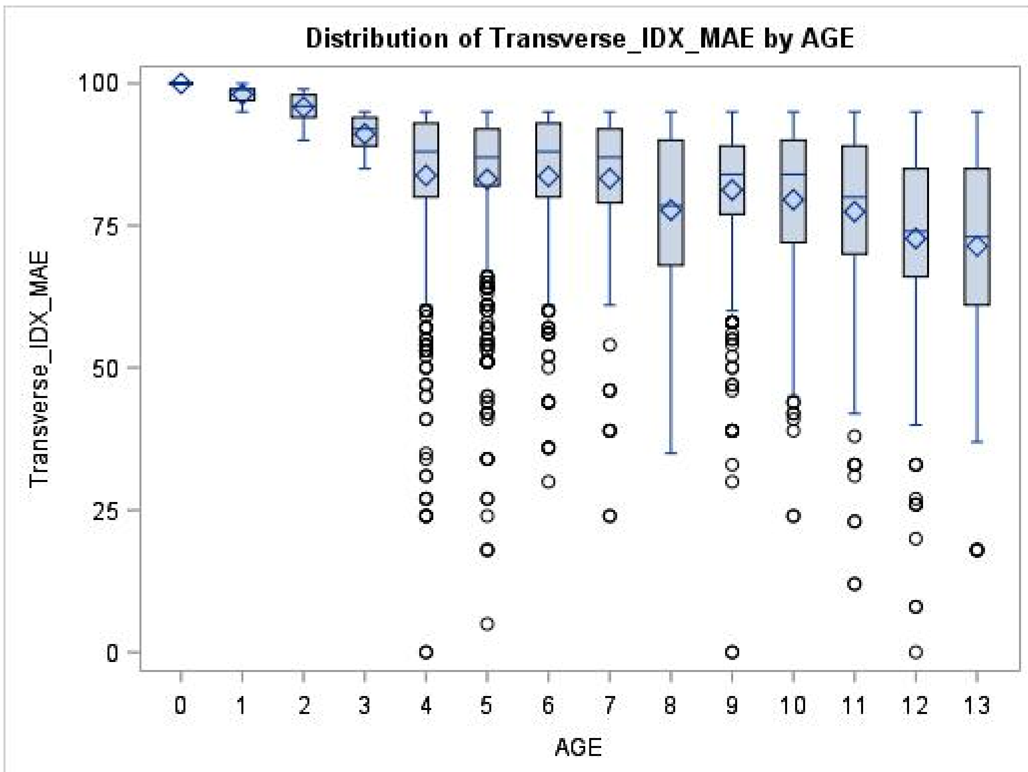

Figure 6: Schematic Box Plot for US_0_5k Transverse_IDX_MAE - Cleaned

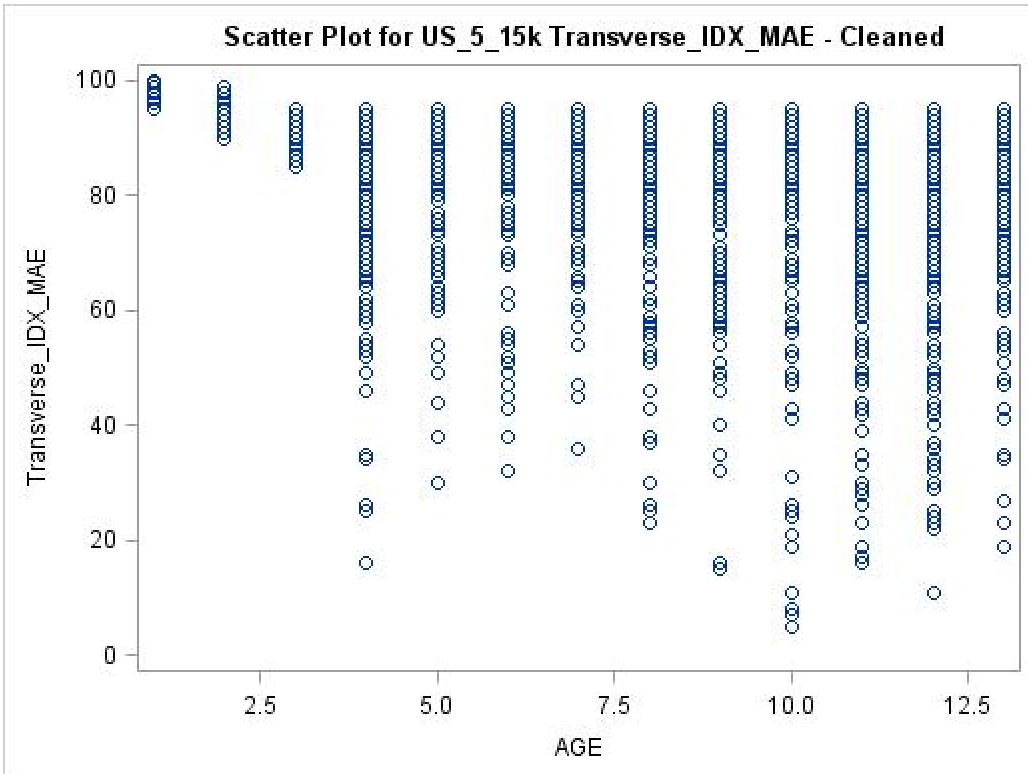

Figure 7: Schematic Scatter Plot for US_5_15k Transverse_IDX_MAE - Cleaned

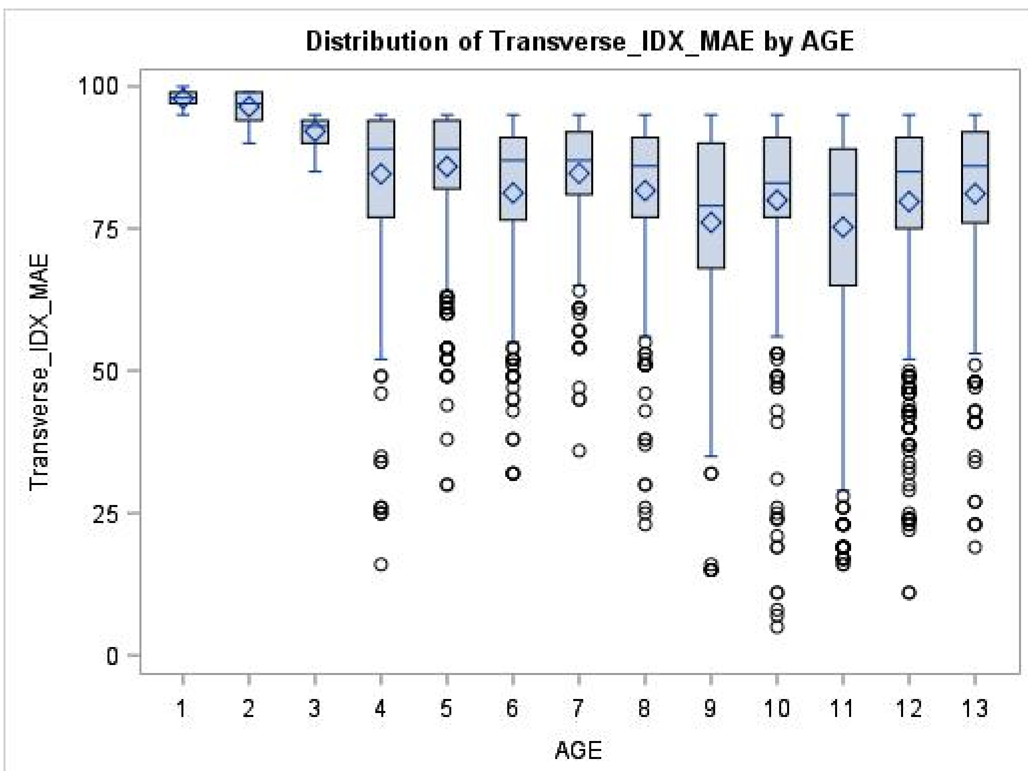

Figure 8: Schematic Box Plot for US_5_15k Transverse_IDX_MAE - Cleaned

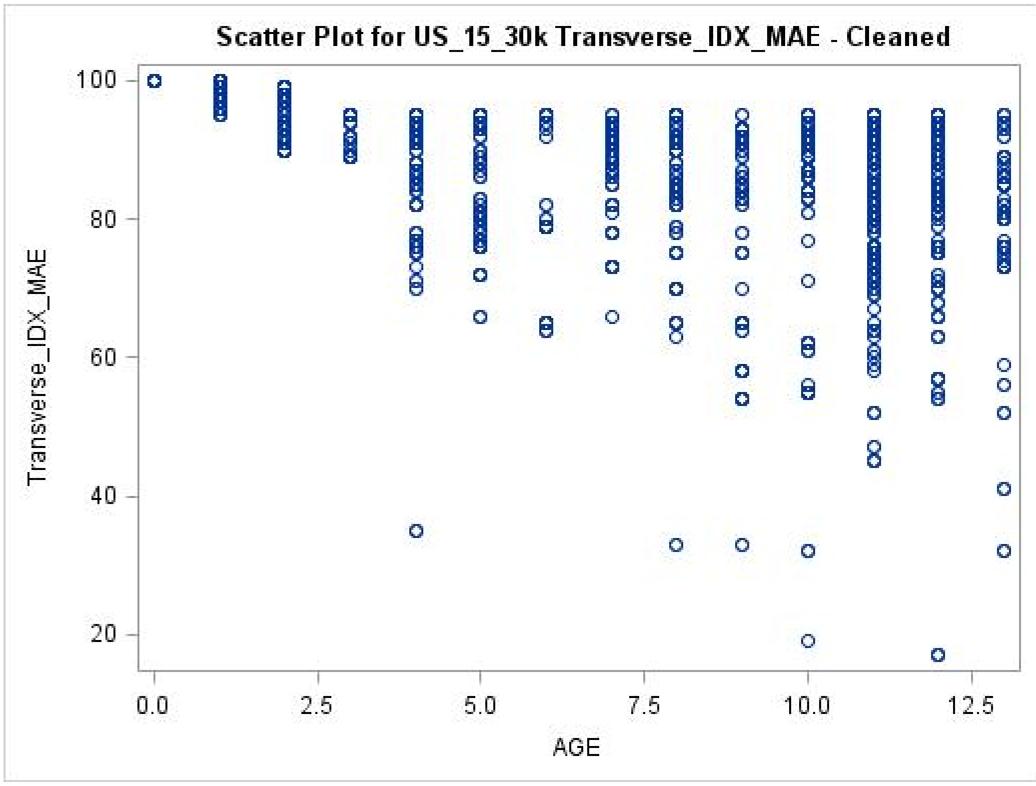

Figure 9: Schematic Scatter Plot for US_15_30k Transverse_IDX_MAE - Cleaned

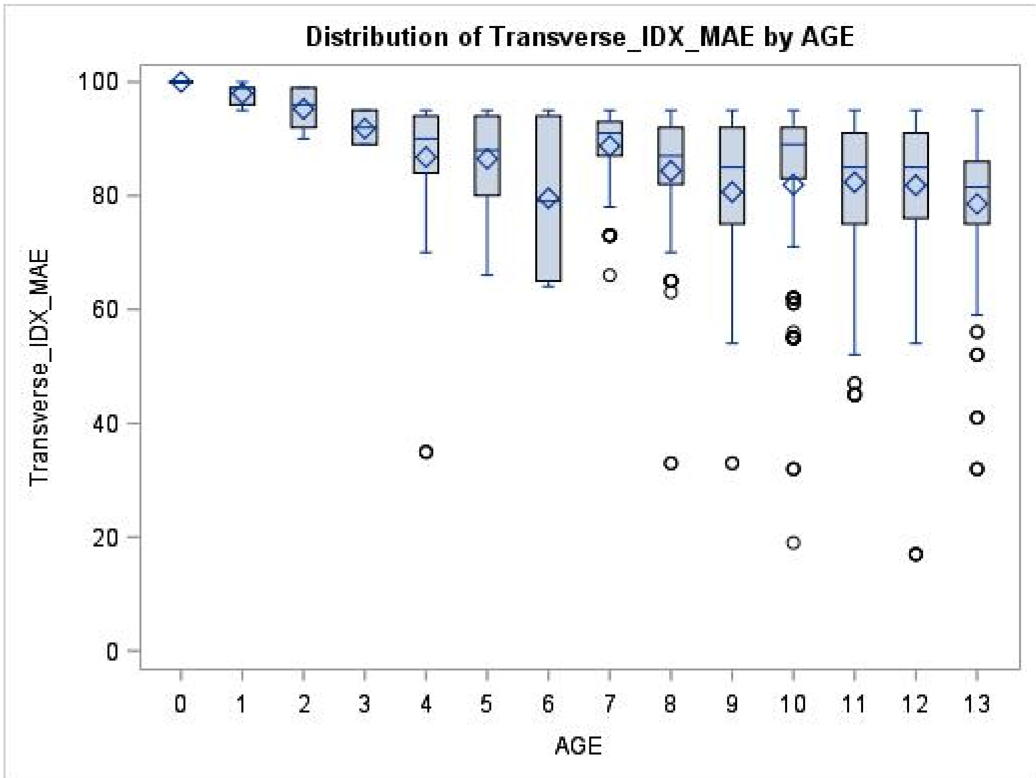

Figure 10: Schematic Box Plot for US_15_30k Transverse_IDX_MAE - Cleaned

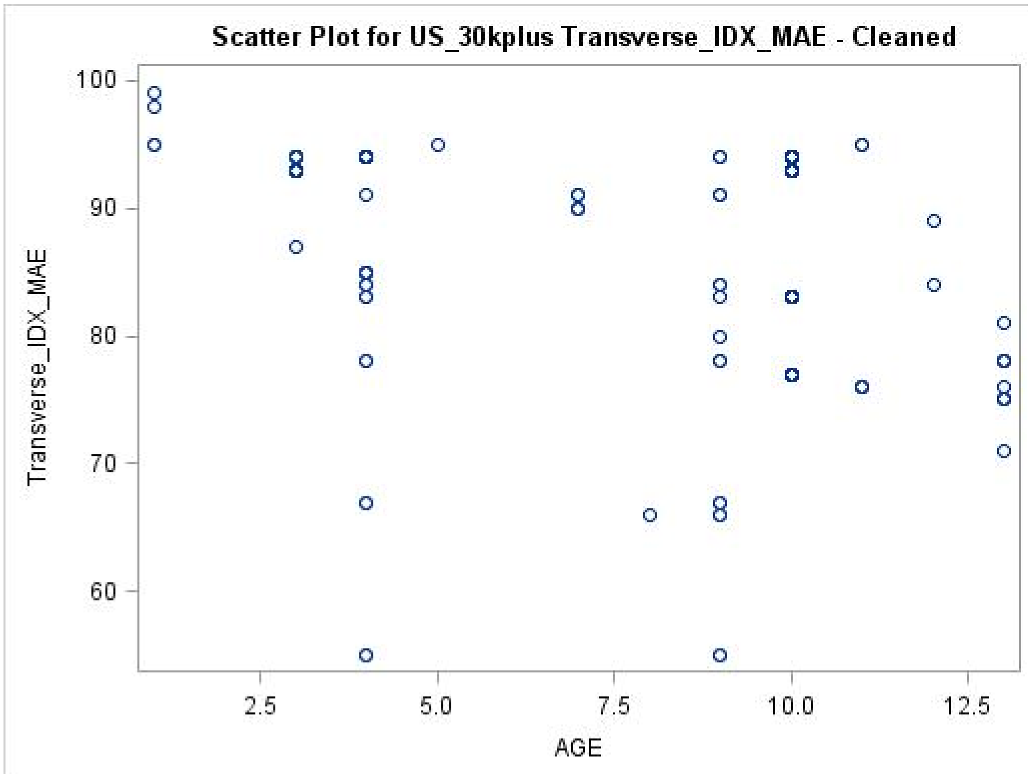

Figure 11: Schematic Scatter Plot for US_30kplus Transverse_IDX_MAE - Cleaned

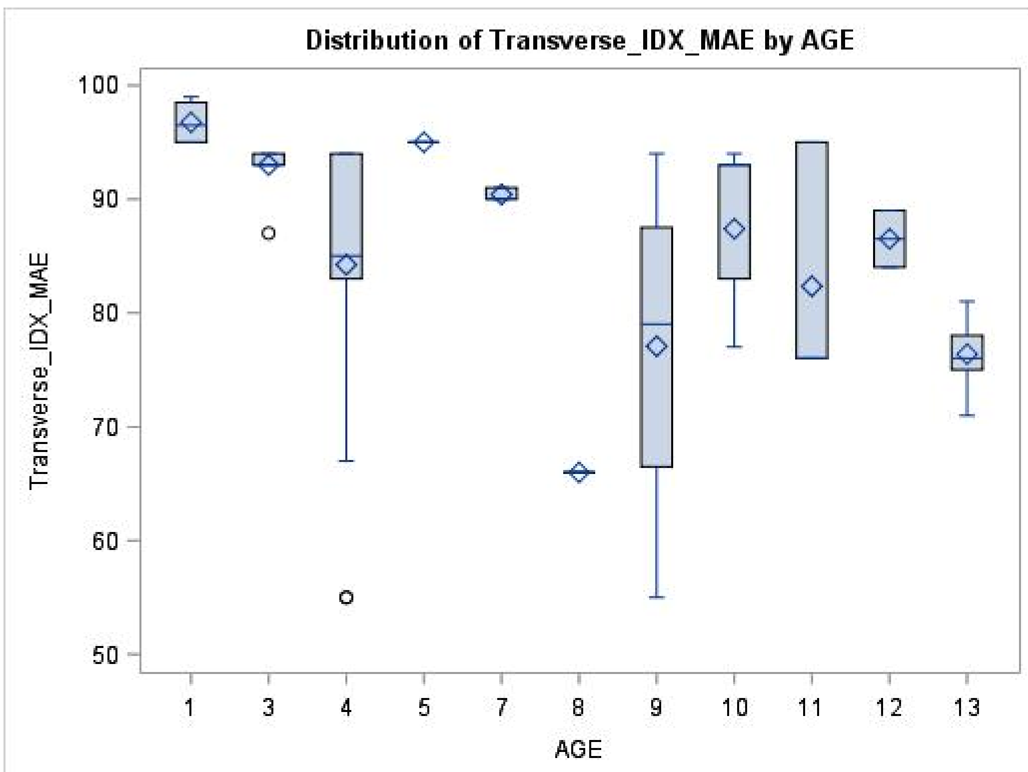

Figure 12: Schematic Box Plot for US_30kplus Transverse_IDX_MAE - Cleaned

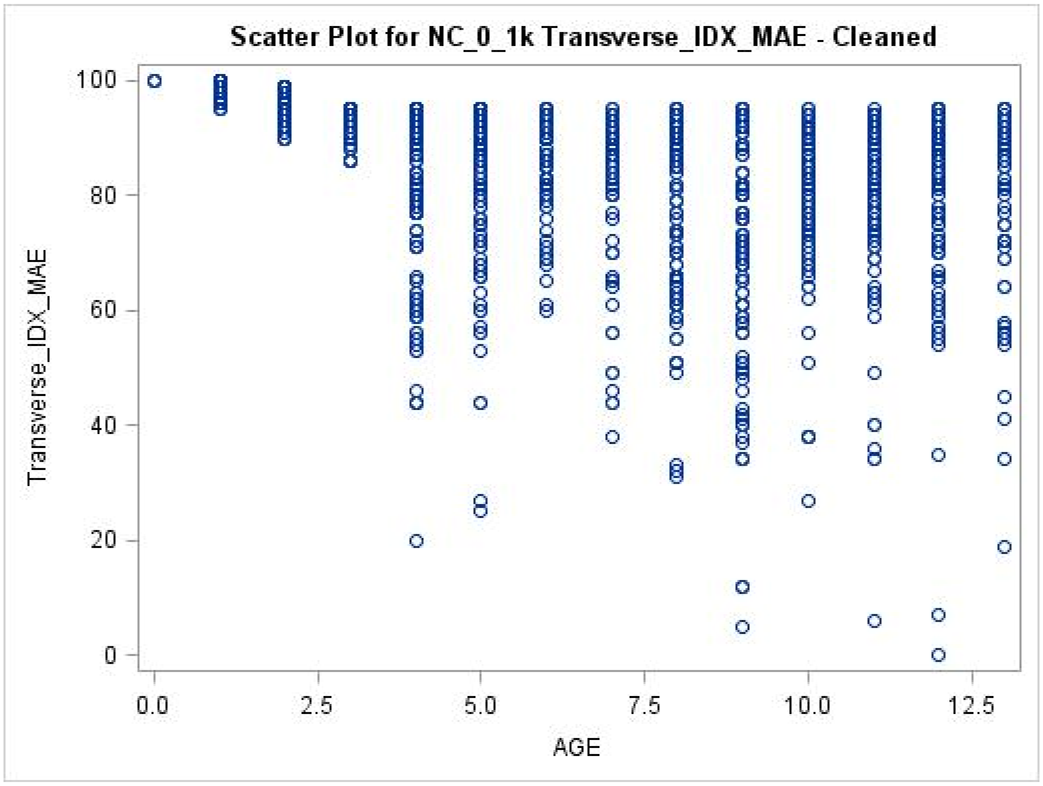

Figure 13: Schematic Scatter Plot for NC_0_1k Transverse_IDX_MAE - Cleaned

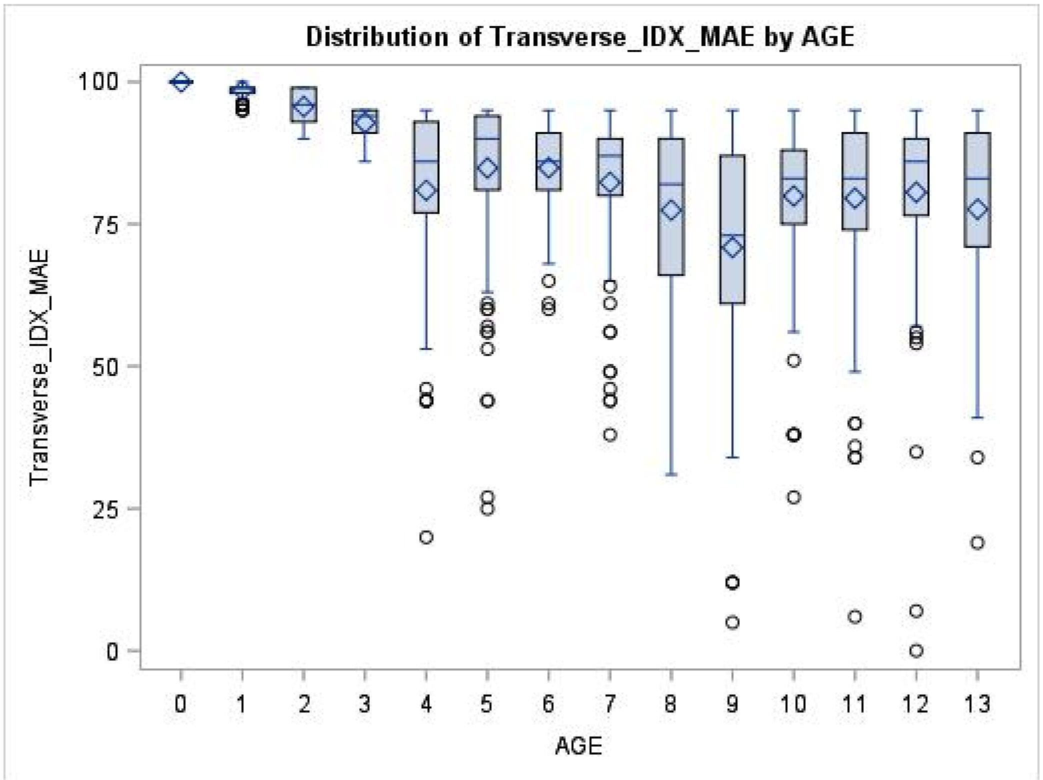

Figure 14: Schematic Box Plot for NC_0_1k Transverse_IDX_MAE - Cleaned

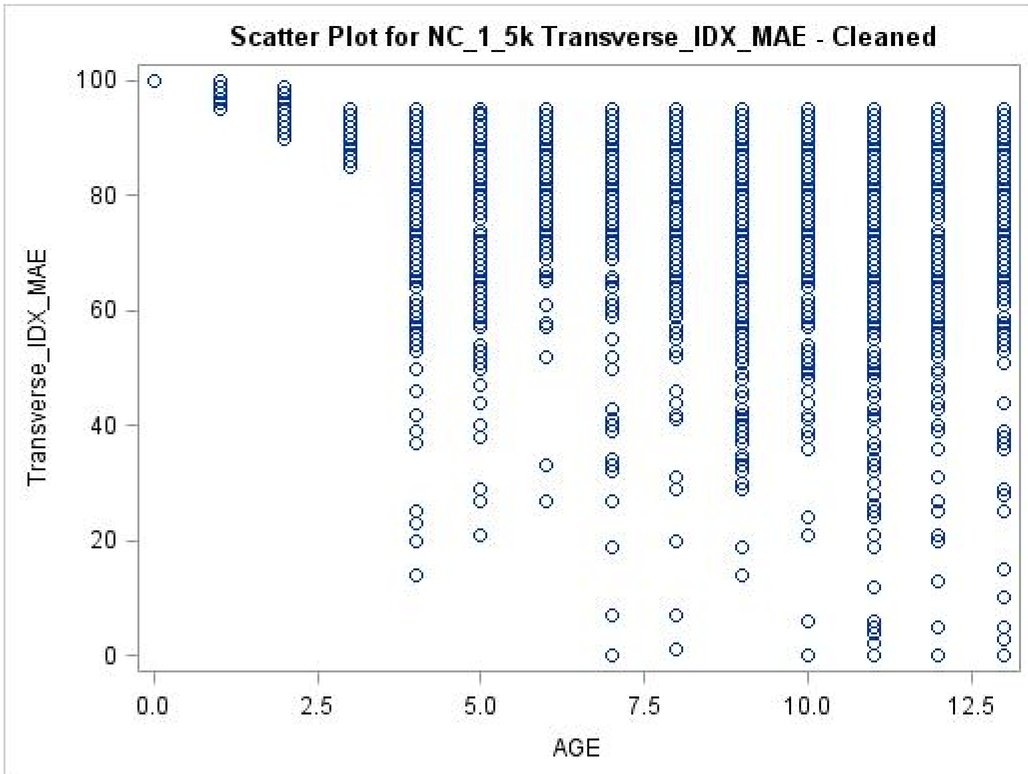

Figure 15: Schematic Scatter Plot for NC_1_5k Transverse_IDX_MAE - Cleaned

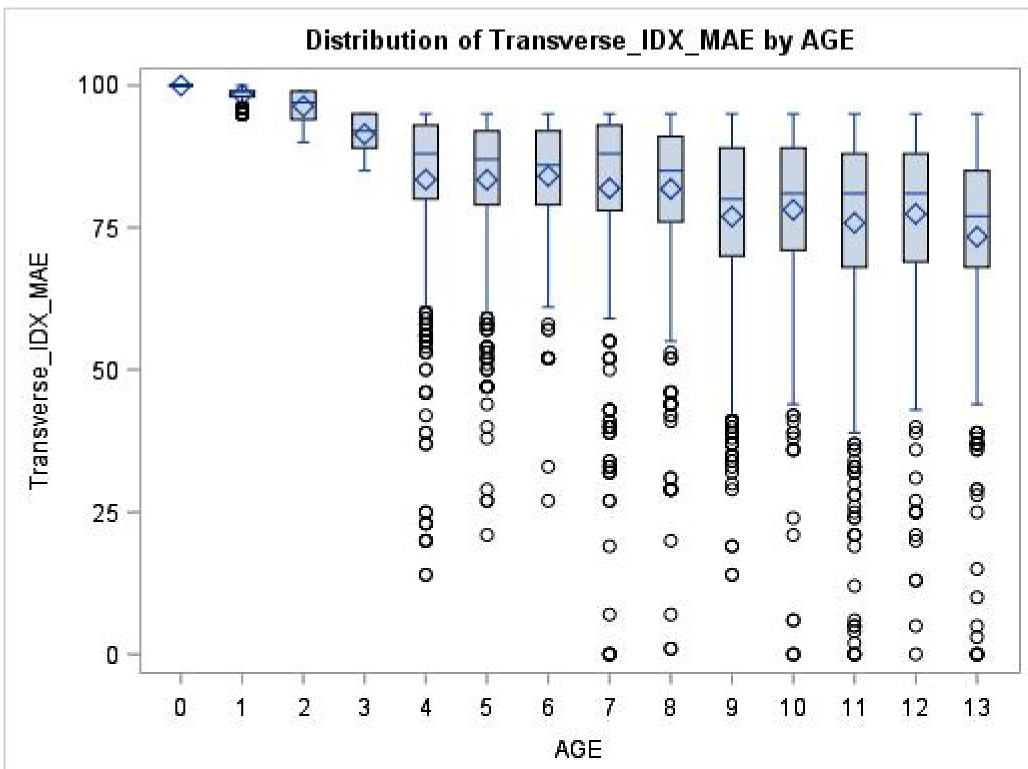

Figure 16: Schematic Box Plot for NC_1_5k Transverse_IDX_MAE - Cleaned

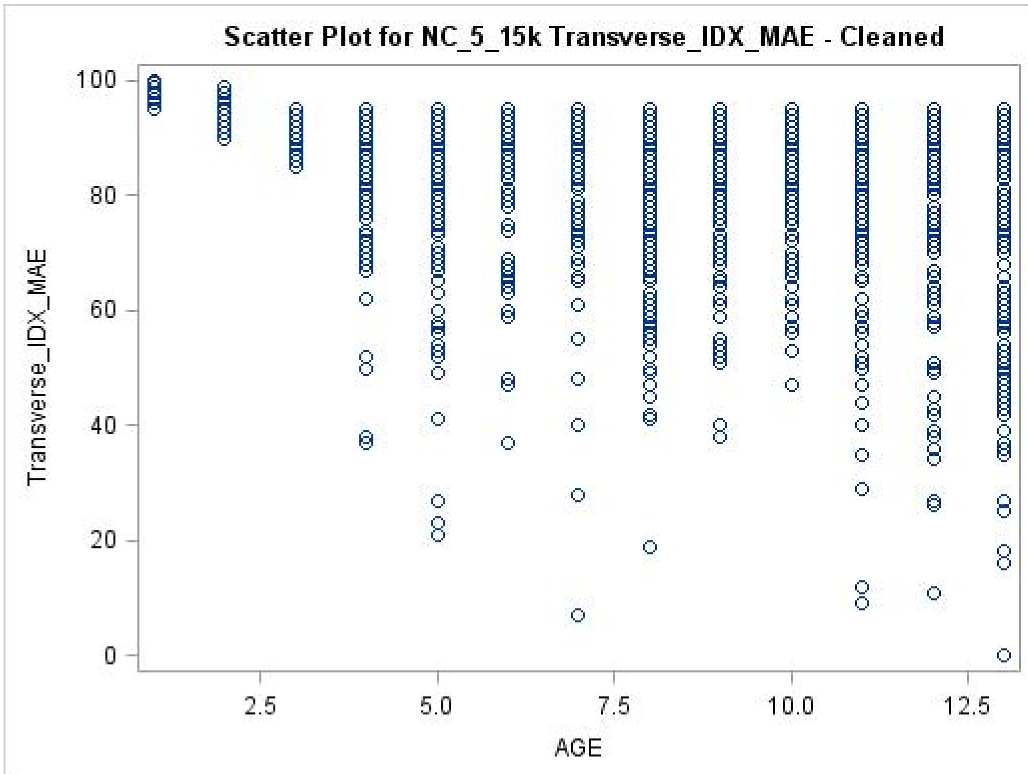

Figure 17: Schematic Scatter Plot for NC_5_15k Transverse_IDX_MAE - Cleaned

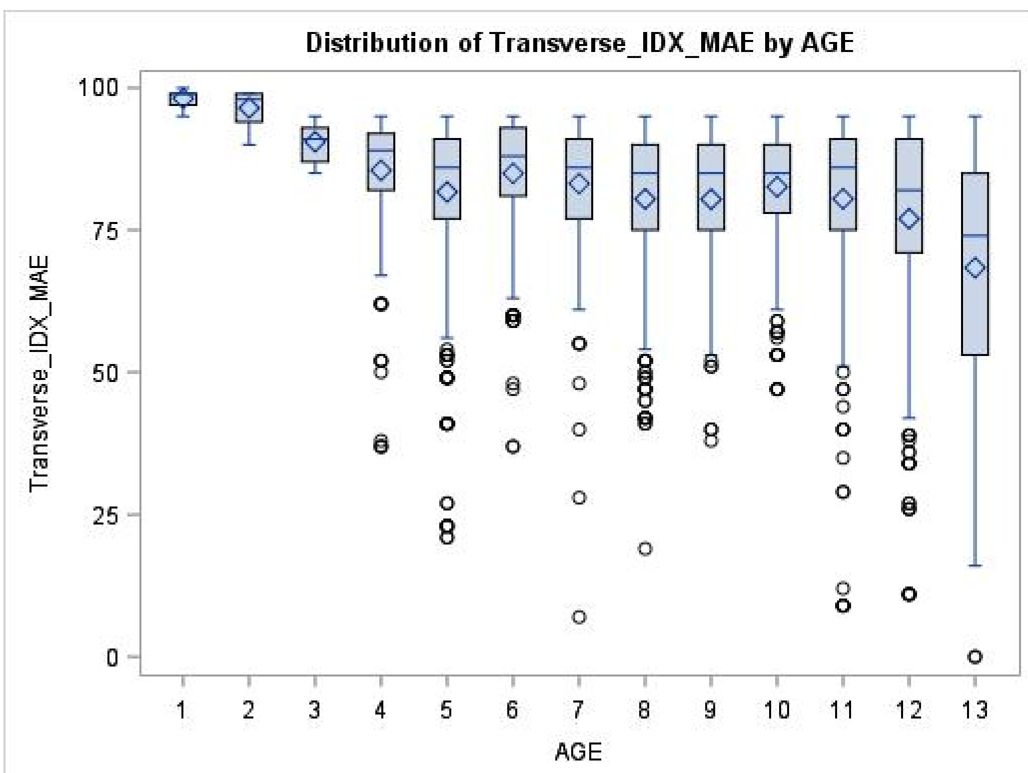

Figure 18: Schematic Box Plot for NC_5_15k Transverse_IDX_MAE - Cleaned

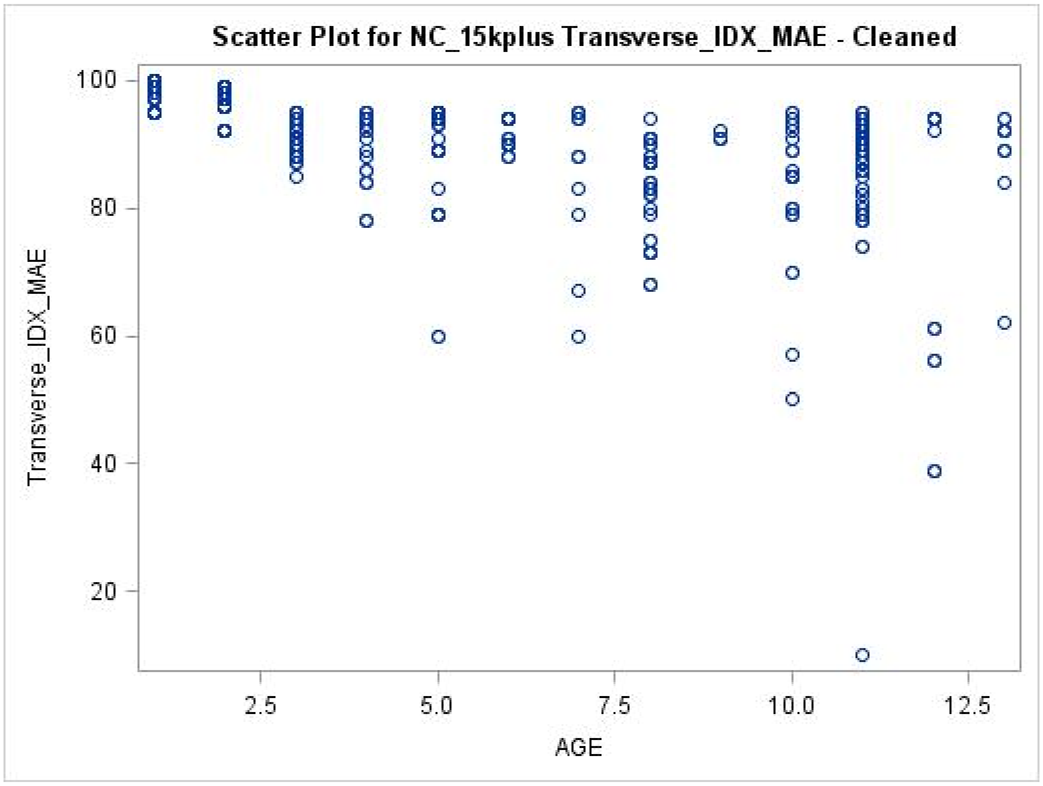

Figure 19: Schematic Scatter Plot for NC_15kplus Transverse_IDX_MAE - Cleaned

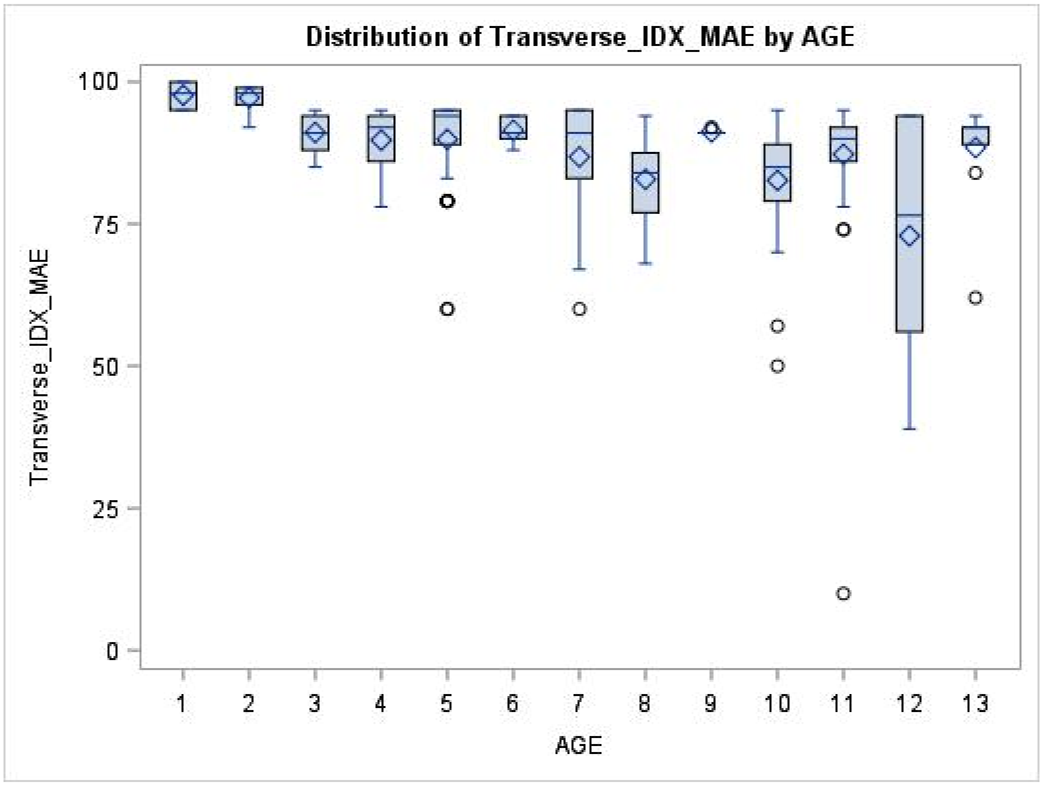

Figure 20: Schematic Box Plot for NC_15kplus Transverse_IDX_MAE - Cleaned

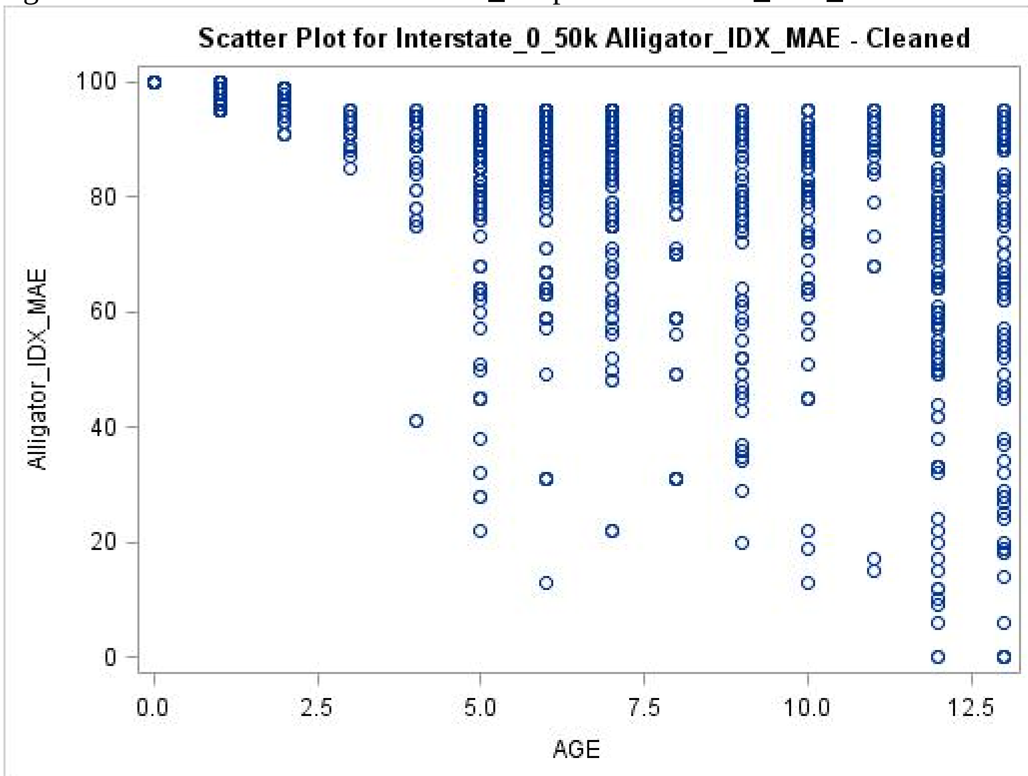

Figure 21: Schematic Scatter Plot for Interstate_0_50k Alligator_IDX_MAE - Cleaned

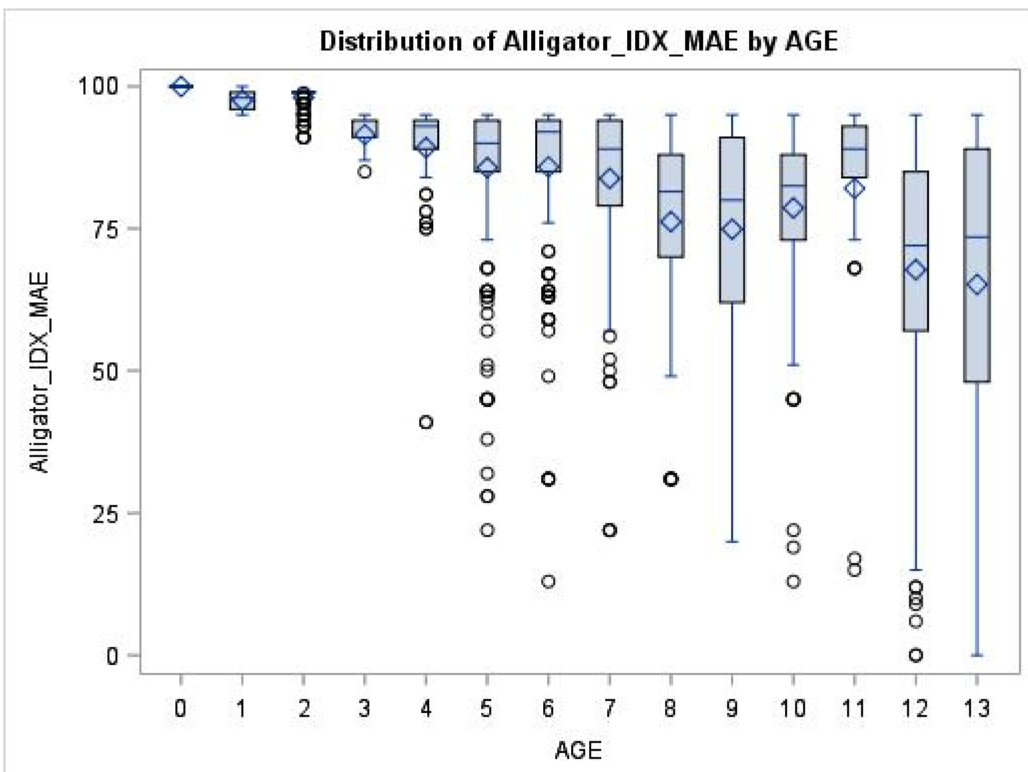

Figure 22: Schematic Box Plot for Interstate_0_50k Alligator_IDX_MAE - Cleaned

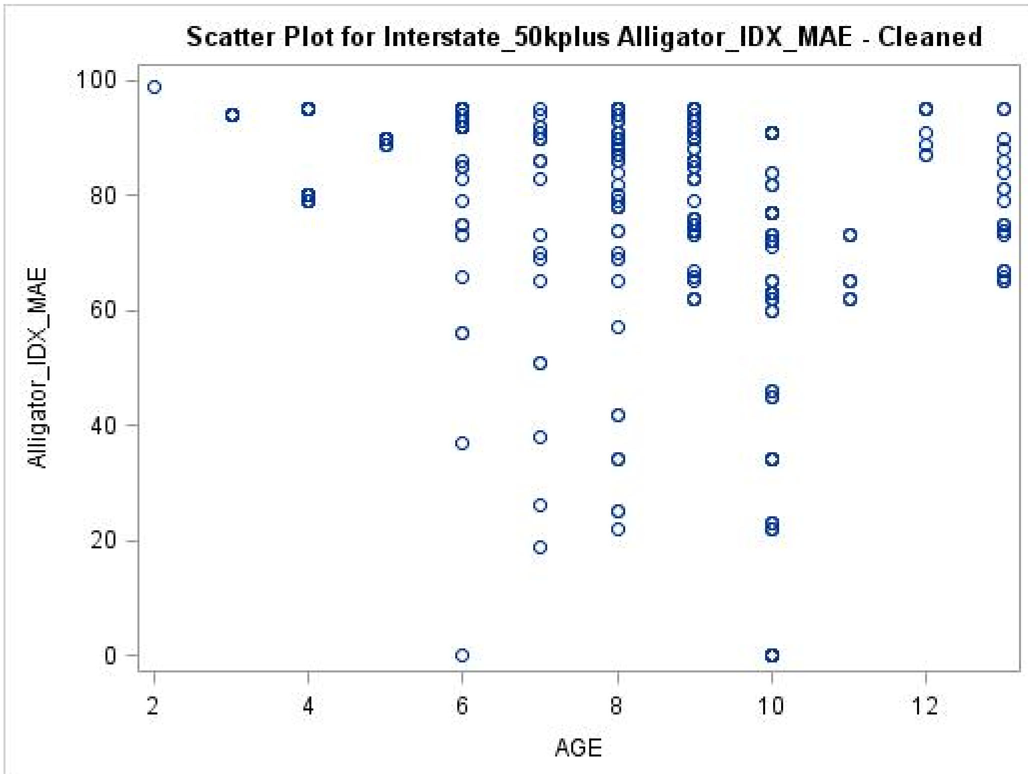

Figure 23: Schematic Scatter Plot for Interstate_50kplus Alligator_IDX_MAE - Cleaned

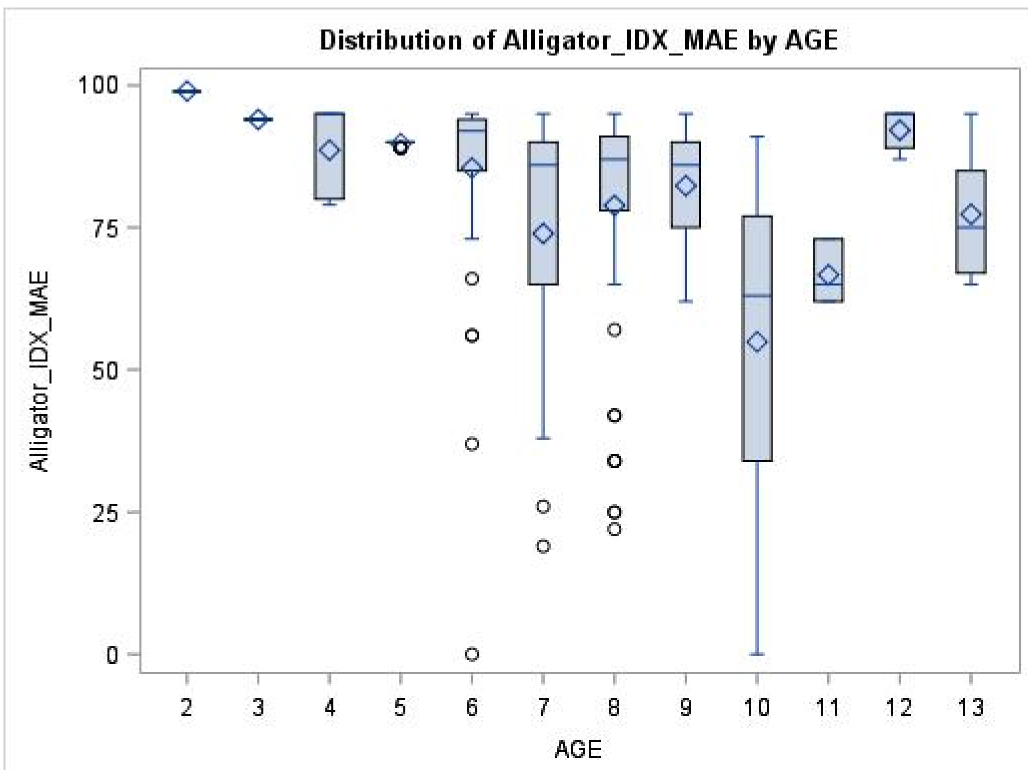

Figure 24: Schematic Box Plot for Interstate_50kplus Alligator_IDX_MAE - Cleaned

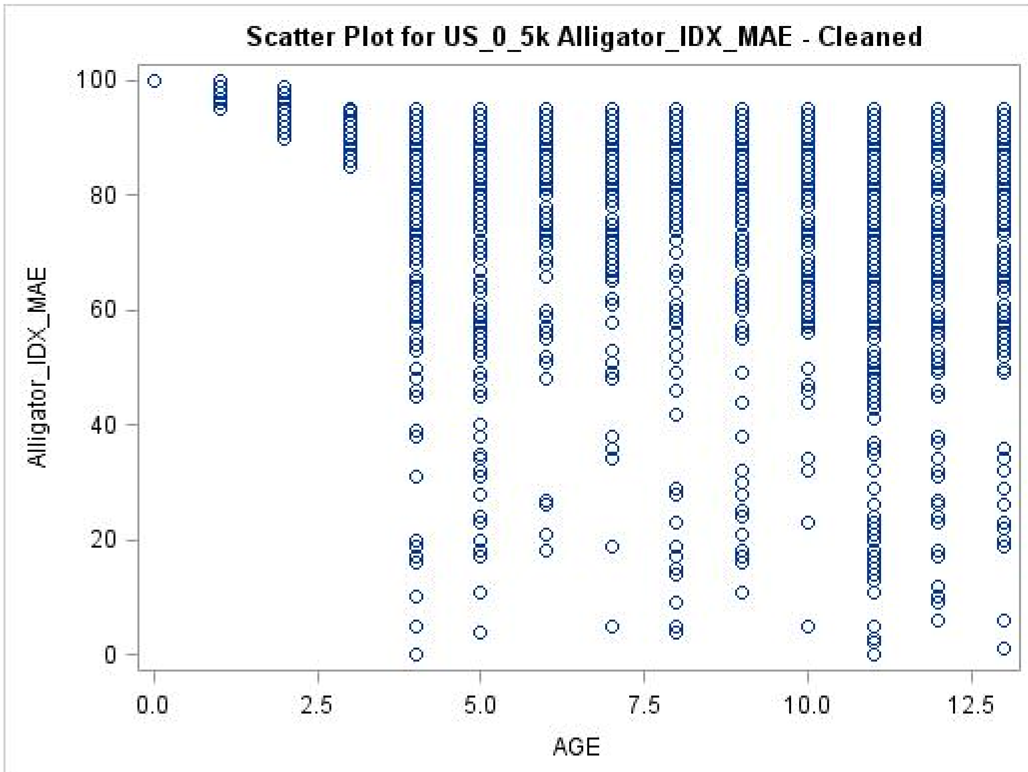

Figure 25: Schematic Scatter Plot for US_0_5k Alligator_IDX_MAE - Cleaned

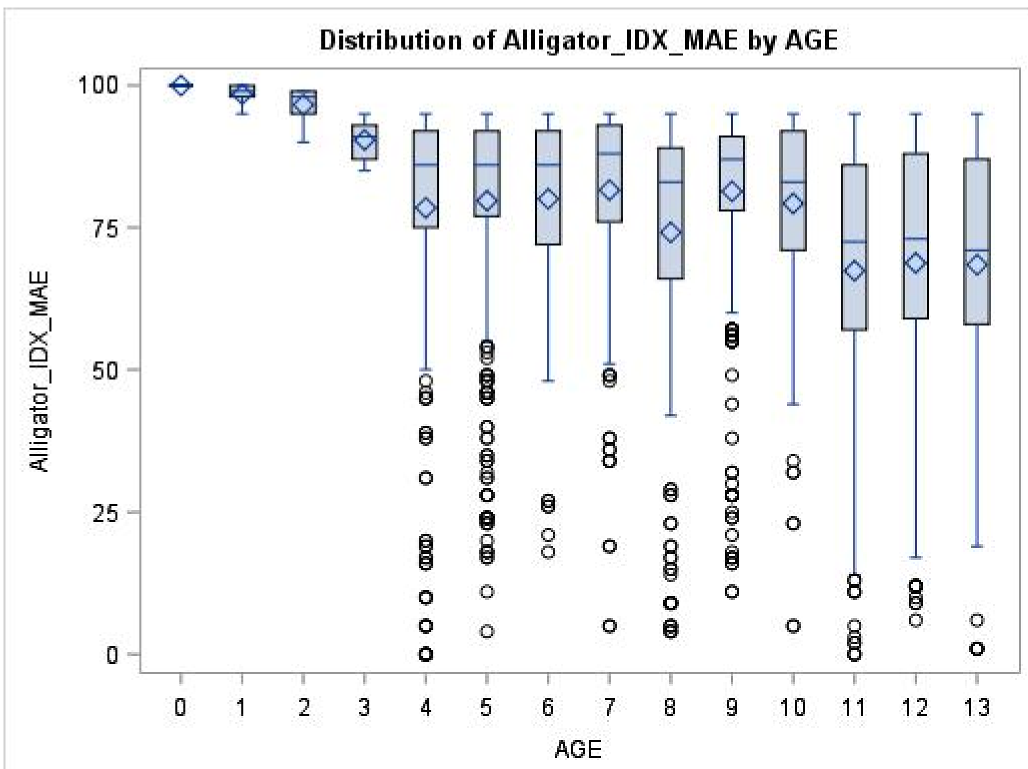

Figure 26: Schematic Box Plot for US_0_5k Alligator_IDX_MAE - Cleaned

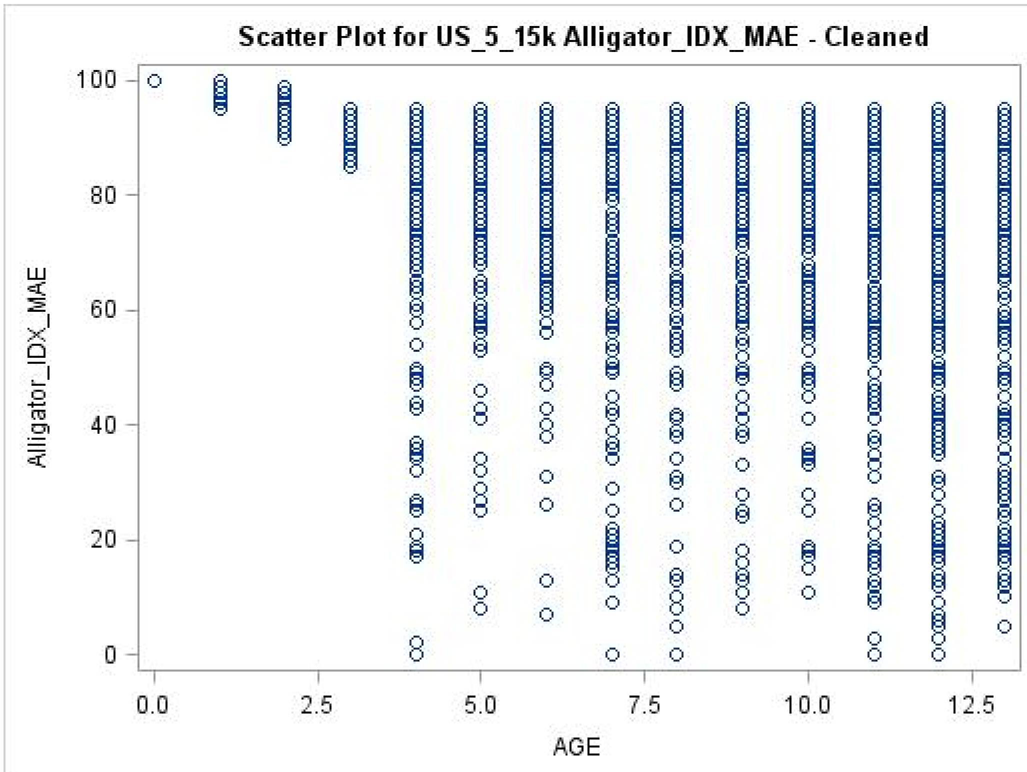

Figure 27: Schematic Scatter Plot for US_5_15k Alligator_IDX_MAE - Cleaned

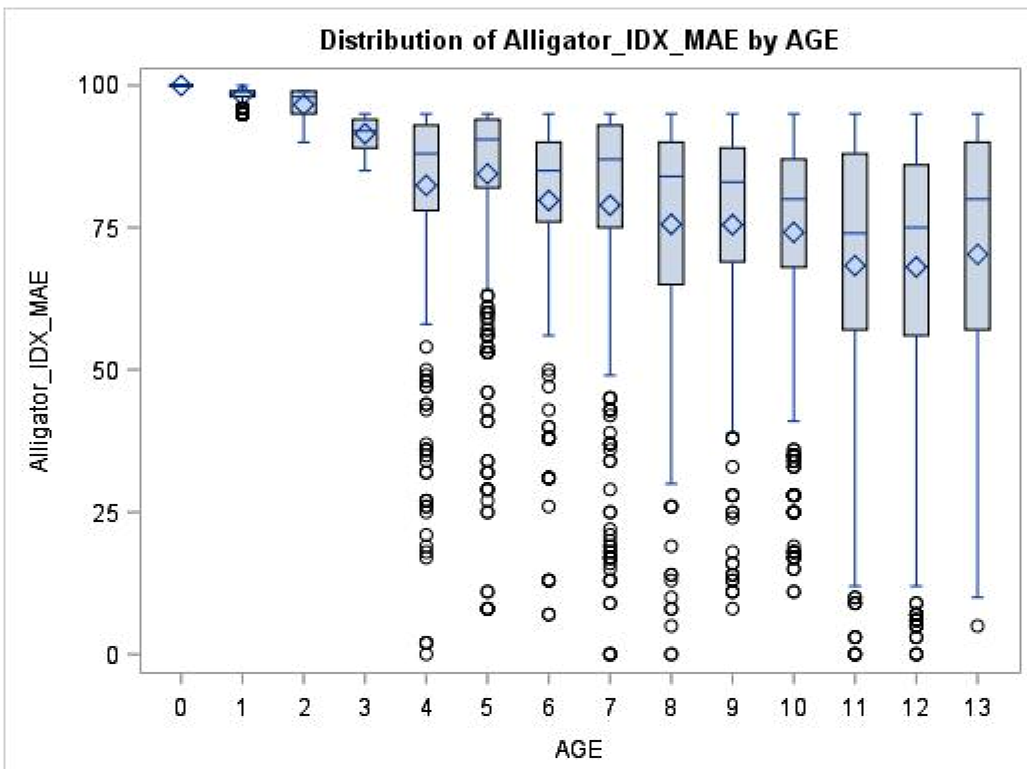

Figure 28: Schematic Box Plot for US_5_15k Alligator_IDX_MAE - Cleaned

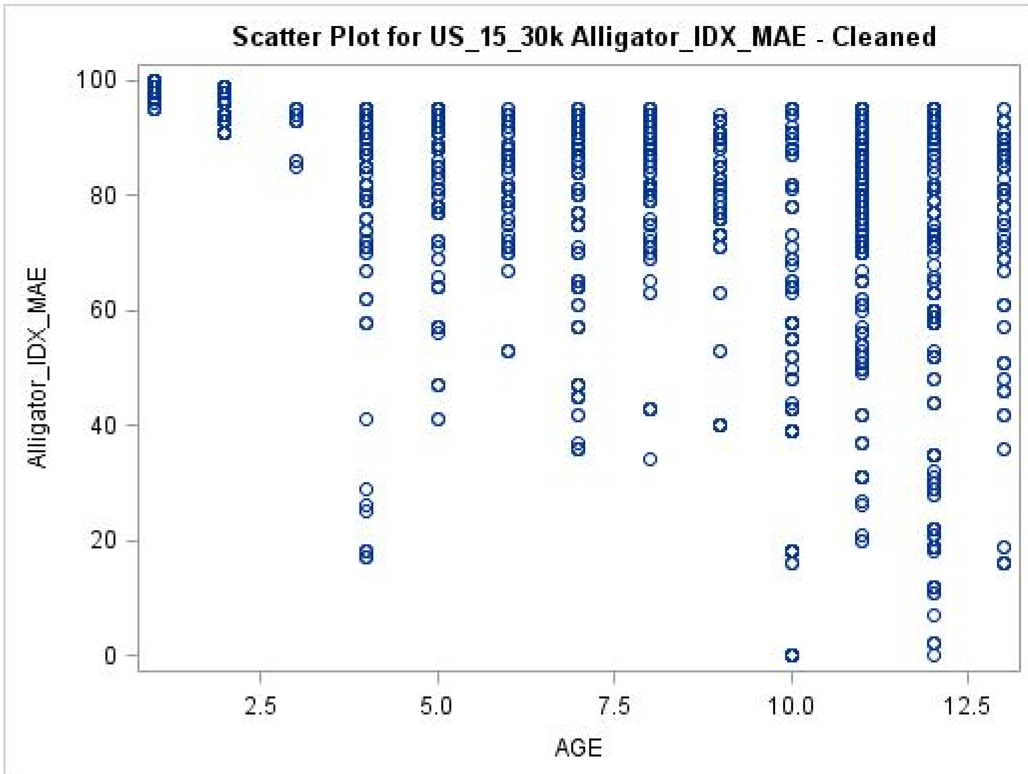

Figure 29: Schematic Scatter Plot for US_15_30k Alligator_IDX_MAE - Cleaned

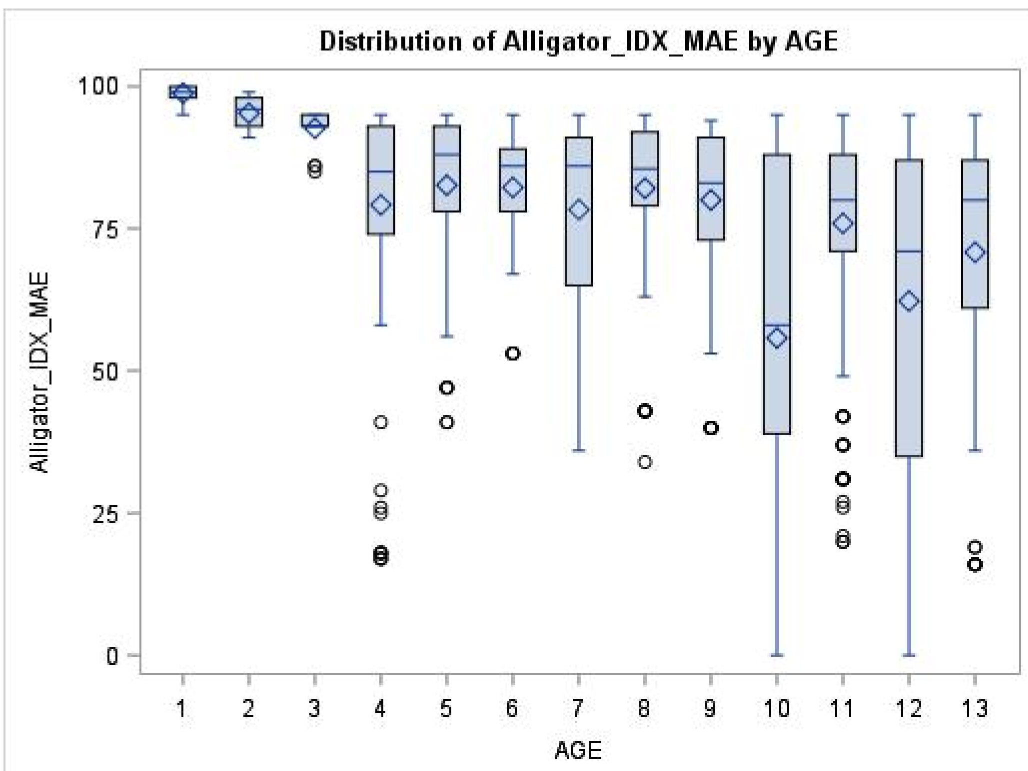

Figure 30: Schematic Box Plot for US_15_30k Alligator_IDX_MAE - Cleaned

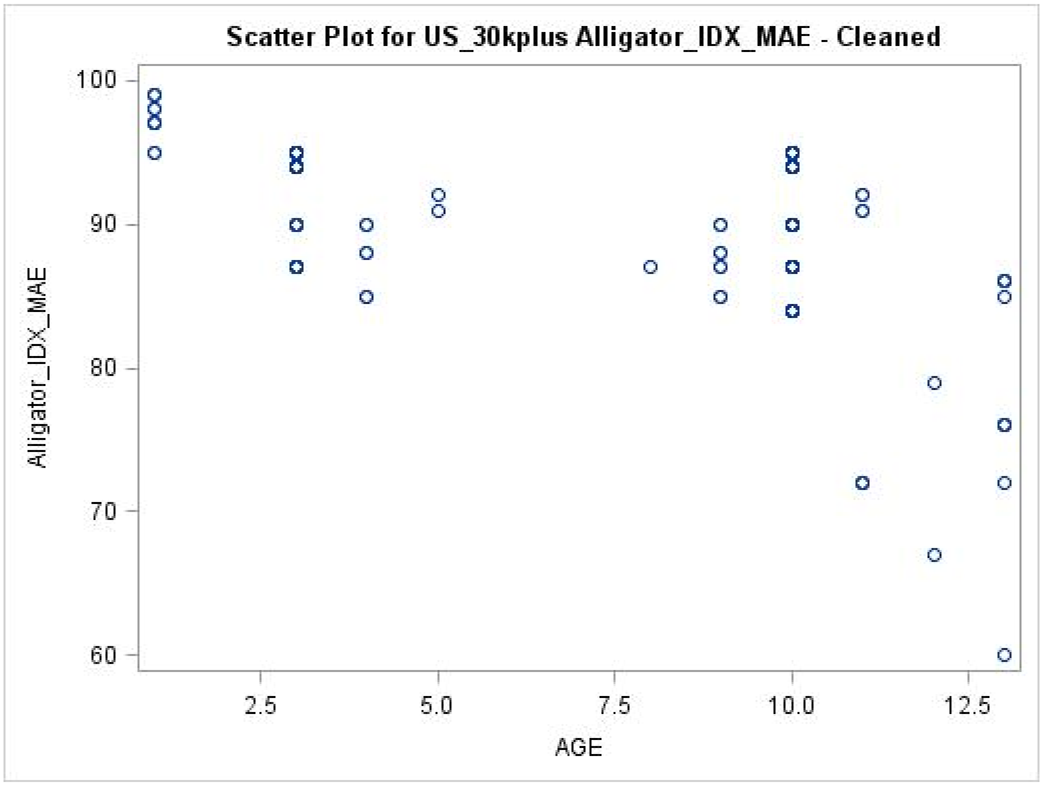

Figure 31: Schematic Scatter Plot for US_30kplus Alligator_IDX_MAE - Cleaned

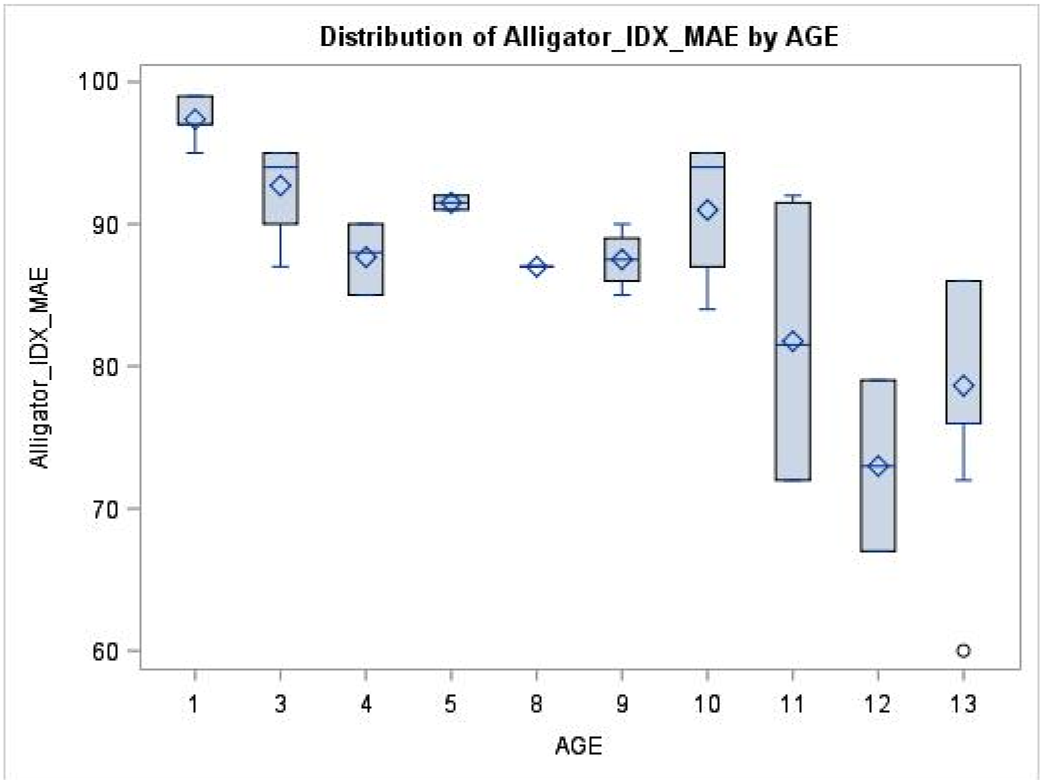

Figure 32: Schematic Box Plot for US_30kplus Alligator_IDX_MAE - Cleaned

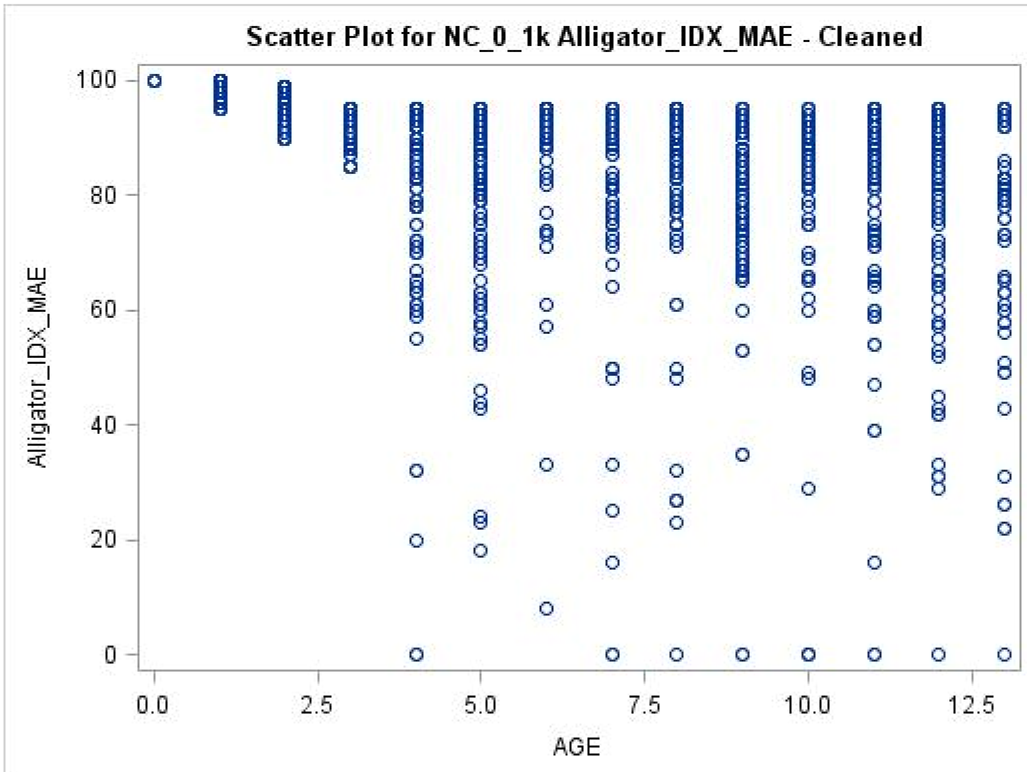

Figure 33: Schematic Scatter Plot for NC_0_1k Alligator_IDX_MAE - Cleaned

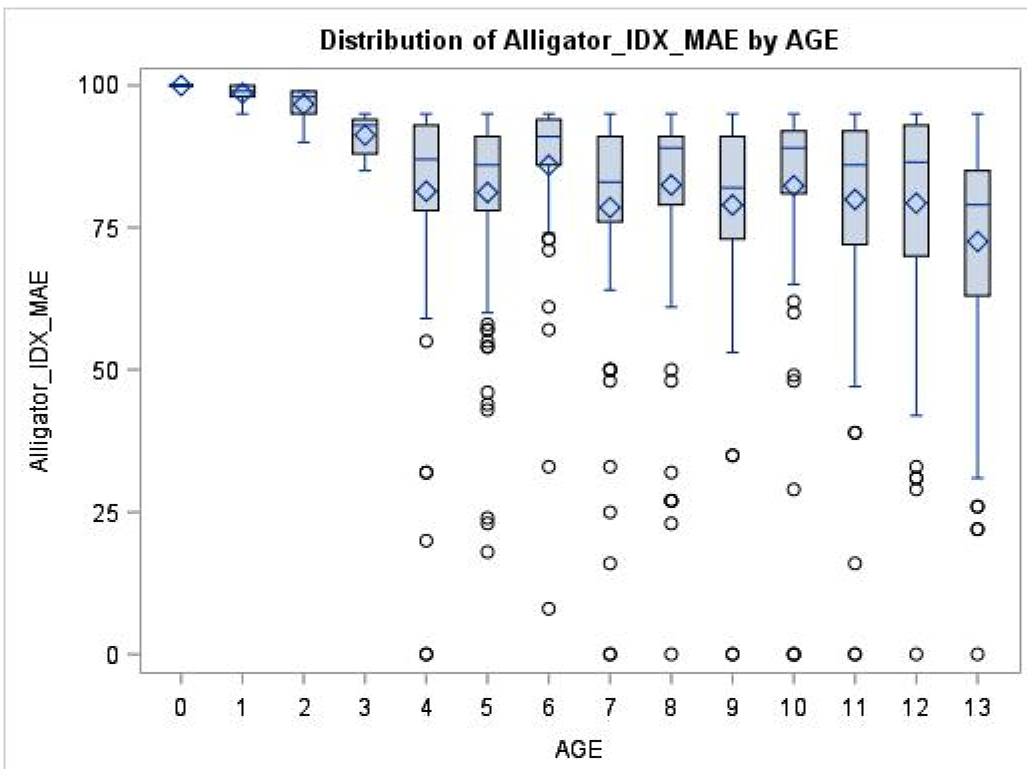

Figure 34: Schematic Box Plot for NC_0_1k Alligator_IDX_MAE - Cleaned

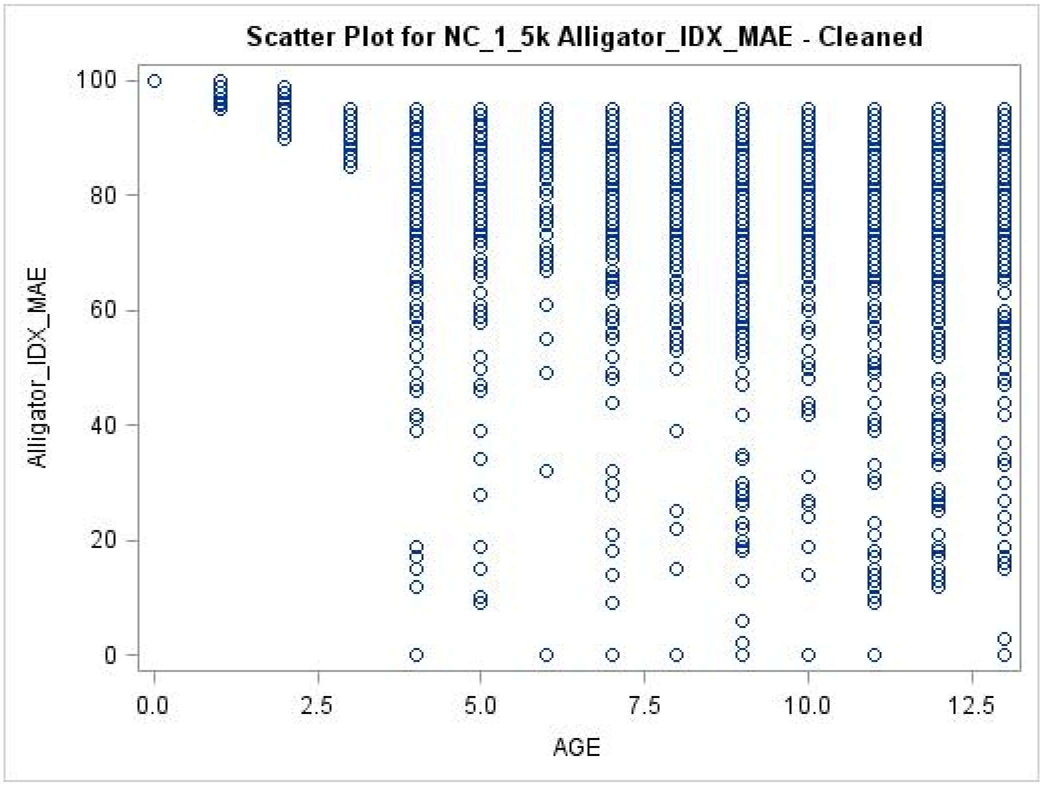

Figure 35: Schematic Scatter Plot for NC_1_5k Alligator_IDX_MAE - Cleaned

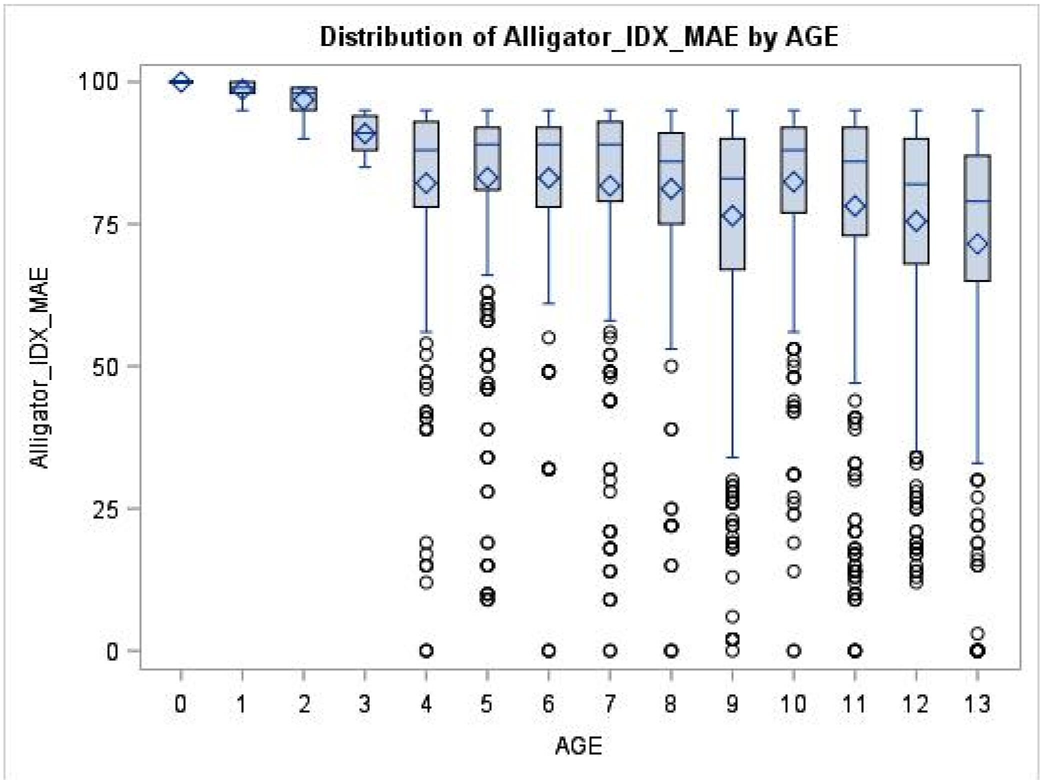

Figure 36: Schematic Box Plot for NC_1_5k Alligator_IDX_MAE - Cleaned

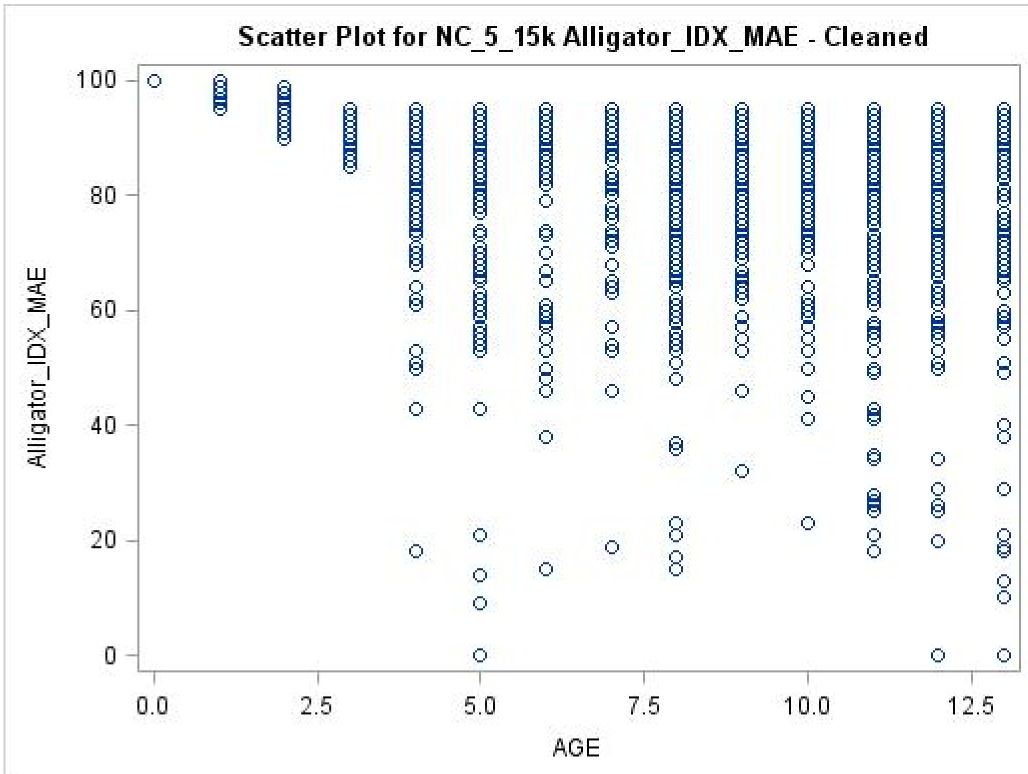

Figure 37: Schematic Scatter Plot for NC_5_15k Alligator_IDX_MAE - Cleaned

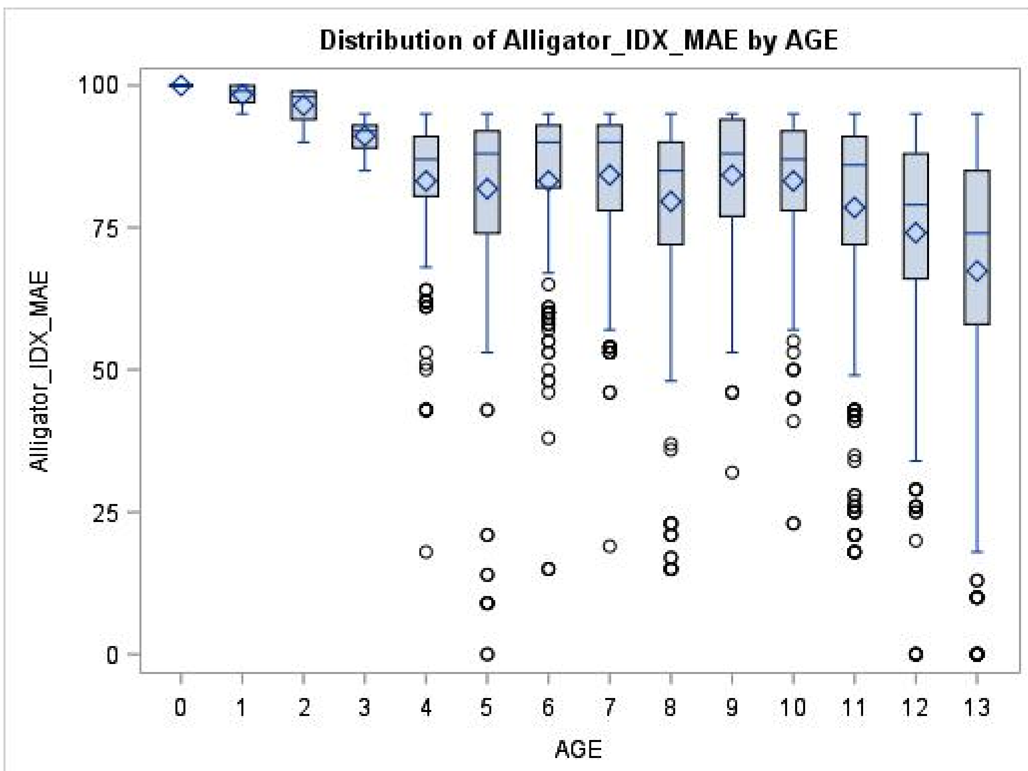

Figure 38: Schematic Box Plot for NC_5_15k Alligator_IDX_MAE - Cleaned

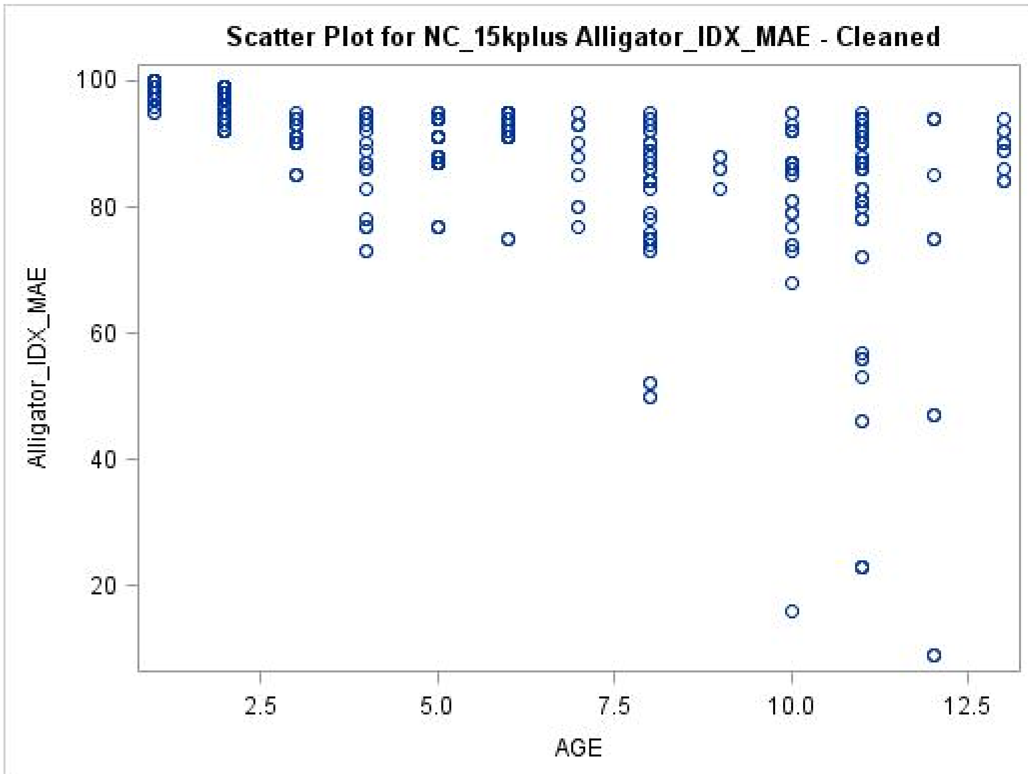

Figure 39: Schematic Scatter Plot for NC_15kplus Alligator_IDX_MAE - Cleaned

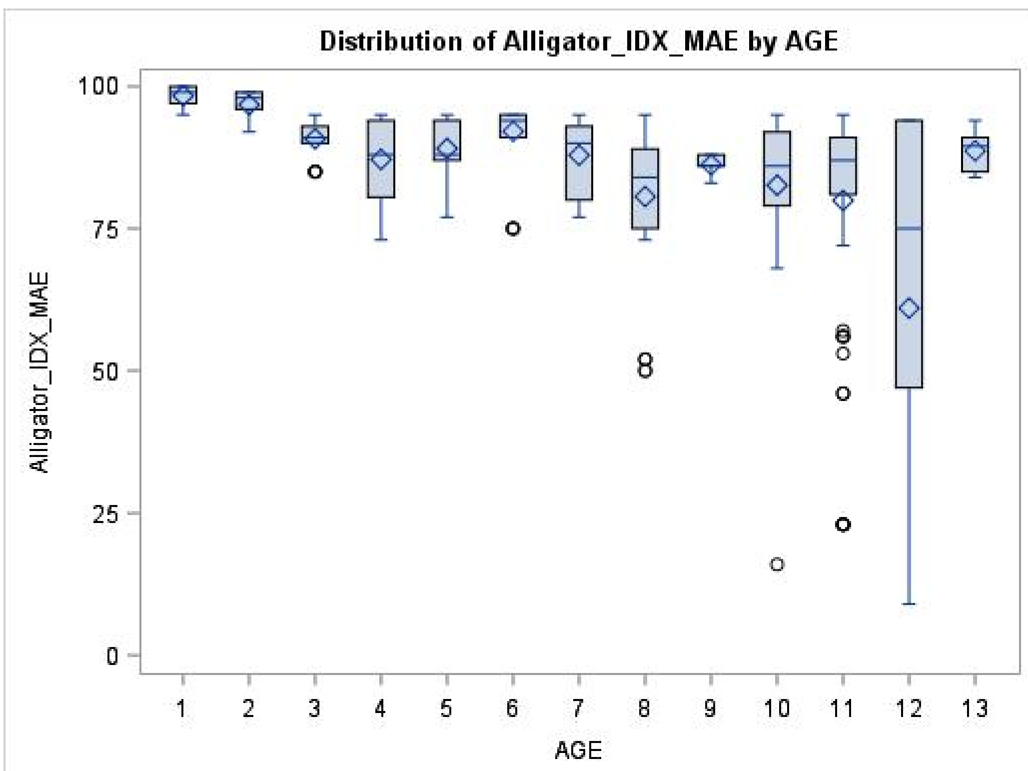

Figure 40: Schematic Box Plot for NC_15kplus Alligator_IDX_MAE - Cleaned

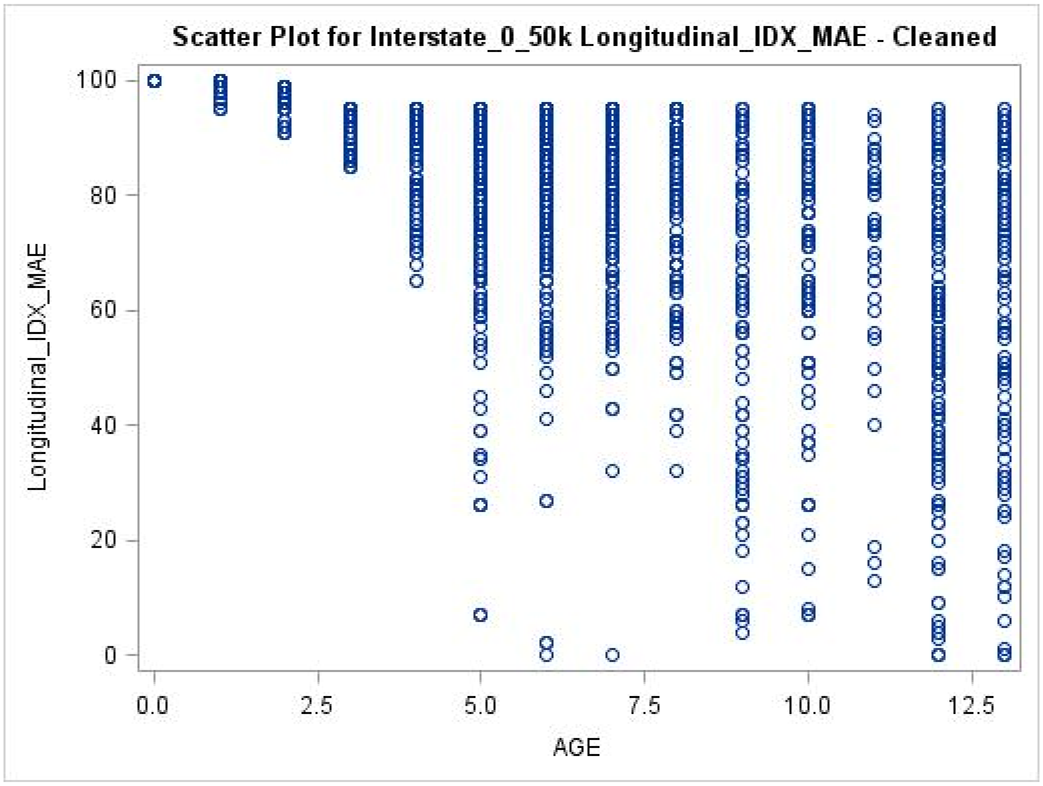

Figure 41: Schematic Scatter Plot for Interstate_0_50k Longitudinal_IDX_MAE - Cleaned

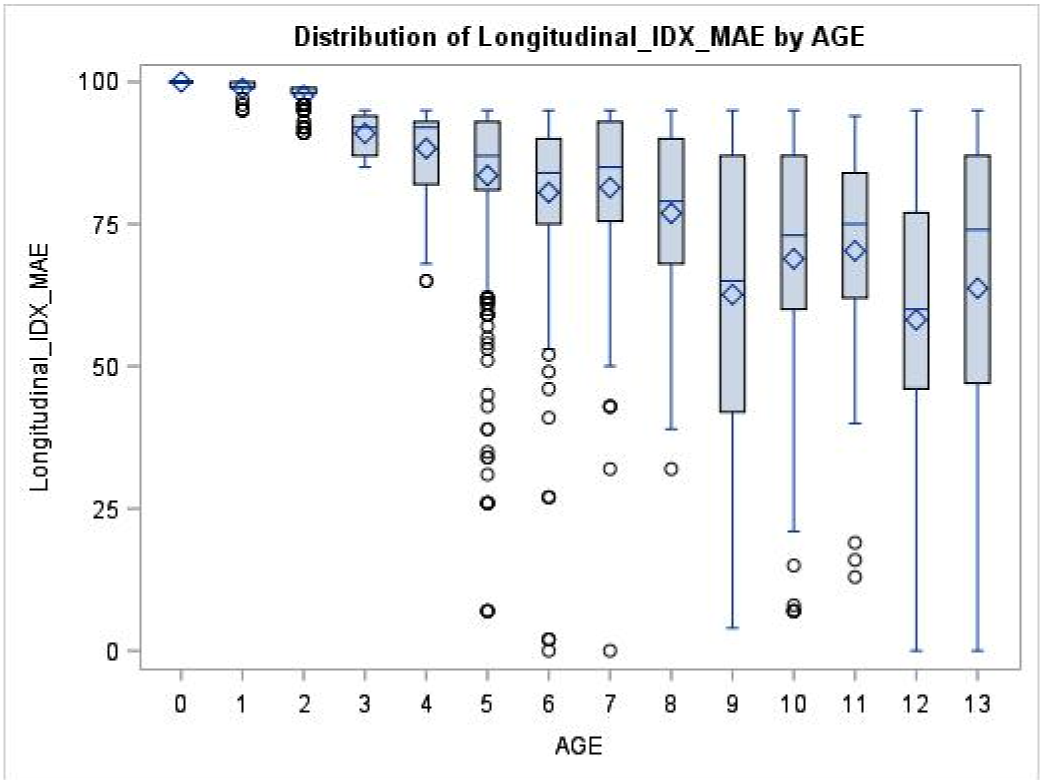

Figure 42: Schematic Box Plot for Interstate_0_50k Longitudinal_IDX_MAE - Cleaned

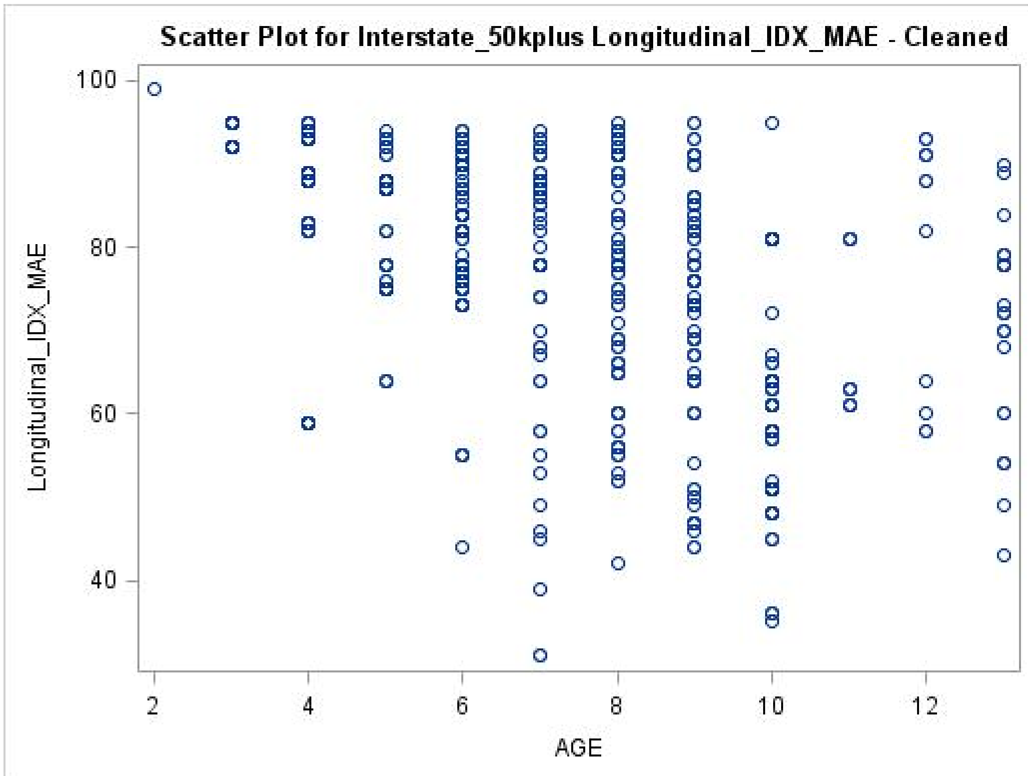

Figure 43: Schematic Scatter Plot for Interstate_50kplus Longitudinal_IDX_MAE - Cleaned

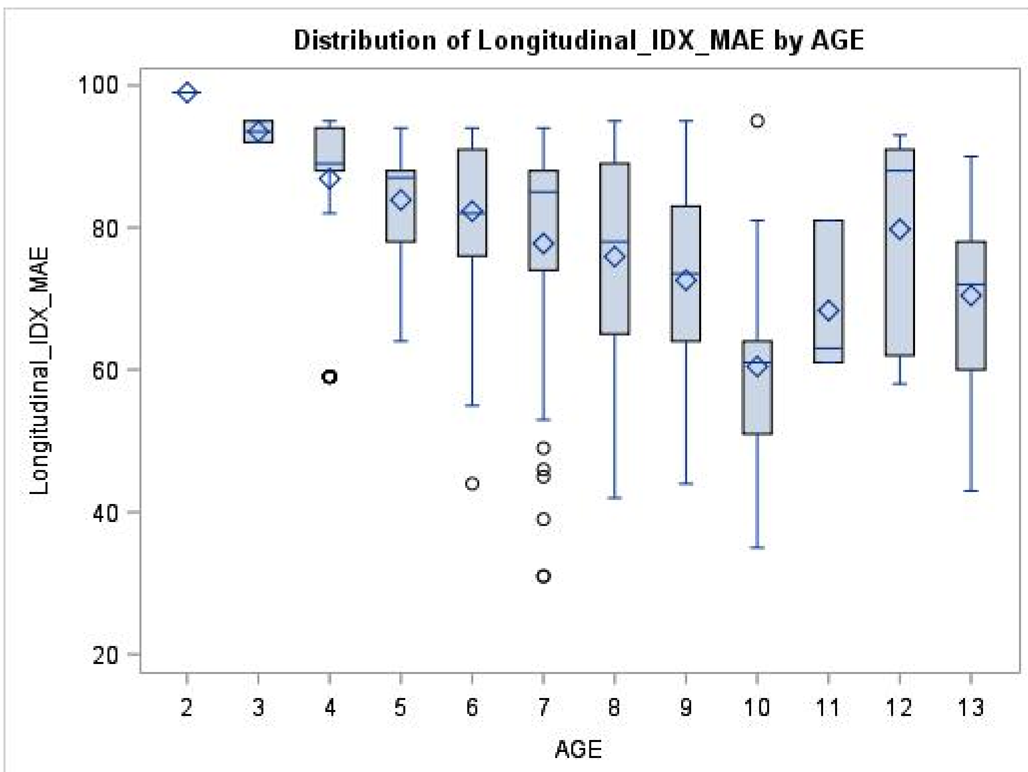

Figure 44: Schematic Box Plot for Interstate_50kplus Longitudinal_IDX_MAE - Cleaned

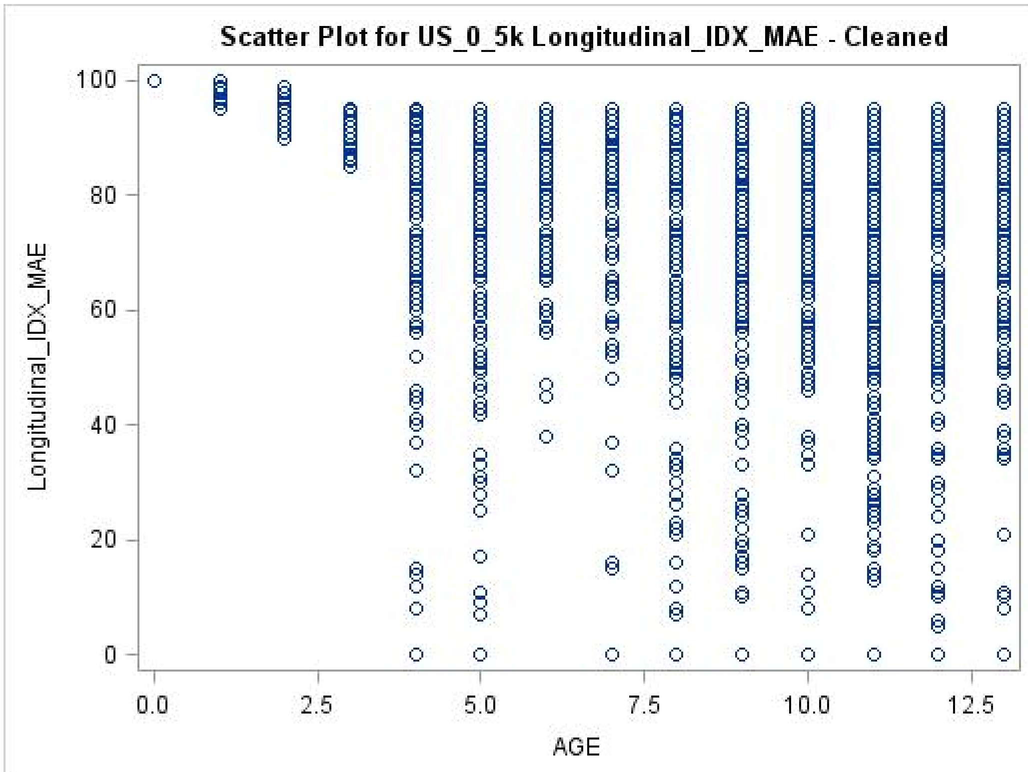

Figure 45: Schematic Scatter Plot for US_0_5k Longitudinal_IDX_MAE - Cleaned

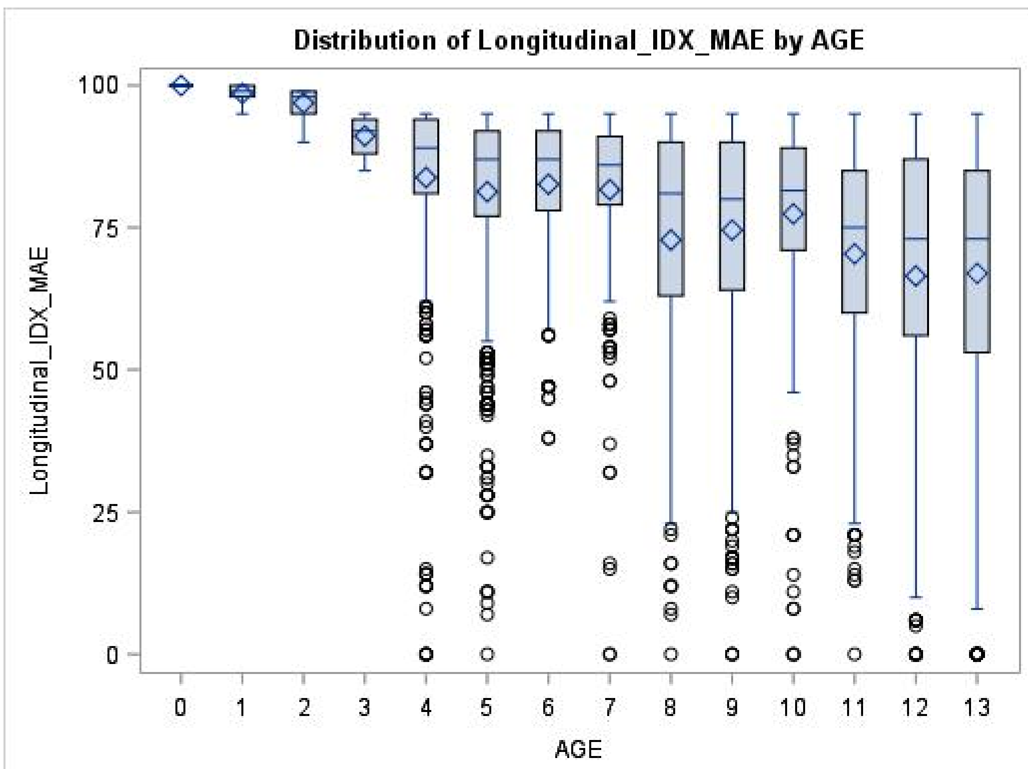

Figure 46: Schematic Box Plot for US_0_5k Longitudinal_IDX_MAE - Cleaned

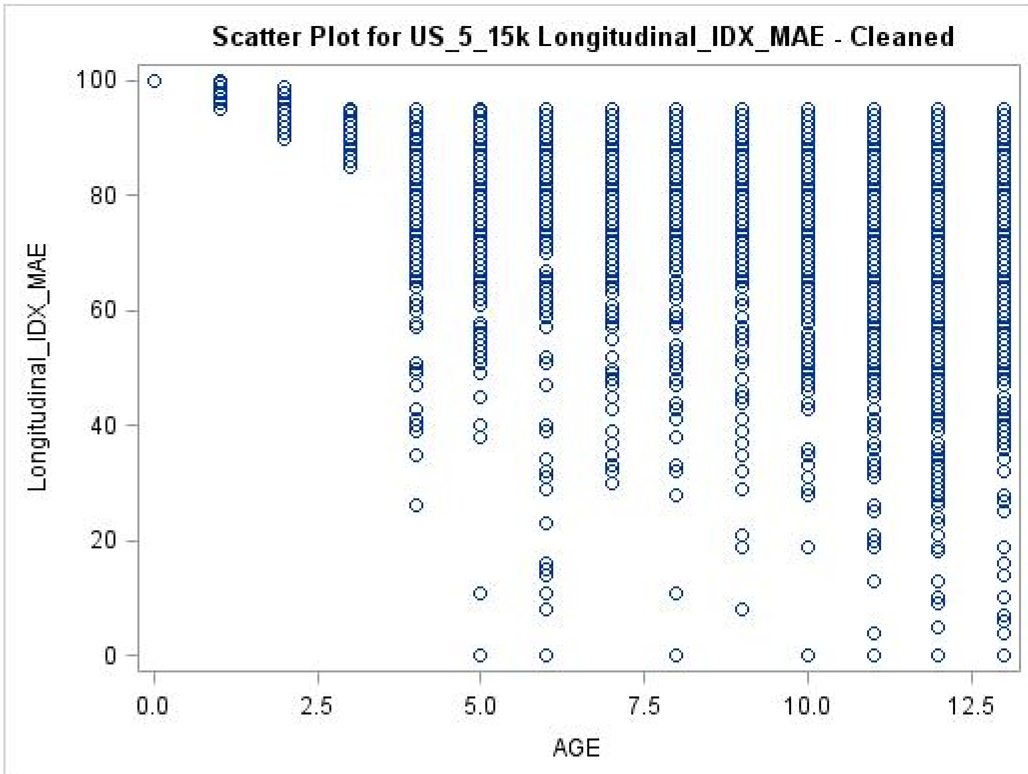

Figure 47: Schematic Scatter Plot for US_5_15k Longitudinal_IDX_MAE - Cleaned

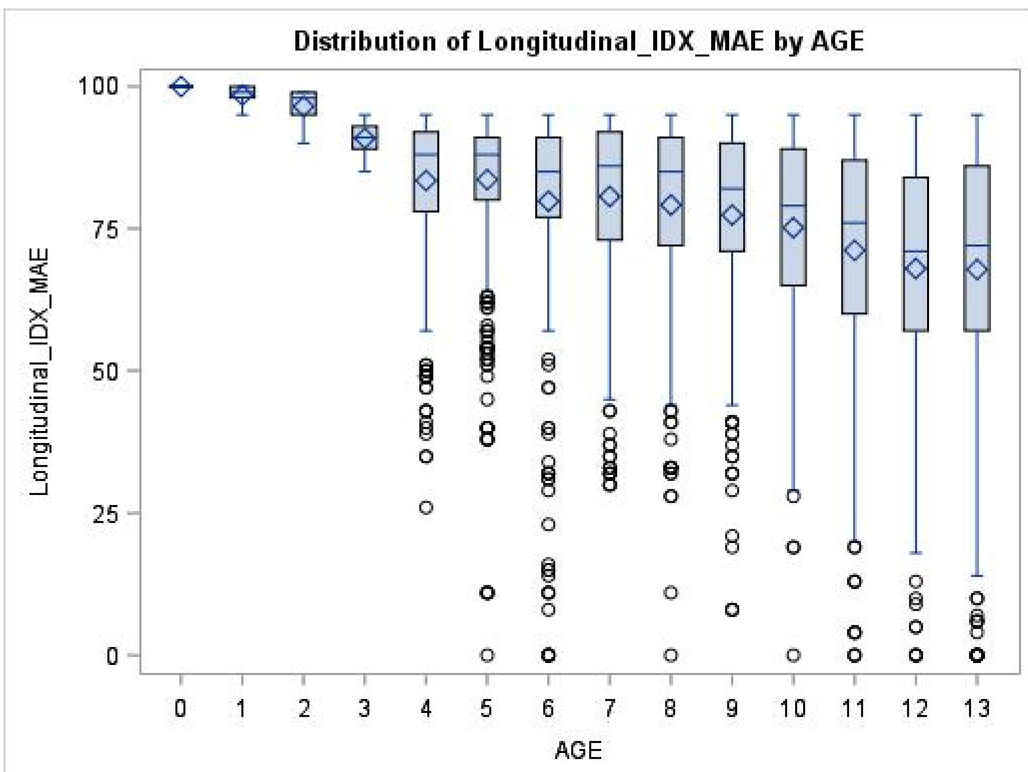

Figure 48: Schematic Box Plot for US_5_15k Longitudinal_IDX_MAE - Cleaned

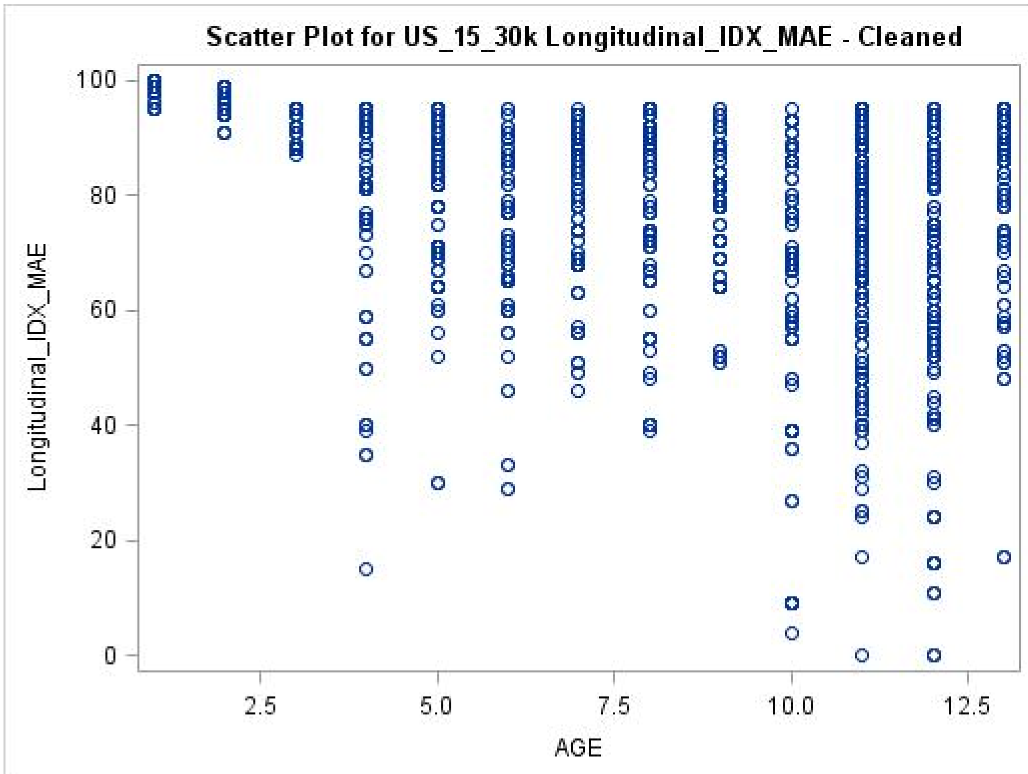

Figure 49: Schematic Scatter Plot for US_15_30k Longitudinal_IDX_MAE - Cleaned

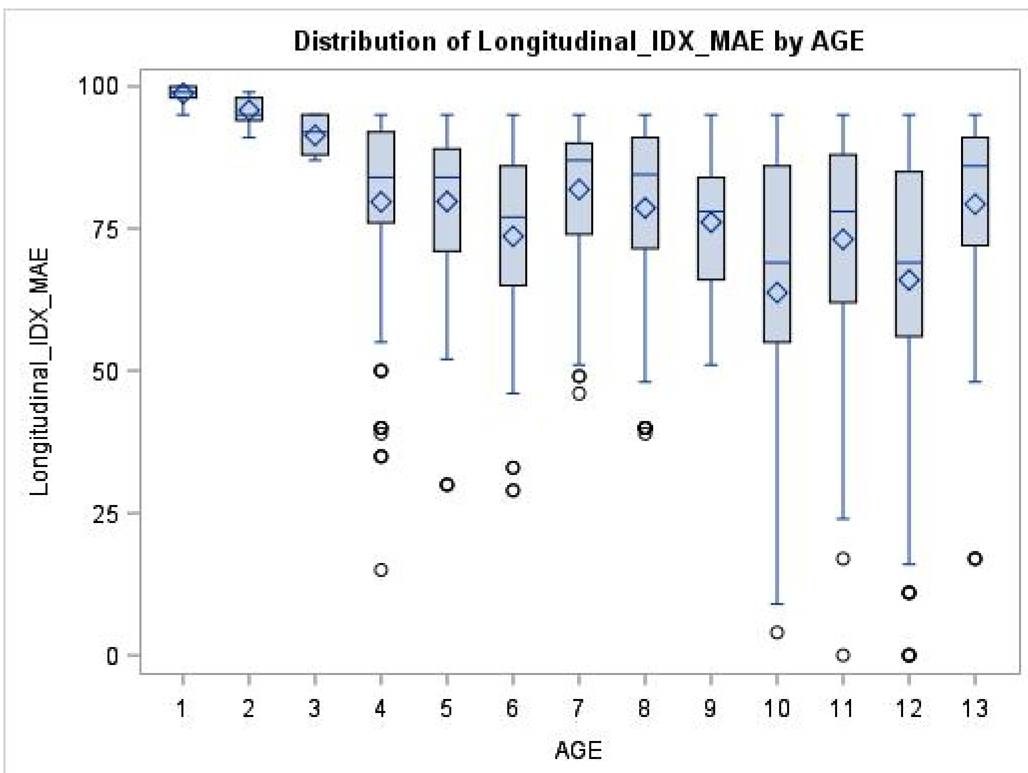

Figure 50: Schematic Box Plot for US_15_30k Longitudinal_IDX_MAE - Cleaned

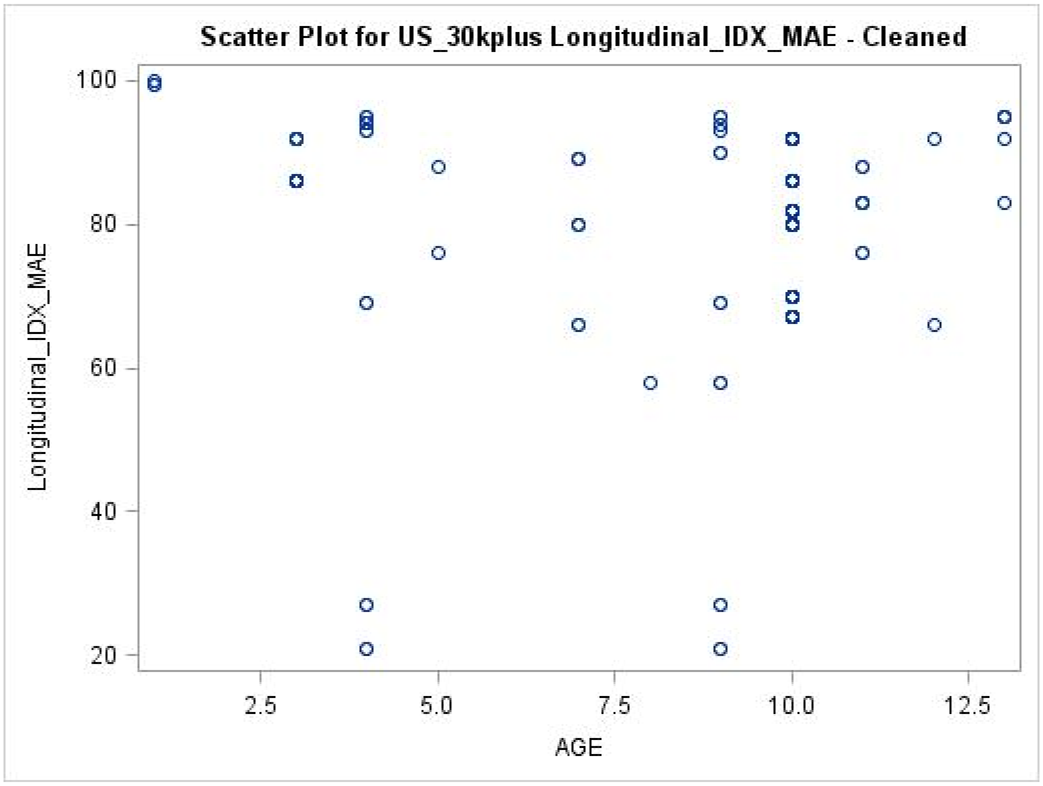

Figure 51: Schematic Scatter Plot for US_30kplus Longitudinal_IDX_MAE - Cleaned

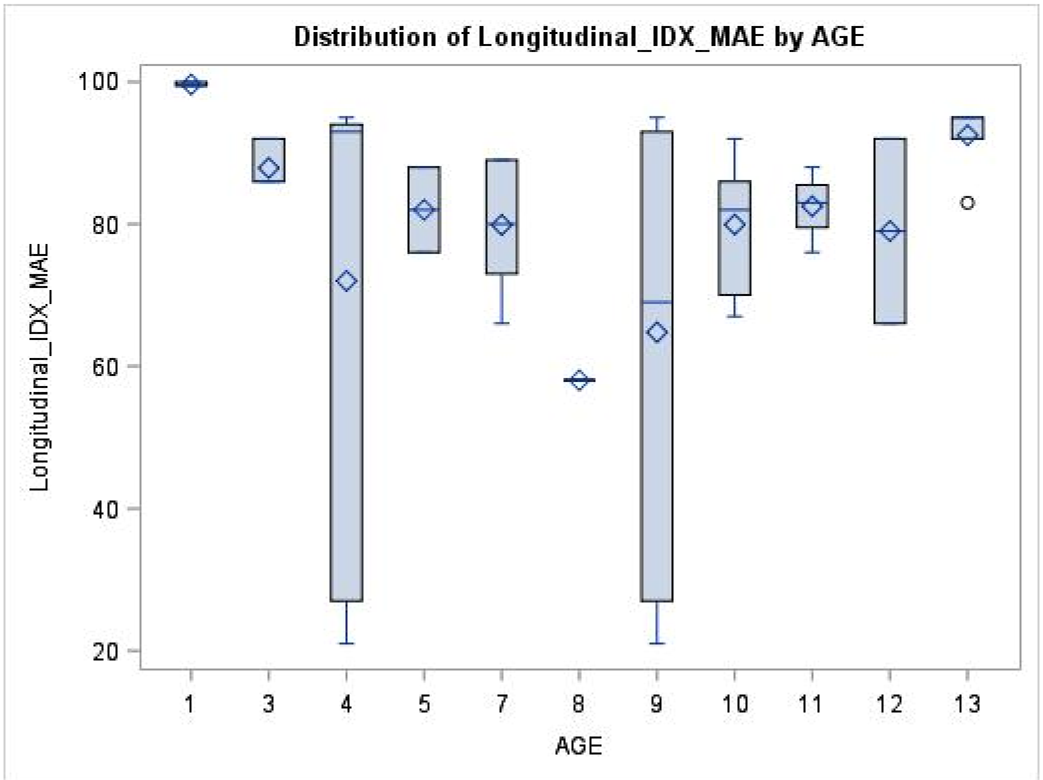

Figure 52: Schematic Box Plot for US_30kplus Longitudinal_IDX_MAE - Cleaned

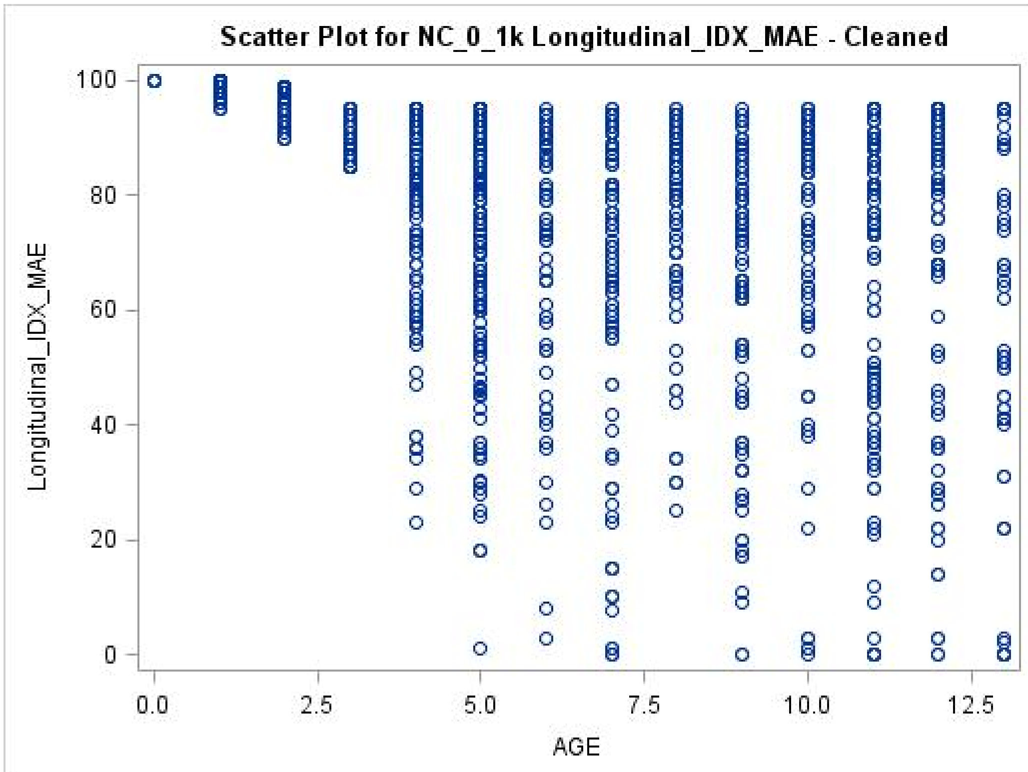

Figure 53: Schematic Scatter Plot for NC_0_1k Longitudinal_IDX_MAE - Cleaned

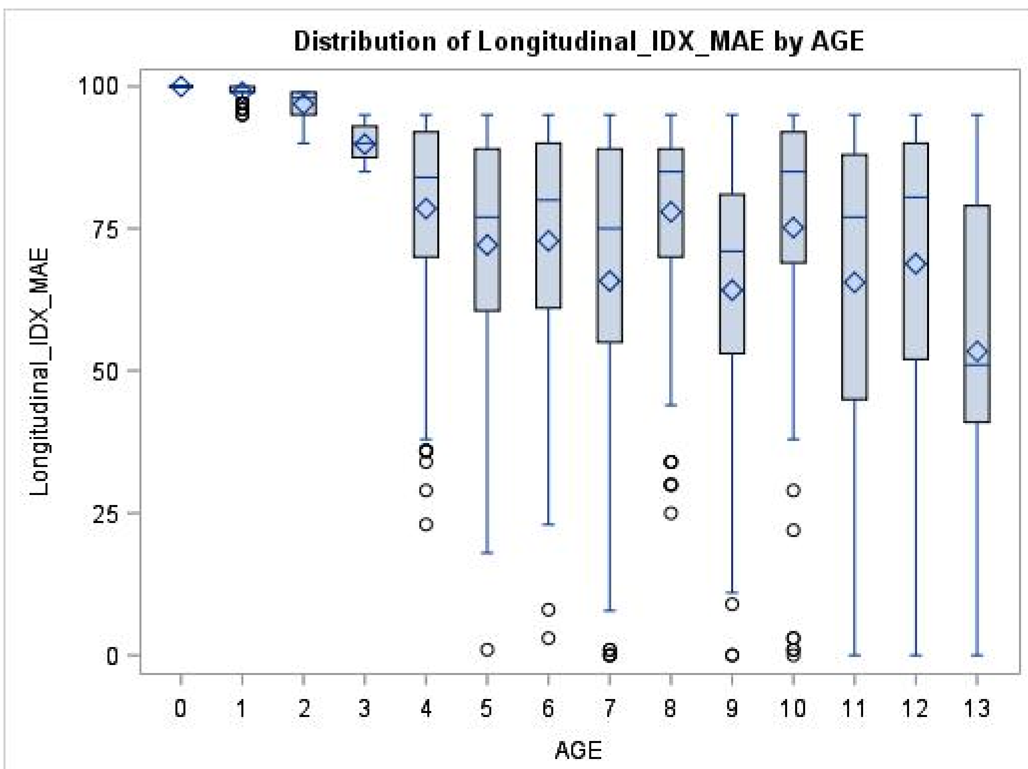

Figure 54: Schematic Box Plot for NC_0_1k Longitudinal_IDX_MAE - Cleaned

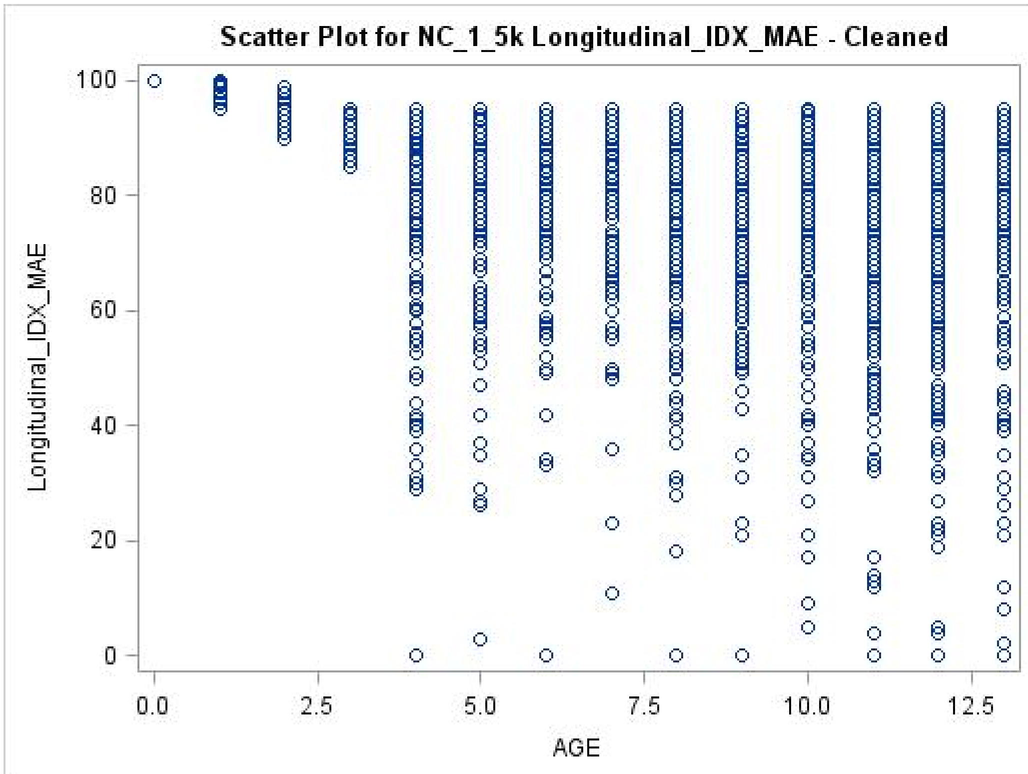

Figure 55: Schematic Scatter Plot for NC_1_5k Longitudinal_IDX_MAE - Cleaned

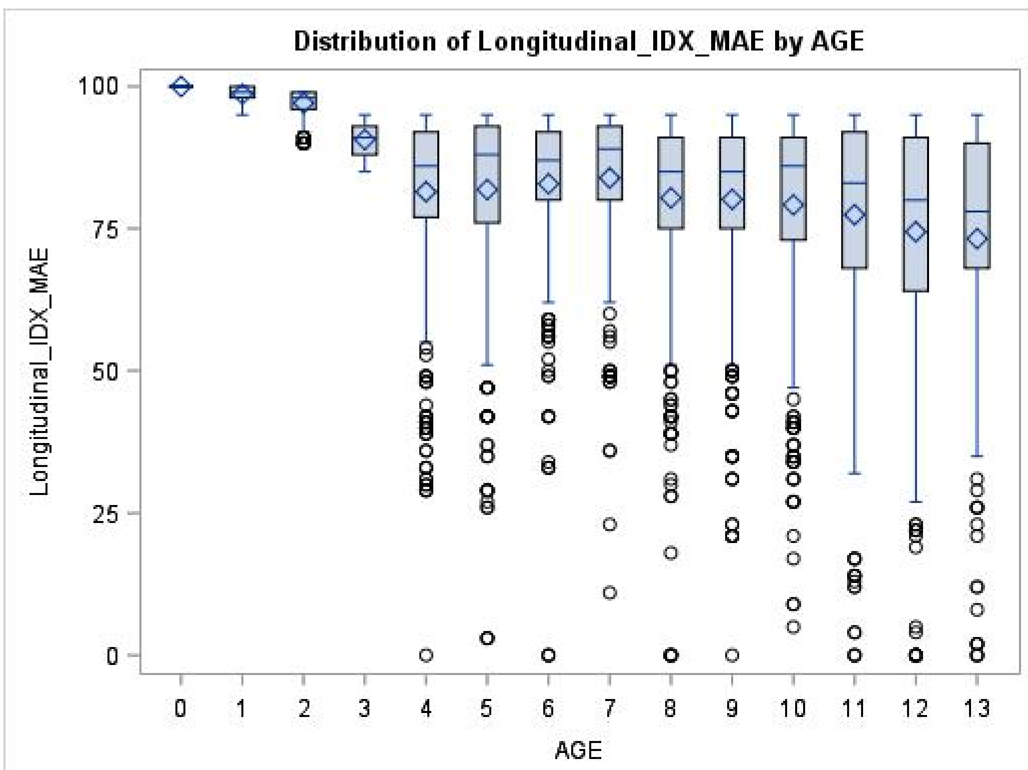

Figure 56: Schematic Box Plot for NC_1_5k Longitudinal_IDX_MAE - Cleaned

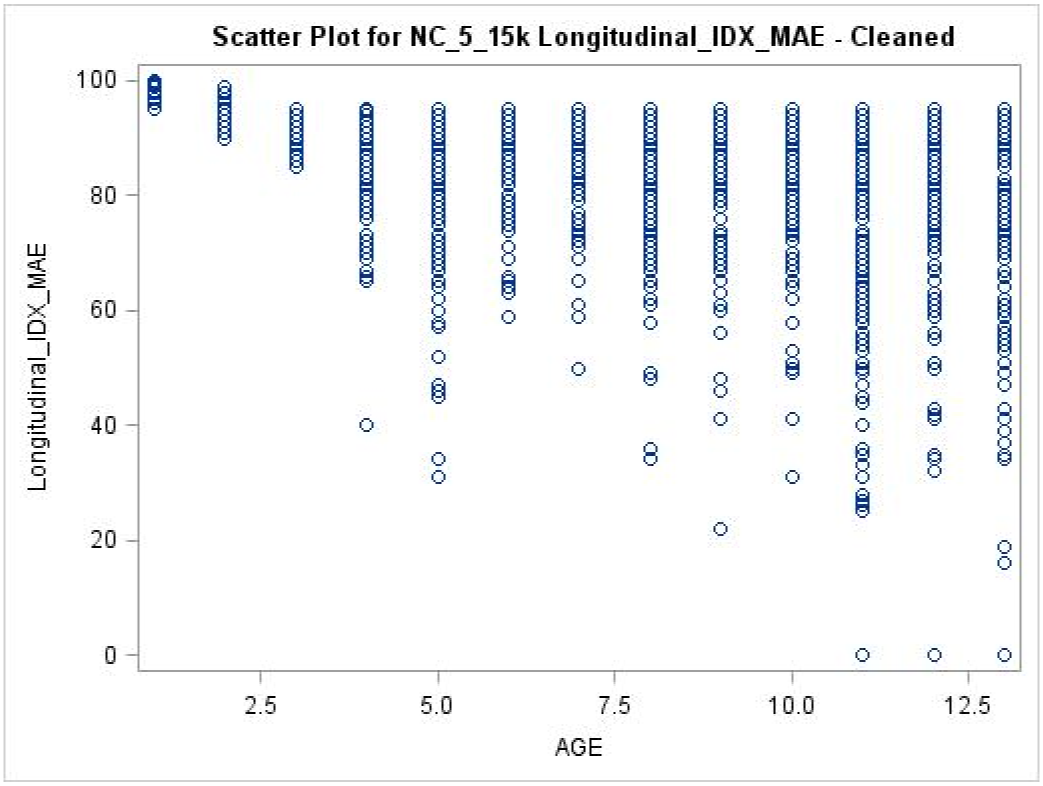

Figure 57: Schematic Scatter Plot for NC_5_15k Longitudinal_IDX_MAE - Cleaned

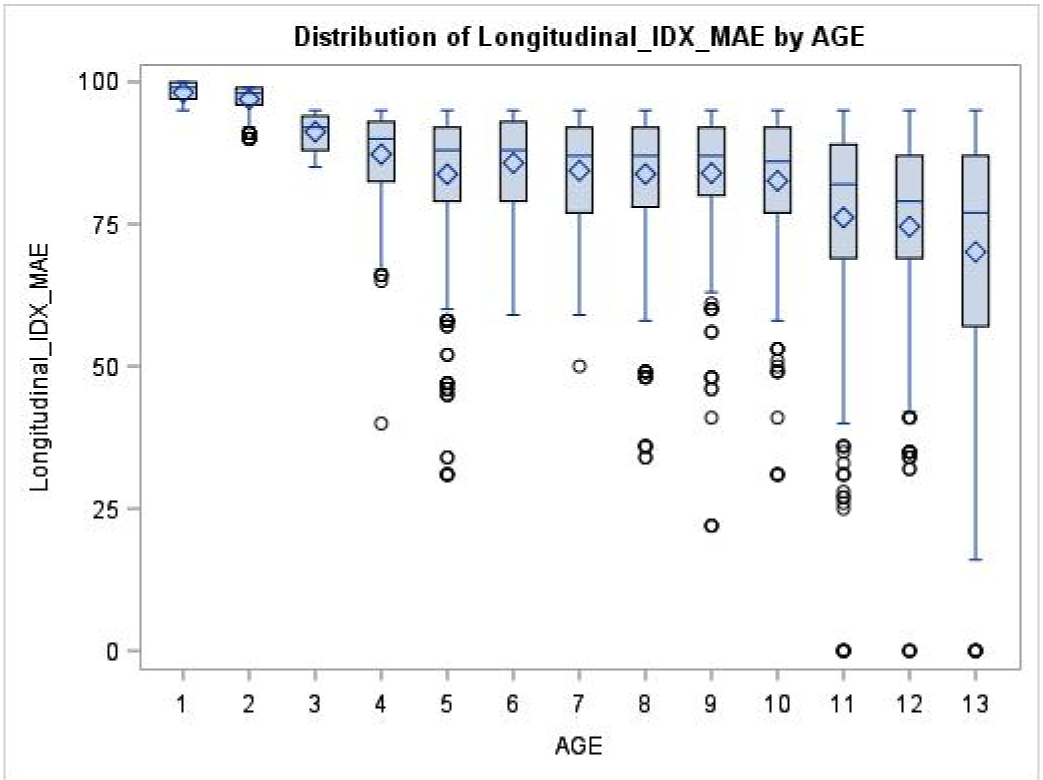

Figure 58: Schematic Box Plot for NC_5_15k Longitudinal_IDX_MAE - Cleaned

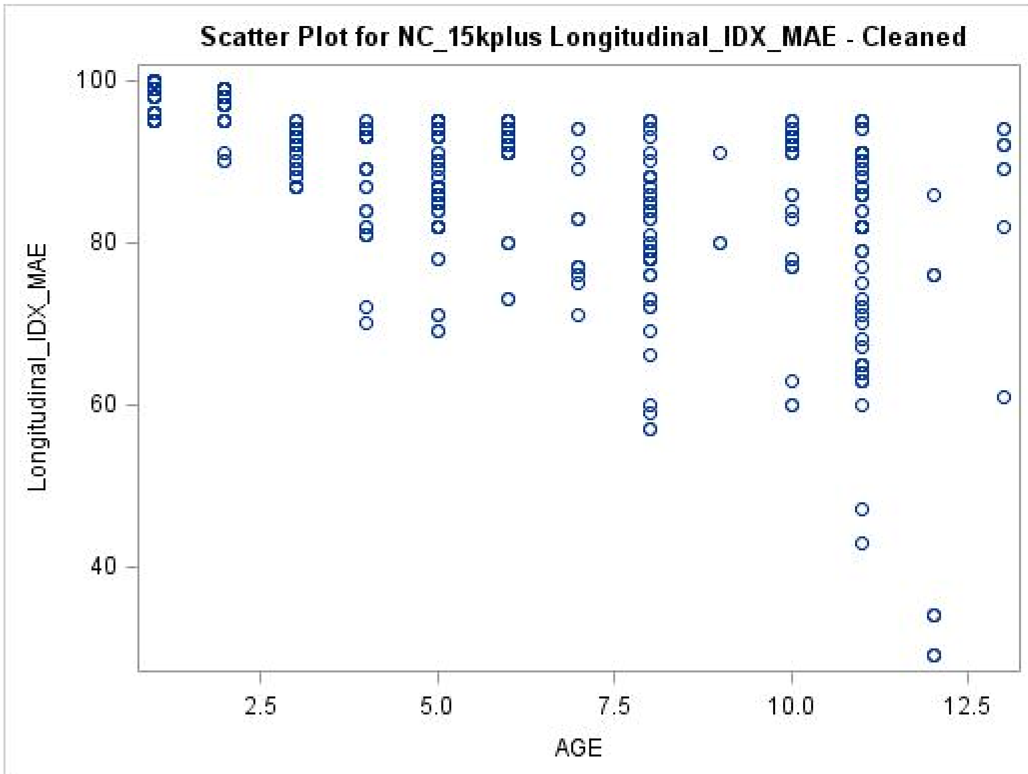

Figure 59: Schematic Scatter Plot for NC_15kplus Longitudinal_IDX_MAE - Cleaned

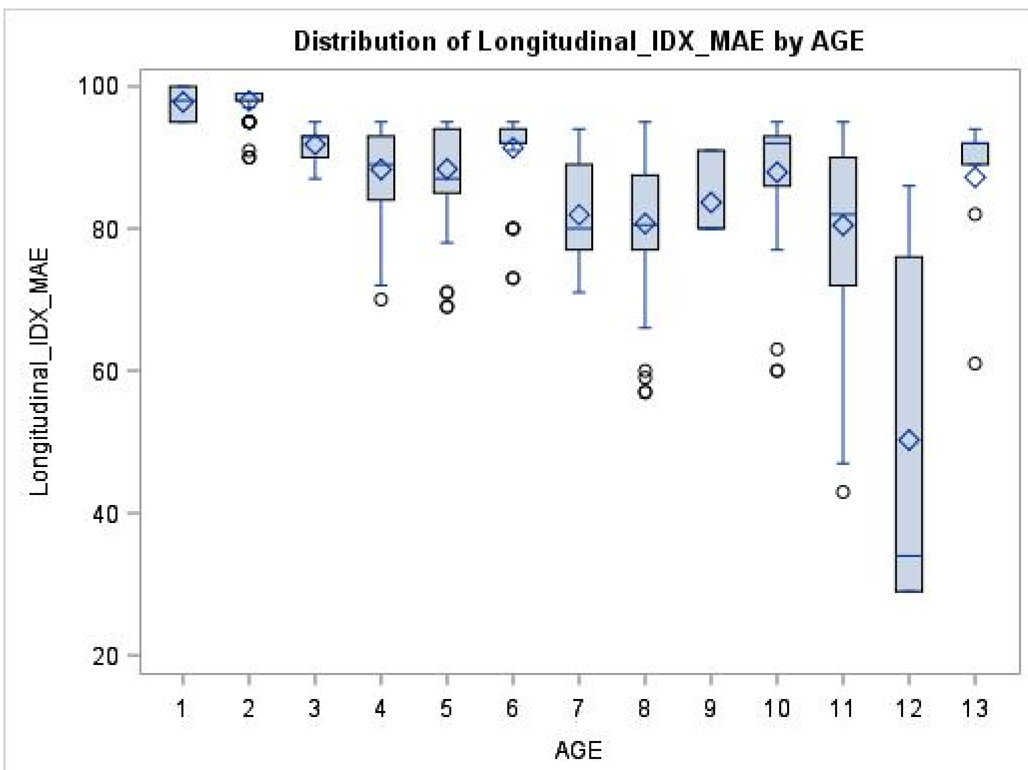

Figure 60: Schematic Box Plot for NC_15kplus Longitudinal_IDX_MAE - Cleaned

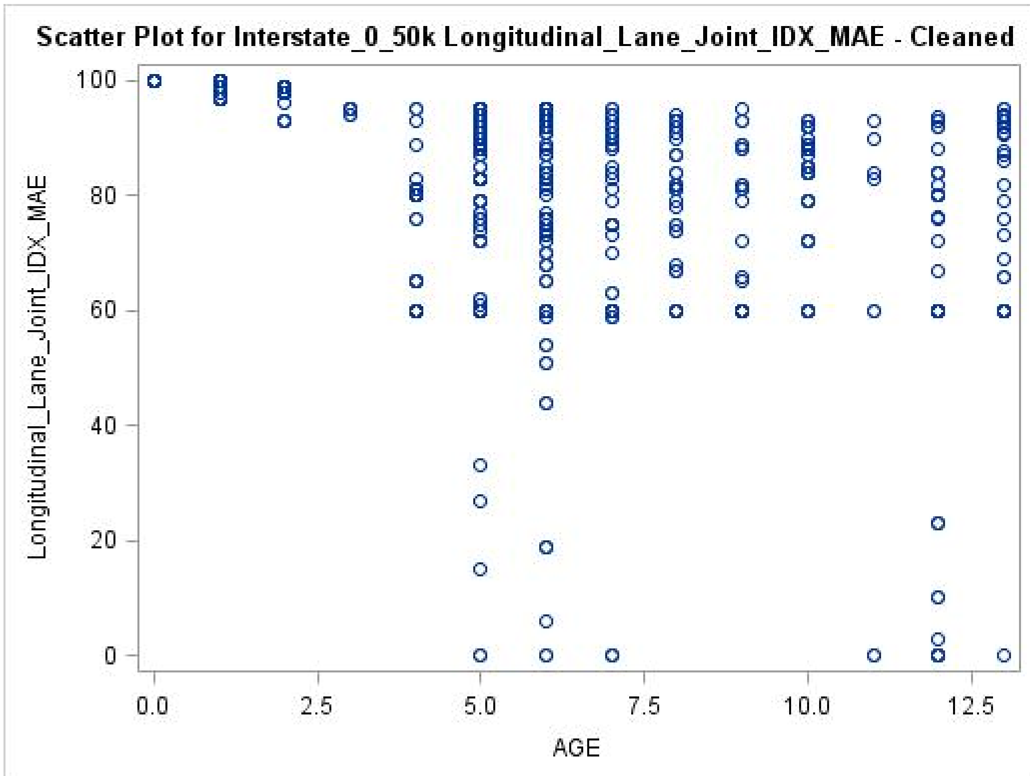

Figure 61: Schematic Scatter Plot for Interstate_0_50k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

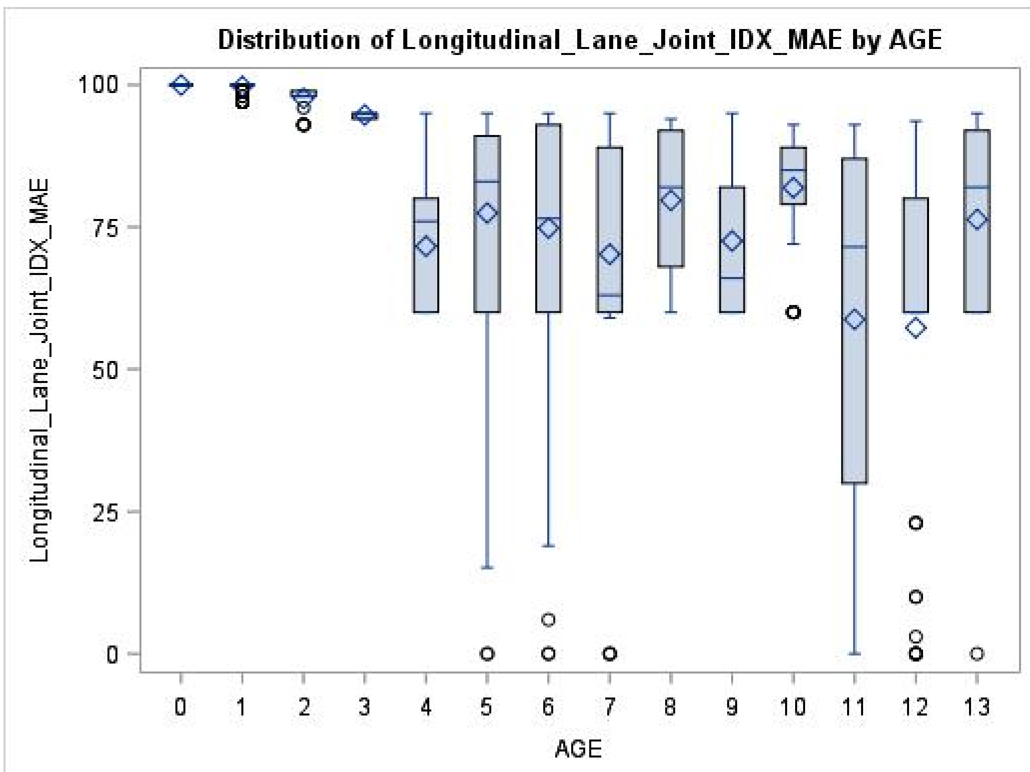

Figure 62: Schematic Box Plot for Interstate_0_50k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

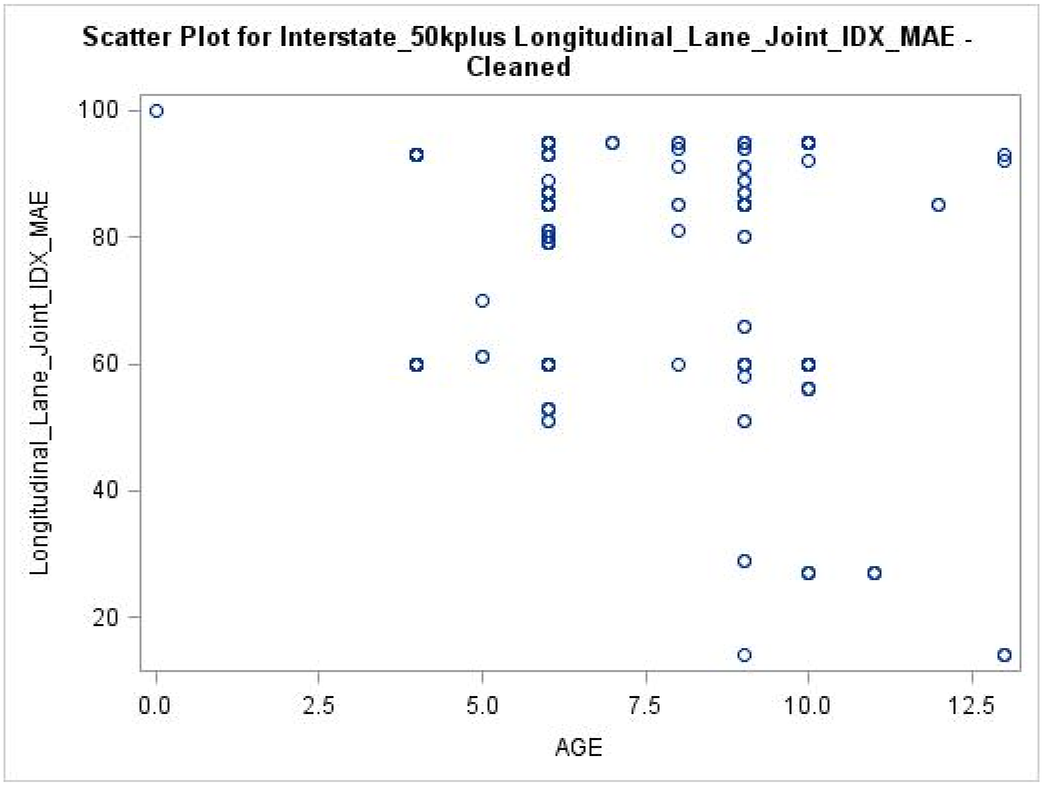

Figure 63: Schematic Scatter Plot for Interstate_50kplus Longitudinal_Lane_Joint_IDX_MAE - Cleaned

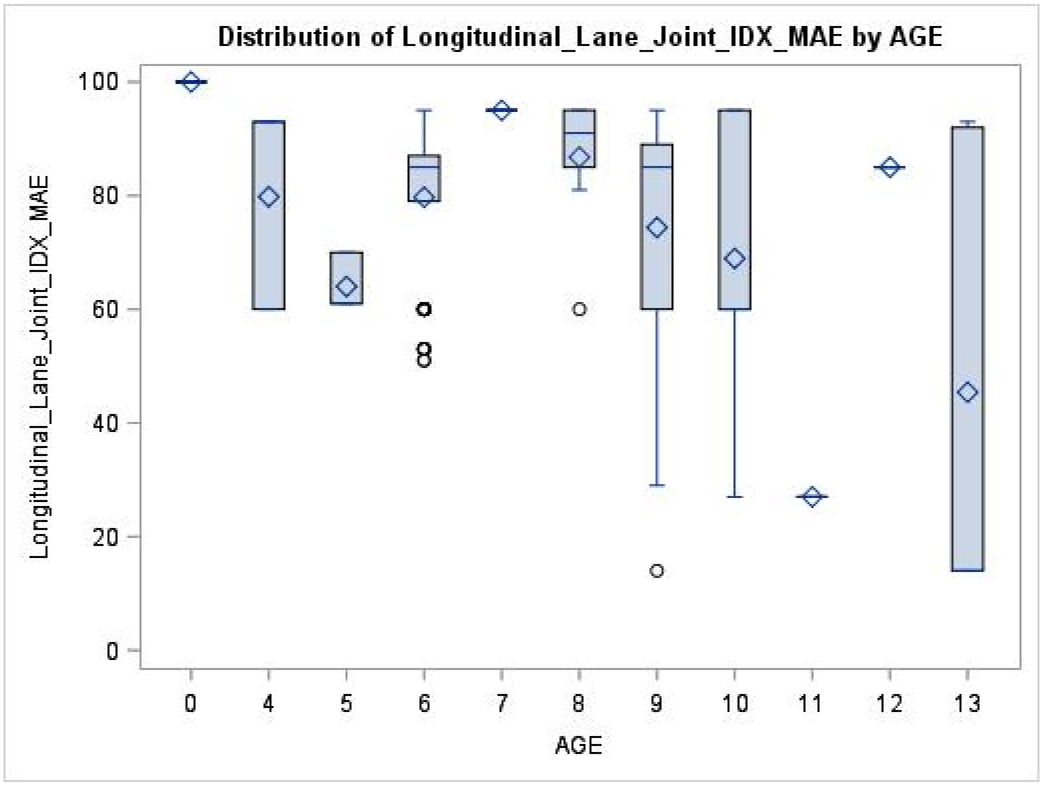

Figure 64: Schematic Box Plot for Interstate_50kplus Longitudinal_Lane_Joint_IDX_MAE - Cleaned

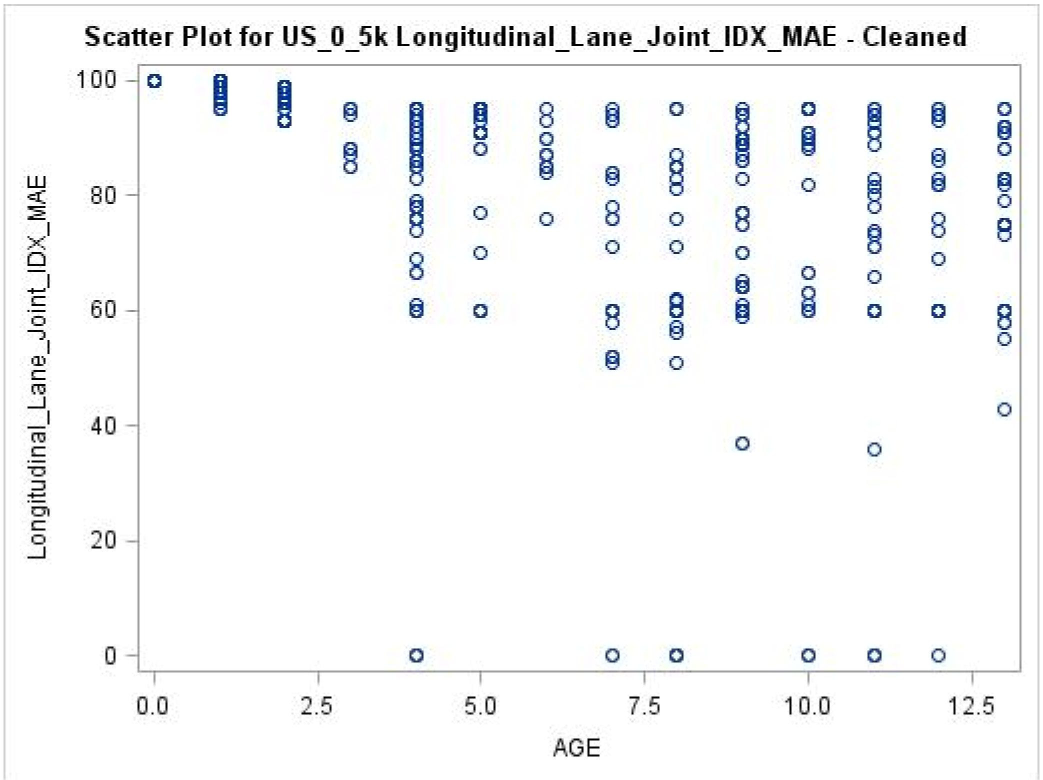

Figure 65: Schematic Scatter Plot for US_0_5k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

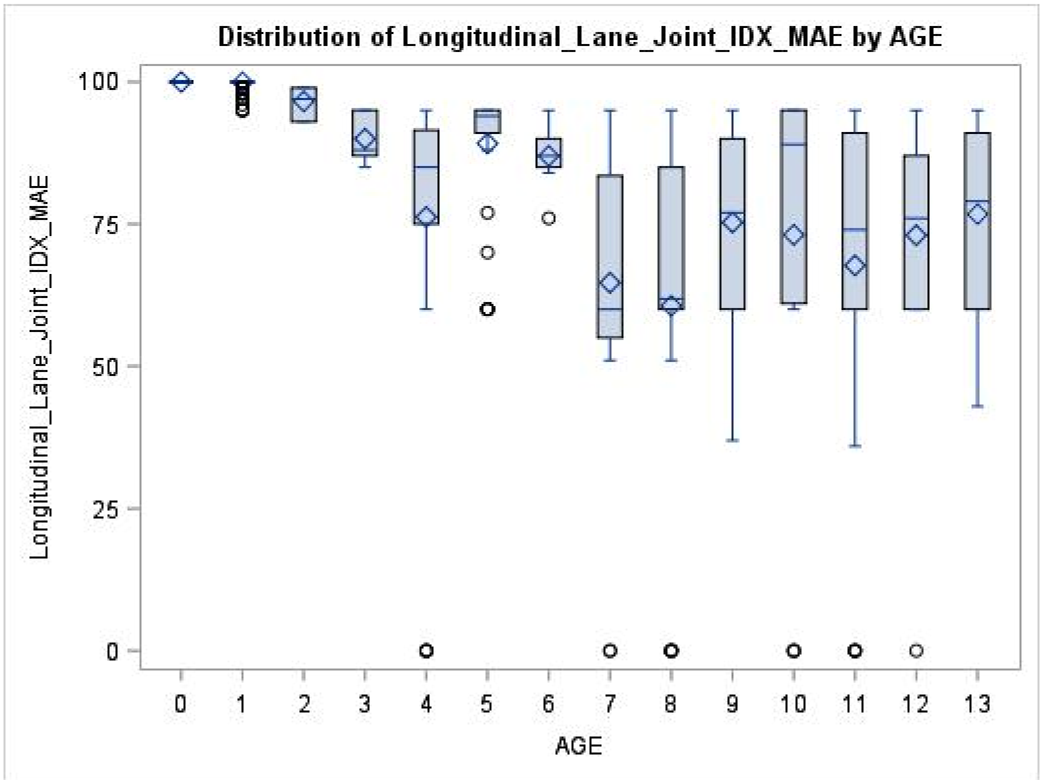

Figure 66: Schematic Box Plot for US_0_5k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

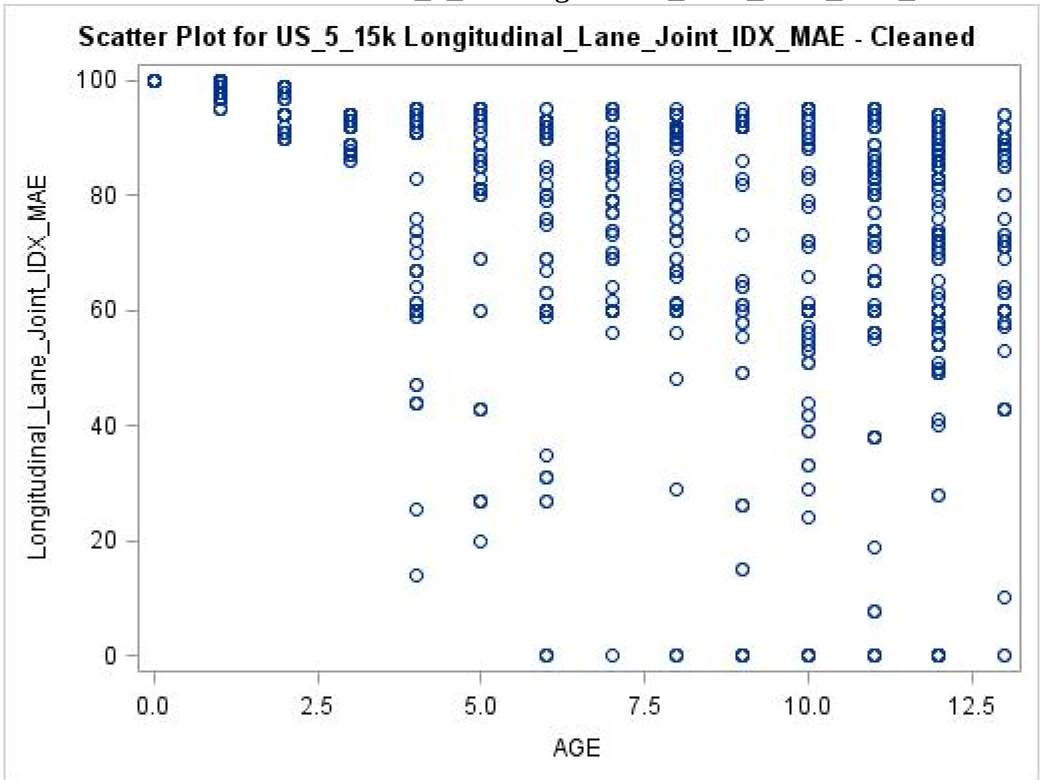

Figure 67: Schematic Scatter Plot for US_5_15k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

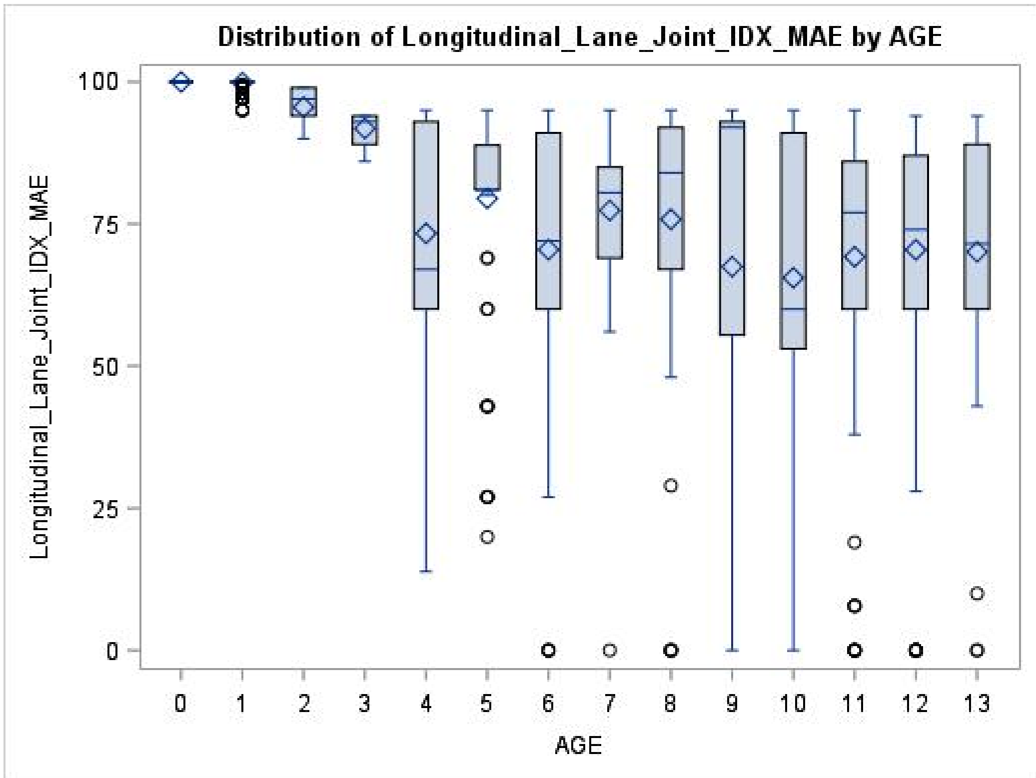

Figure 68: Schematic Box Plot for US_5_15k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

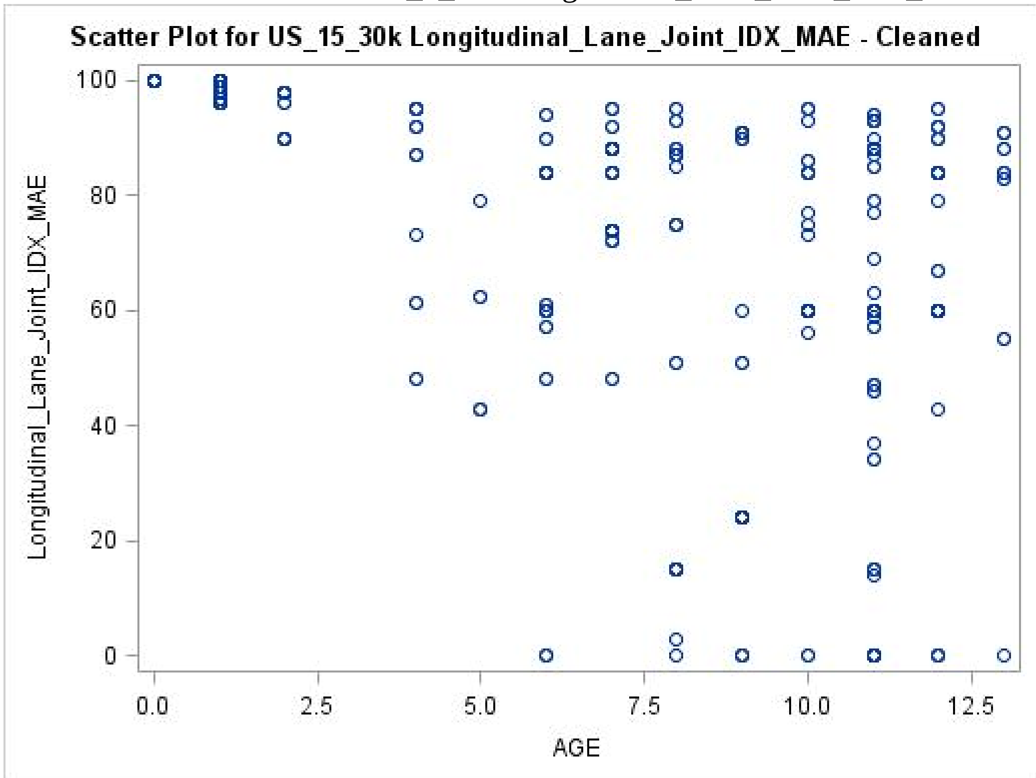

Figure 69: Schematic Scatter Plot for US_15_30k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

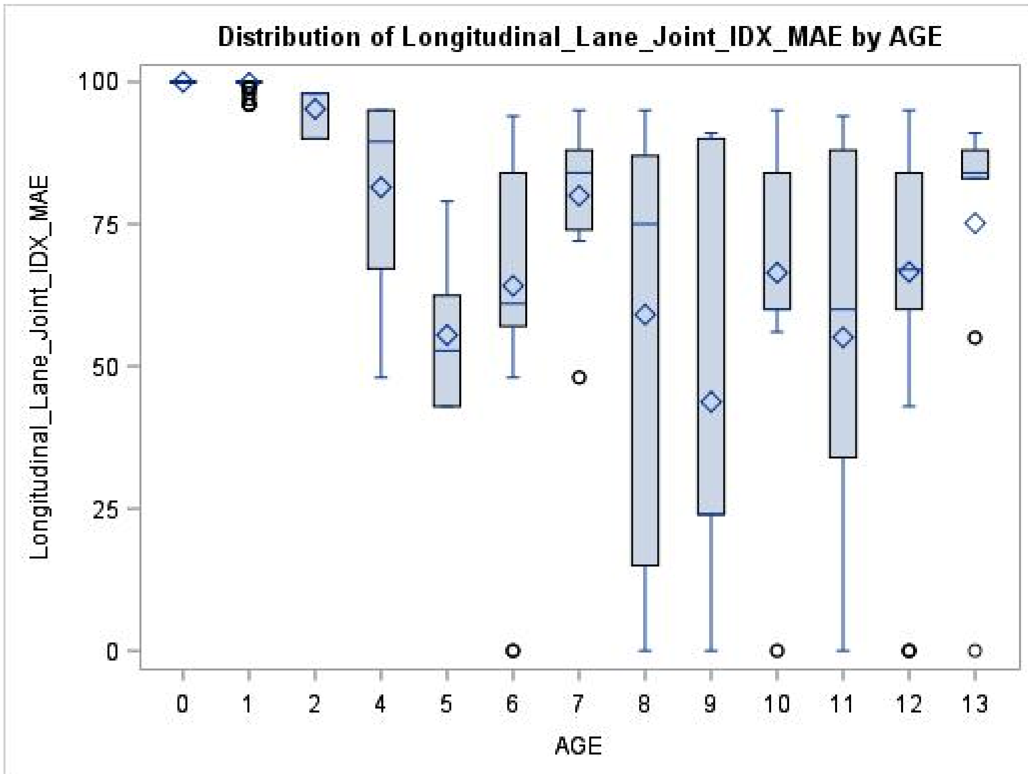

Figure 70: Schematic Box Plot for US_15_30k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

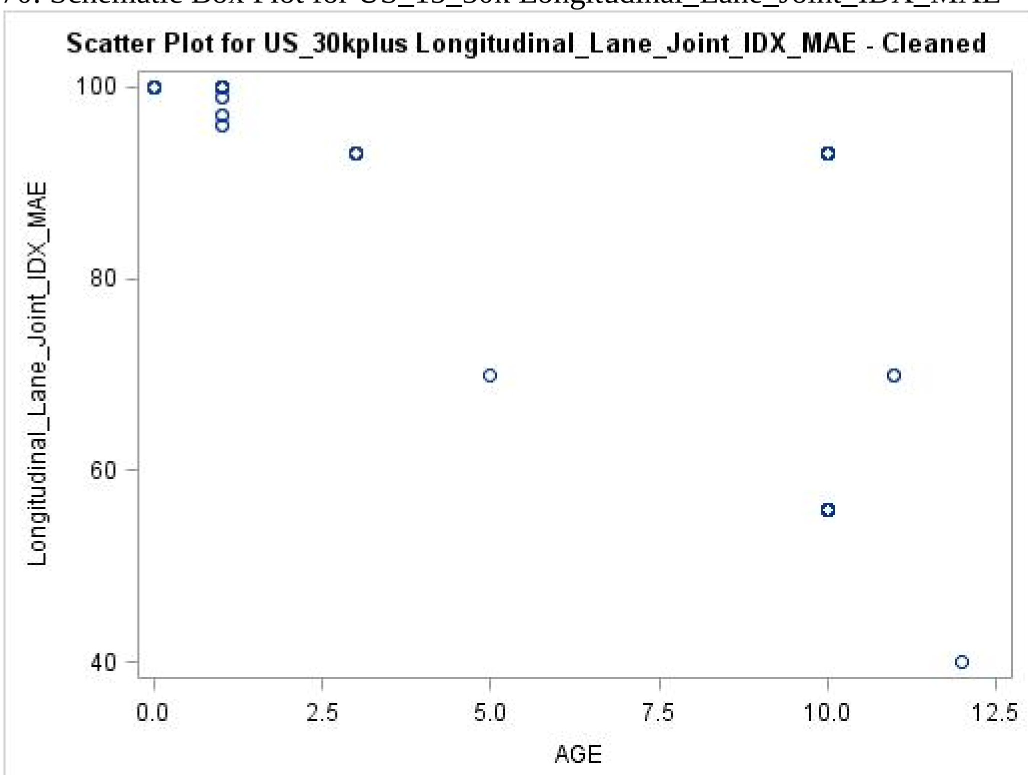

Figure 71: Schematic Scatter Plot for US_30kplus Longitudinal_Lane_Joint_IDX_MAE - Cleaned

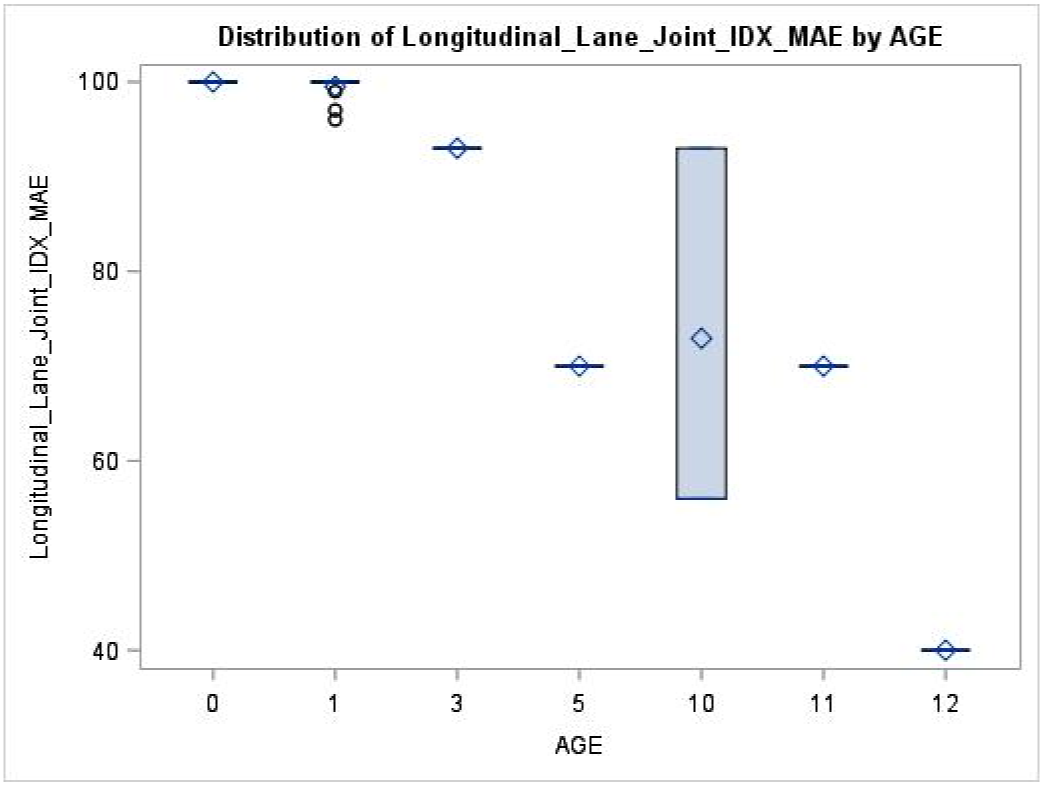

Figure 72: Schematic Box Plot for US_30kplus Longitudinal_Lane_Joint_IDX_MAE - Cleaned

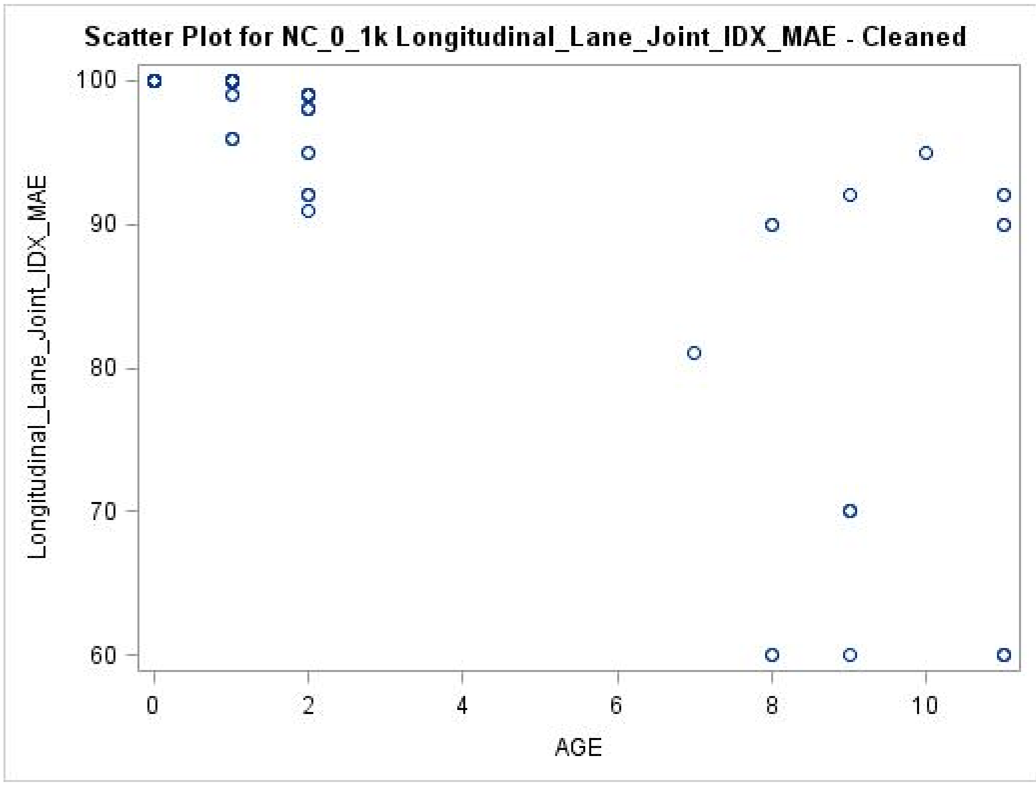

Figure 73: Schematic Scatter Plot for NC_0_1k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

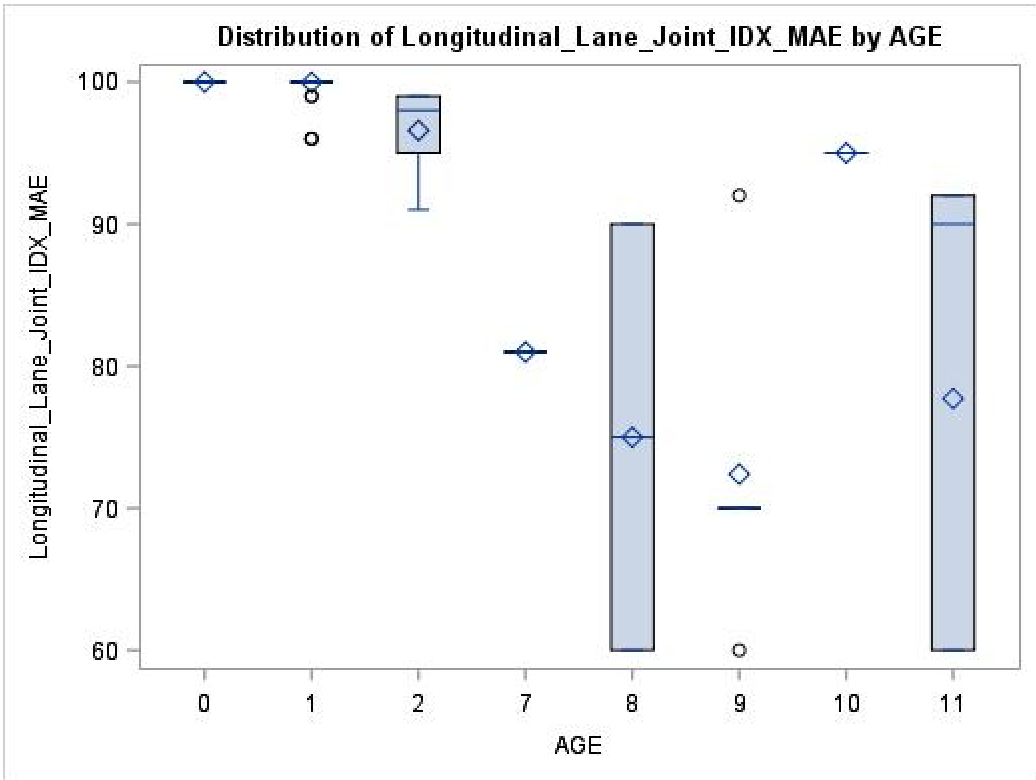

Figure 74: Schematic Box Plot for NC_0_1k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

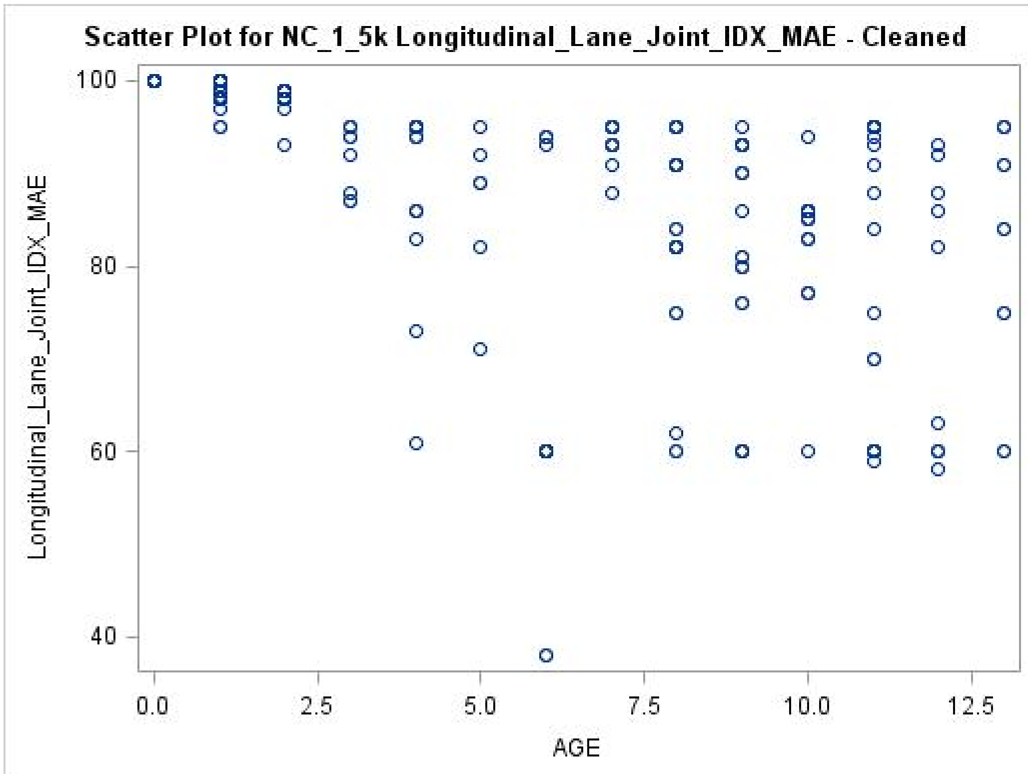

Figure 75: Schematic Scatter Plot for NC_1_5k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

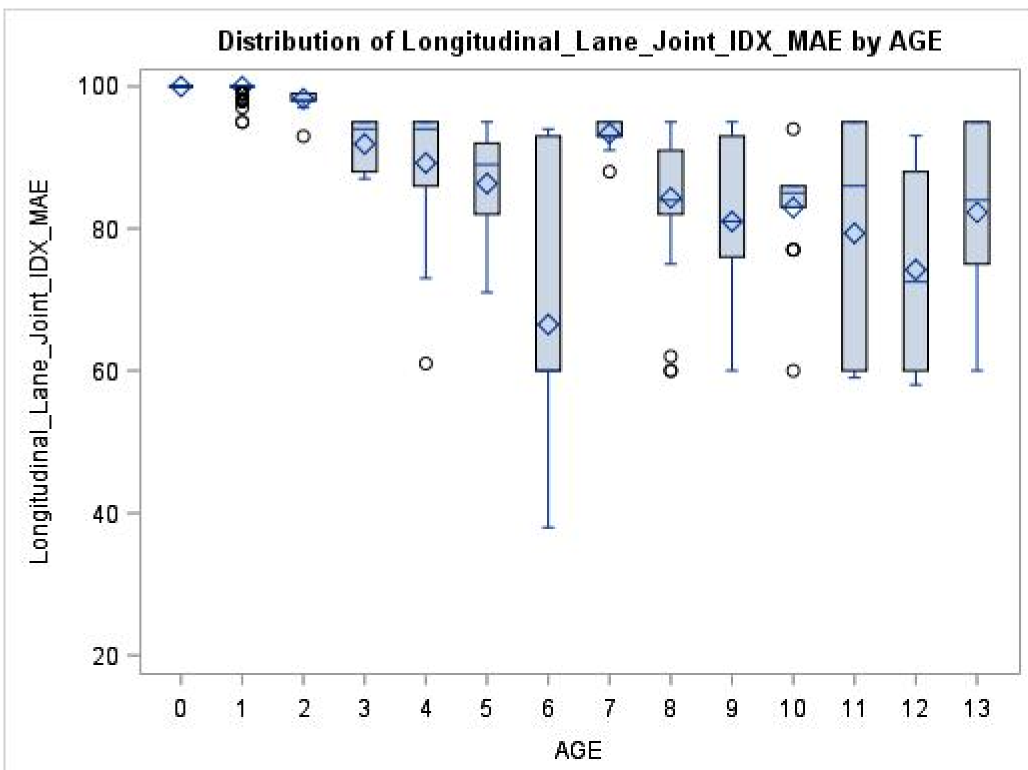

Figure 76: Schematic Box Plot for NC_1_5k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

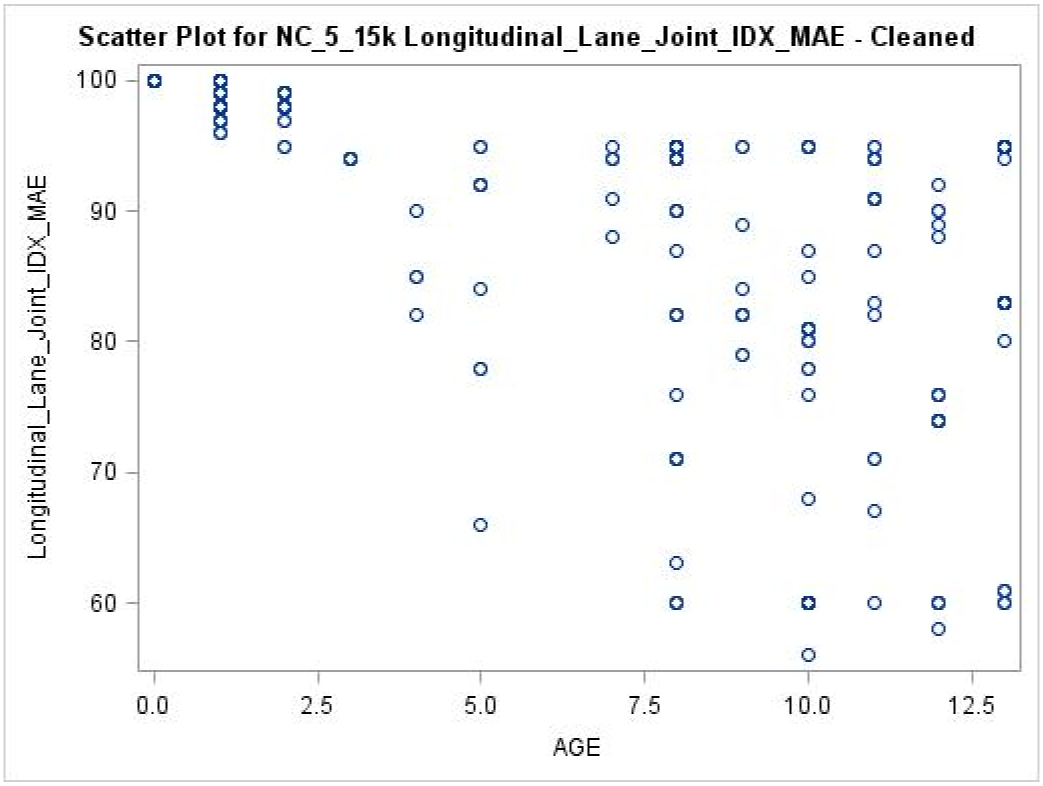

Figure 77: Schematic Scatter Plot for NC_5_15k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

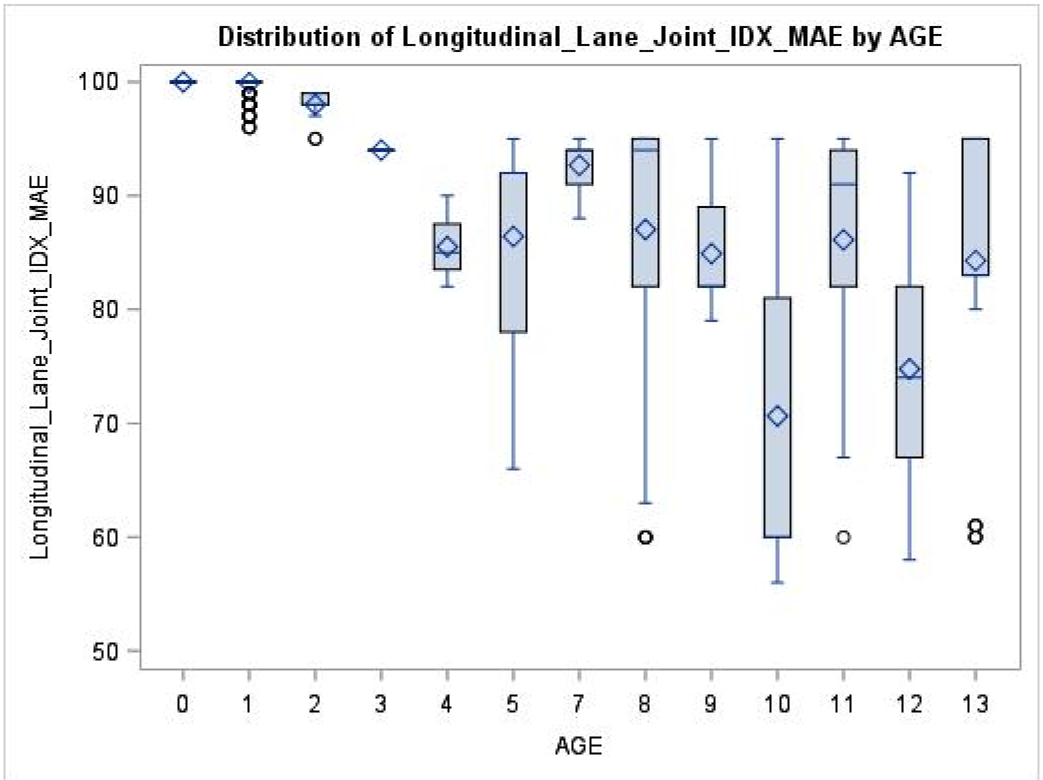

Figure 78: Schematic Box Plot for NC_5_15k Longitudinal_Lane_Joint_IDX_MAE - Cleaned

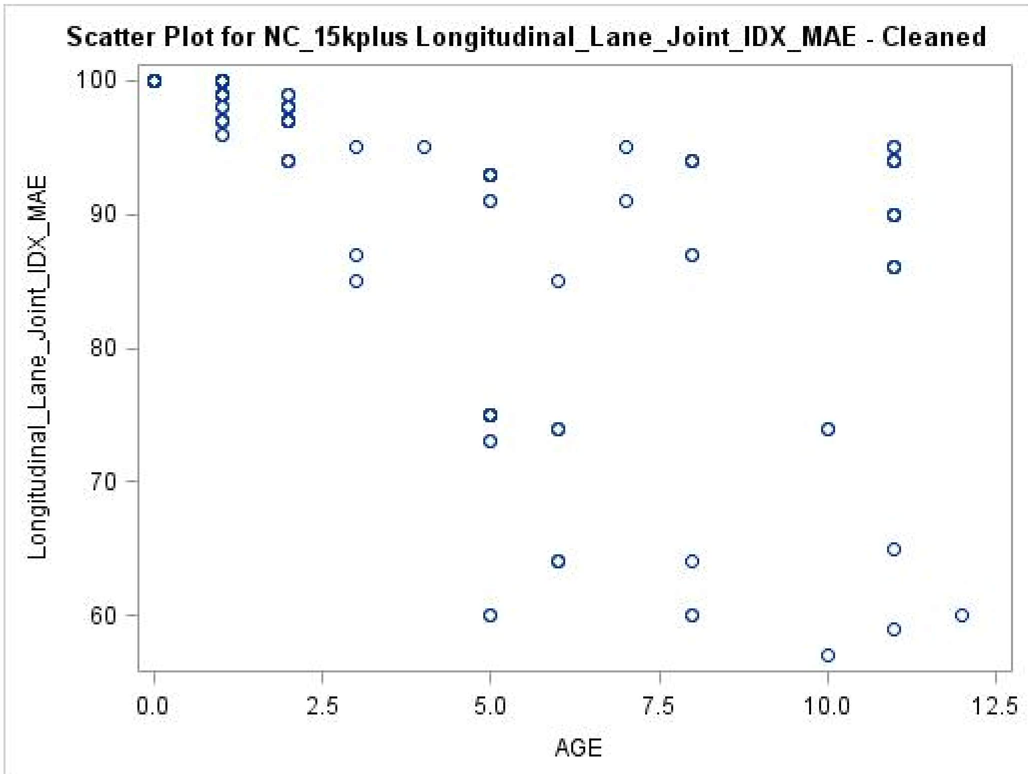

Figure 79: Schematic Scatter Plot for NC_15kplus Longitudinal_Lane_Joint_IDX_MAE - Cleaned

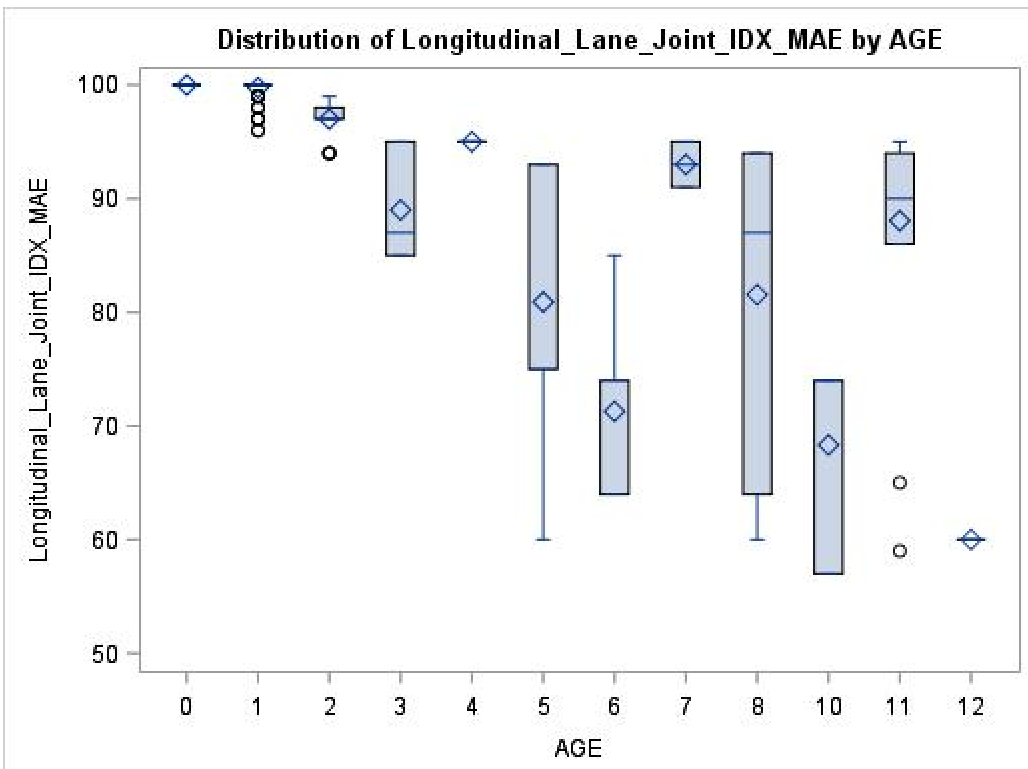

Figure 80: Schematic Box Plot for NC_15kplus Longitudinal_Lane_Joint_IDX_MAE - Cleaned

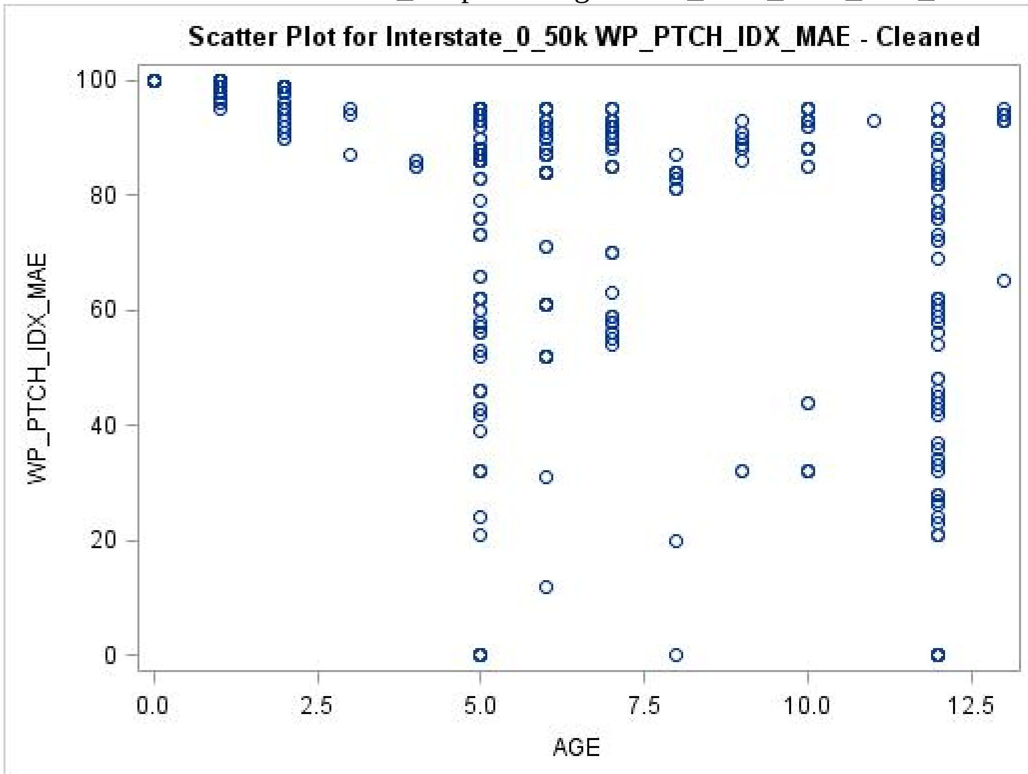

Figure 81: Schematic Scatter Plot for Interstate_0_50k WP_PTCH_IDX_MAE - Cleaned

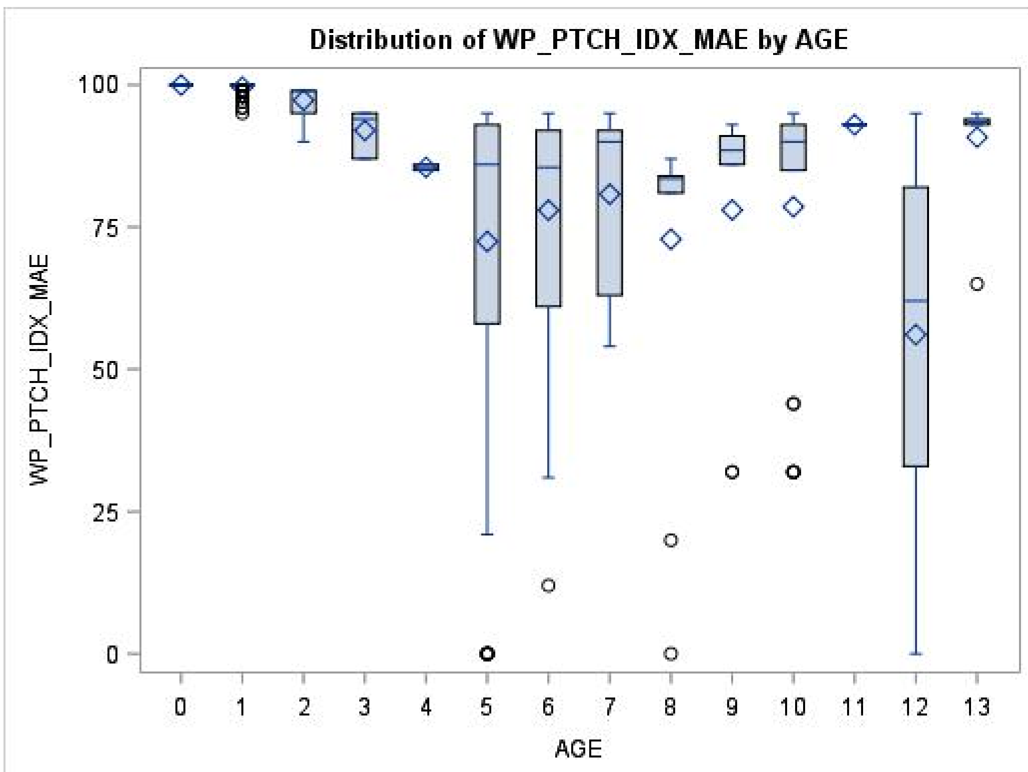

Figure 82: Schematic Box Plot for Interstate_0_50k WP_PTCH_IDX_MAE - Cleaned

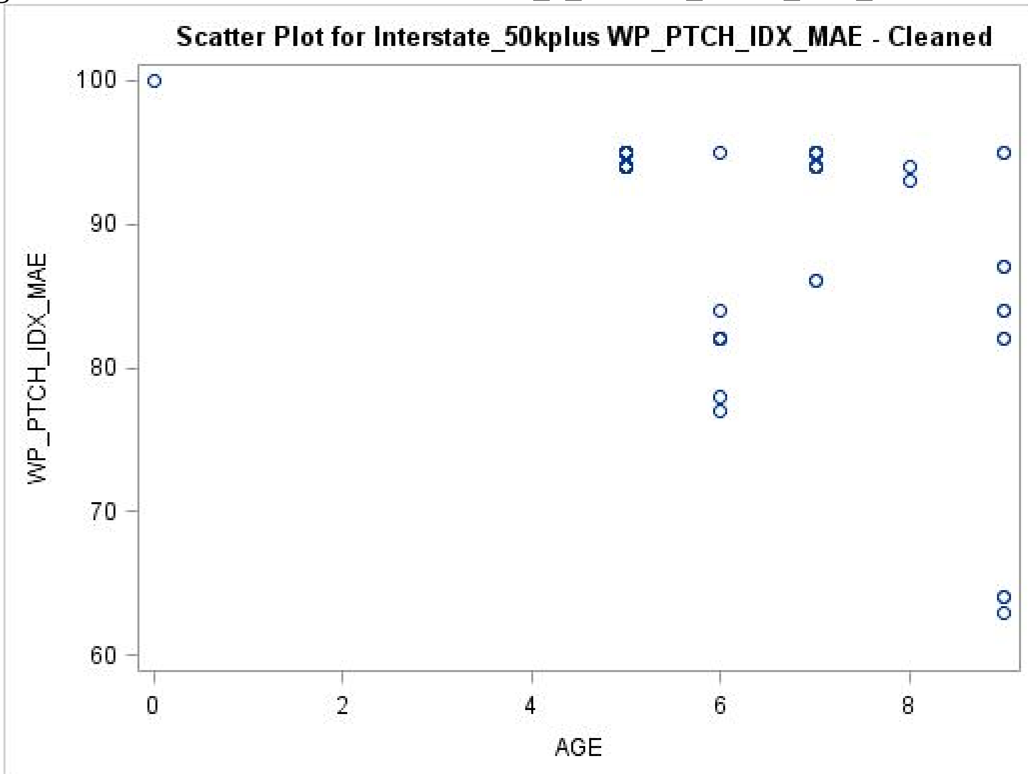

Figure 83: Schematic Scatter Plot for Interstate_50kplus WP_PTCH_IDX_MAE - Cleaned

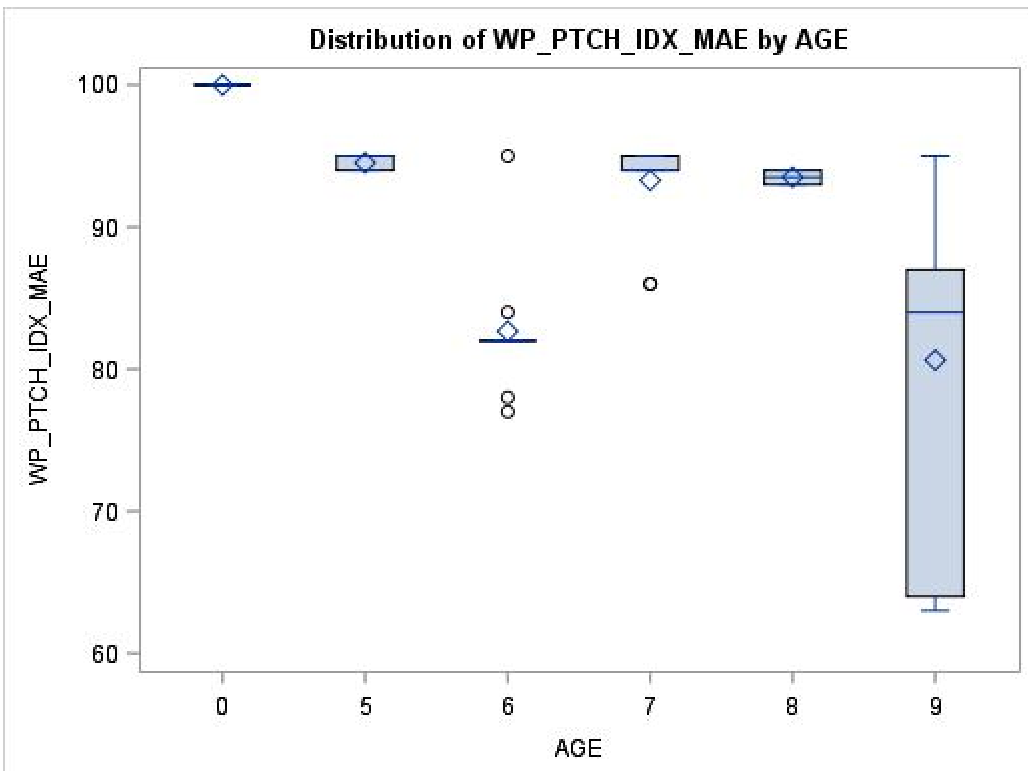

Figure 84: Schematic Box Plot for Interstate_50kplus WP_PTCH_IDX_MAE - Cleaned

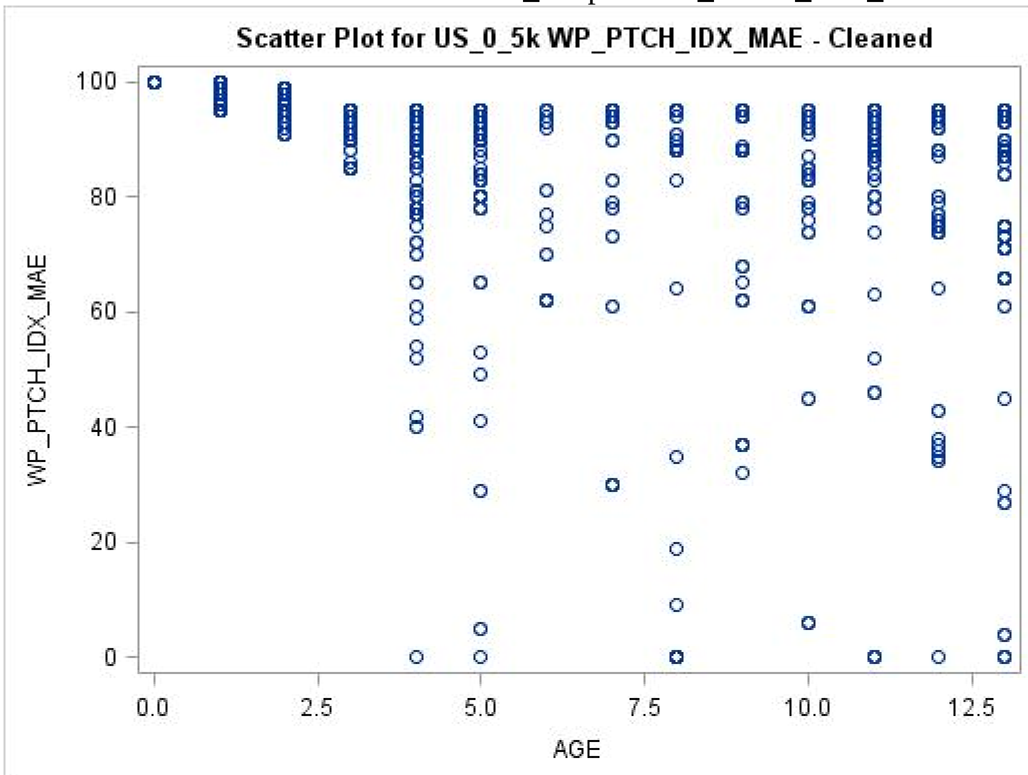

Figure 85: Schematic Scatter Plot for US_0_5k WP_PTCH_IDX_MAE - Cleaned

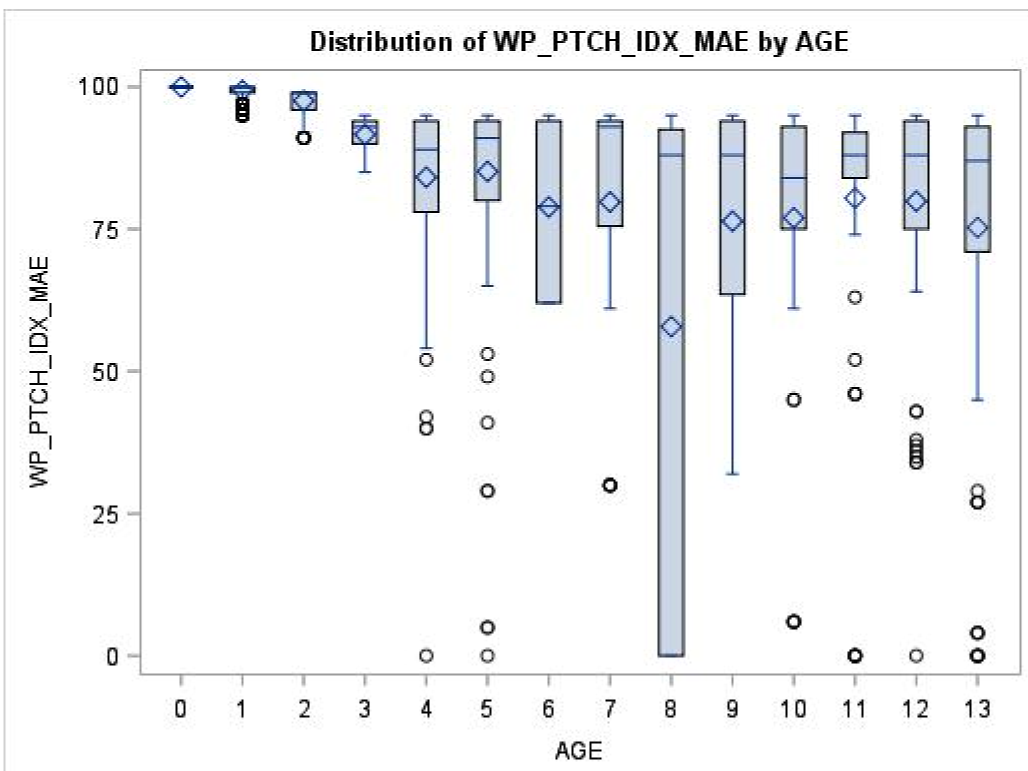

Figure 86: Schematic Box Plot for US_0_5k WP_PTCH_IDX_MAE - Cleaned

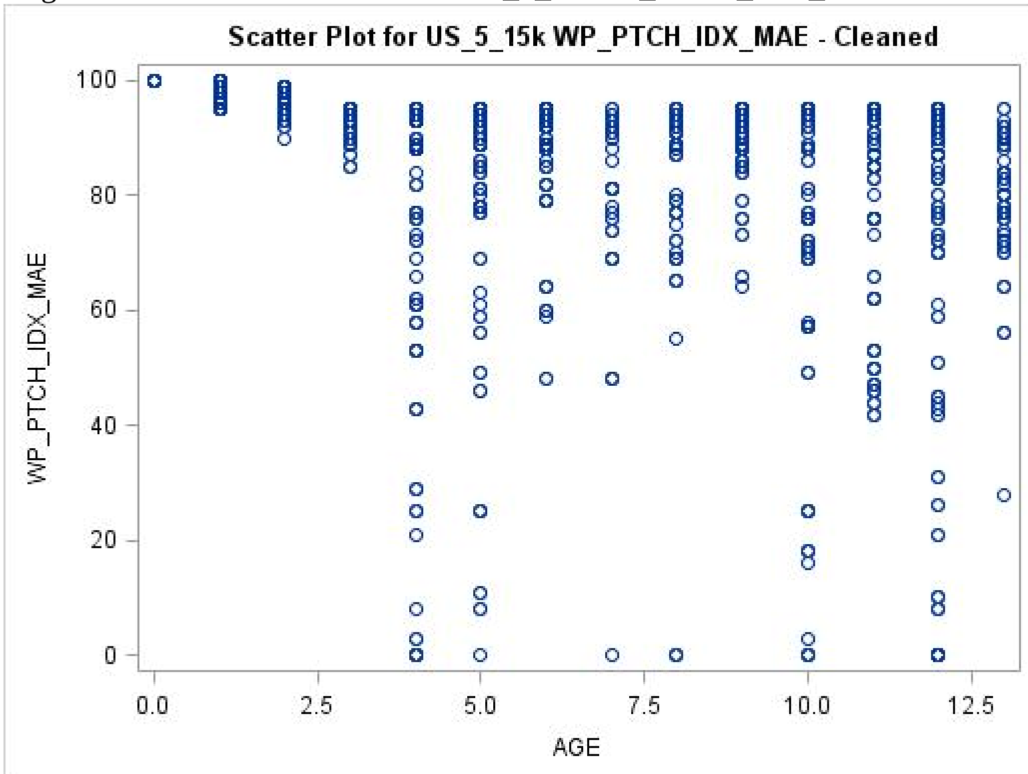

Figure 87: Schematic Scatter Plot for US_5_15k WP_PTCH_IDX_MAE - Cleaned

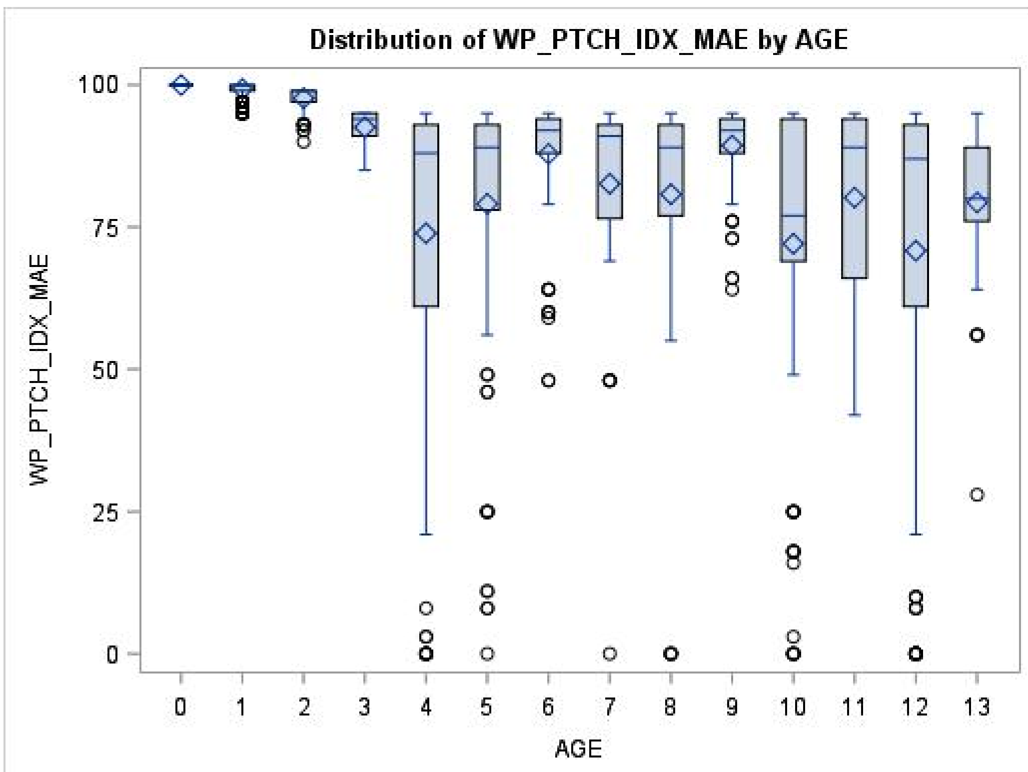

Figure 88: Schematic Box Plot for US_5_15k WP_PTCH_IDX_MAE - Cleaned

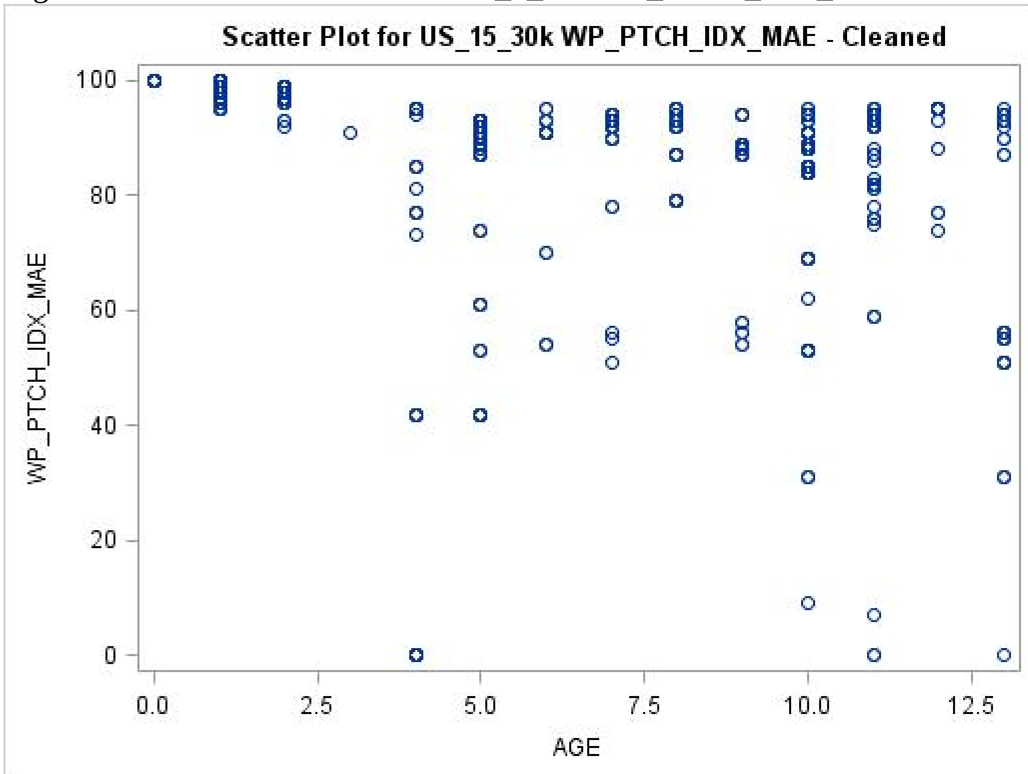

Figure 89: Schematic Scatter Plot for US_15_30k WP_PTCH_IDX_MAE - Cleaned

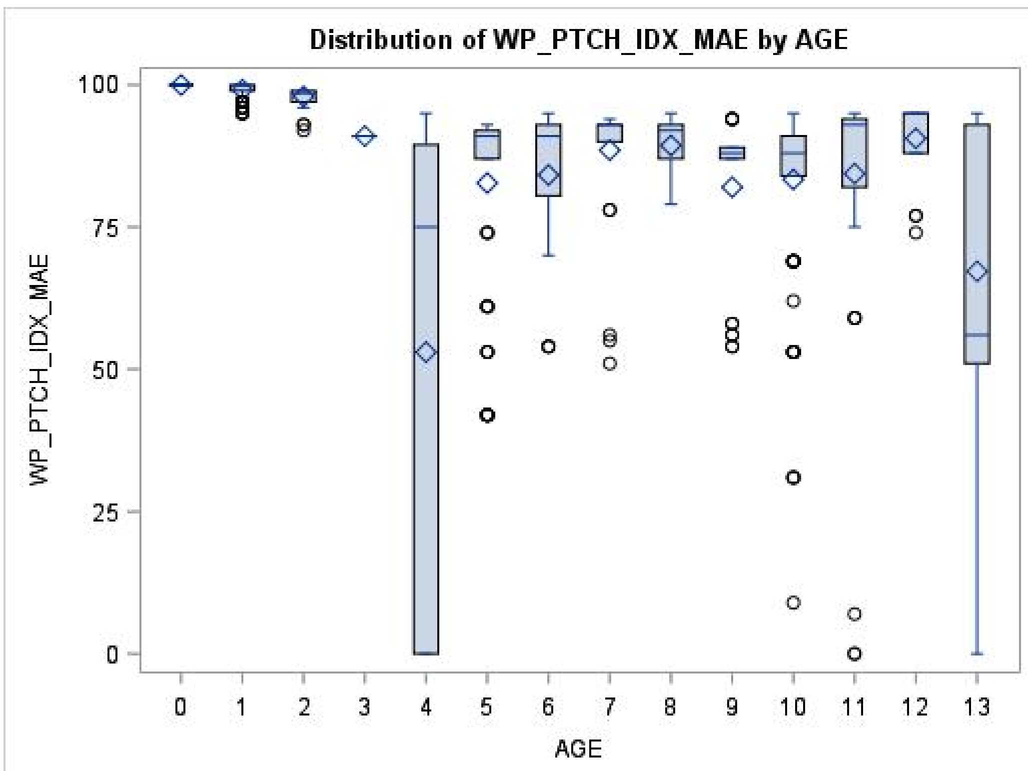

Figure 90: Schematic Box Plot for US_15_30k WP_PTCH_IDX_MAE - Cleaned

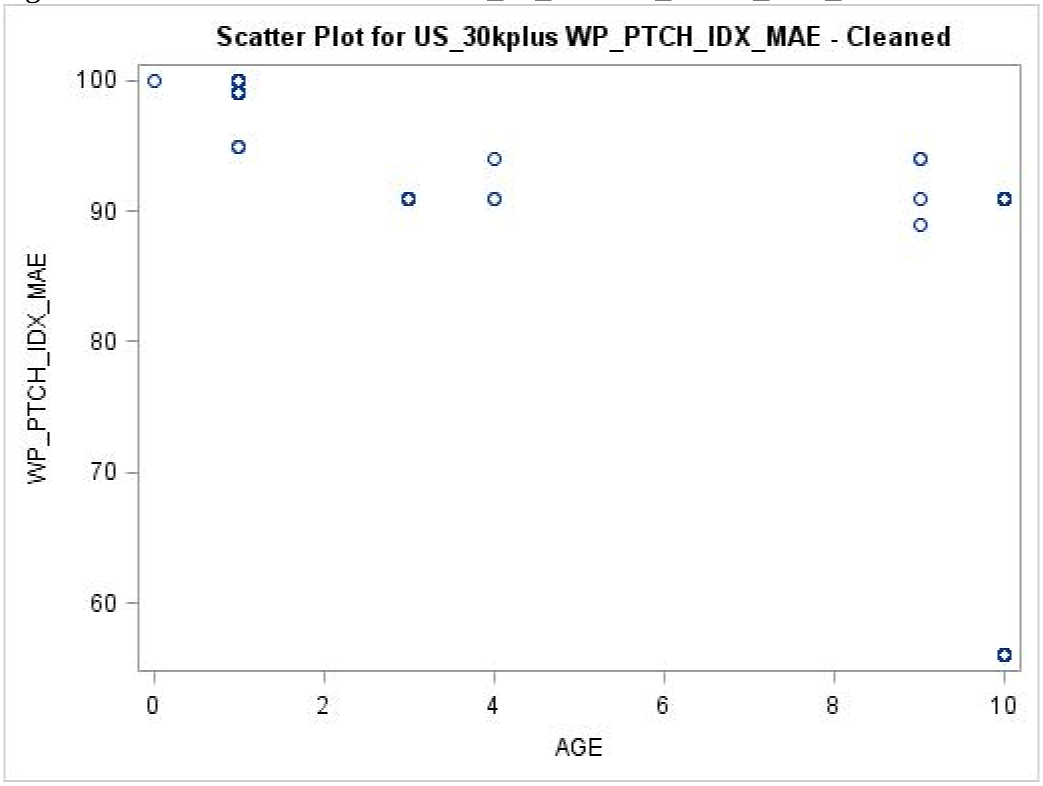

Figure 91: Schematic Scatter Plot for US_30kplus WP_PTCH_IDX_MAE - Cleaned

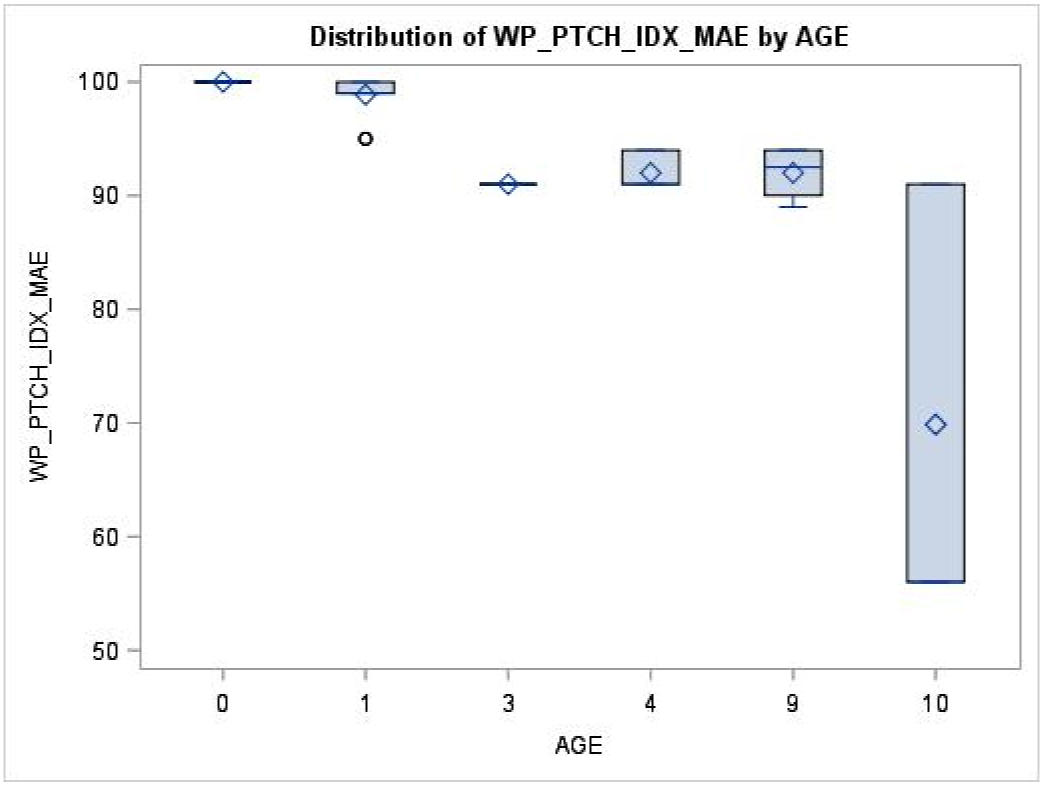

Figure 92: Schematic Box Plot for US_30kplus WP_PTCH_IDX_MAE - Cleaned

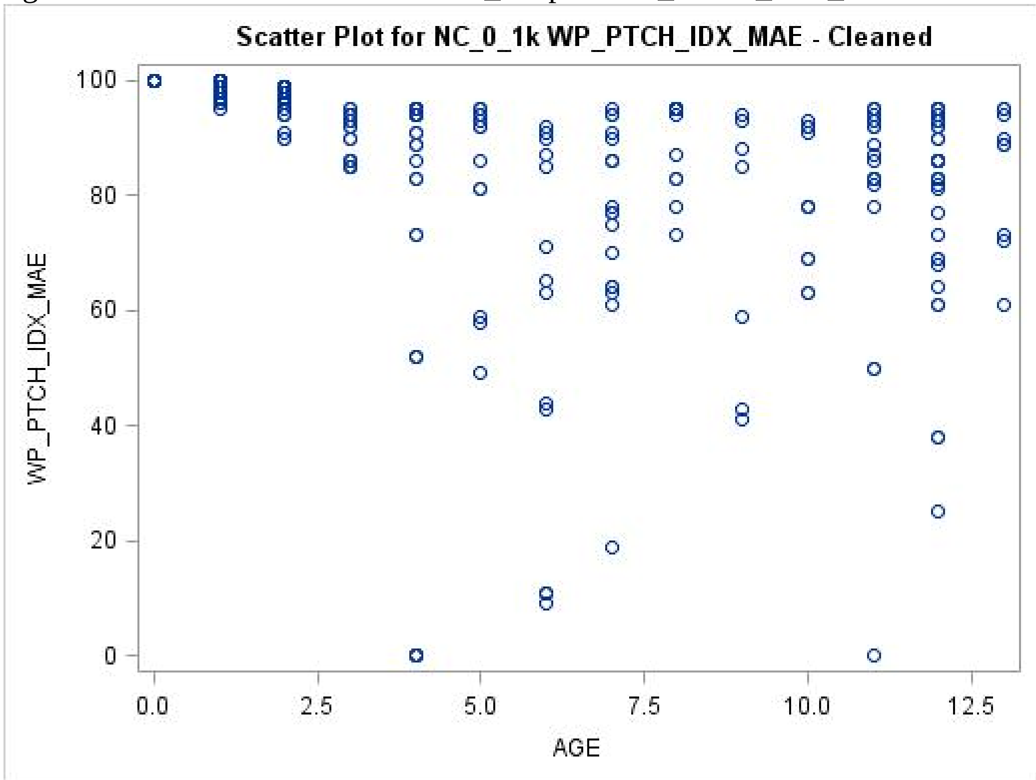

Figure 93: Schematic Scatter Plot for NC_0_1k WP_PTCH_IDX_MAE - Cleaned

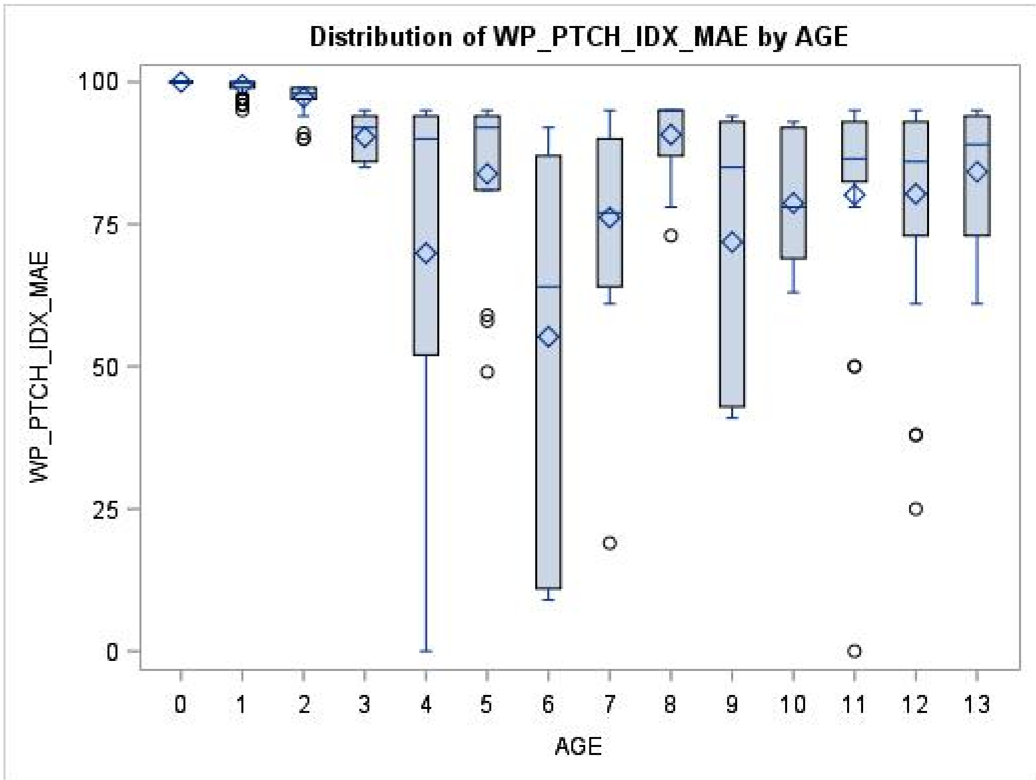

Figure 94: Schematic Box Plot for NC_0_1k WP_PTCH_IDX_MAE - Cleaned

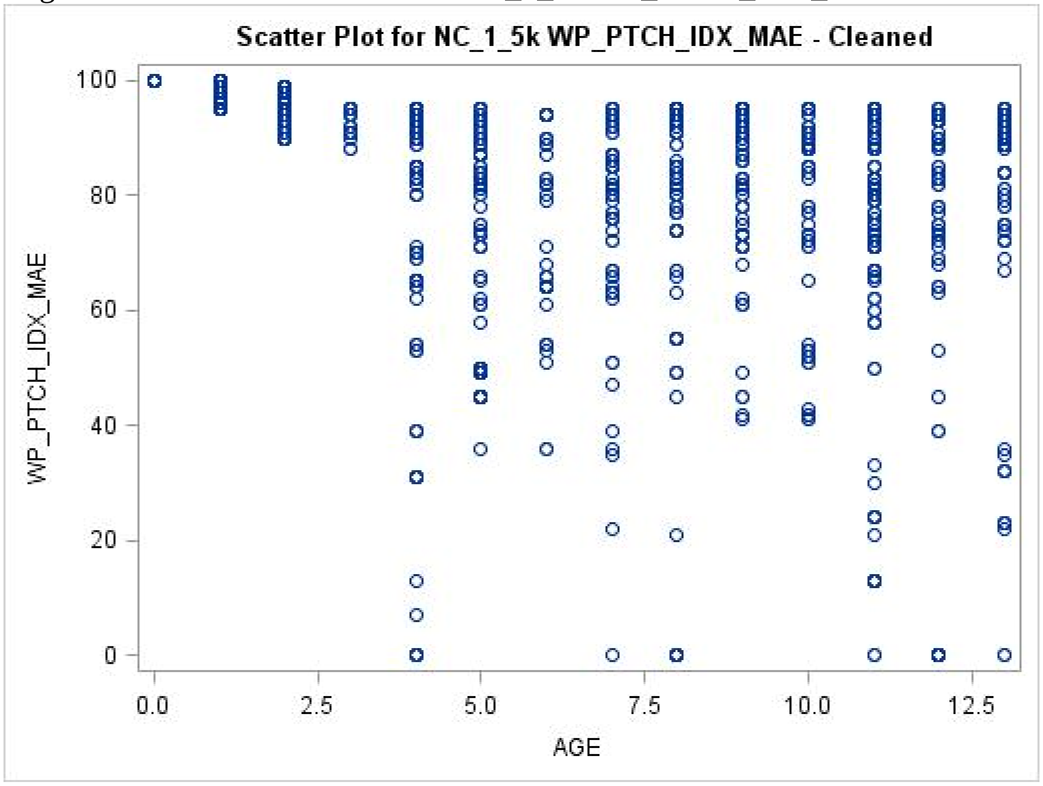

Figure 95: Schematic Scatter Plot for NC_1_5k WP_PTCH_IDX_MAE - Cleaned

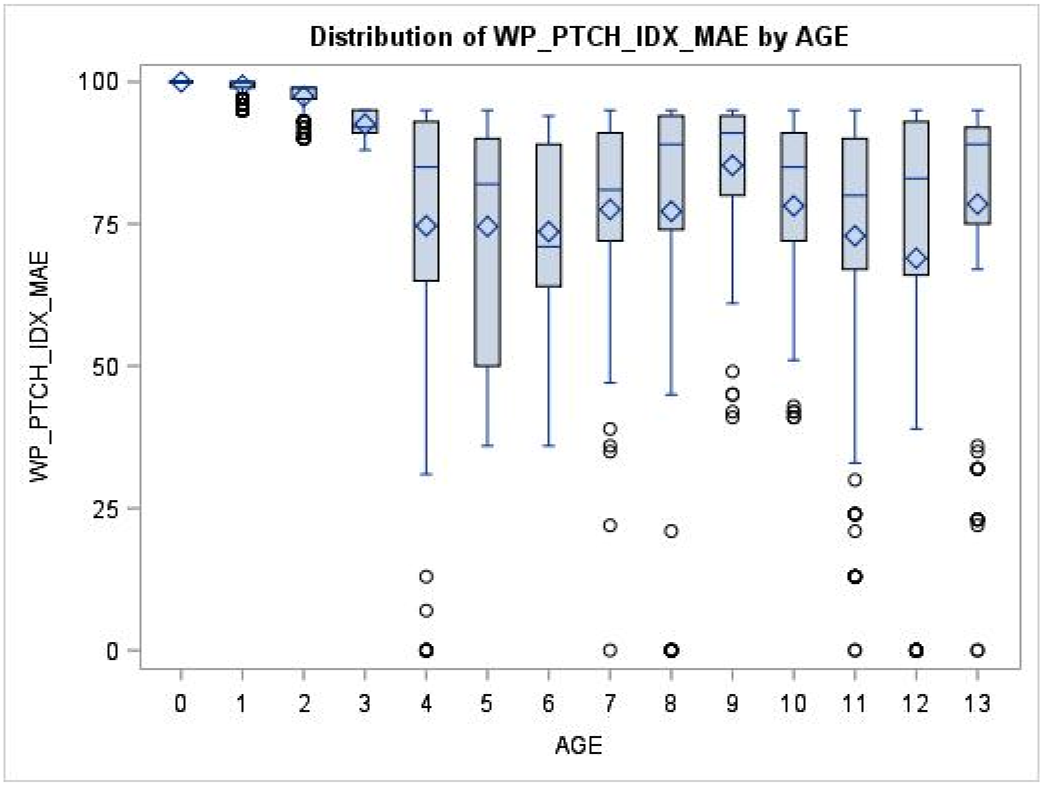

Figure 96: Schematic Box Plot for NC_1_5k WP_PTCH_IDX_MAE - Cleaned

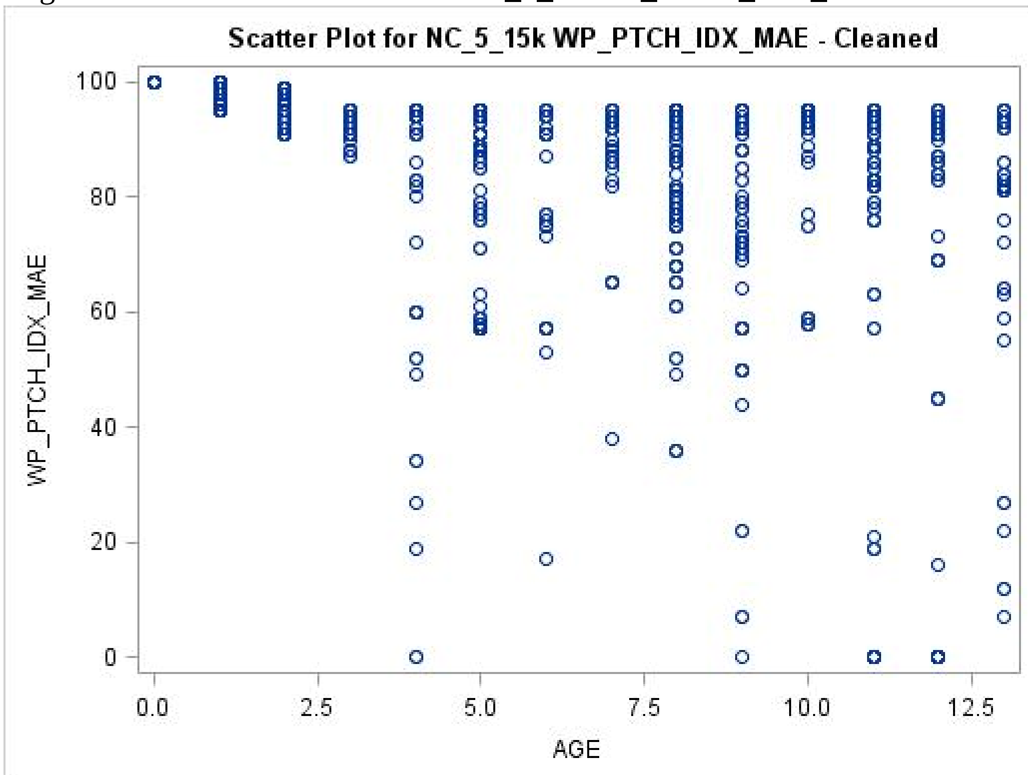

Figure 97: Schematic Scatter Plot for NC_5_15k WP_PTCH_IDX_MAE - Cleaned

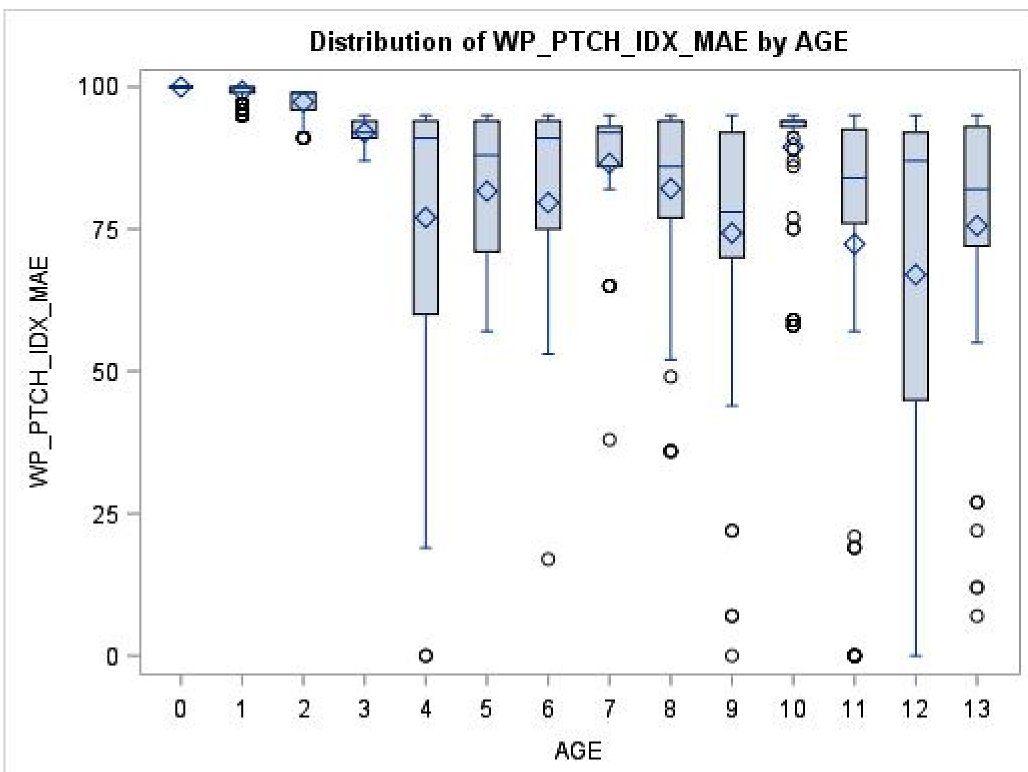

Figure 98: Schematic Box Plot for NC_5_15k WP_PTCH_IDX_MAE - Cleaned

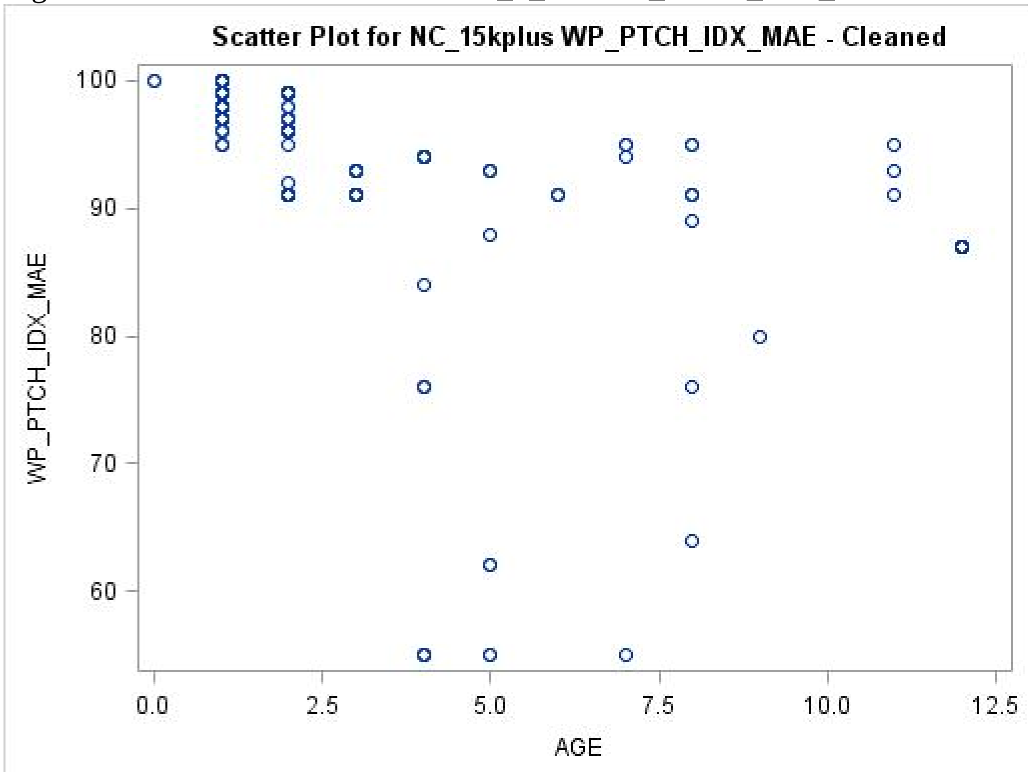

Figure 99: Schematic Scatter Plot for NC_15kplus WP_PTCH_IDX_MAE - Cleaned

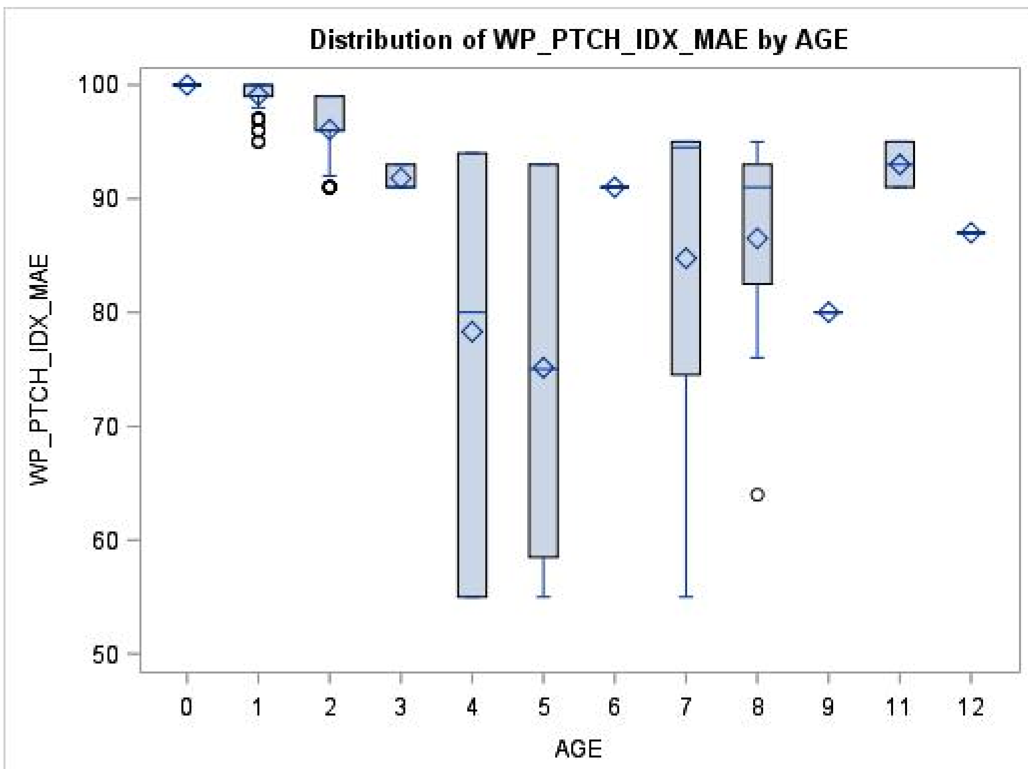

Figure 100: Schematic Box Plot for NC_15kplus WP_PTCH_IDX_MAE - Cleaned

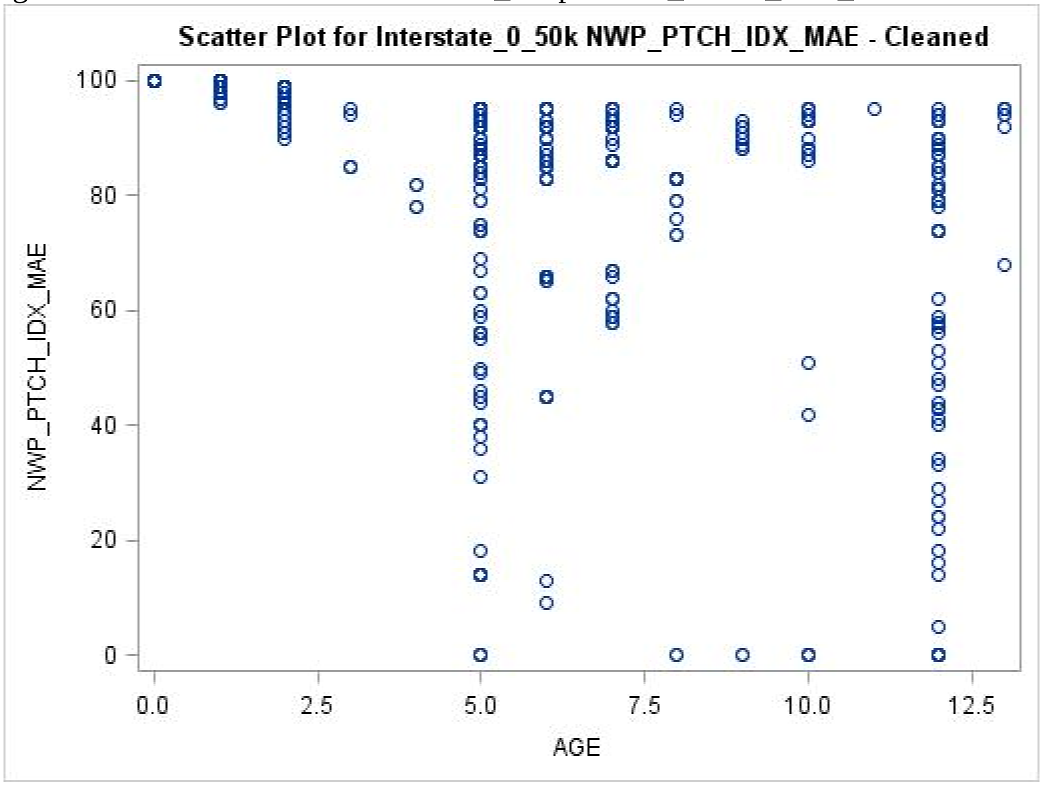

Figure 101: Schematic Scatter Plot for Interstate_0_50k NWP_PTCH_IDX_MAE - Cleaned

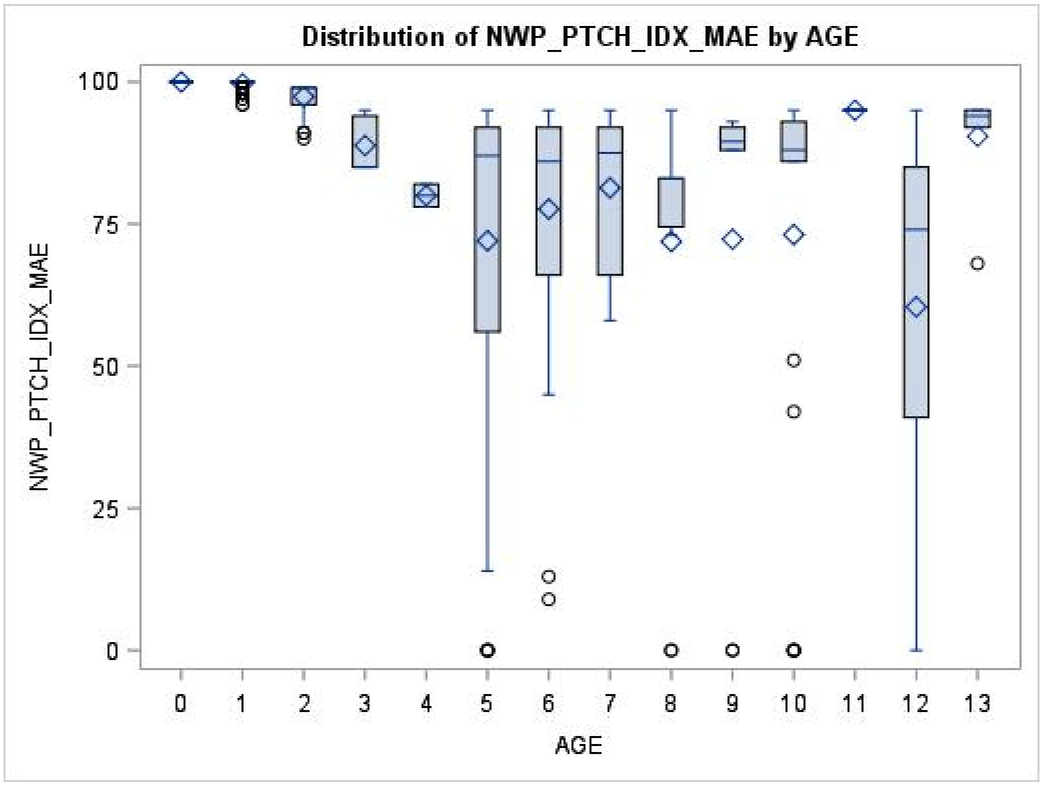

Figure 102: Schematic Box Plot for Interstate_0_50k NWP_PTCH_IDX_MAE - Cleaned

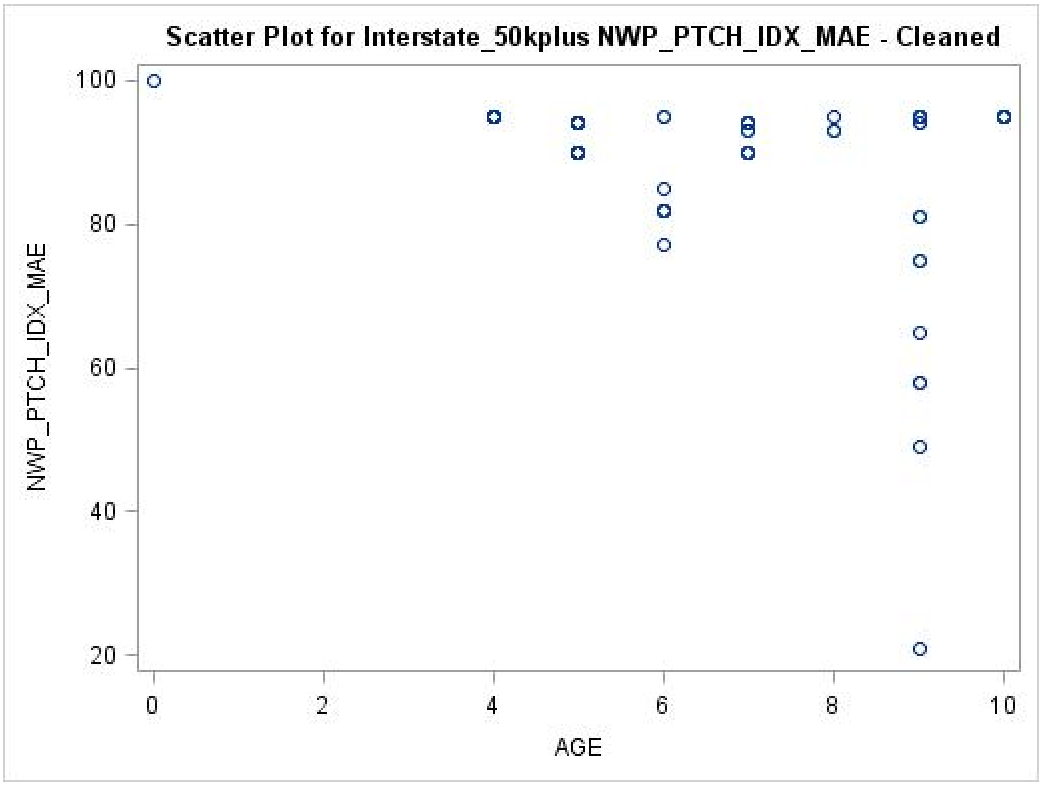

Figure 103: Schematic Scatter Plot for Interstate_50kplus NWP_PTCH_IDX_MAE - Cleaned

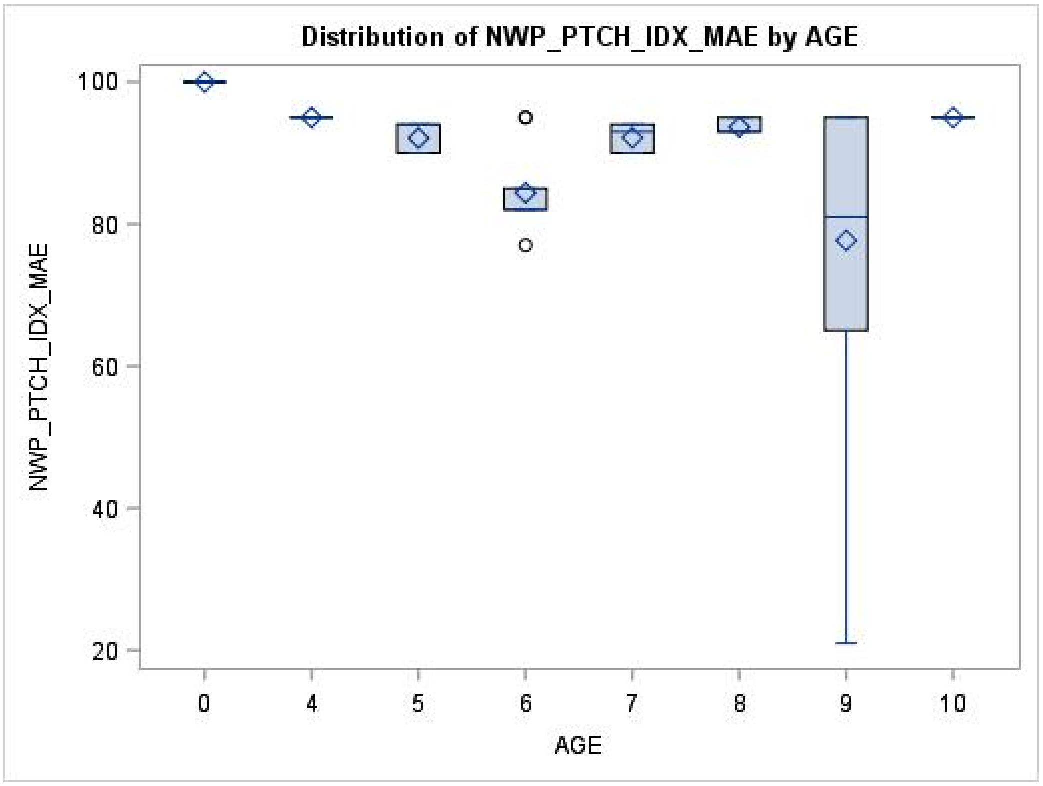

Figure 104: Schematic Box Plot for Interstate_50kplus NWP_PTCH_IDX_MAE - Cleaned

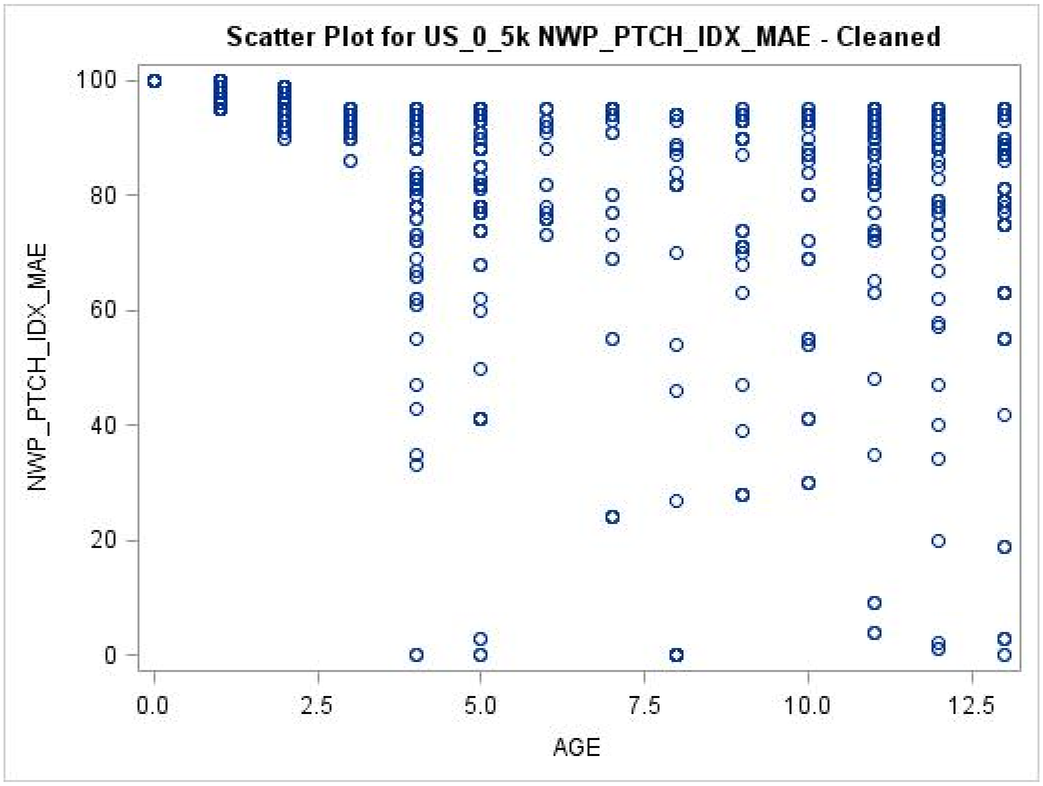

Figure 105: Schematic Scatter Plot for US_0_5k NWP_PTCH_IDX_MAE - Cleaned

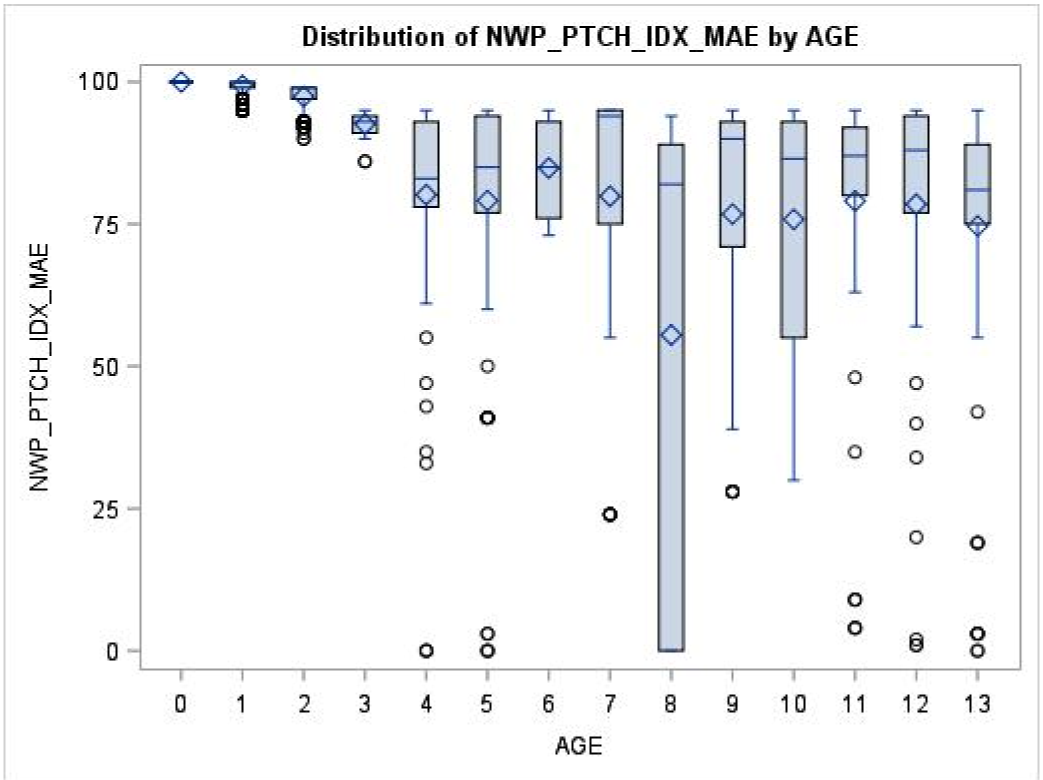

Figure 106: Schematic Box Plot for US_0_5k NWP_PTCH_IDX_MAE - Cleaned

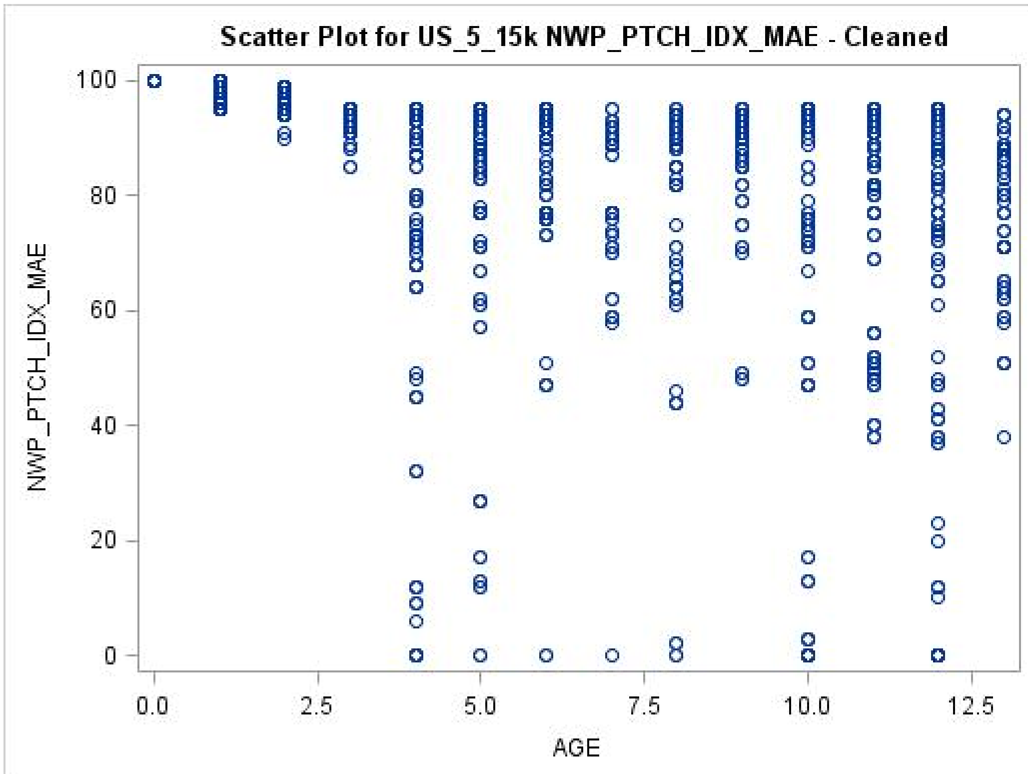

Figure 107: Schematic Scatter Plot for US_5_15k NWP_PTCH_IDX_MAE - Cleaned

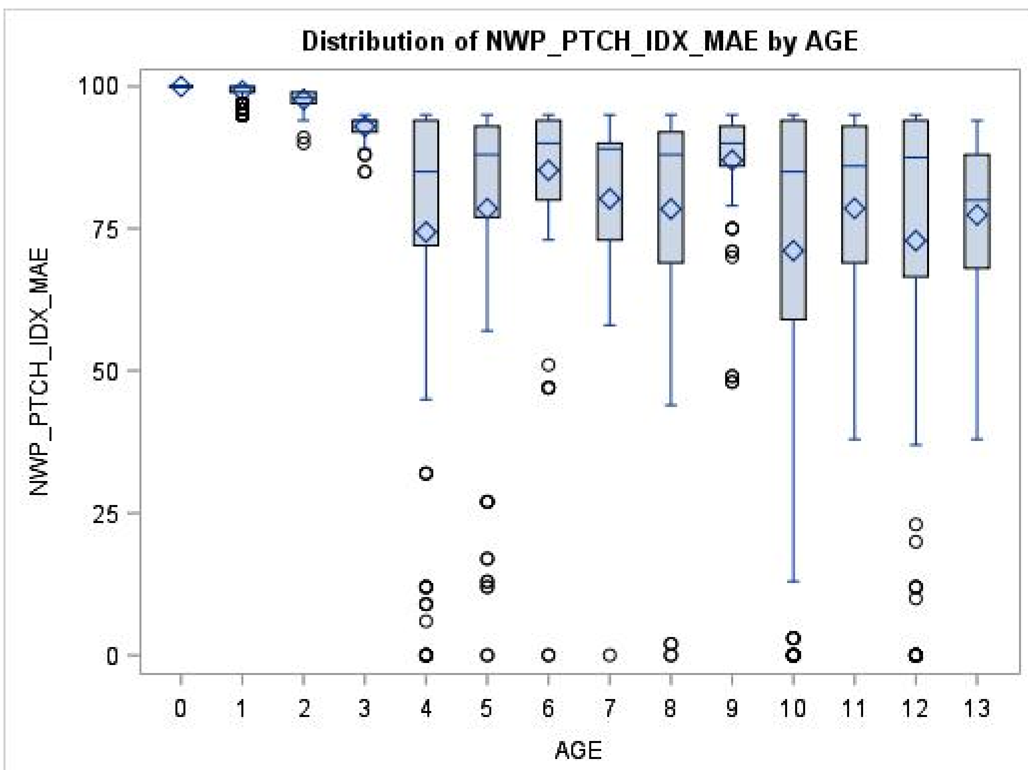

Figure 108: Schematic Box Plot for US_5_15k NWP_PTCH_IDX_MAE - Cleaned

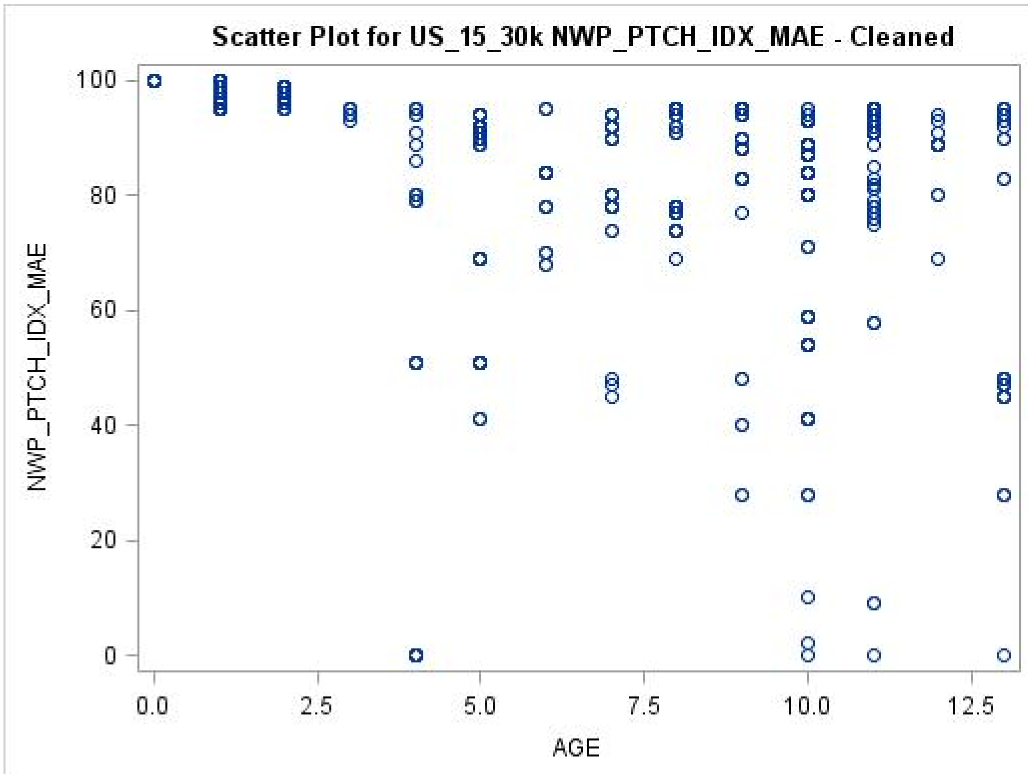

Figure 109: Schematic Scatter Plot for US_15_30k NWP_PTCH_IDX_MAE - Cleaned

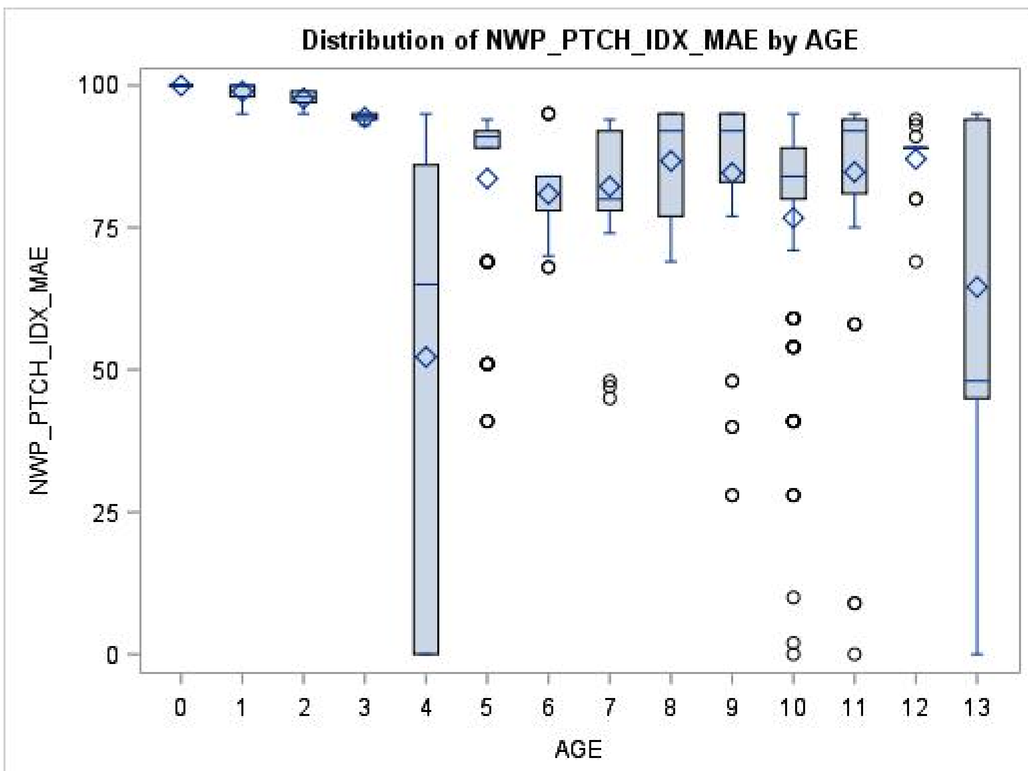

Figure 110: Schematic Box Plot for US_15_30k NWP_PTCH_IDX_MAE - Cleaned

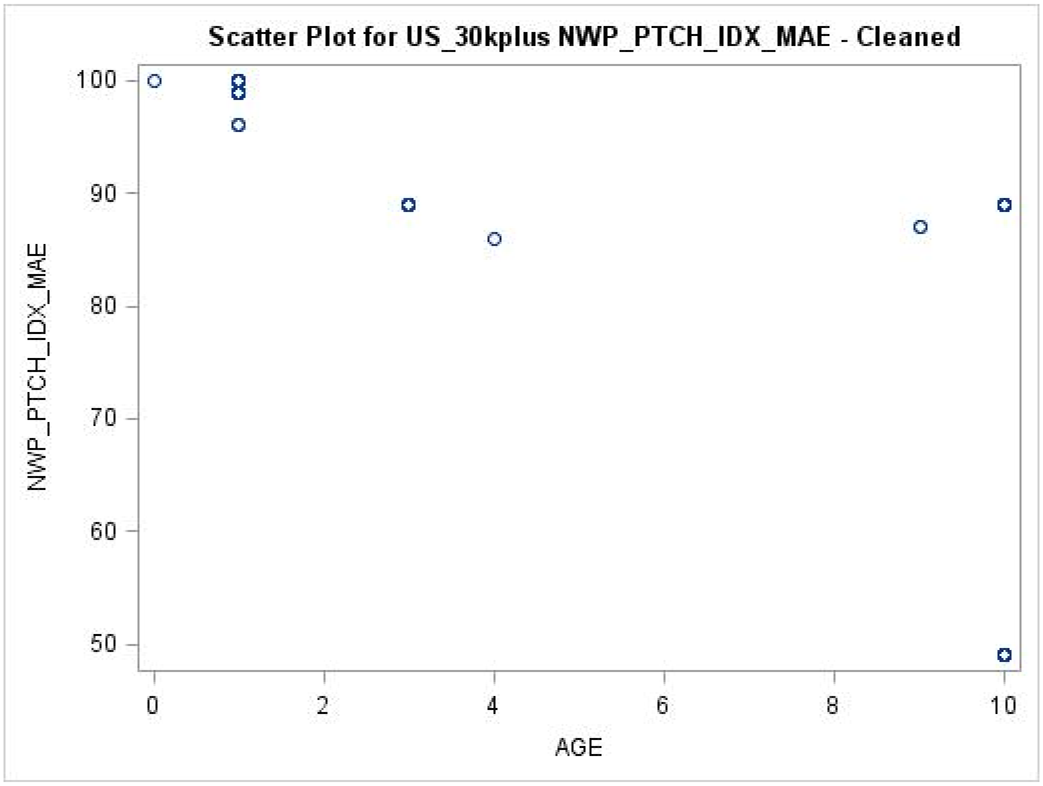

Figure 111: Schematic Scatter Plot for US_30kplus NWP_PTCH_IDX_MAE - Cleaned

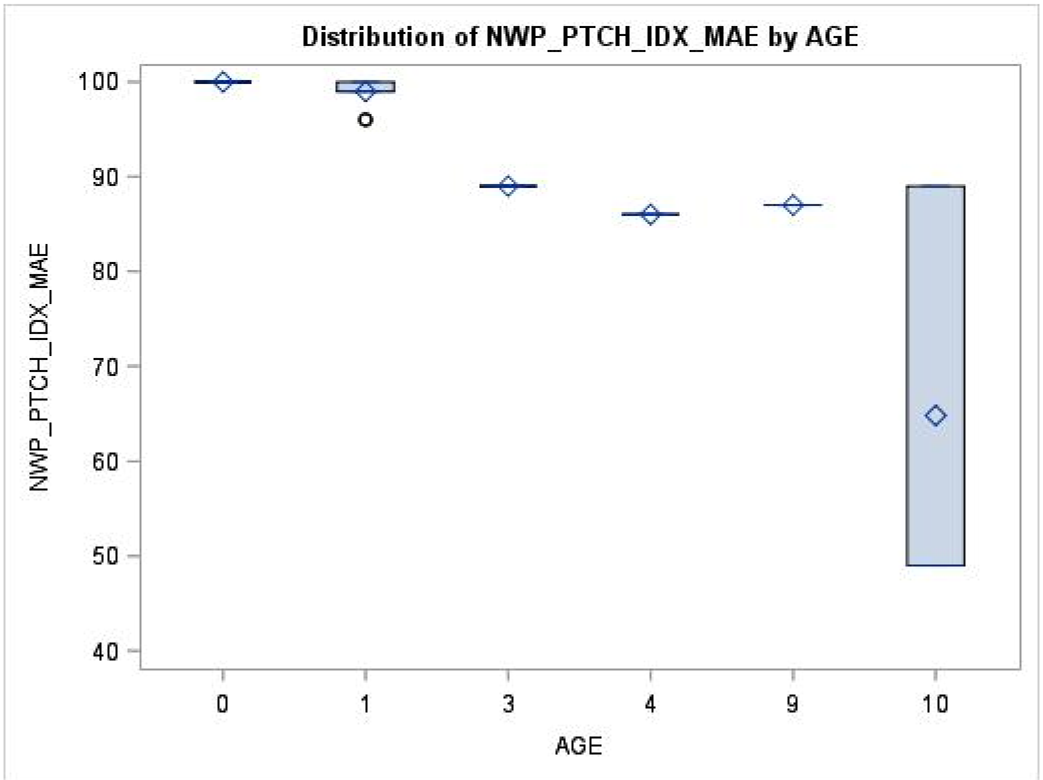

Figure 112: Schematic Box Plot for US_30kplus NWP_PTCH_IDX_MAE - Cleaned

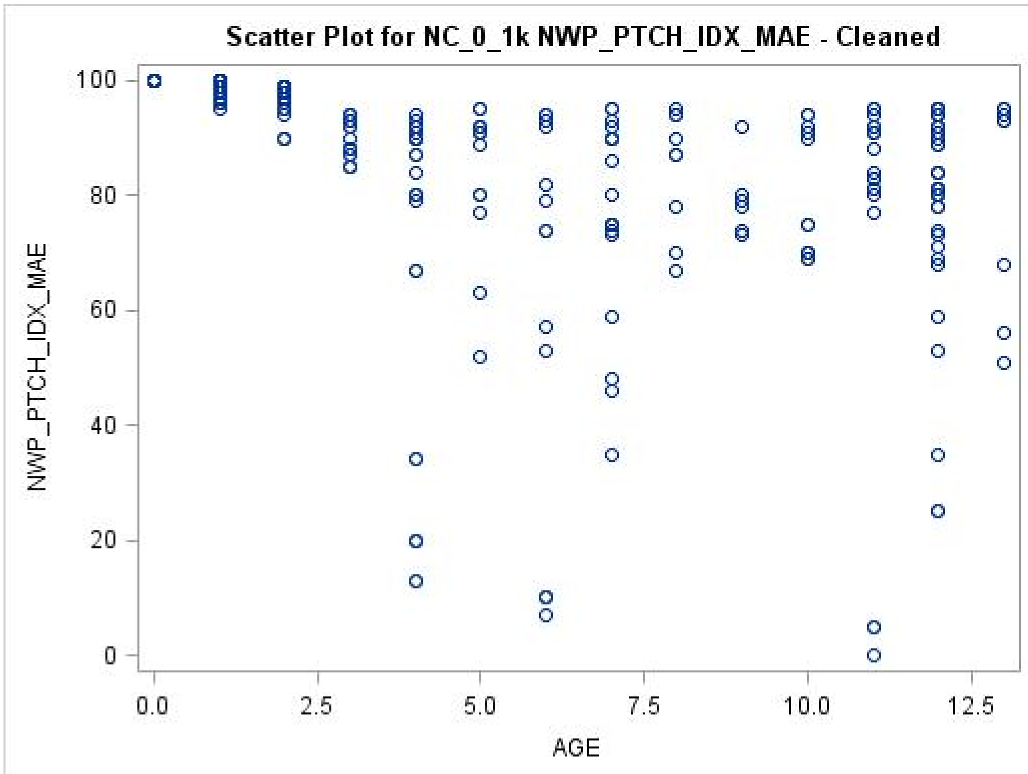

Figure 113: Schematic Scatter Plot for NC_0_1k NWP_PTCH_IDX_MAE - Cleaned

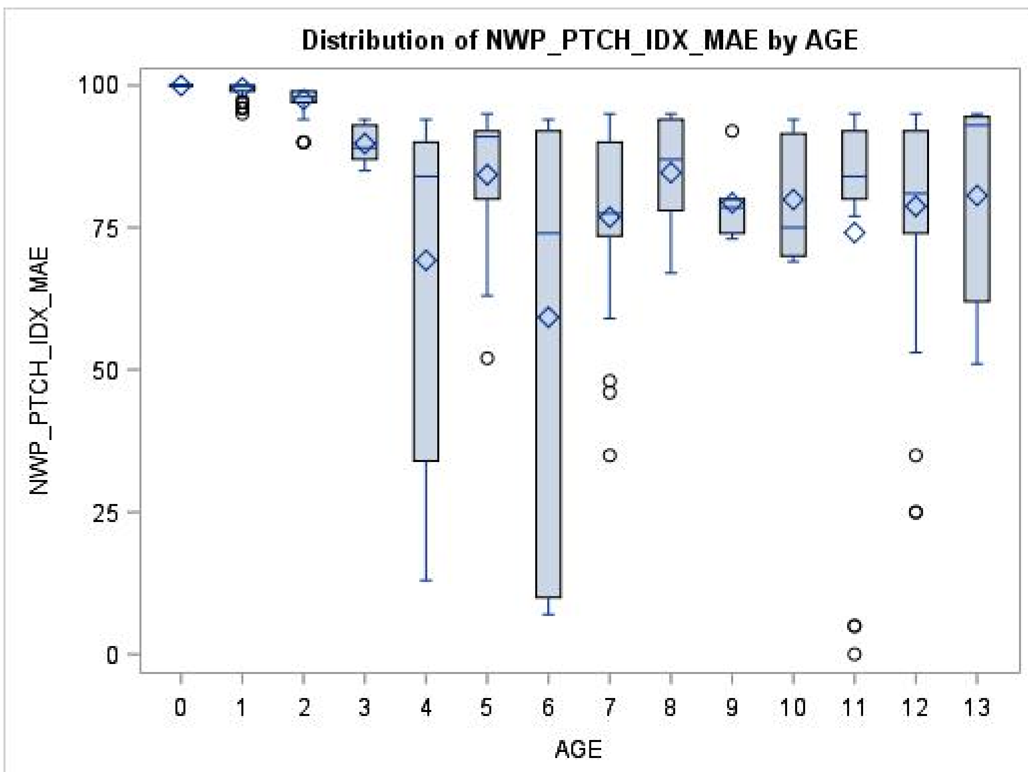

Figure 114: Schematic Box Plot for NC_0_1k NWP_PTCH_IDX_MAE - Cleaned

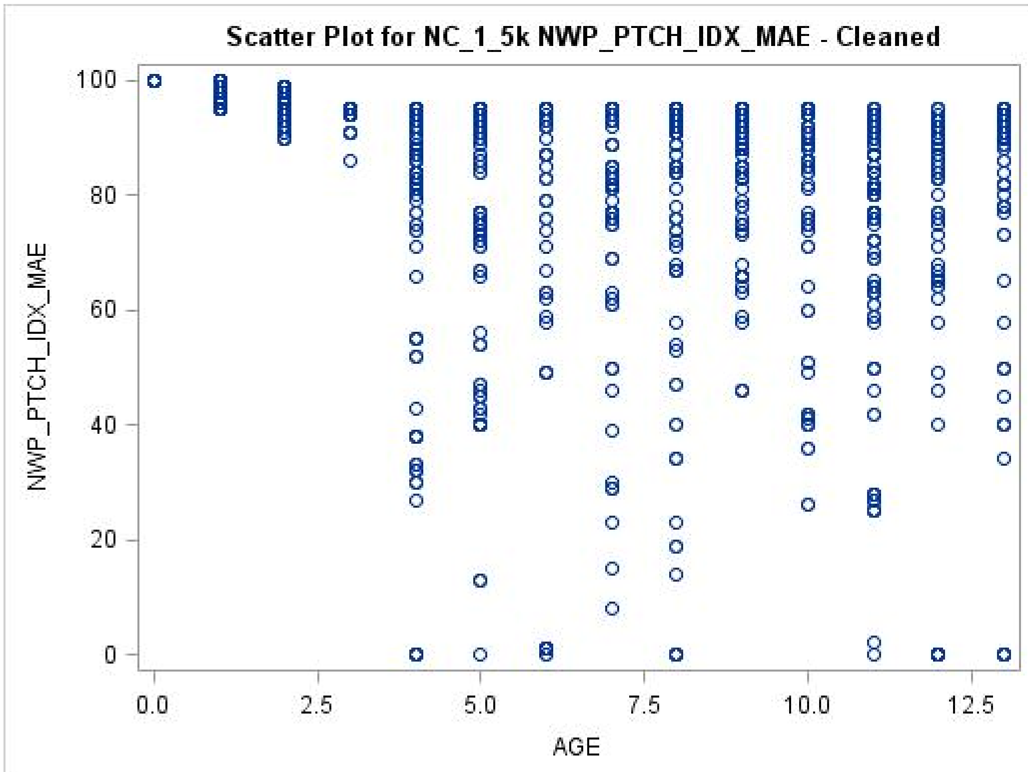

Figure 115: Schematic Scatter Plot for NC_1_5k NWP_PTCH_IDX_MAE - Cleaned

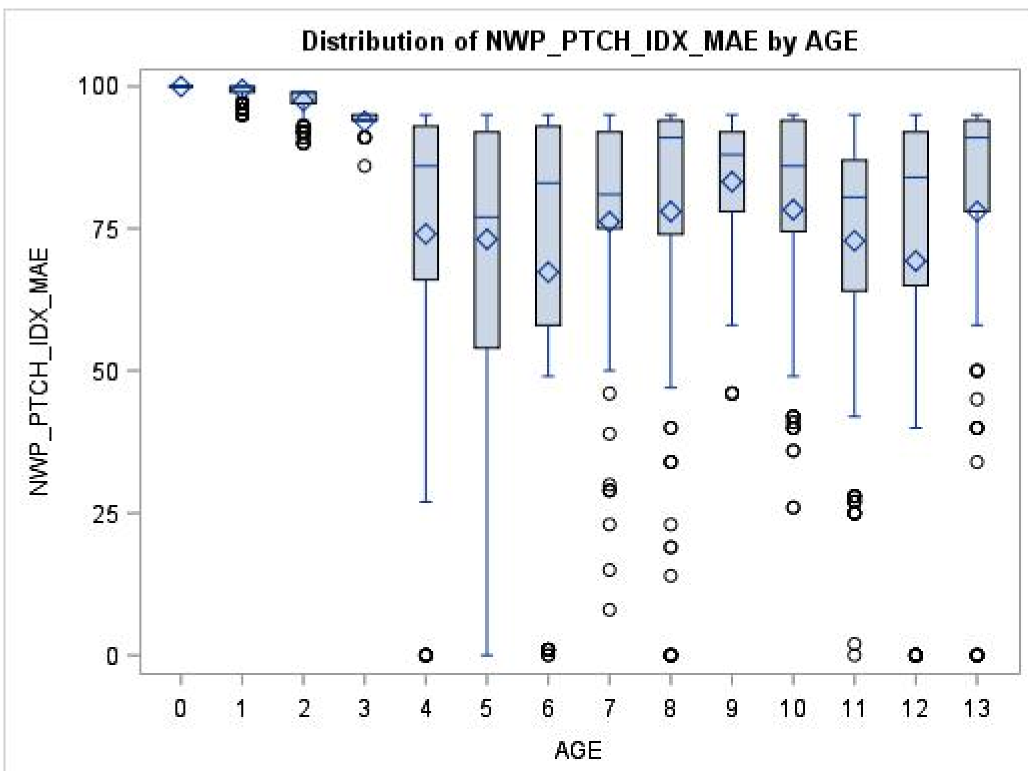

Figure 116: Schematic Box Plot for NC_1_5k NWP_PTCH_IDX_MAE - Cleaned

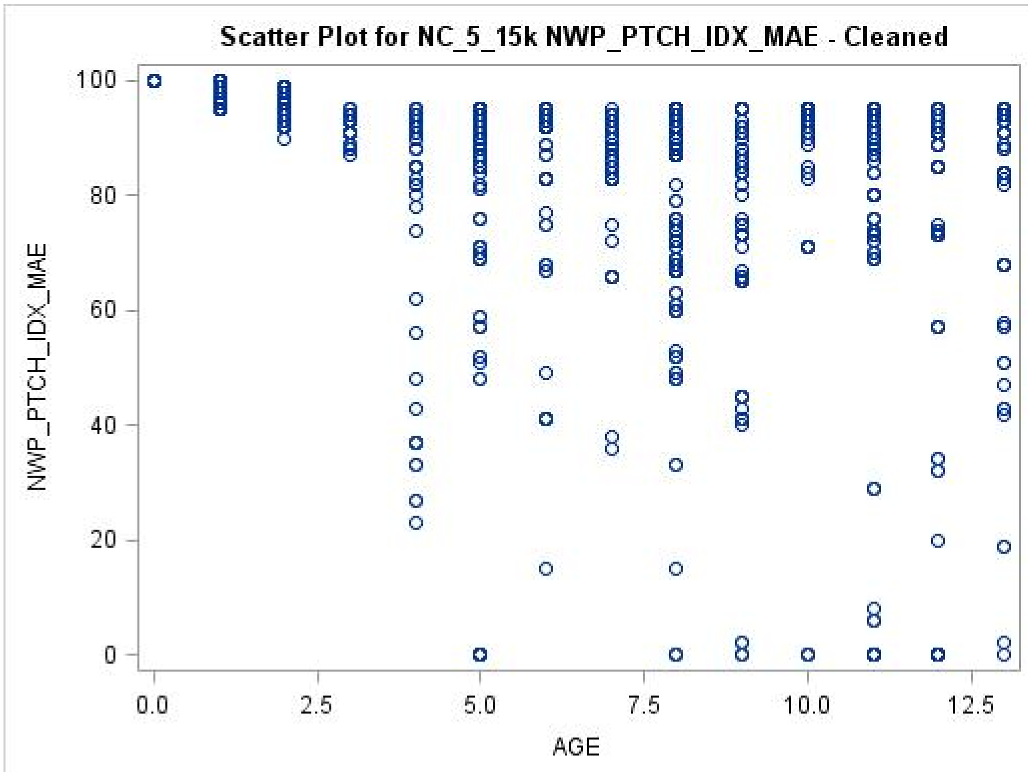

Figure 117: Schematic Scatter Plot for NC_5_15k NWP_PTCH_IDX_MAE - Cleaned

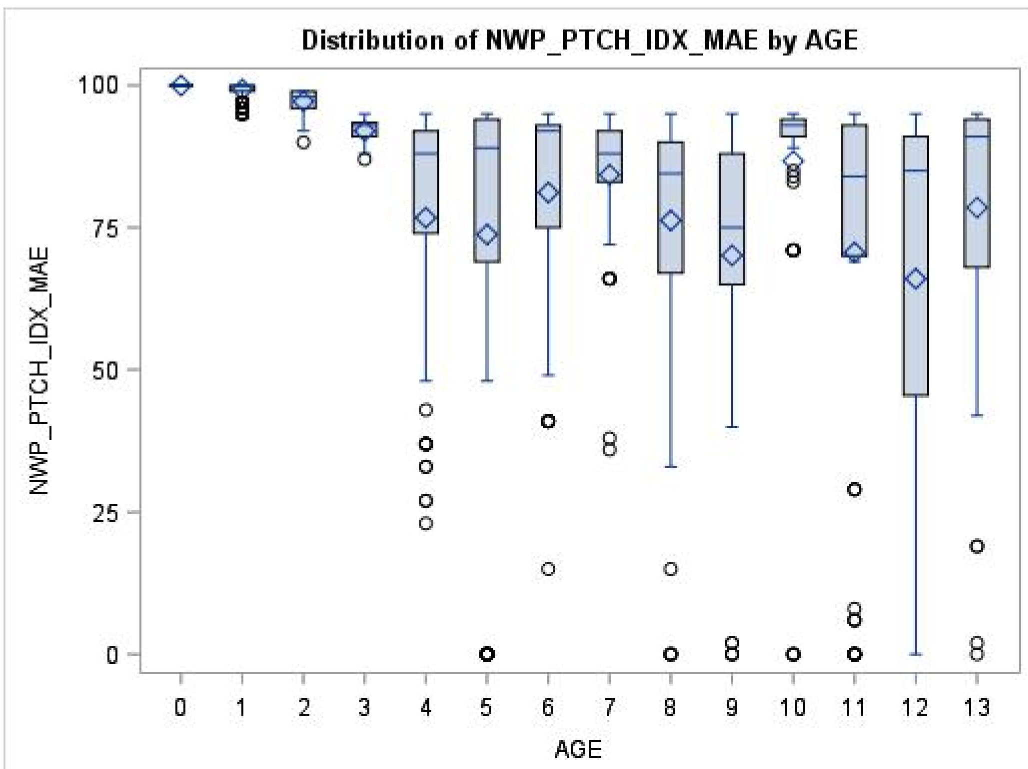

Figure 118: Schematic Box Plot for NC_5_15k NWP_PTCH_IDX_MAE - Cleaned

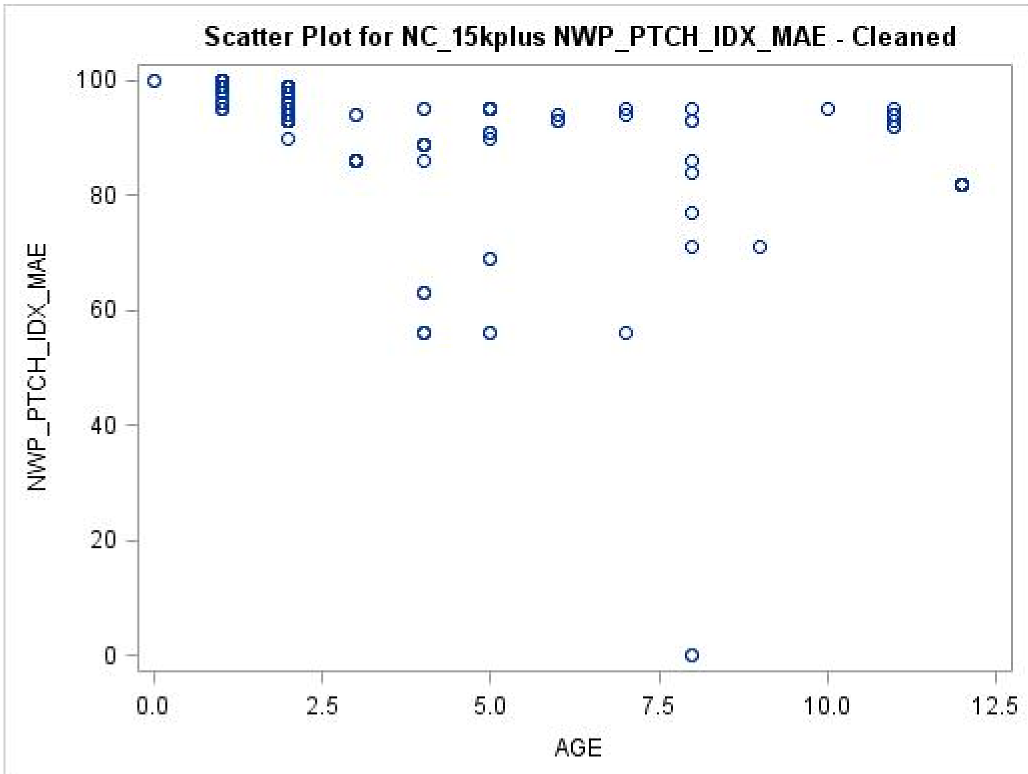

Figure 119: Schematic Scatter Plot for NC_15kplus NWP_PTCH_IDX_MAE - Cleaned

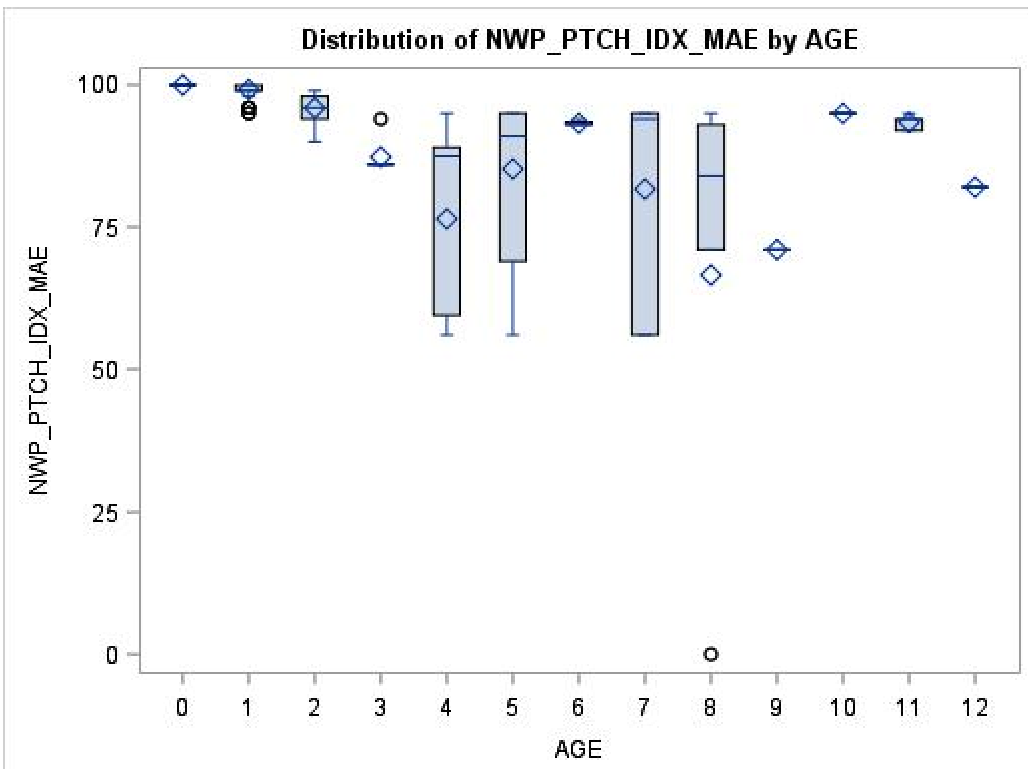

Figure 120: Schematic Box Plot for NC_15kplus NWP_PTCH_IDX_MAE - Cleaned

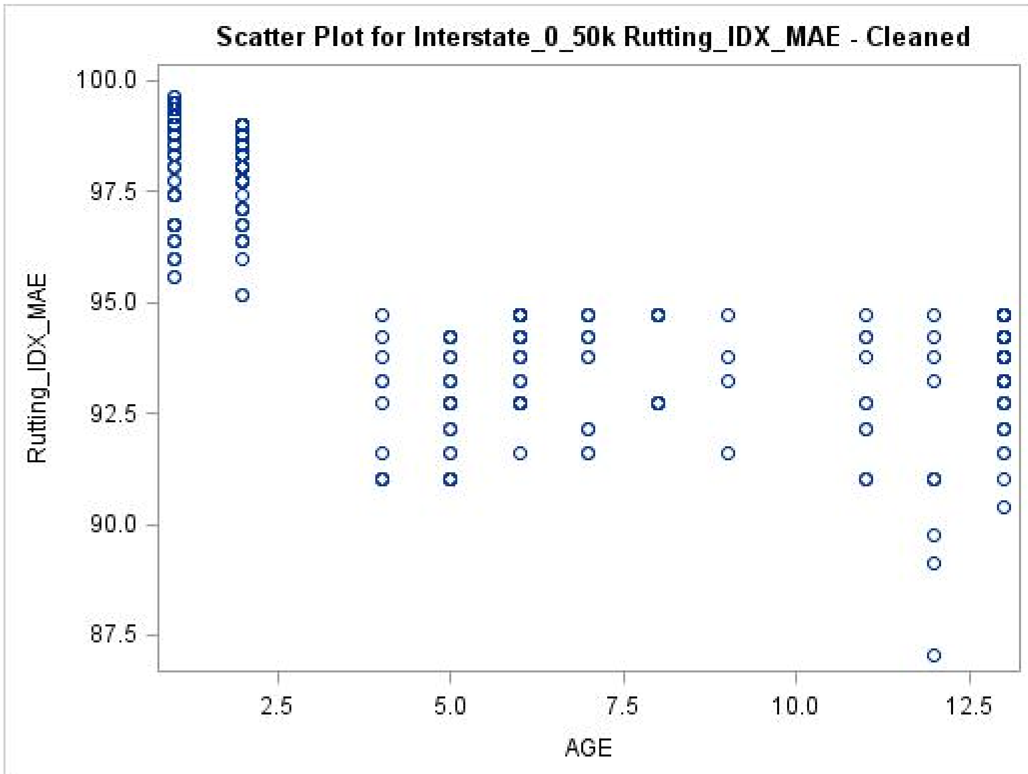

Figure 121: Schematic Scatter Plot for Interstate_0_50k Rutting_IDX_MAE - Cleaned

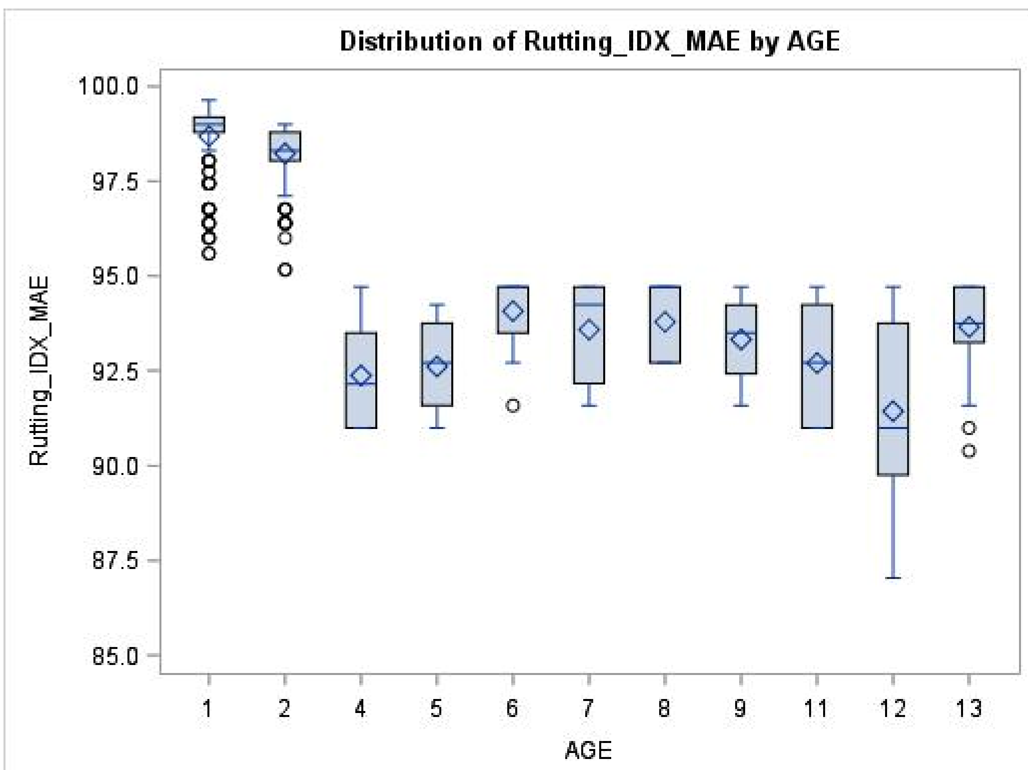

Figure 122: Schematic Box Plot for Interstate_0_50k Rutting_IDX_MAE - Cleaned

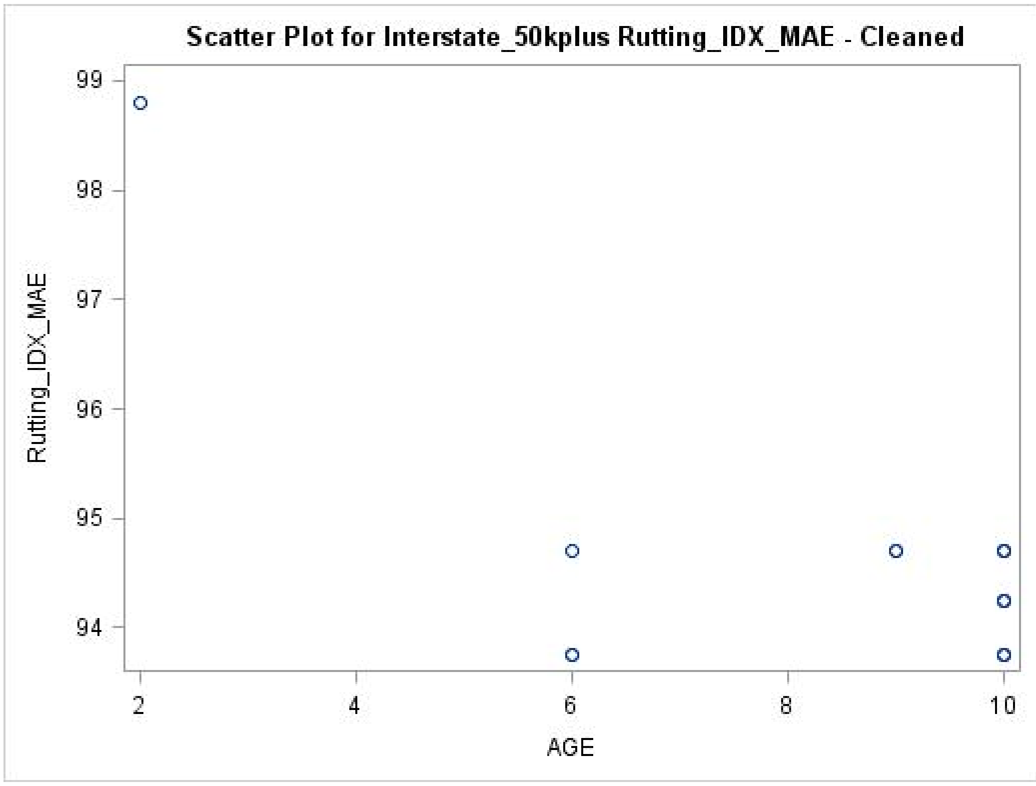

Figure 123: Schematic Scatter Plot for Interstate_50kplus Rutting_IDX_MAE - Cleaned

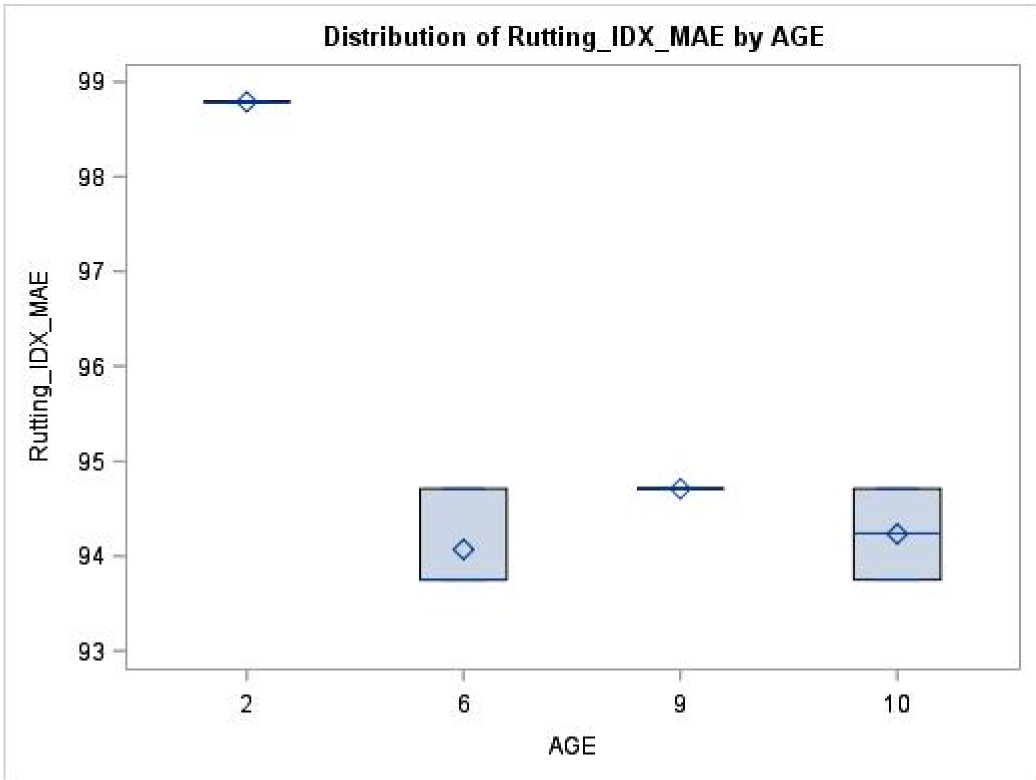

Figure 124: Schematic Box Plot for Interstate_50kplus Rutting_IDX_MAE - Cleaned

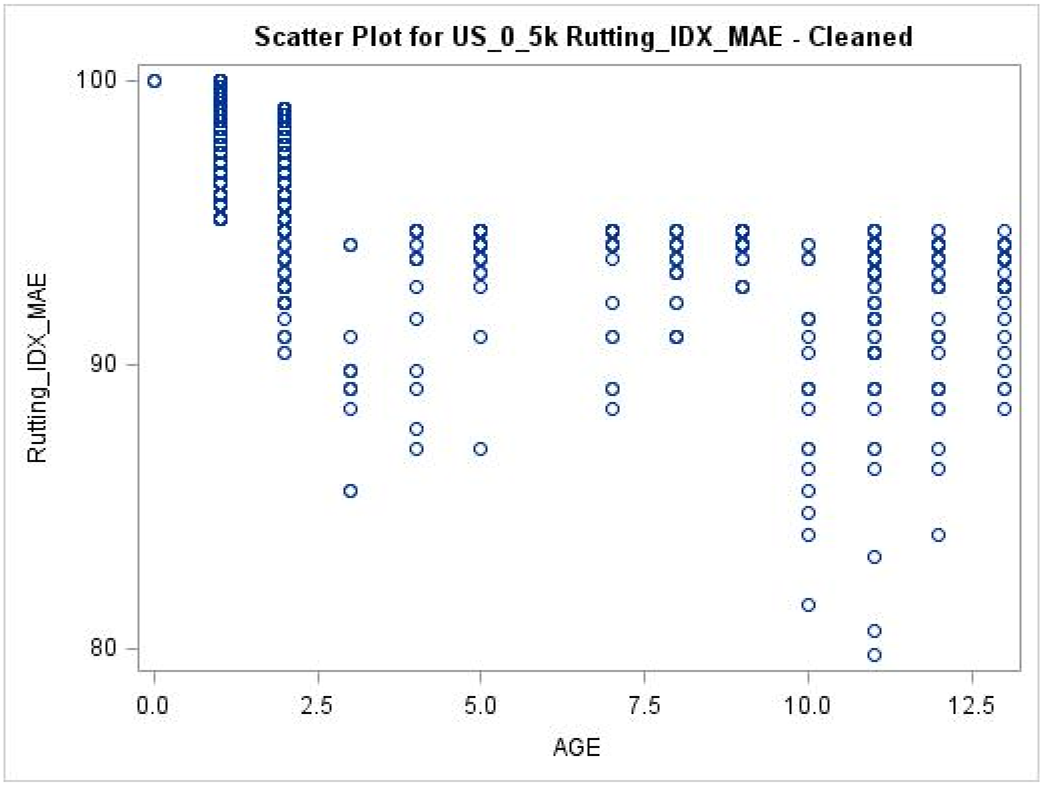

Figure 125: Schematic Scatter Plot for US_0_5k Rutting_IDX_MAE - Cleaned

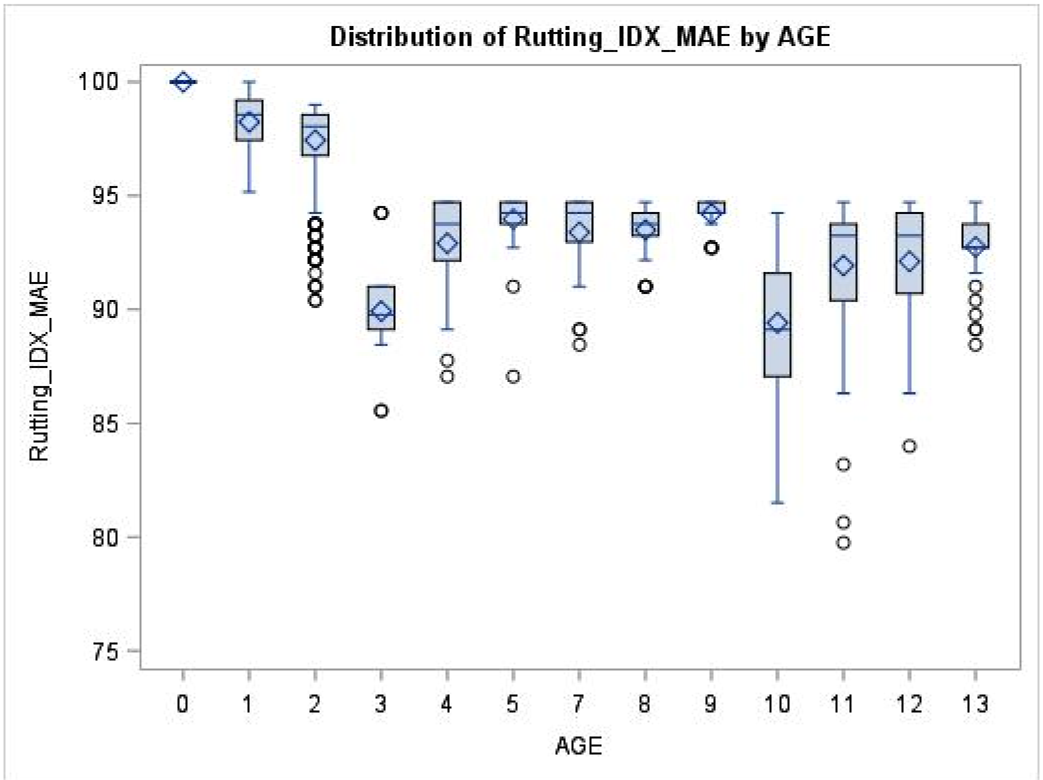

Figure 126: Schematic Box Plot for US_0_5k Rutting_IDX_MAE - Cleaned

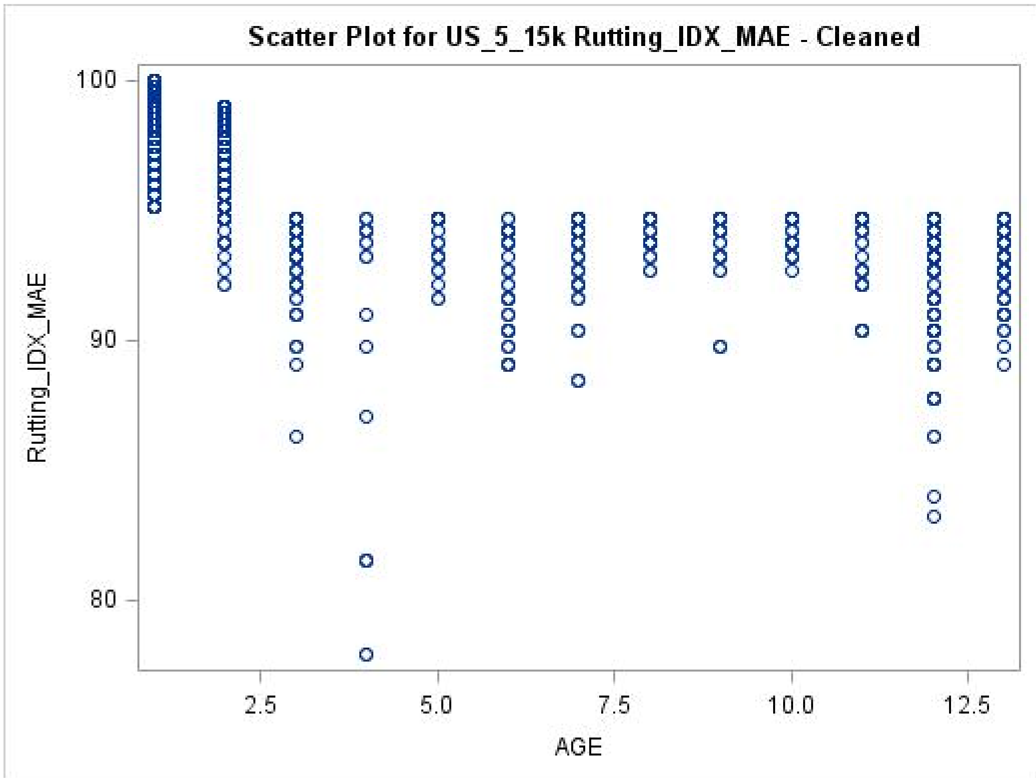

Figure 127: Schematic Scatter Plot for US_5_15k Rutting_IDX_MAE - Cleaned

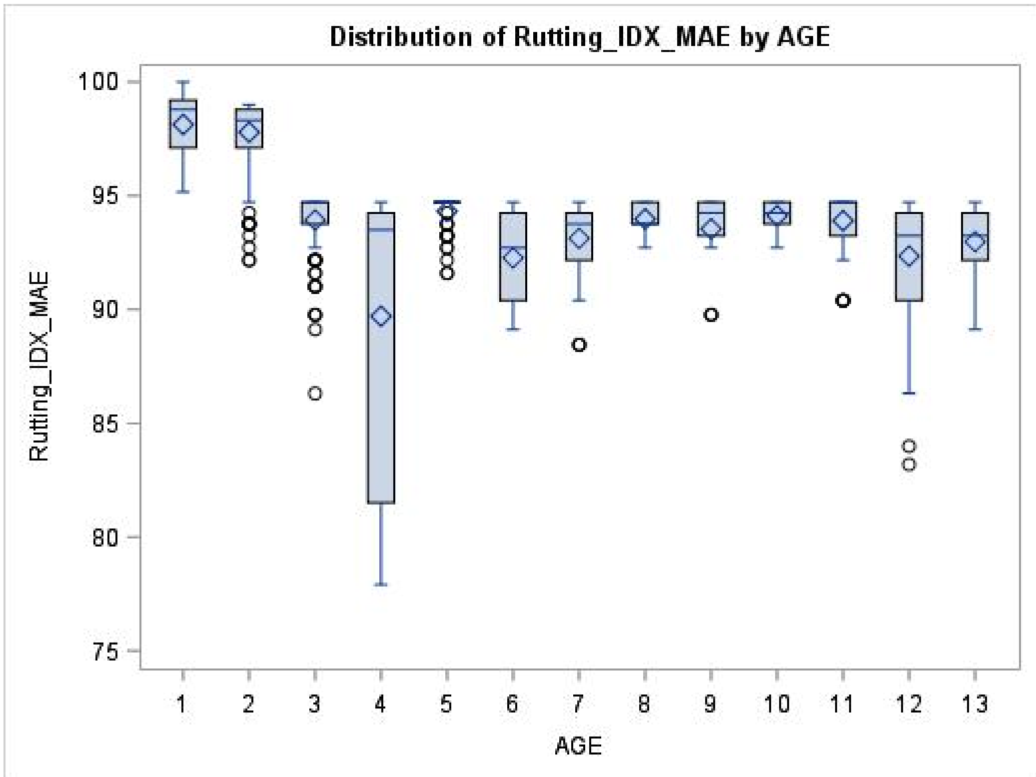

Figure 128: Schematic Box Plot for US_5_15k Rutting_IDX_MAE - Cleaned

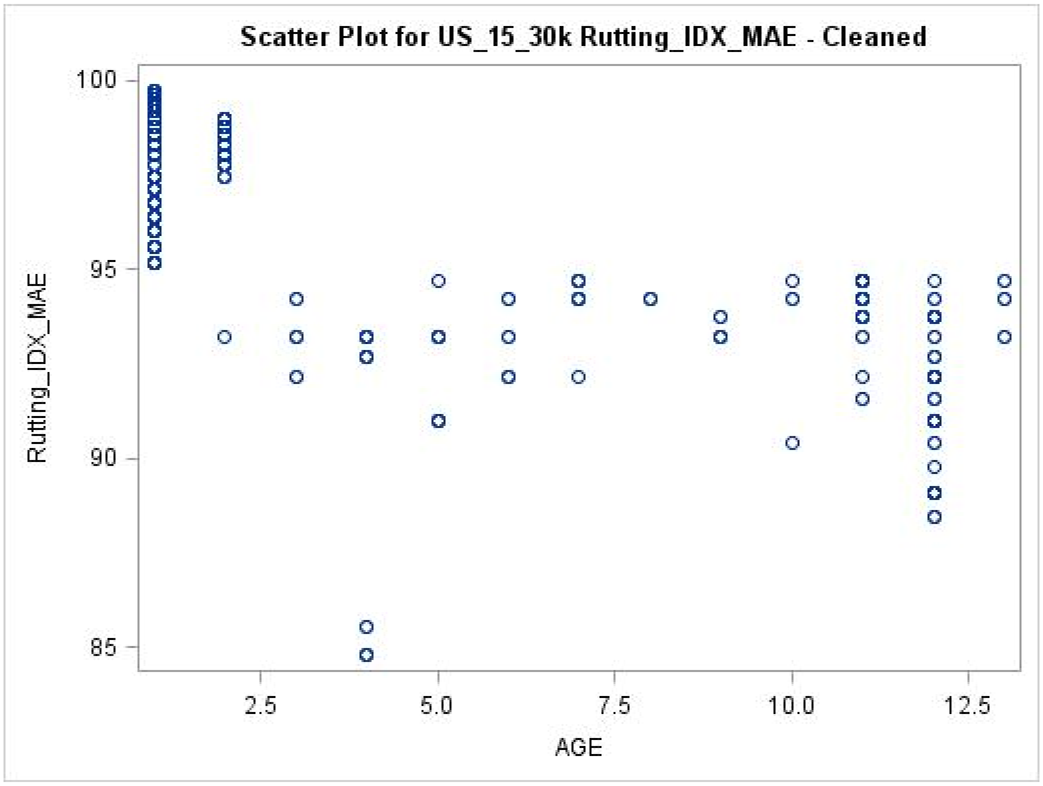

Figure 129: Schematic Scatter Plot for US_15_30k Rutting_IDX_MAE - Cleaned

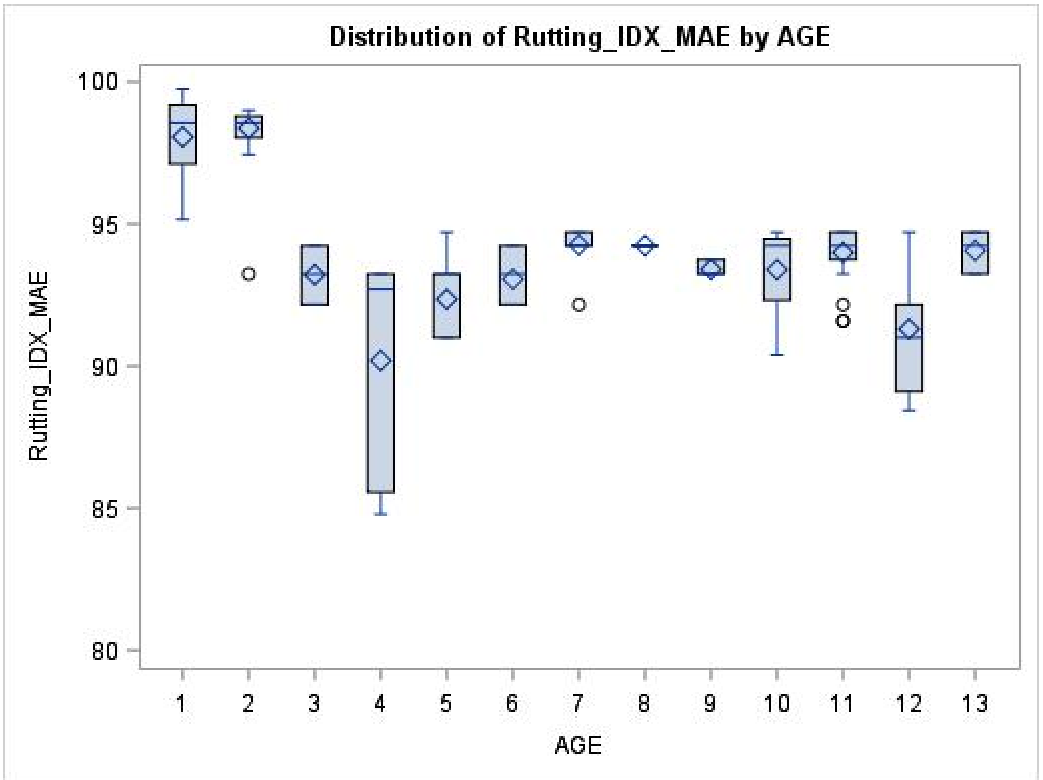

Figure 130: Schematic Box Plot for US_15_30k Rutting_IDX_MAE - Cleaned

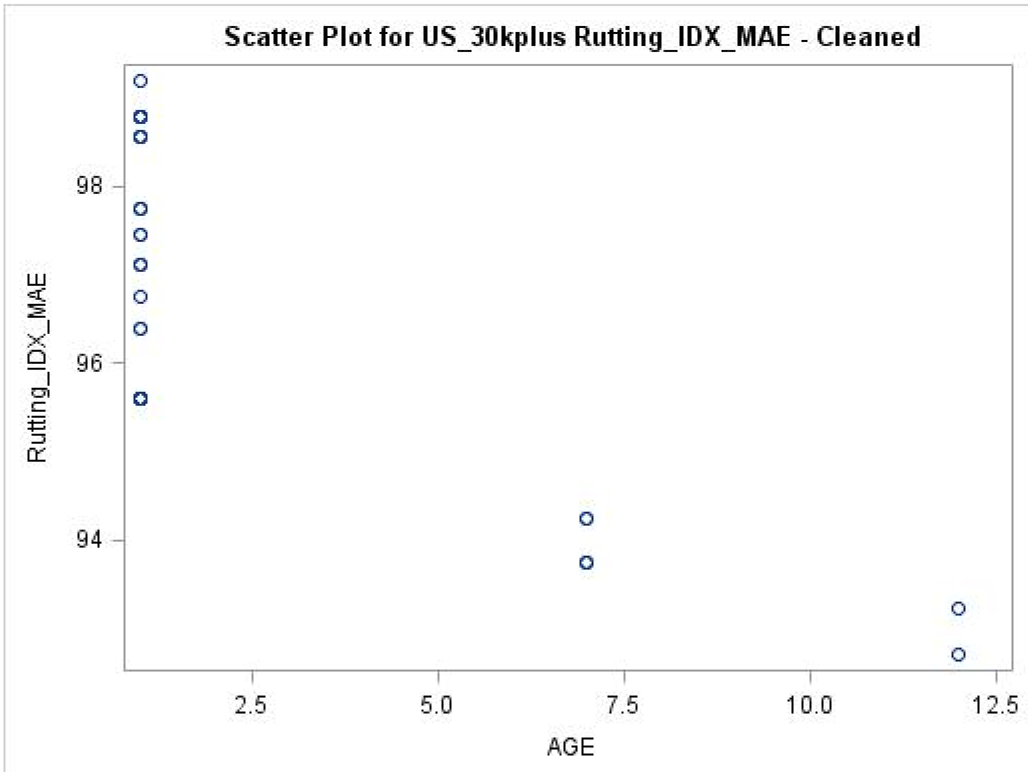

Figure 131: Schematic Scatter Plot for US_30kplus Rutting_IDX_MAE - Cleaned

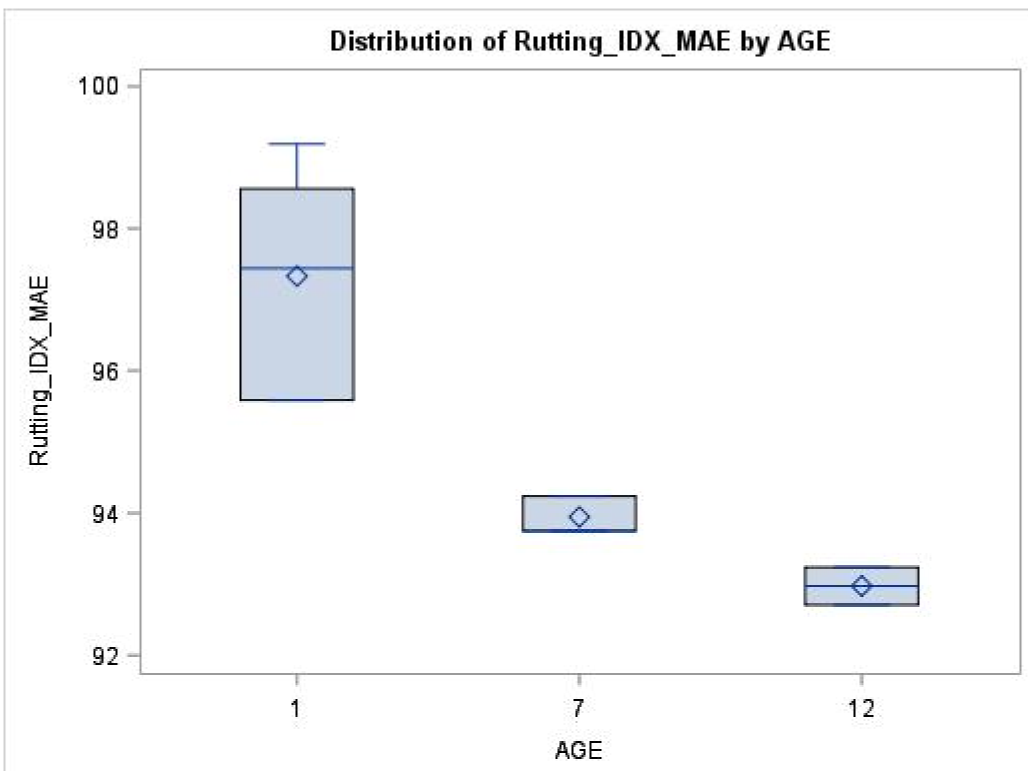

Figure 132: Schematic Box Plot for US_30kplus Rutting_IDX_MAE - Cleaned

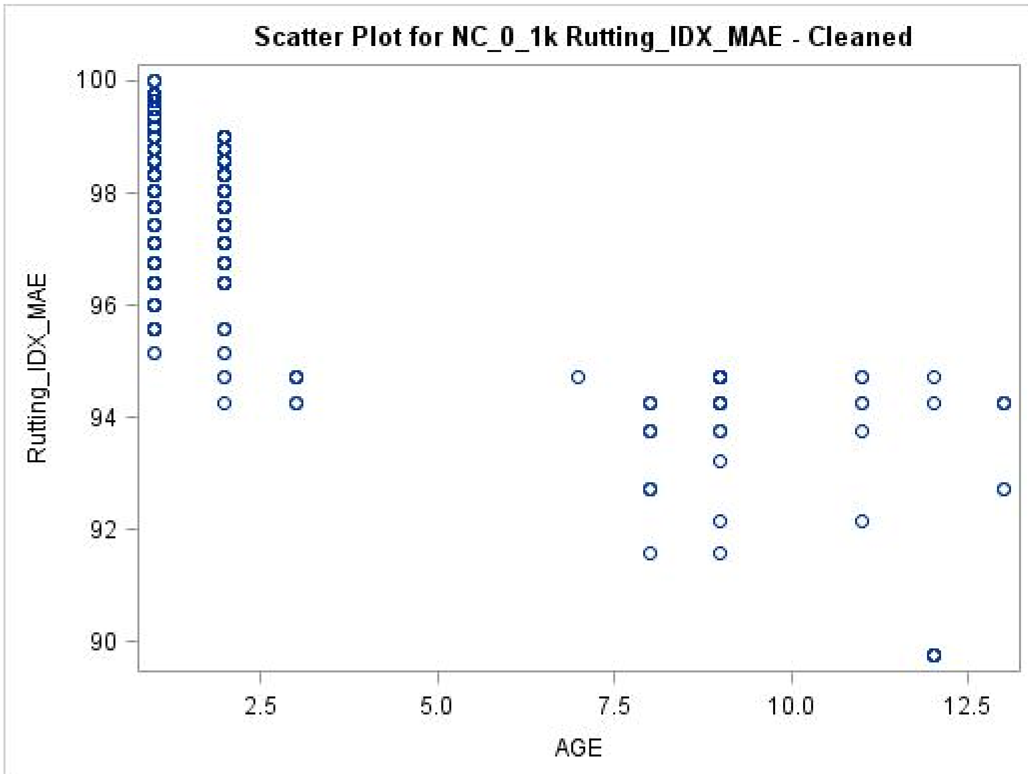

Figure 133: Schematic Scatter Plot for NC_0_1k Rutting_IDX_MAE - Cleaned

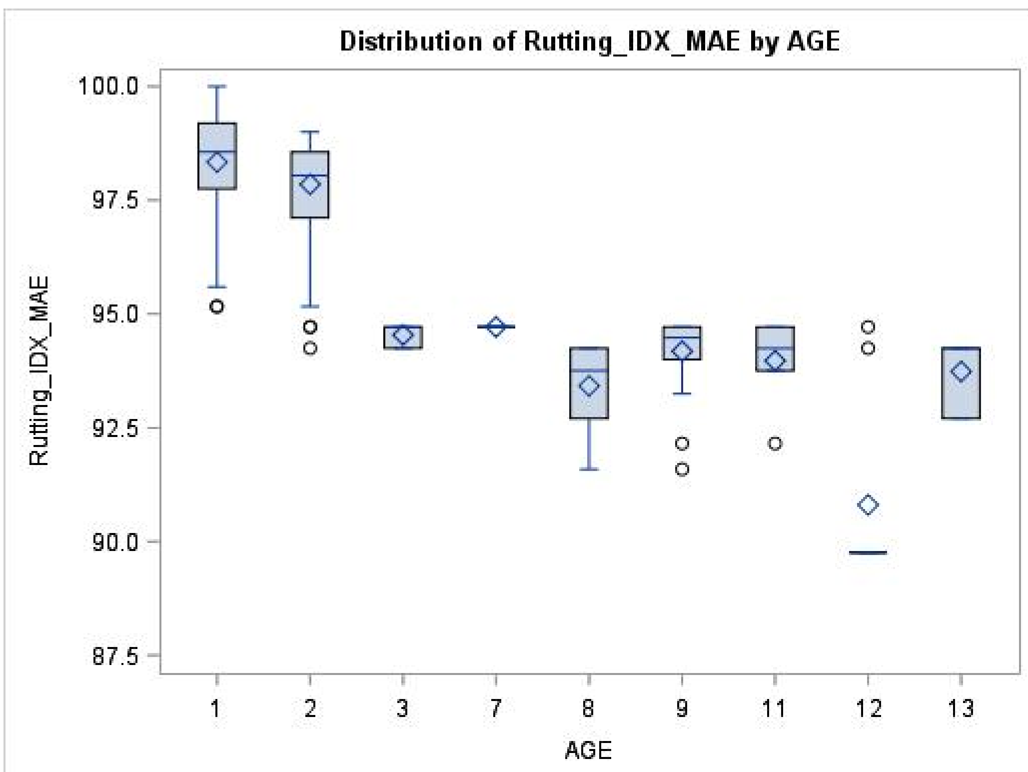

Figure 134: Schematic Box Plot for NC_0_1k Rutting_IDX_MAE - Cleaned

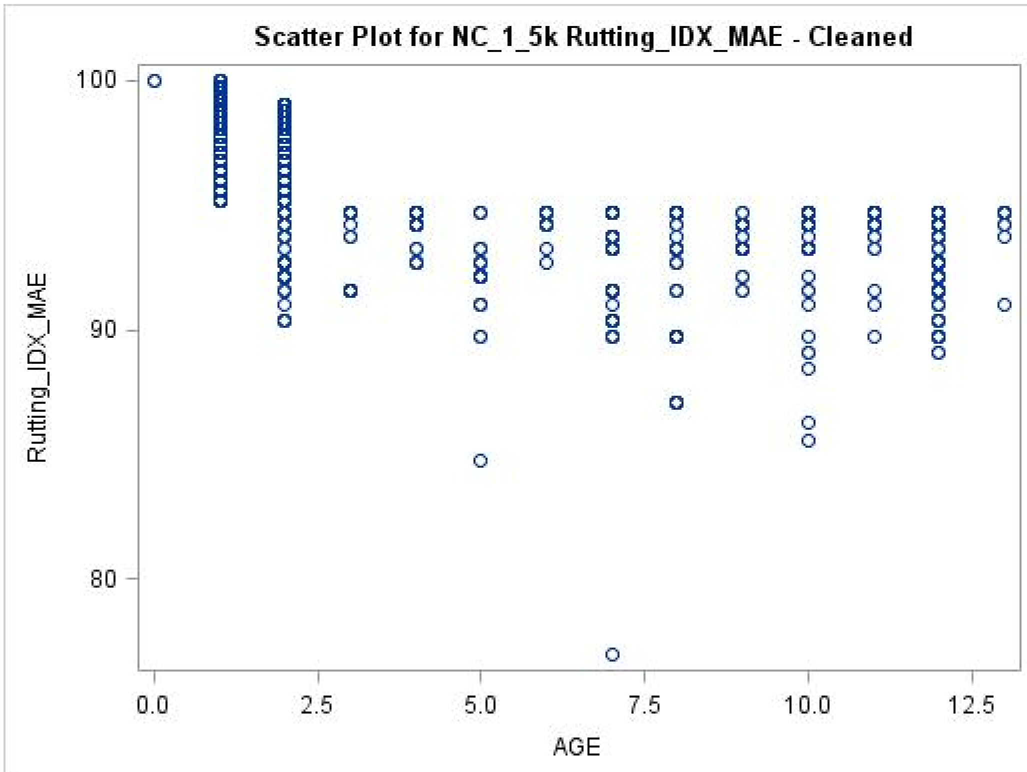

Figure 135: Schematic Scatter Plot for NC_1_5k Rutting_IDX_MAE - Cleaned

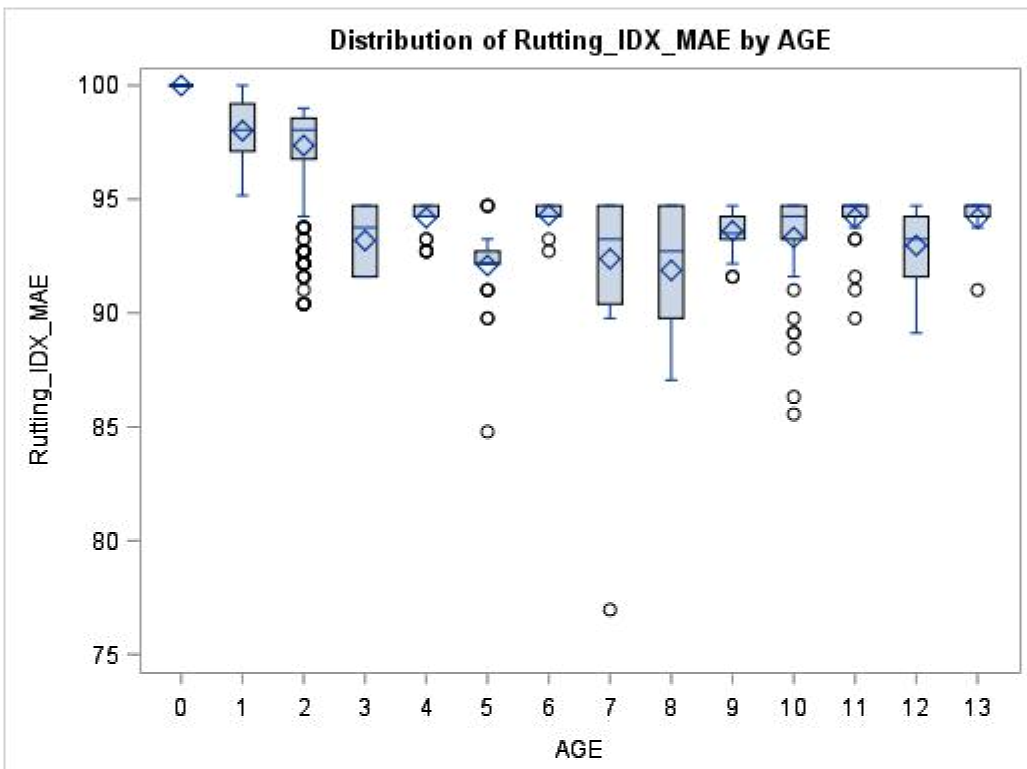

Figure 136: Schematic Box Plot for NC_1_5k Rutting_IDX_MAE - Cleaned

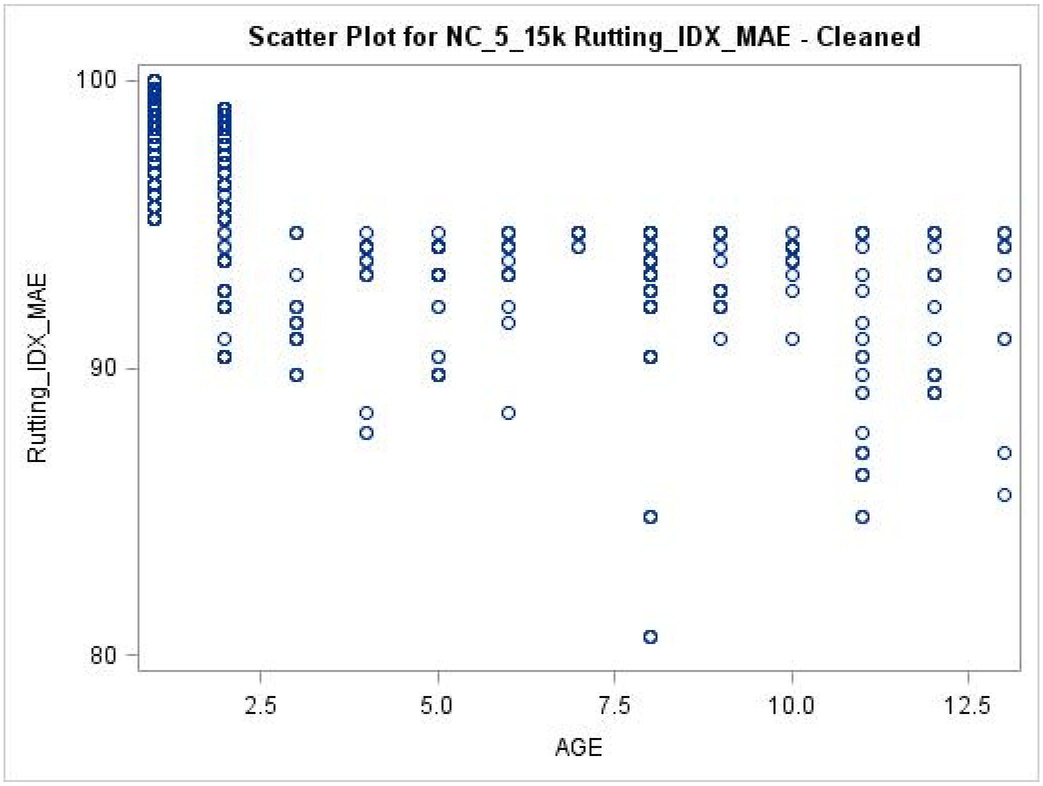

Figure 137: Schematic Scatter Plot for NC_5_15k Rutting_IDX_MAE - Cleaned

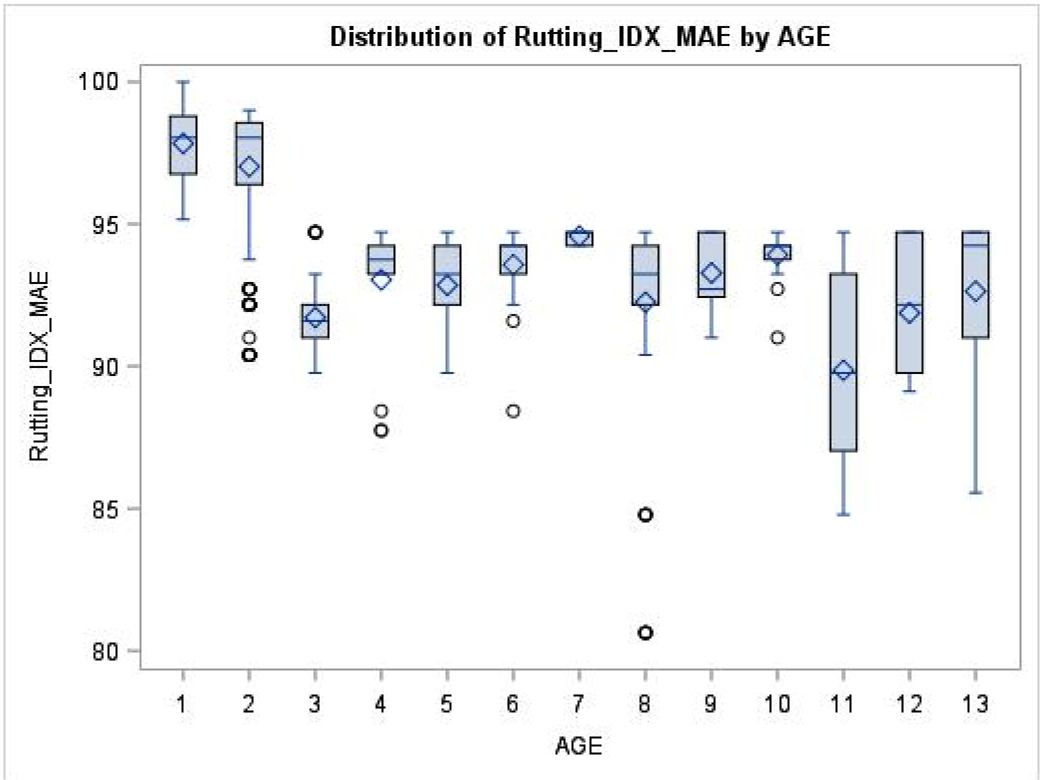

Figure 138: Schematic Box Plot for NC_5_15k Rutting_IDX_MAE - Cleaned

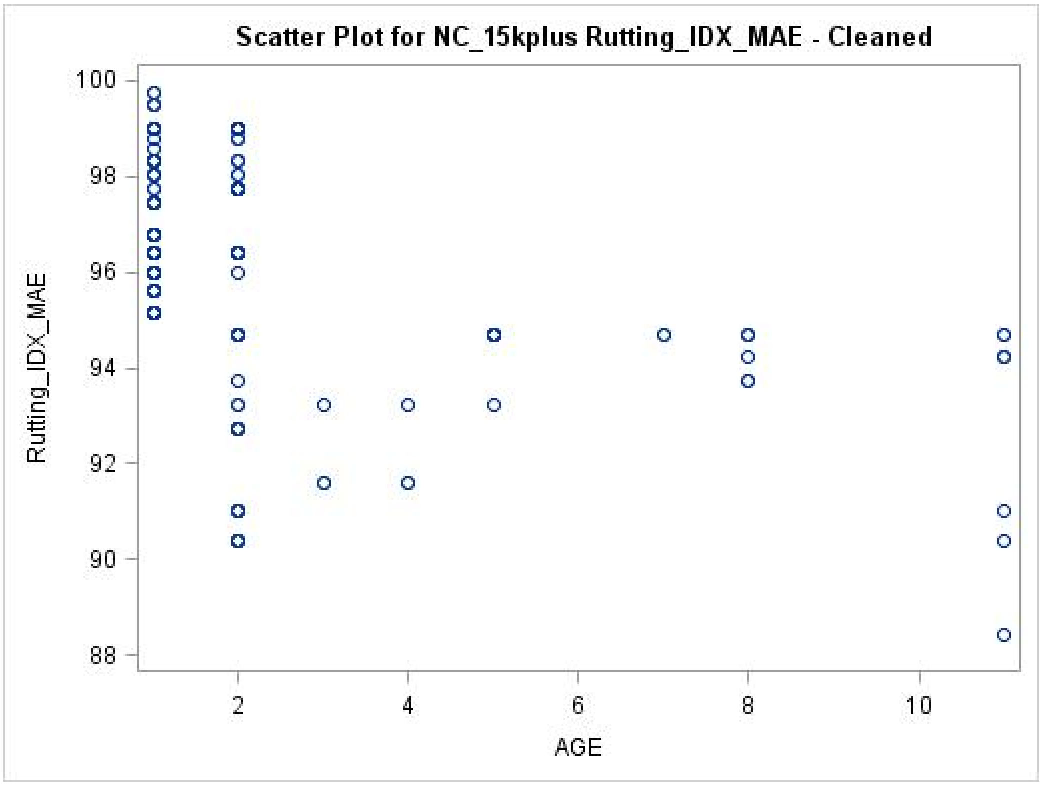

Figure 139: Schematic Scatter Plot for NC_15kplus Rutting_IDX_MAE - Cleaned

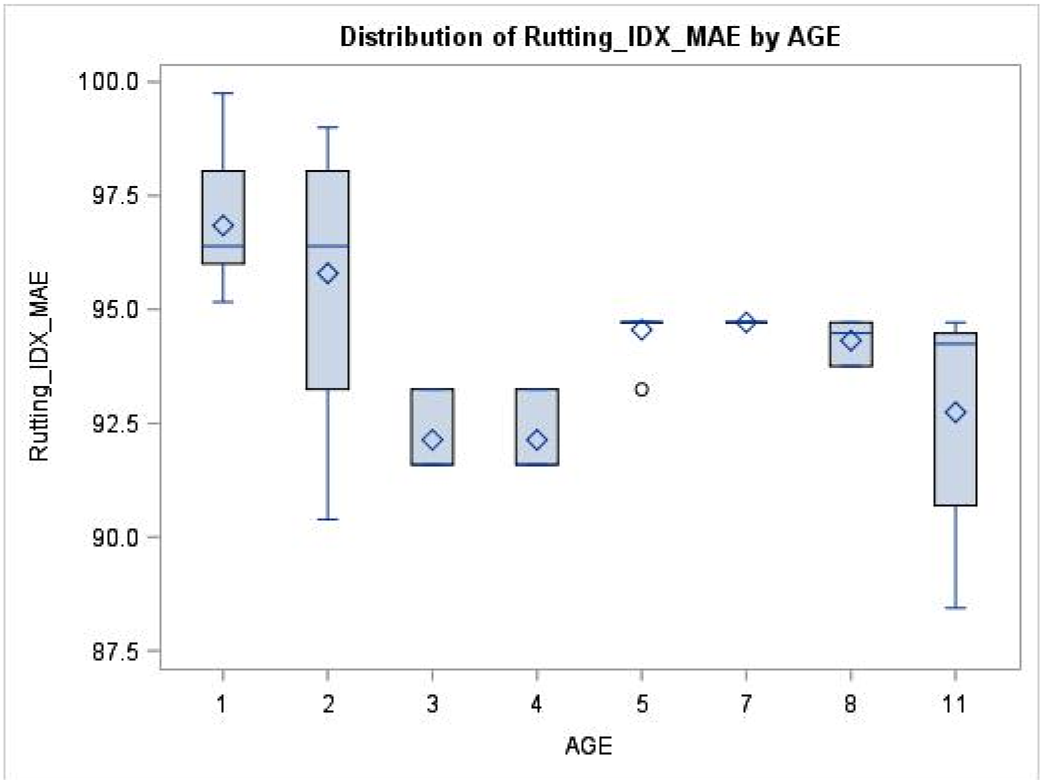

Figure 140: Schematic Box Plot for NC_15kplus Rutting_IDX_MAE - Cleaned

Appendix C – Distress Curves for ASP Pavements

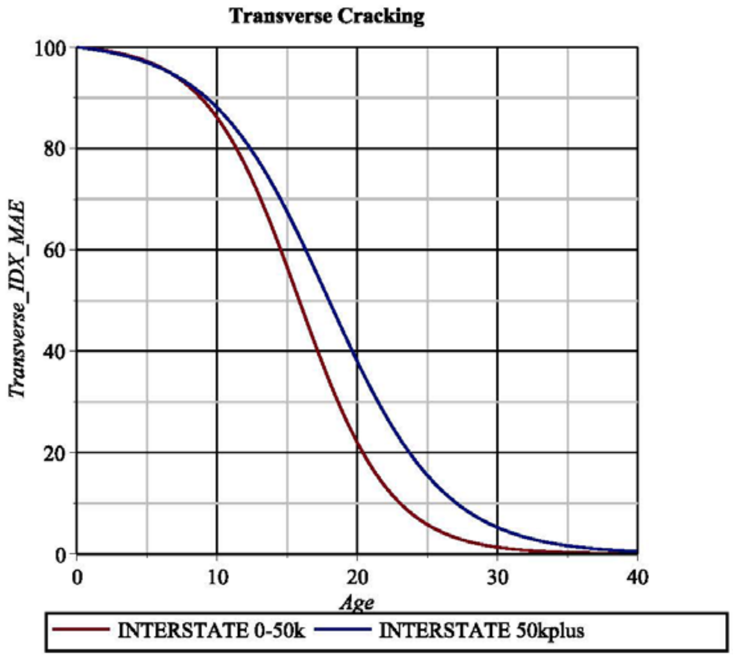

Figure 1: Transverse Cracking Curves (Interstate 0-50k, Interstate 50kplus)

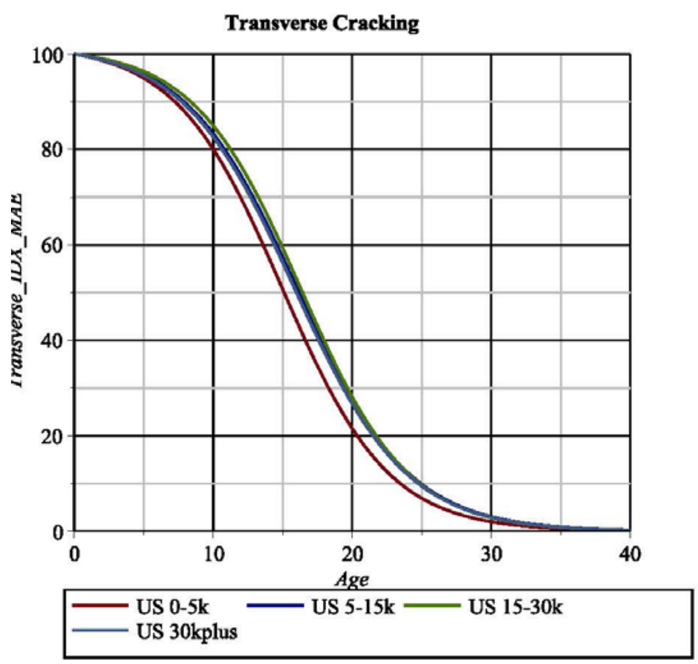

Figure 2: Transverse Cracking Curves (US 0-5k, US 5-15k, US 15-30k, US 30kplus)

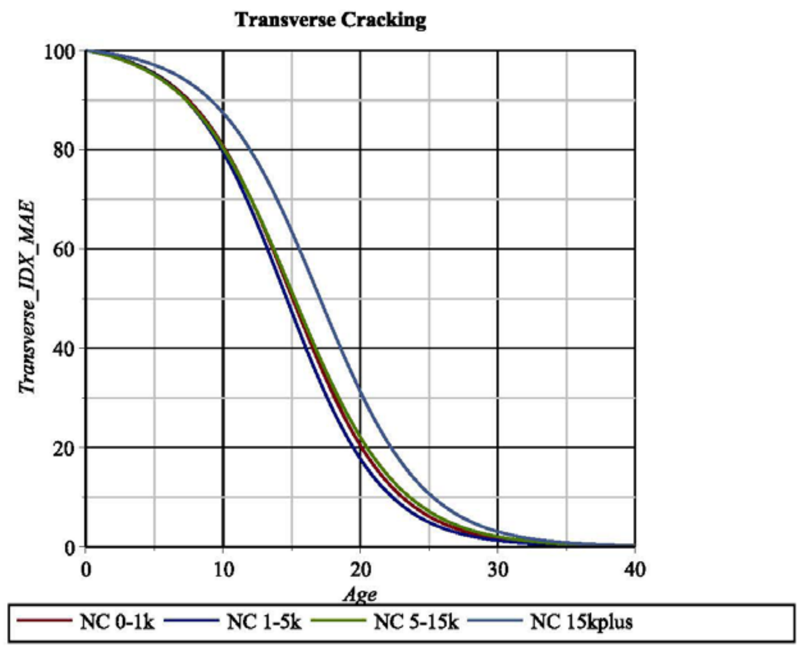

Figure 3: Transverse Cracking Curves (NC 0-1k, NC 1-5k, NC 5-15k, NC 15kplus)

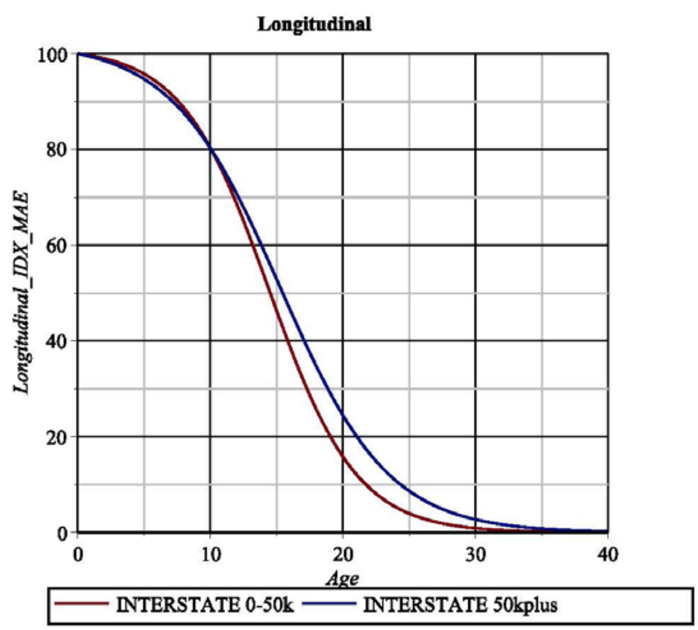

Figure 4: Longitudinal Cracking Curves (Interstate 0-50k, Interstate 50kplus)

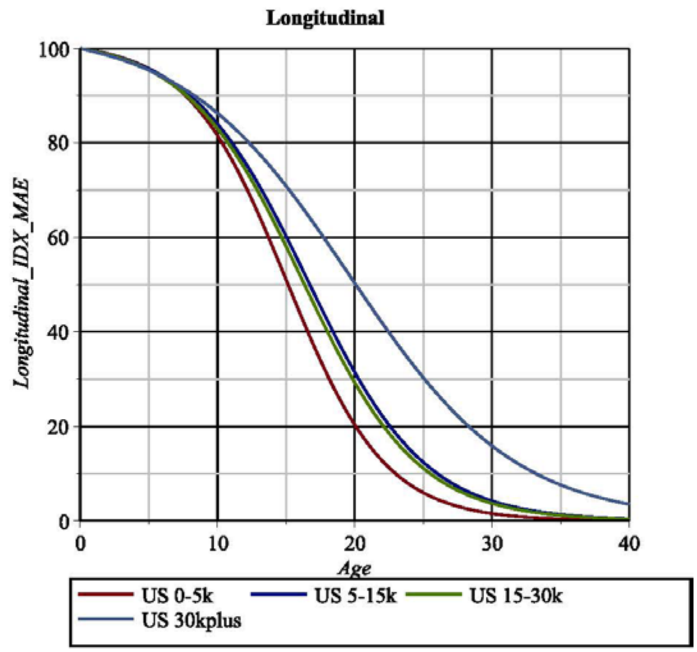

Figure 5: Longitudinal Cracking Curves (US 0-5k, US 5-15k, US 15-30k, US 30kplus)

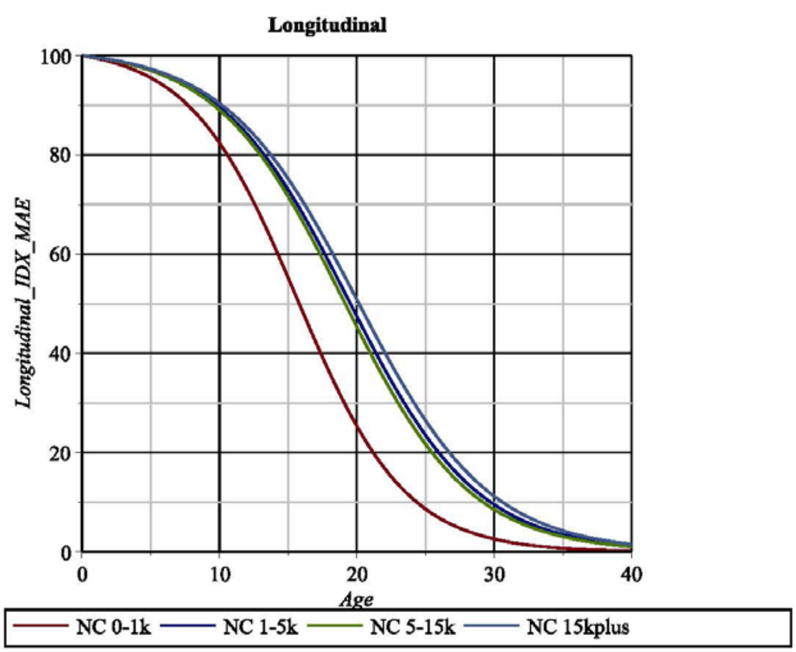

Figure 6: Longitudinal Cracking Curves (NC 0-1k, NC 1-5k, NC 5-15k, NC 15kplus)

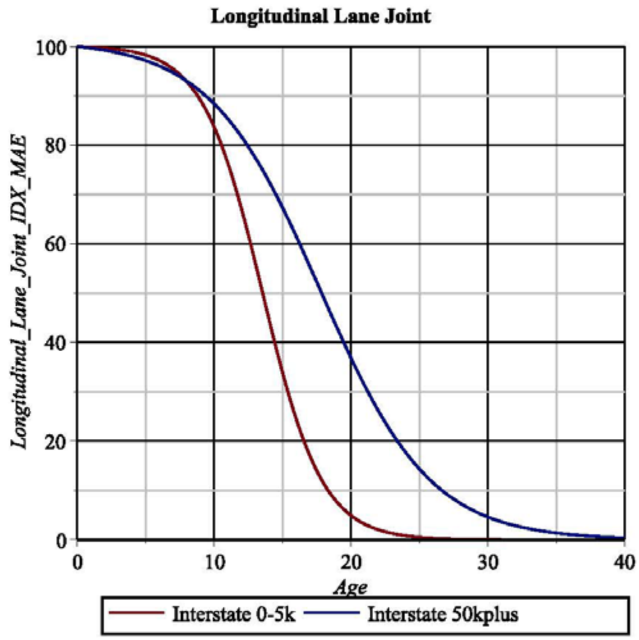

Figure 7: Longitudinal Lane Joint Curves (Interstate 0_50k, Interstate 50kplus)

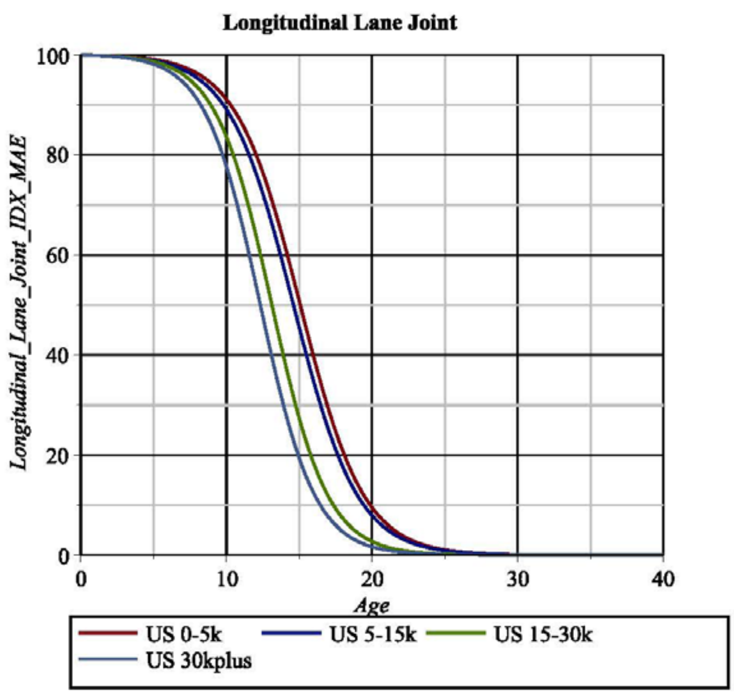

Figure 8: Longitudinal Lane Joint Curves (US 0_5k. US 5_15k, US 15_30k, US 30kplus)

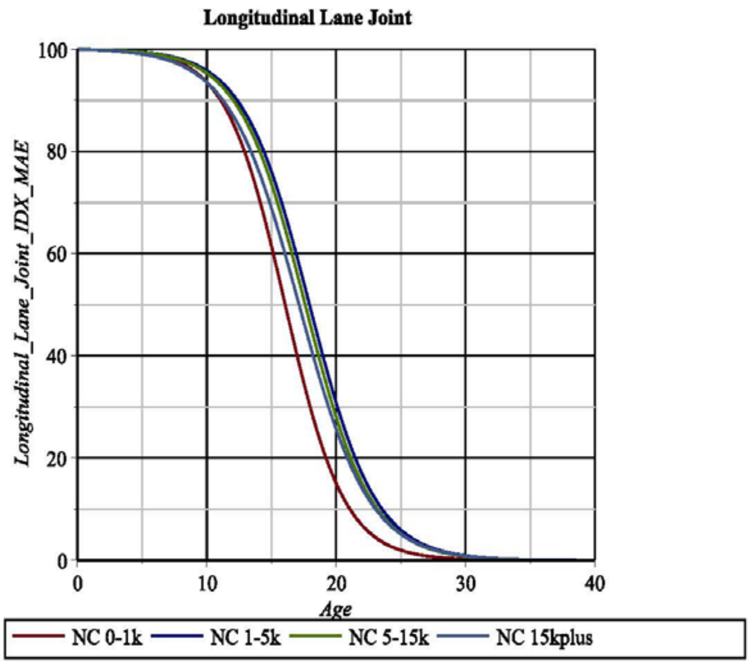

Figure 9: Longitudinal Lane Joint Curves (NC 0_1k, NC 1_5k, NC 5_15k, NC 15kplus)

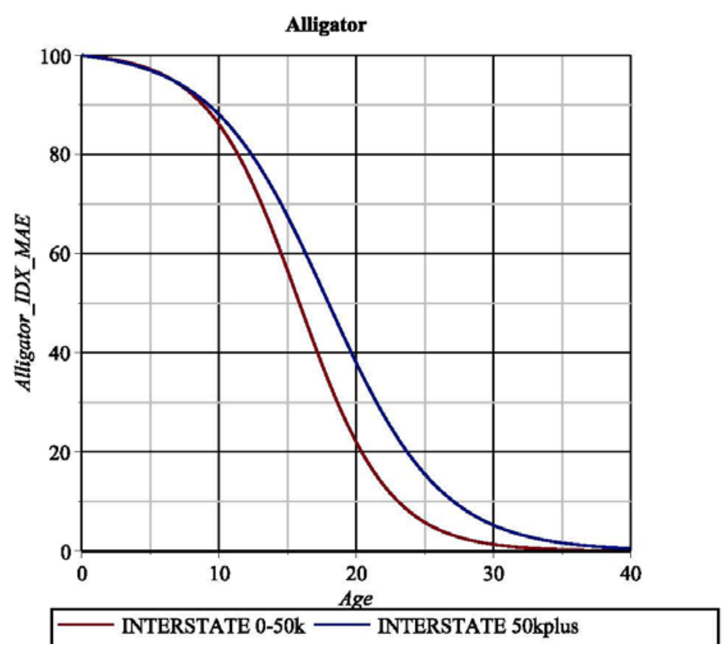

Figure 10: Alligator Cracking Curves (Interstate 0-50k, Interstate 50kplus)

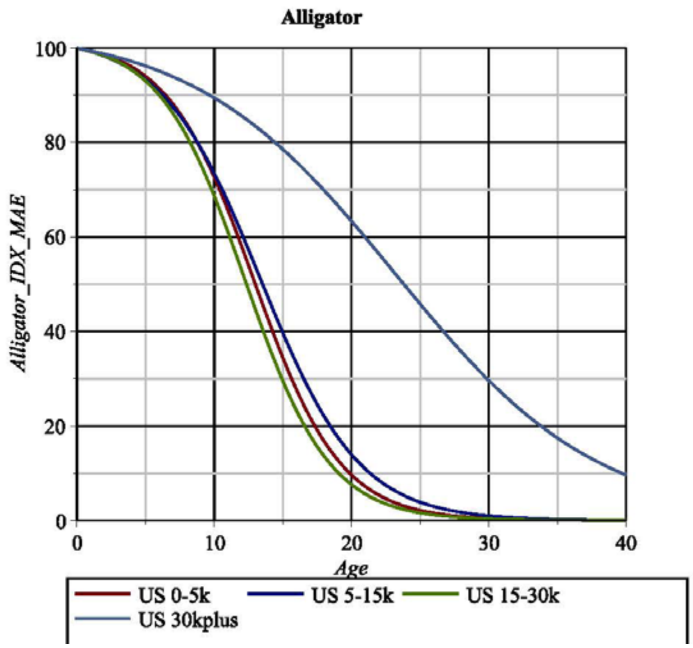

Figure 11: Alligator Cracking Curves (US 0-5k, US 5-15k, US 15-30k, US 30kplus)

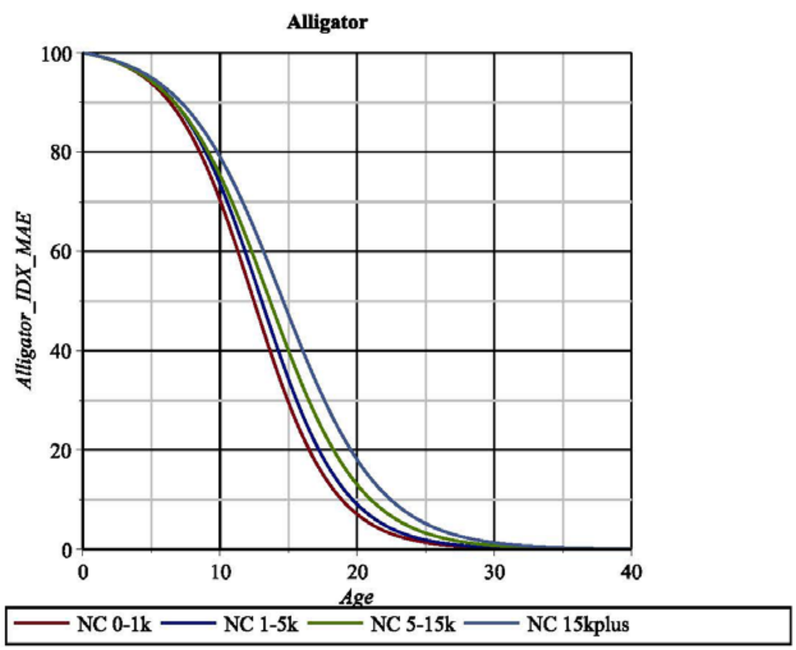

Figure 12: Alligator Cracking Curves (NC 0-1k, NC 1-5k, NC 5-15k, NC 15kplus)

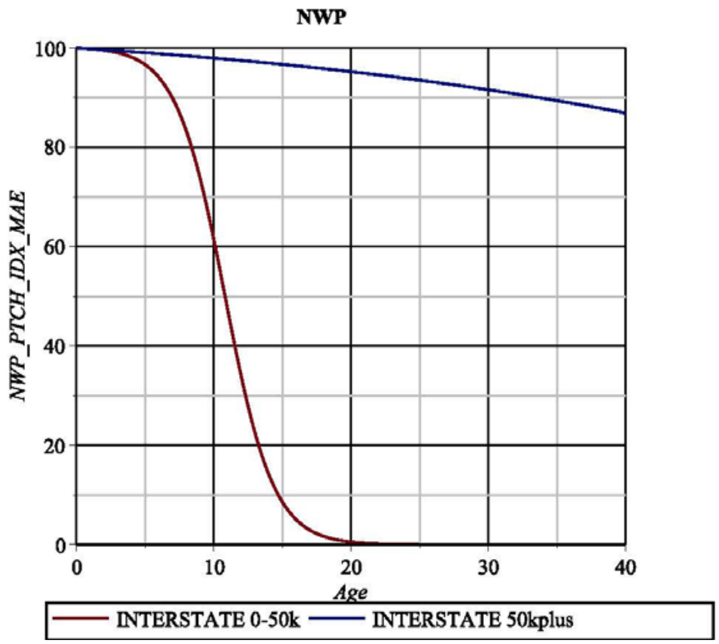

Figure 13: NWP Curves (Interstate 0-50k, Interstate 50kplus)

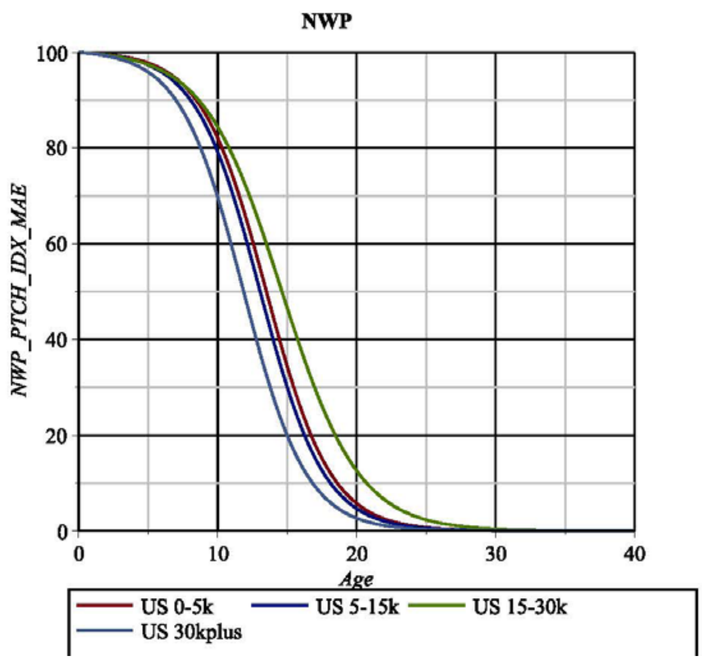

Figure 14: NWP Curves (US 0-5k, US 5-15k, US 15-30k, US 30kplus)

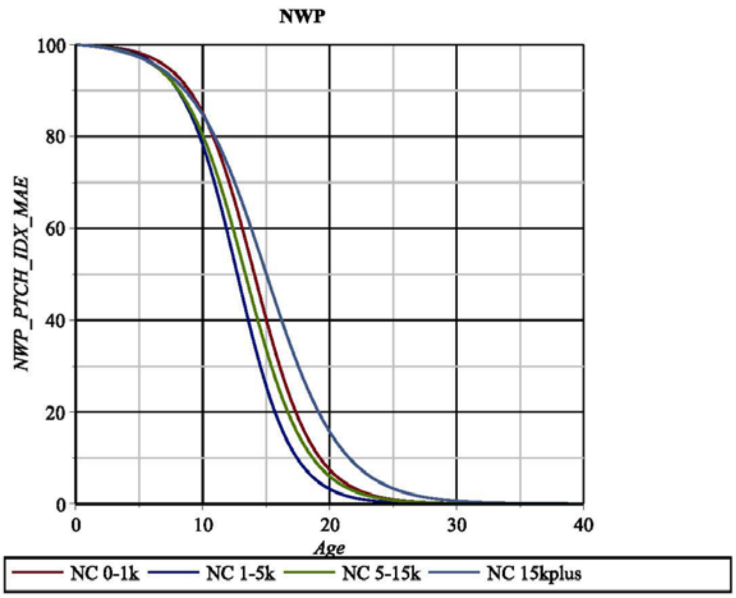

Figure 15: NWP Curves (NC 0-1k, NC 1-5k, NC 5-15k, NC 15kplus)

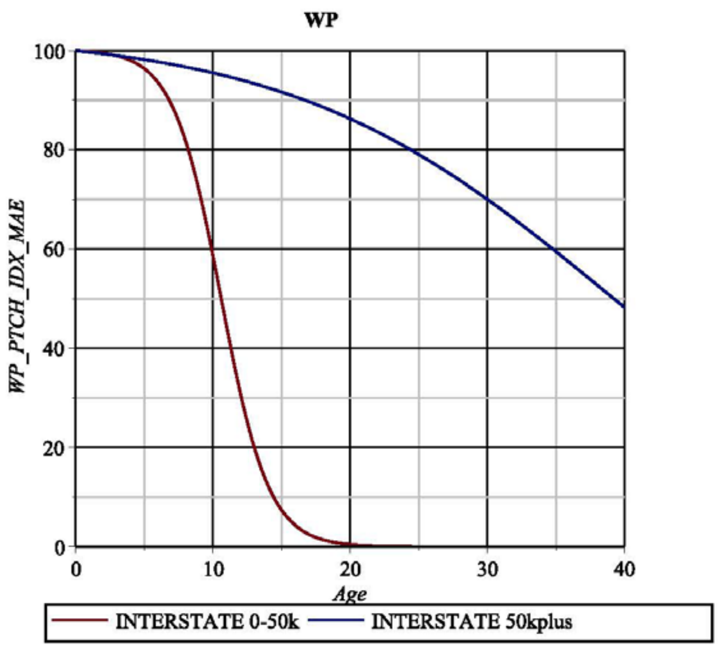

Figure 16: WP Curves (Interstate 0-50K, Interstate 50kplus)

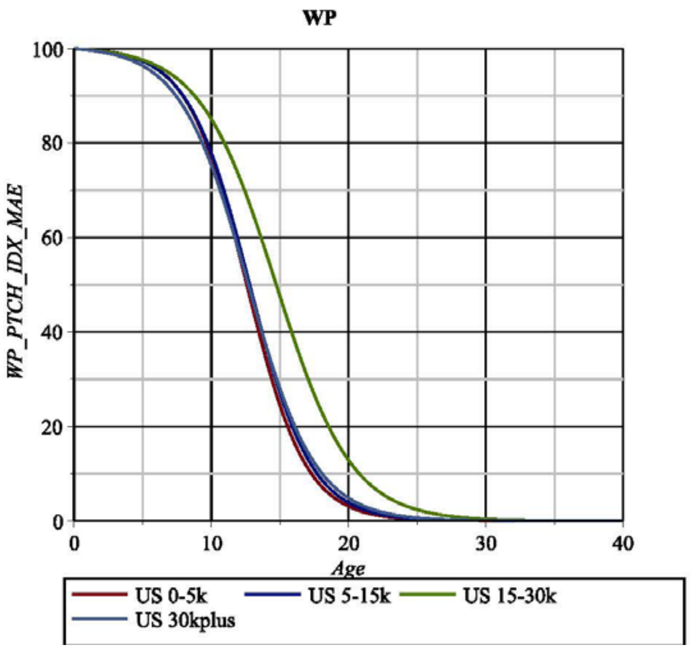

Figure 17: WP Curves (US 0-5K, US 5-15k, US 15-30k, US 30kplus)

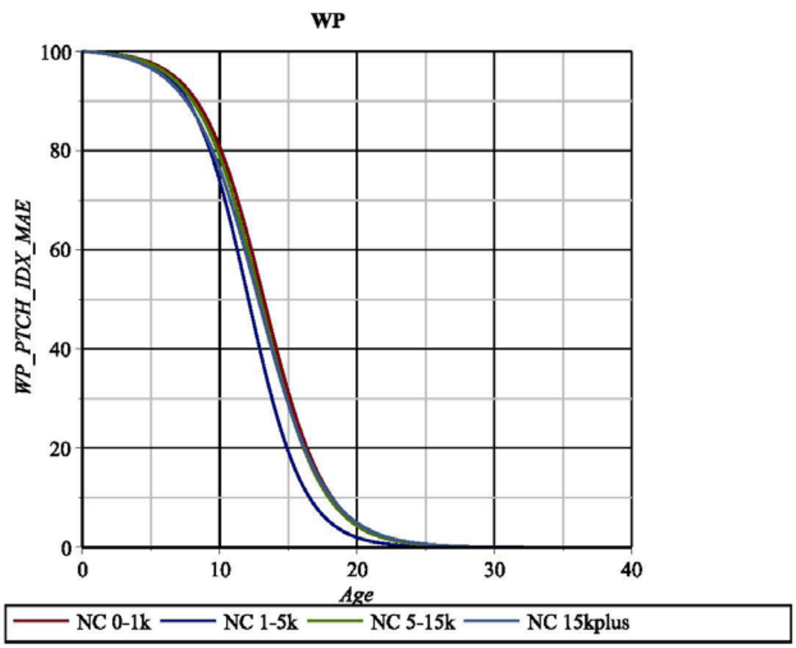

Figure 18: WP Curves (NC 0-1k, NC 1-5k, NC 5-15k, NC 15kplus)

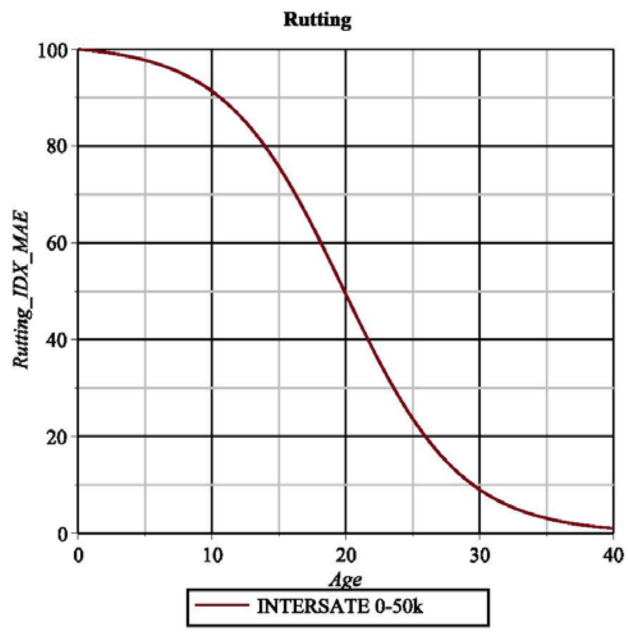

Figure 19: Rutting Curves (Interstate 0-50k)

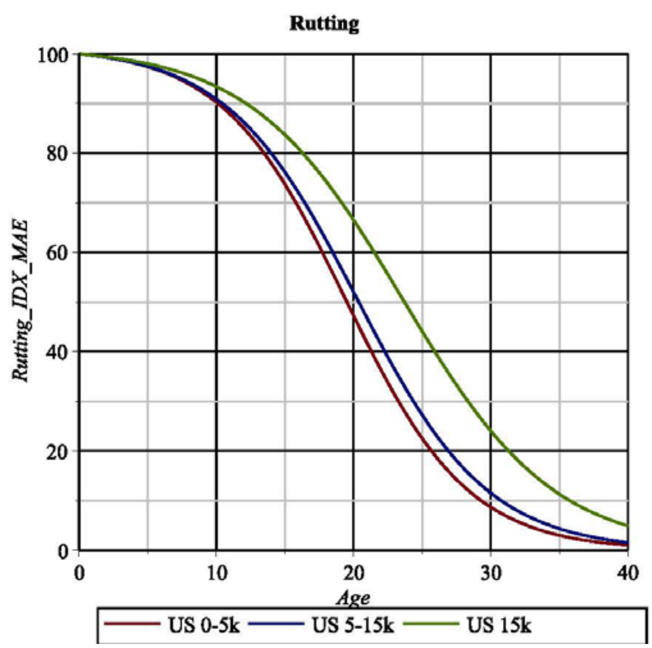

Figure 20: Rutting Curves (US 0-5k, US 5-15k, US 15k)

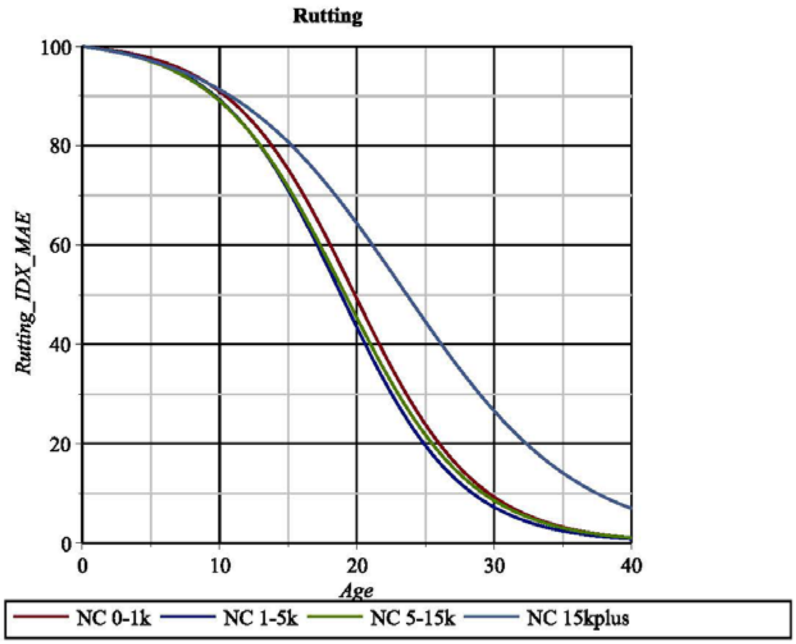

Figure 21: Rutting Curves (NC 0-1k, NC 1-5k, NC 5-15k, NC 15kplus)

Appendix D – Distress Comparison Curves for ASP Pavements

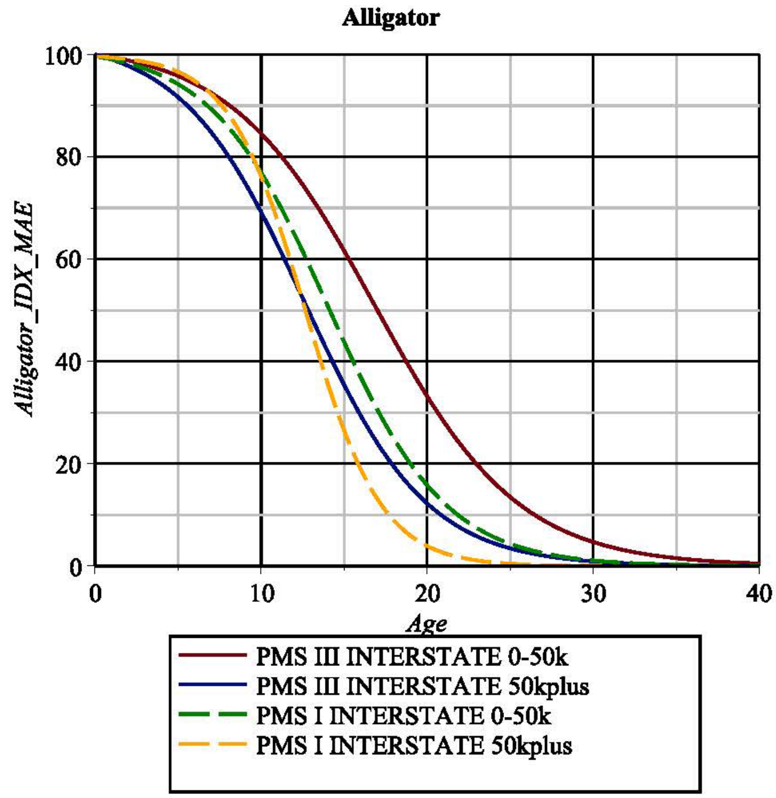

Figure 1: Alligator Cracking Comparison Curves (PMS I Interstate 0-50, PMS 1 Interstate 50kplus, PMS III Interstate 0-50k, PMS III Interstate 50kplus)

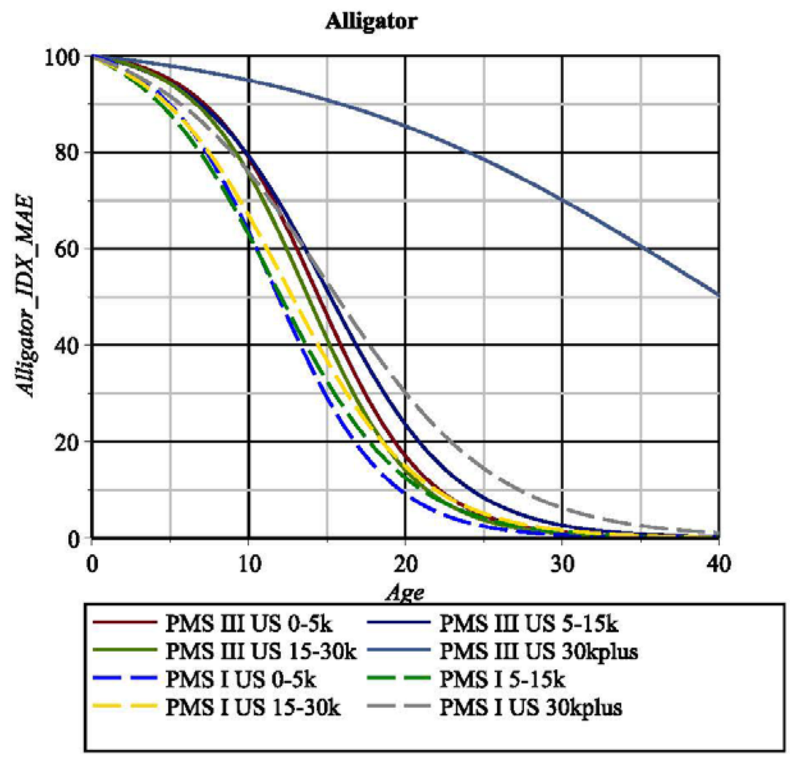

Figure 2: Alligator Cracking Comparison Curves (PMS I US 0-5k, PMS I US 5-15k, PMS I US 15-30k, PMS 1 US 30kplus, PMS III US 0-5k, PMS III US 5-15k, PMS III US 15-30k, PMS III US 50kplus)

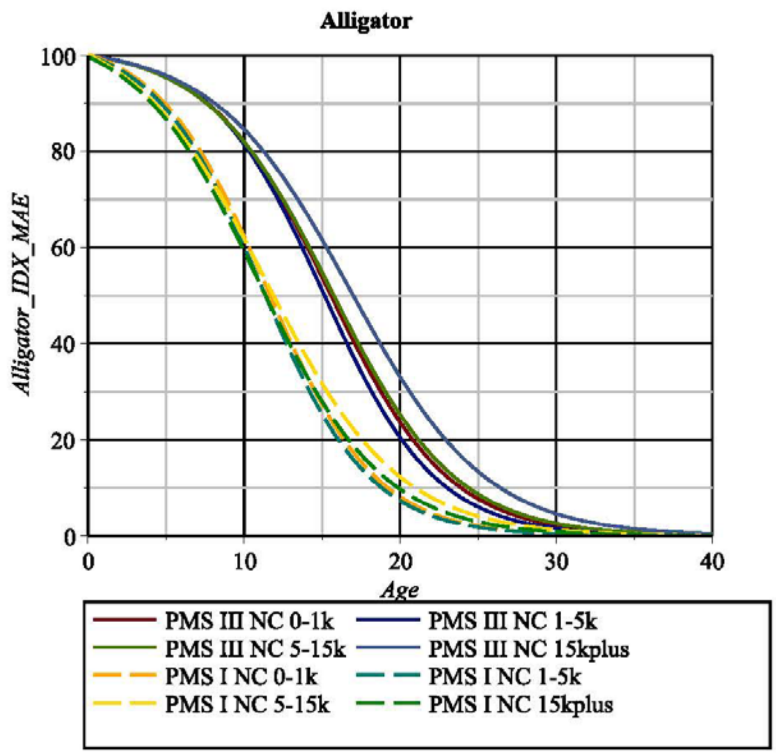

Figure 3: Alligator Cracking Comparison Curves (PMS I NC 0-1k, PMS I NC 1-5k, PMS I NC 5-15k, PMS I NC 15kplus, PMS III NC 0-1k, PMS III NC 1-5k, PMS NC 5-15k, PMS III NC 15kplus)

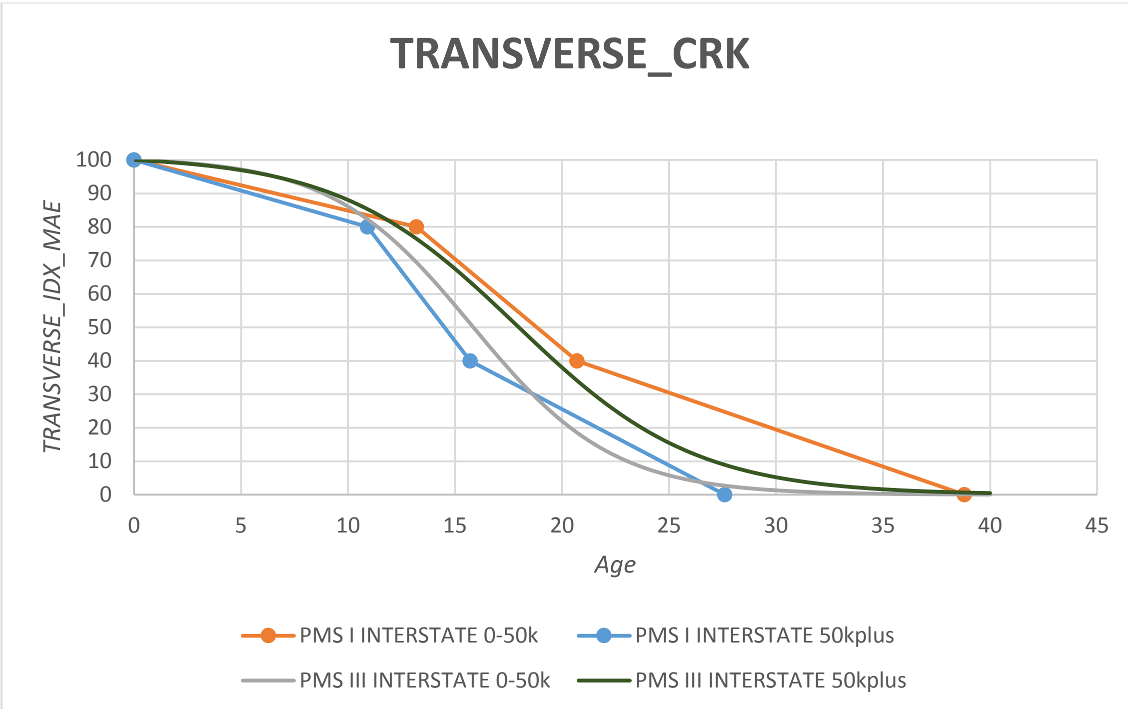

Figure 4: Transverse Cracking Comparison Curves (PMS I Interstate 0-50, PMS 1 Interstate 50kplus, PMS III Interstate 0-50k, PMS III Interstate 50kplus)

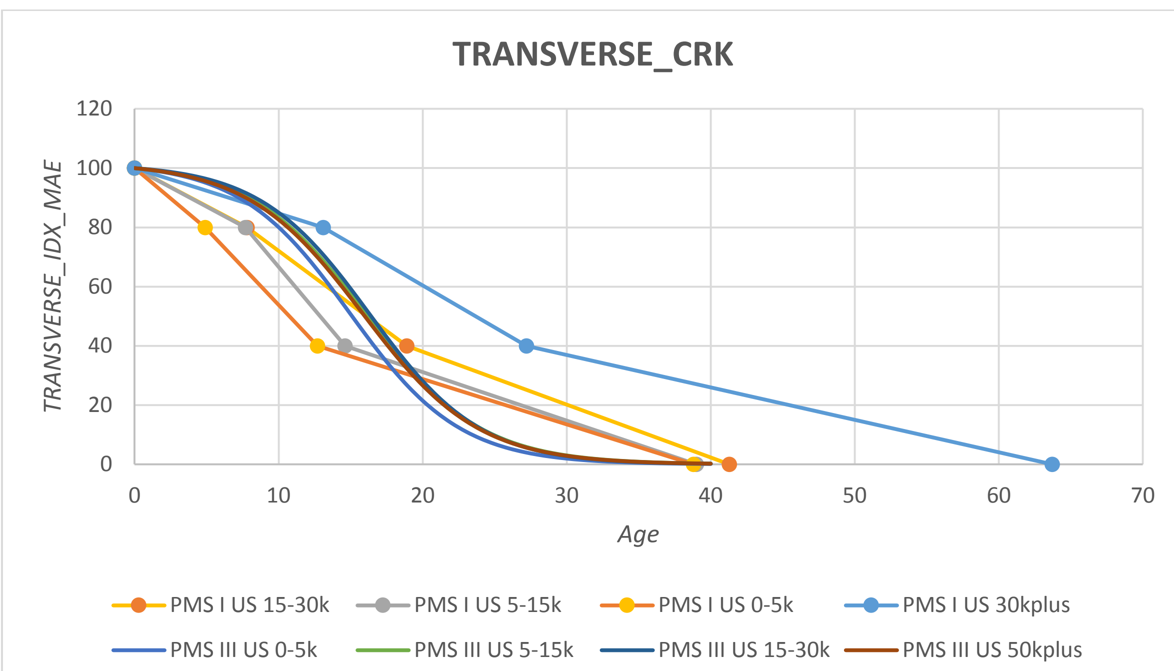

Figure 5: Transverse Cracking Comparison Curves (PMS I US 0-5k, PMS I US 5-15k, PMS I US 15-30k, PMS 1 US 30kplus, PMS III US 0-5k, PMS III US 5-15k, PMS III US 15-30k, PMS III US 50kplus)

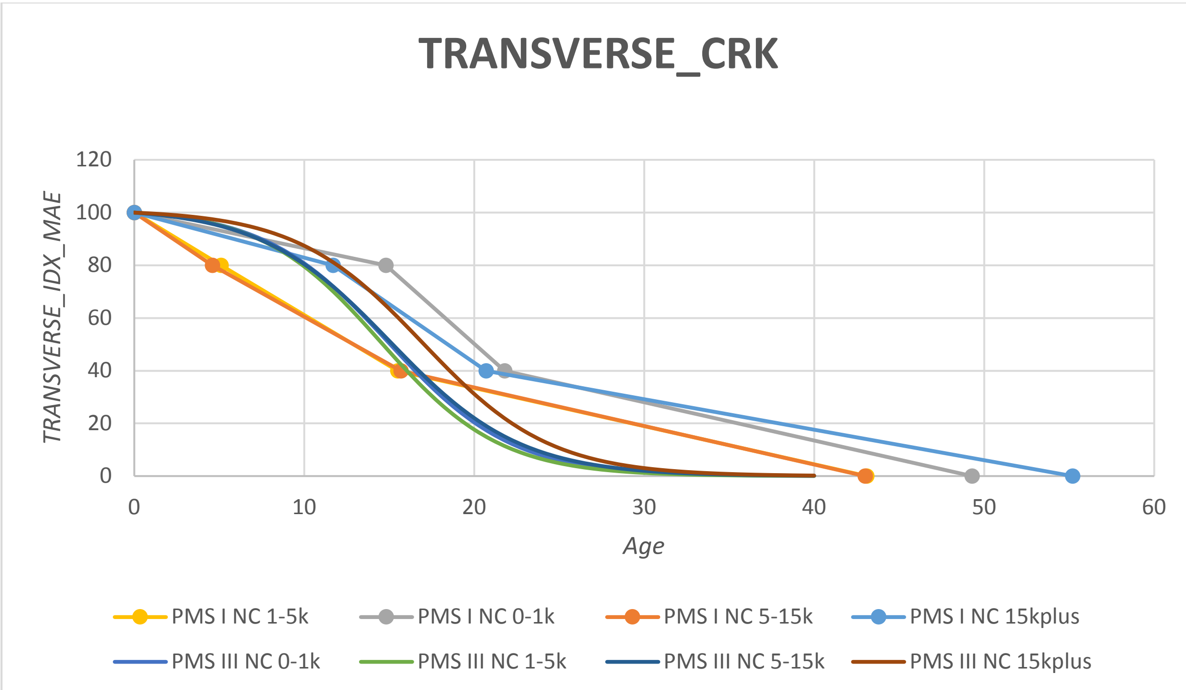

Figure 6: Transverse Cracking Comparison Curves (PMS I NC 0-1k, PMS I NC 1-5k, PMS I NC 5-15k, PMS I NC 15kplus, PMS III NC 0-1k, PMS III NC 1-5k, PMS NC 5-15k, PMS III NC 15kplus)

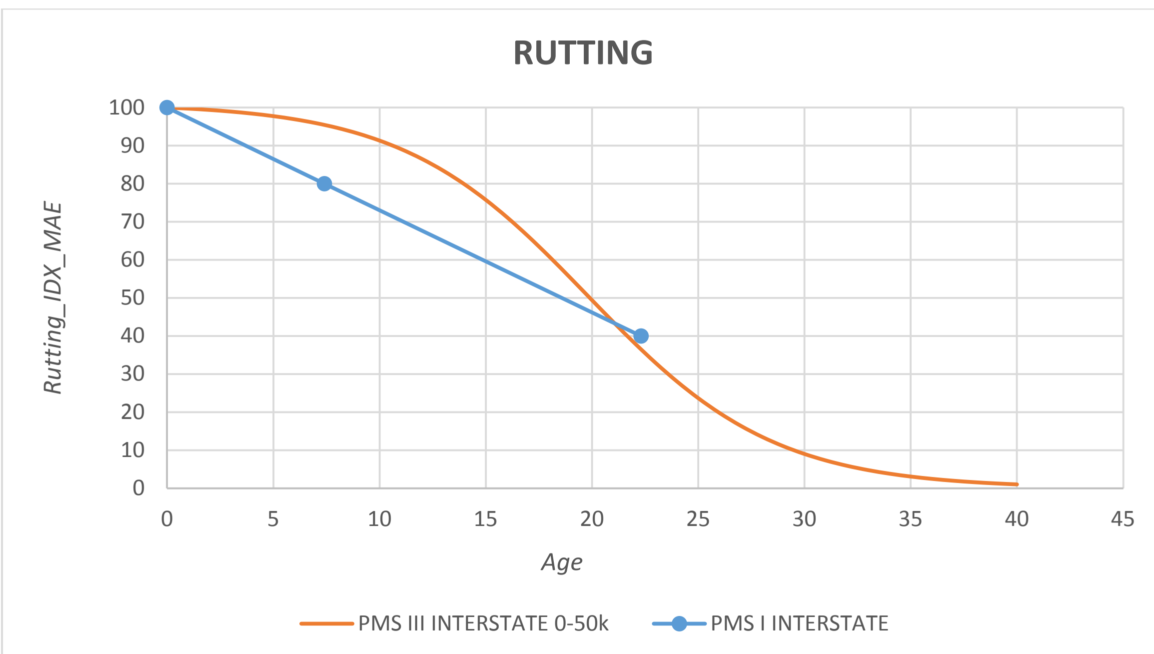

Figure 7: Rutting Comparison Curves (PMS I Interstate, PMS III Interstate 0-50k)

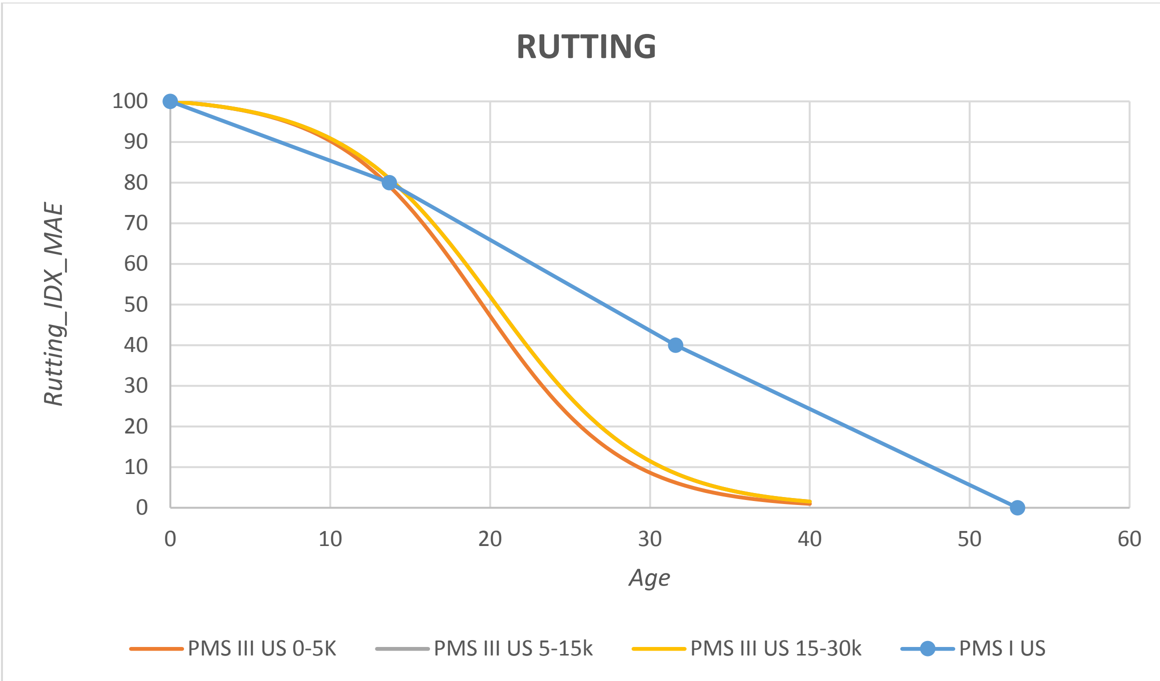

Figure 8: Rutting Comparison Curves (PMS I US, PMS III US 0-5k, PMS III US 5-15k, PMS III US 15-30k)

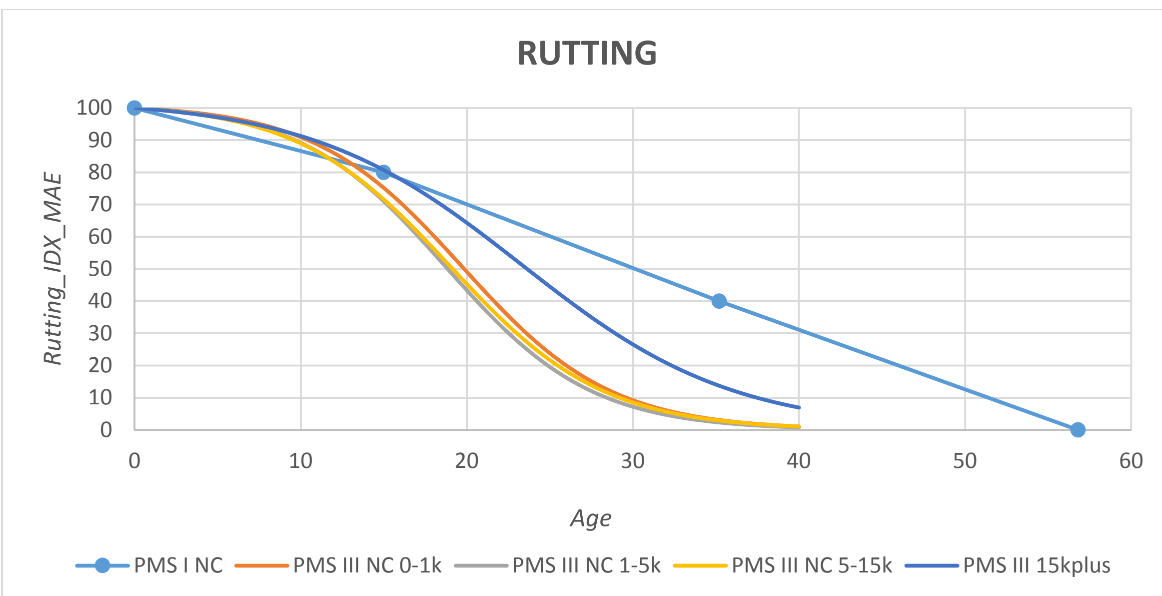

Figure 9: Rutting Comparison Curves (PMS I NC, PMS III NC 0-1k, PMS III NC 1-5k, PMS III NC 5-15k, PMS III NC 15kplus)

Appendix E – PCR Curves for ASP Pavements

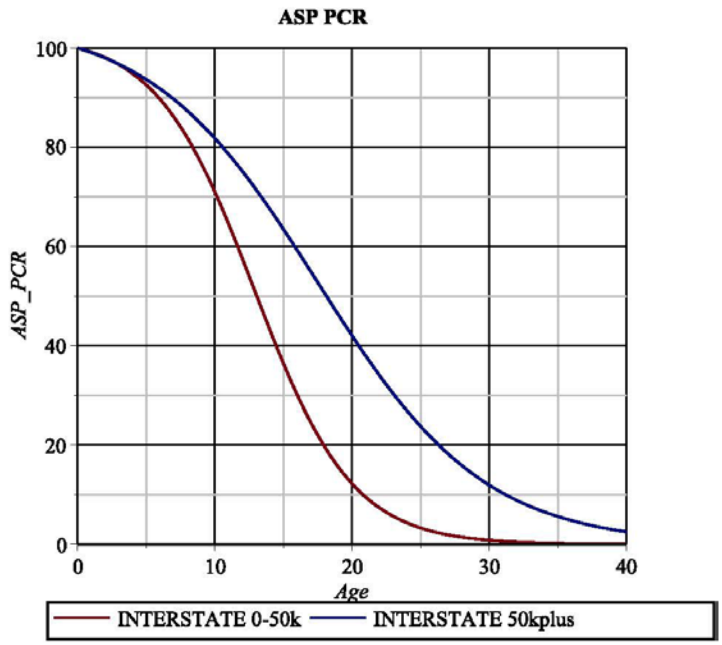

Figure 1: ASP PCR Curves (Interstate 0-50k, Interstate 50kplus)

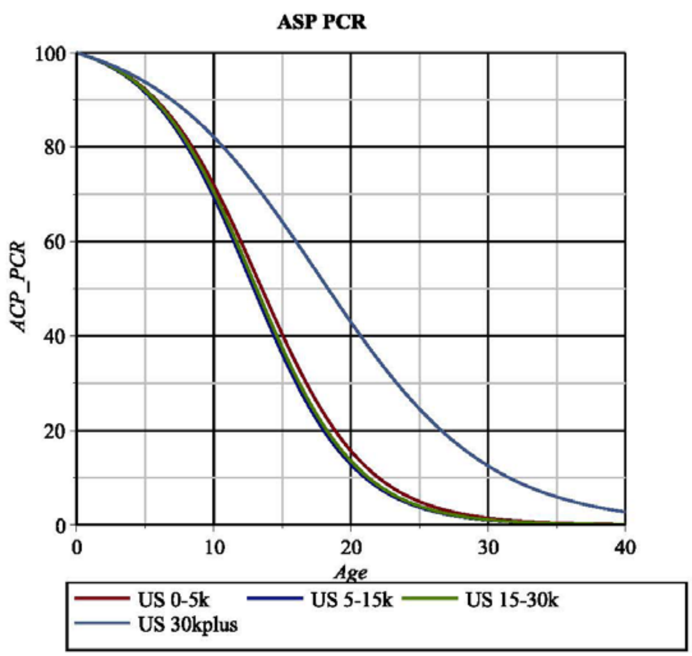

Figure 2: ASP PCR Curves (US 0-5k, US 5-15k, US 15-30k, US 30kplus)

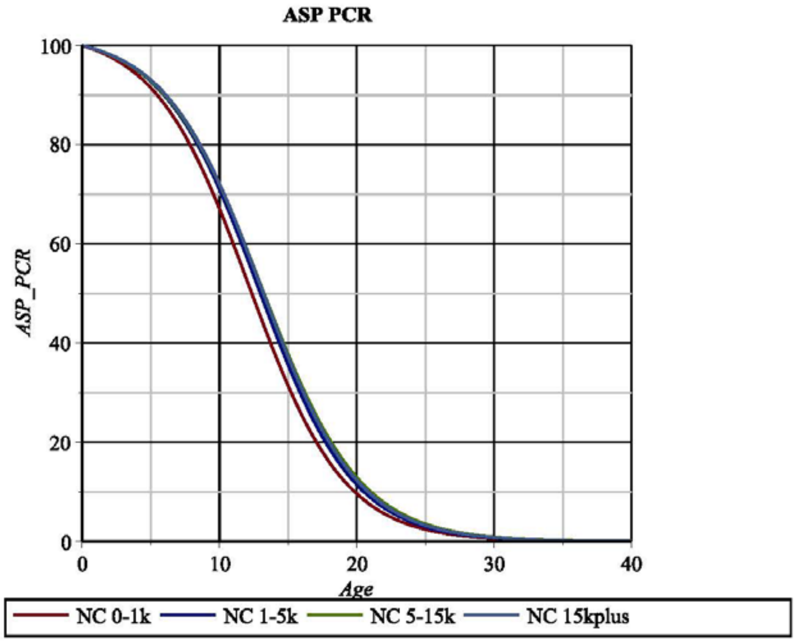

Figure 3: ASP PCR Curves (NC 0-1k, NC 1-5k, NC 5-15k, NC 15kplus)

Appendix F – Distress Curves for JCP Pavements

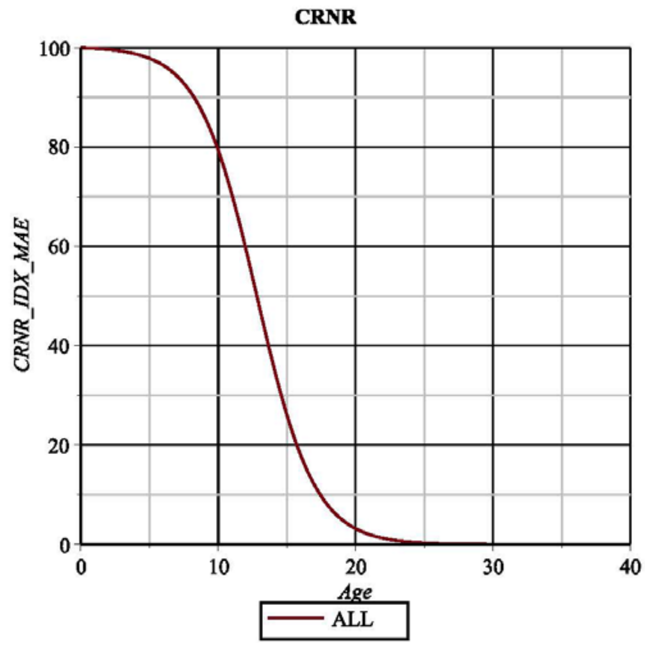

Figure 1: Corner Breaks Curve (ALL)

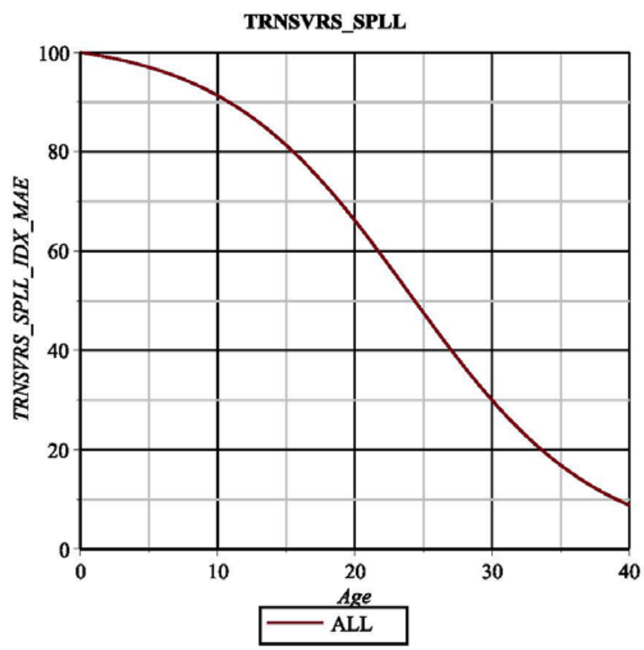

Figure 2: Transverse Joint Spalling Curve (ALL)

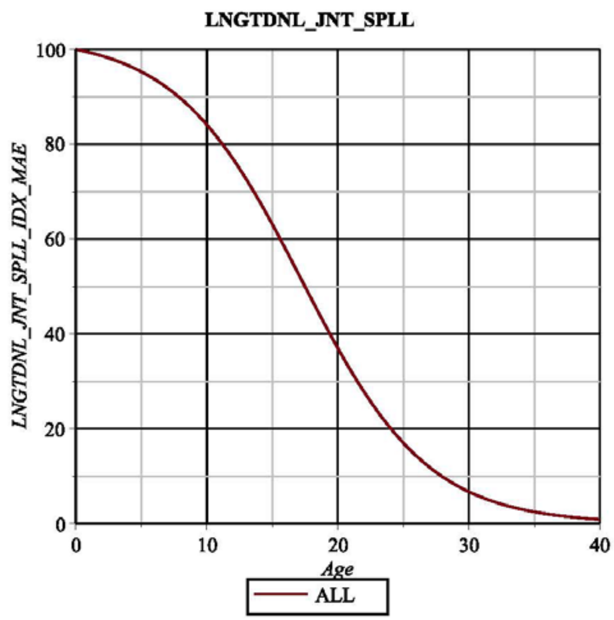

Figure 3: Longitudinal Joint Spalling Curve (ALL)

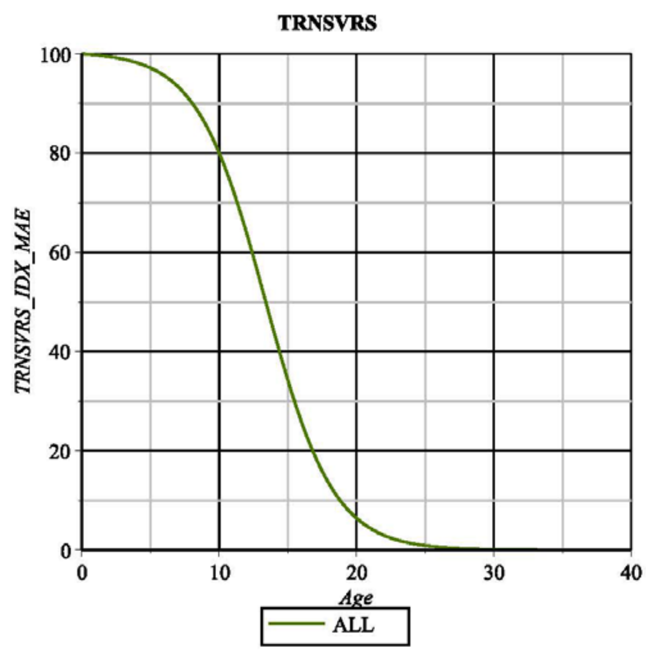

Figure 4: Transverse Cracking Curve (ALL)

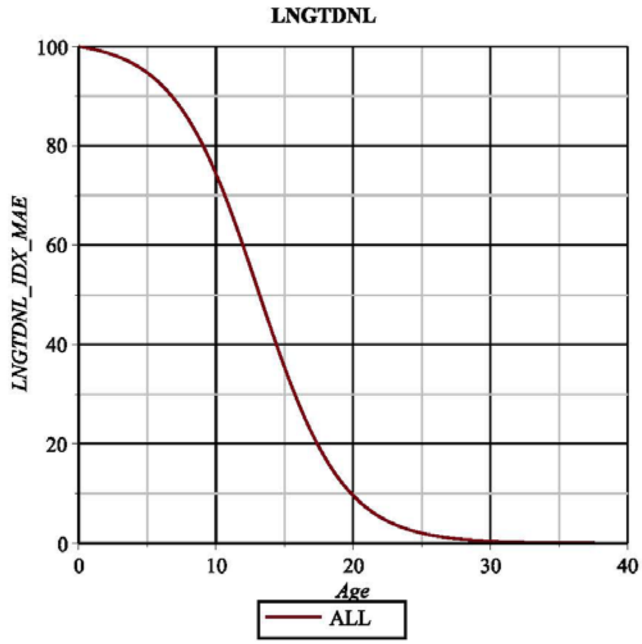

Figure 5: Longitudinal Cracking Curve (ALL)

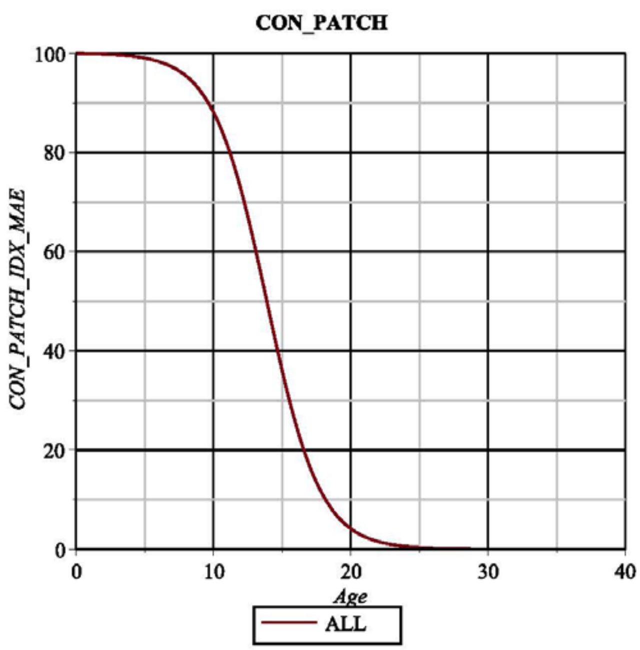

Figure 6: Concrete Patching Curve (ALL)

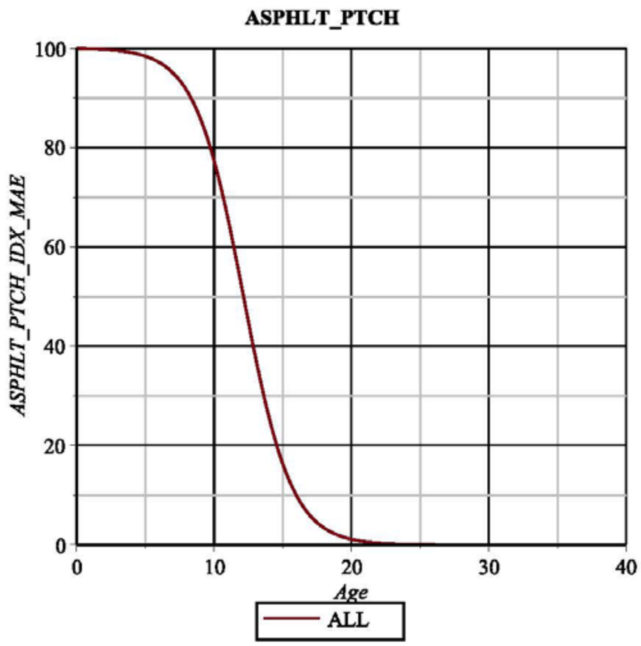

Figure 7: Asphalt Patching Curve (ALL)

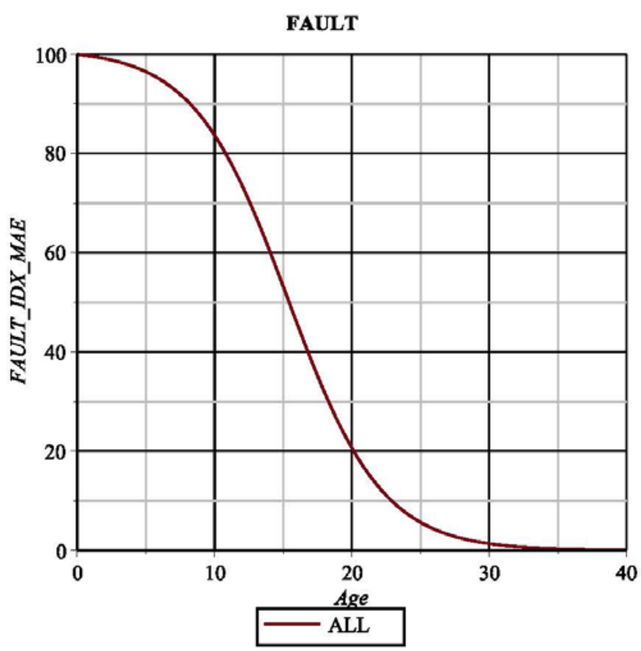

Figure 8: Joint Fault Curve (ALL)

Appendix G – PCR Curve for JCP Pavements

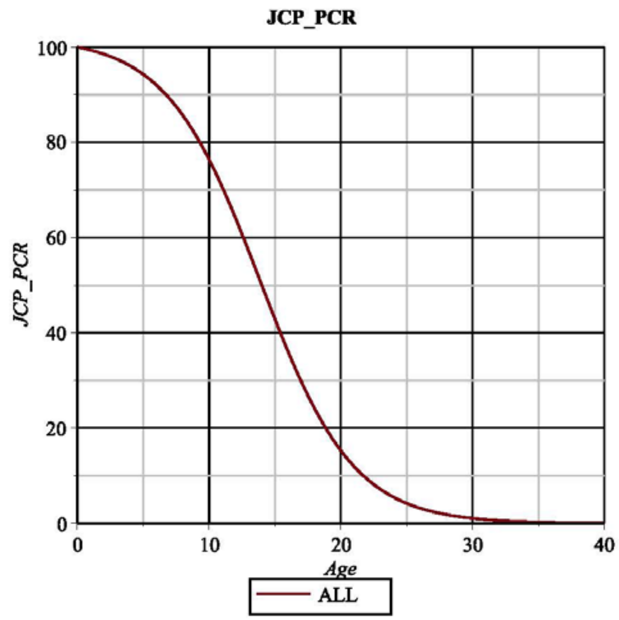

Figure 1: JCP_PCR Curve (ALL)

Appendix H – CBA Results Based on Thirty Three Sets of Weight Factors

Period	Benefit	NCDOT Rating Number	Interstate	US	NC	SR
Year 1	446.57	0.82	2.9	2.5	1.7	1.0
Year 2	416.05	0.78	2.9	2.5	1.7	1.0
Year 3	385.94	0.74	2.9	2.5	1.7	1.0
Year 4	357.12	0.70	2.9	2.5	1.7	1.0
Year 5	330.04	0.67	2.9	2.5	1.7	1.0
Year 1	453.96	0.81	1.9	1.4	1.3	1.0
Year 2	424.81	0.78	1.9	1.4	1.3	1.0
Year 3	395.80	0.74	1.9	1.4	1.3	1.0
Year 4	367.81	0.70	1.9	1.4	1.3	1.0
Year 5	341.44	0.68	1.9	1.4	1.3	1.0
Year 1	454.92	0.81	1.7	1.4	1.3	1.0
Year 2	426.1	0.77	1.7	1.4	1.3	1.0
Year 3	397.36	0.74	1.7	1.4	1.3	1.0
Year 4	369.59	0.70	1.7	1.4	1.3	1.0
Year 5	343.41	0.68	1.7	1.4	1.3	1.0
Year 1	445.53	0.82	2.2	1.8	1.2	1.0
Year 2	414.72	0.78	2.2	1.8	1.2	1.0
Year 3	384.38	0.74	2.2	1.8	1.2	1.0
Year 4	355.36	0.70	2.2	1.8	1.2	1.0
Year 5	328.11	0.67	2.2	1.8	1.2	1.0
Year 1	447.12	0.82	2.4	1.8	1.3	1.0
Year 2	416.53	0.78	2.4	1.8	1.3	1.0
Year 3	386.38	0.74	2.4	1.8	1.3	1.0
Year 4	357.48	0.70	2.4	1.8	1.3	1.0
Year 5	330.34	0.68	2.4	1.8	1.3	1.0
Year 1	451.53	0.81	3.0	1.9	1.7	1.0
Year 2	421.67	0.78	3.0	1.9	1.7	1.0
Year 3	392.1	0.74	3.0	1.9	1.7	1.0
Year 4	363.64	0.70	3.0	1.9	1.7	1.0
Year 5	336.87	0.68	3.0	1.9	1.7	1.0
Year 1	434.7	0.82	3.0	2.6	1.2	1.0
Year 2	401.8	0.79	3.0	2.6	1.2	1.0
Year 3	369.78	0.75	3.0	2.6	1.2	1.0
Year 4	339.49	0.70	3.0	2.6	1.2	1.0
Year 5	311.22	0.67	3.0	2.6	1.2	1.0
Year 1	455.05	0.81	2.3	2.1	1.9	1.0
Year 2	426.38	0.77	2.3	2.1	1.9	1.0
Year 3	397.77	0.74	2.3	2.1	1.9	1.0

Year 4	370.11	0.70	2.3	2.1	1.9	1.0
Year 5	344.02	0.68	2.3	2.1	1.9	1.0
Year 1	444.93	0.82	2.4	2	1.3	1.0
Year 2	414.02	0.78	2.4	2	1.3	1.0
Year 3	383.61	0.74	2.4	2	1.3	1.0
Year 4	354.53	0.70	2.4	2	1.3	1.0
Year 5	327.26	0.67	2.4	2	1.3	1.0
Year 1	446.73	0.82	2.8	1.7	1.3	1.0
Year 2	415.77	0.78	2.8	1.7	1.3	1.0
Year 3	385.31	0.75	2.8	1.7	1.3	1.0
Year 4	356.11	0.70	2.8	1.7	1.3	1.0
Year 5	328.73	0.68	2.8	1.7	1.3	1.0
Year 1	444.59	0.82	2.2	2.1	1.3	1.0
Year 2	413.8	0.78	2.2	2.1	1.3	1.0
Year 3	383.46	0.74	2.2	2.1	1.3	1.0
Year 4	354.49	0.70	2.2	2.1	1.3	1.0
Year 5	327.31	0.67	2.2	2.1	1.3	1.0
Year 1	442.52	0.82	2.5	2.2	1.3	1.0
Year 2	411.19	0.78	2.5	2.2	1.3	1.0
Year 3	380.44	0.74	2.5	2.2	1.3	1.0
Year 4	351.07	0.70	2.5	2.2	1.3	1.0
Year 5	323.63	0.67	2.5	2.2	1.3	1.0
Year 1	444.14	0.82	1.9	1.8	1.1	1.0
Year 2	413.25	0.78	1.9	1.8	1.1	1.0
Year 3	382.83	0.74	1.9	1.8	1.1	1.0
Year 4	353.79	0.70	1.9	1.8	1.1	1.0
Year 5	326.57	0.67	1.9	1.8	1.1	1.0
Year 1	441.92	0.82	2.8	2.4	1.4	1.0
Year 2	410.41	0.78	2.8	2.4	1.4	1.0
Year 3	379.53	0.74	2.8	2.4	1.4	1.0
Year 4	350.06	0.70	2.8	2.4	1.4	1.0
Year 5	322.52	0.67	2.8	2.4	1.4	1.0
Year 1	443.63	0.82	3.0	2.6	1.6	1.0
Year 2	412.49	0.78	3.0	2.6	1.6	1.0
Year 3	381.91	0.74	3.0	2.6	1.6	1.0
Year 4	352.69	0.70	3.0	2.6	1.6	1.0
Year 5	325.34	0.67	3.0	2.6	1.6	1.0
Year 1	438.69	0.82	2.8	2.5	1.3	1.0
Year 2	406.59	0.78	2.8	2.5	1.3	1.0
Year 3	375.24	0.74	2.8	2.5	1.3	1.0
Year 4	345.44	0.70	2.8	2.5	1.3	1.0

Year 5	317.6	0.67	2.8	2.5	1.3	1.0
Year 1	449.72	0.82	2.6	1.5	1.3	1.0
Year 2	419.33	0.78	2.6	1.5	1.3	1.0
Year 3	389.35	0.74	2.6	1.5	1.3	1.0
Year 4	360.53	0.71	2.6	1.5	1.3	1.0
Year 5	333.46	0.68	2.6	1.5	1.3	1.0
Year 1	451.82	0.81	2.9	2.6	2.1	1.0
Year 2	422.45	0.78	2.9	2.6	2.1	1.0
Year 3	393.26	0.74	2.9	2.6	2.1	1.0
Year 4	365.17	0.70	2.9	2.6	2.1	1.0
Year 5	338.71	0.68	2.9	2.6	2.1	1.0
Year 1	454.64	0.81	1.8	1.7	1.5	1.0
Year 2	425.93	0.77	1.8	1.7	1.5	1.0
Year 3	397.28	0.74	1.8	1.7	1.5	1.0
Year 4	369.60	0.70	1.8	1.7	1.5	1.0
Year 5	343.48	0.68	1.8	1.7	1.5	1.0
Year 1	441.54	0.82	2.9	1.7	1.1	1.0
Year 2	409.41	0.79	2.9	1.7	1.1	1.0
Year 3	377.97	0.75	2.9	1.7	1.1	1.0
Year 4	347.99	0.70	2.9	1.7	1.1	1.0
Year 5	319.95	0.68	2.9	1.7	1.1	1.0
Year 1	450.03	0.81	2.0	1.5	1.2	1.0
Year 2	420.06	0.78	2.0	1.5	1.2	1.0
Year 3	390.38	0.74	2.0	1.5	1.2	1.0
Year 4	361.88	0.70	2.0	1.5	1.2	1.0
Year 5	335.08	0.68	2.0	1.5	1.2	1.0
Year 1	446.55	0.82	2.6	2.4	1.6	1.0
Year 2	416.11	0.78	2.6	2.4	1.6	1.0
Year 3	386.07	0.74	2.6	2.4	1.6	1.0
Year 4	357.31	0.70	2.6	2.4	1.6	1.0
Year 5	330.28	0.67	2.6	2.4	1.6	1.0
Year 1	449.66	0.82	2.9	1.4	1.3	1.0
Year 2	419.05	0.78	2.9	1.4	1.3	1.0
Year 3	388.87	0.75	2.9	1.4	1.3	1.0
Year 4	359.86	0.71	2.9	1.4	1.3	1.0
Year 5	332.6	0.68	2.9	1.4	1.3	1.0
Year 1	453.43	0.81	2.7	2.3	2	1.0
Year 2	424.35	0.78	2.7	2.3	2	1.0
Year 3	395.39	0.74	2.7	2.3	2	1.0
Year 4	367.46	0.70	2.7	2.3	2	1.0
Year 5	341.14	0.68	2.7	2.3	2	1.0

Year 1	454.88	0.81	2.2	2	1.8	1.0
Year 2	426.17	0.77	2.2	2	1.8	1.0
Year 3	397.52	0.74	2.2	2	1.8	1.0
Year 4	369.84	0.70	2.2	2	1.8	1.0
Year 5	343.73	0.68	2.2	2	1.8	1.0
Year 1	443.32	0.82	2.1	1.8	1.1	1.0
Year 2	412.11	0.78	2.1	1.8	1.1	1.0
Year 3	381.46	0.74	2.1	1.8	1.1	1.0
Year 4	352.20	0.70	2.1	1.8	1.1	1.0
Year 5	324.8	0.67	2.1	1.8	1.1	1.0
Year 1	445.09	0.82	2.7	2.1	1.4	1.0
Year 2	414.11	0.78	2.7	2.1	1.4	1.0
Year 3	383.65	0.74	2.7	2.1	1.4	1.0
Year 4	354.51	0.70	2.7	2.1	1.4	1.0
Year 5	327.17	0.67	2.7	2.1	1.4	1.0
Year 1	453.26	0.81	2.4	2.1	1.8	1.0
Year 2	424.16	0.78	2.4	2.1	1.8	1.0
Year 3	395.20	0.74	2.4	2.1	1.8	1.0
Year 4	367.27	0.70	2.4	2.1	1.8	1.0
Year 5	340.94	0.68	2.4	2.1	1.8	1.0
Year 1	452.27	0.81	1.8	1.4	1.2	1.0
Year 2	422.82	0.78	1.8	1.4	1.2	1.0
Year 3	393.57	0.74	1.8	1.4	1.2	1.0
Year 4	365.41	0.70	1.8	1.4	1.2	1.0
Year 5	338.89	0.68	1.8	1.4	1.2	1.0
Year 1	448.54	0.82	2.9	1.5	1.3	1.0
Year 2	417.77	0.78	2.9	1.5	1.3	1.0
Year 3	387.47	0.75	2.9	1.5	1.3	1.0
Year 4	358.37	0.71	2.9	1.5	1.3	1.0
Year 5	331.03	0.68	2.9	1.5	1.3	1.0
Year 1	449.84	0.81	2.0	1.7	1.3	1.0
Year 2	419.98	0.78	2.0	1.7	1.3	1.0
Year 3	390.41	0.74	2.0	1.7	1.3	1.0
Year 4	362.00	0.70	2.0	1.7	1.3	1.0
Year 5	335.28	0.68	2.0	1.7	1.3	1.0
Year 1	455.48	0.81	1.3	1.2	1.1	1.0
Year 2	426.92	0.77	1.3	1.2	1.1	1.0
Year 3	398.38	0.74	1.3	1.2	1.1	1.0
Year 4	370.80	0.70	1.3	1.2	1.1	1.0
Year 5	344.76	0.68	1.3	1.2	1.1	1.0
Year 1	453.31	0.81	3.0	2.7	2.3	1.0

Year 2	424.26	0.78	3.0	2.7	2.3	1.0
Year 3	395.34	0.74	3.0	2.7	2.3	1.0
Year 4	367.44	0.70	3.0	2.7	2.3	1.0
Year 5	341.14	0.68	3.0	2.7	2.3	1.0

Appendix I – CBA Results Based on Nine Sets of Possible Weight Factors

Period	Benefit	NCDOT Rating Number	Interstate	US	NC	SR
Year 1	442.96	0.82	2.38	2.13	1.51	1.0
Year 2	409.08	0.78	2.38	2.13	1.51	1.0
Year 3	376.19	0.75	2.38	2.13	1.51	1.0
Year 4	347.19	0.7	2.38	2.13	1.51	1.0
Year 5	318.82	0.66	2.38	2.13	1.51	1.0
Year 1	443.16	0.82	2.42	2.02	1.47	1.0
Year 2	409.24	0.78	2.42	2.02	1.47	1.0
Year 3	376.32	0.75	2.42	2.02	1.47	1.0
Year 4	347.26	0.7	2.42	2.02	1.47	1.0
Year 5	318.87	0.67	2.42	2.02	1.47	1.0
Year 1	443.31	0.82	2.45	1.92	1.43	1.0
Year 2	409.35	0.78	2.45	1.92	1.43	1.0
Year 3	376.39	0.75	2.45	1.92	1.43	1.0
Year 4	347.3	0.7	2.45	1.92	1.43	1.0
Year 5	318.86	0.67	2.45	1.92	1.43	1.0
Year 1	443.34	0.82	2.49	1.81	1.38	1.0
Year 2	409.29	0.78	2.49	1.81	1.38	1.0
Year 3	376.27	0.75	2.49	1.81	1.38	1.0
Year 4	347.1	0.7	2.49	1.81	1.38	1.0
Year 5	318.63	0.67	2.49	1.81	1.38	1.0
Year 1	443.16	0.82	2.53	1.74	1.34	1.0
Year 2	409.02	0.78	2.53	1.74	1.34	1.0
Year 3	375.93	0.75	2.53	1.74	1.34	1.0
Year 4	346.67	0.7	2.53	1.74	1.34	1.0
Year 5	318.13	0.67	2.53	1.74	1.34	1.0
Year 1	443.63	0.82	2.57	1.59	1.29	1.0
Year 2	409.47	0.79	2.57	1.59	1.29	1.0
Year 3	376.33	0.75	2.57	1.59	1.29	1.0
Year 4	347.03	0.7	2.57	1.59	1.29	1.0
Year 5	318.4	0.67	2.57	1.59	1.29	1.0
Year 1	441.08	0.82	2.6	1.74	1.25	1.0
Year 2	406.59	0.79	2.6	1.74	1.25	1.0
Year 3	373.18	0.75	2.6	1.74	1.25	1.0
Year 4	343.61	0.7	2.6	1.74	1.25	1.0
Year 5	314.84	0.67	2.6	1.74	1.25	1.0
Year 1	443.31	0.82	2.64	1.45	1.21	1.0
Year 2	408.97	0.79	2.64	1.45	1.21	1.0
Year 3	375.65	0.75	2.64	1.45	1.21	1.0

Year 4	346.17	0.7	2.64	1.45	1.21	1.0
Year 5	317.37	0.67	2.64	1.45	1.21	1.0
Year 1	444.33	0.82	2.68	1.26	1.16	1.0
Year 2	410.01	0.79	2.68	1.26	1.16	1.0
Year 3	376.69	0.75	2.68	1.26	1.16	1.0
Year 4	347.19	0.7	2.68	1.26	1.16	1.0
Year 5	318.38	0.67	2.68	1.26	1.16	1.0