THE RELATIONSHIP BETWEEN INITIAL CONSTRUCTION IRI AND NETWORK IRI

by

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A thesis submitted to the faculty of
The University North Carolina at Charlotte
in partial fulfillment of the requirements
for the degree of Master of Science in
Construction and Facilities Management

Charlotte

2014

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ABSTRACT

XIAZHI FANG. The relationship between initial construction IRI and network IRI.
(Under the direction of DR. DON CHEN)

The main objectives of this study are to develop the relationship between initial IRI and network IRI and to predict service lives of pavements. The raw data used in this research, including IRI, pavement ages, Annual Average Daily Traffic (AADT), and locations of pavements, were provided by North Carolina Department of Transportation (NCDOT). The raw data were merged, linear regression, analysis of variance (ANOVA), and contrasts were conducted to investigate the relationship, and to estimate pavements' service lives. The conclusions revealed that pavements with smaller initial IRI last longer, and that average service lives after construction and treatments for US, NC, and the SR roadways are 16.4, 9.5, and 6.7 years, respectively.

ACKNOWLEDGEMENTS

One of the joys of completion is to look over the journey I have passed and remember all the precious people who have guided, helped, and supported me in this process.

I would like to express my deepest gratitude to my advisor, Dr. Chen, for his excellent guidance, caring, and patience in the whole process, and helping me to develop the background in pavement system in North Carolina during the research. I would also like to thank my committee members, Dr. John Hildreth and Dr. Tara Cavalline, for their guidance and encourages in my research.

I would like to thank Yuru Zhang, who as a good friend, was always willing to company in the library late to the midnight. There wouldn’t have been so much laughter without her.

Finally, I would like to thank my parents who are always there to show their loves and cares for me.

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CHAPTER 1: INTRODUCTION

1.1 Background and Significance

Roughness is an important parameter that can be used to evaluate pavement performance. It is an indicator of distortion and variation of the pavement surface, and it can also measure the quality of delivered roadway construction, which serves as an acceptance criterion for new construction projects. For roadway users, pavement roughness directly affects drivers' comfort, fuel efficiency, safety, and vehicle depreciation (Wen, 2011).

The International Roughness Index (IRI) is used to quantify pavement roughness. Nationwide, IRI has been widely used by state DOTs to evaluate the condition of roadways and to predict roadway investment needs (Shafizadeh and Mnnering, 2006). IRI is one of the key factors associated with users' perceptions of road roughness, which can be a critical element affecting resource allocation (Shafizadeh and Mannering, 2006). Park et al. (2007) indicated that IRI can be assessed as a predictor variable of pavement conditions. Additionally, a relationship between IRI and pavement performance can be used to determine when treatments are required and what performance trend is expected after the rehabilitation treatment (Kargah-Ostadi et al., 2010).

The North Carolina Department of Transportation (NCDOT) has collected IRI ratings since 1998. The Pavement Management Unit has used IRI information to track and understand the performance of pavements. The Construction Unit is planning to implement the IRI as an approval criterion for roadway constructions and rehabilitations in North Carolina.

1.2 Research Objectives

This research was conducted to fulfill the needs of these two units in NCDOT. The objective of this research is two-fold: 1) to develop a relationship between the initial construction IRI and the network IRI, and 2) to estimate the service lives of pavement classifications. The findings of this research can be used to answer the following questions: What is the rate of change in IRI over time? And will pavements with smaller initial IRI last longer?

In order to achieve these objectives, the rates of change in IRI over time were obtained by regressing the network IRI against the initial IRI and pavement age. Other factors, including average annual daily traffic (AADT), pavement classification (Interstate, US, NC, and SR), and the locations of roadways (regions in North Carolina), were also included in the analyses. The analysis of variance (ANOVA) was used to compare the magnitudes of the change rates of different initial IRI groups, and contrasts were used to compare the network IRI values of different initial IRI groups. Then, the service lives of roadway families were estimated by developing polynomial regression models and calculating the numbers of years for pavements to reach the IRI threshold. In this research, service life is number of years IRI reaches the predefined IRI threshold.

CHAPTER 2: LITERATURE REVIEW

A comprehensive literature review was conducted to study the background of IRI and to explore the methodologies that will be used in this study.

2.1 Pavement Performance

Pavement performance is defined as the ability of a pavement to satisfy the traffic as designed (Yoder and Witczack, 1975), and can be evaluated by the data collected from a pavement condition survey (Gramling, 1994). There are many factors that influence pavement performance. Generally, these factors include traffic volume, pavement material properties and composition, environmental associated factors, pavement thickness, and maintenance levels.

Roughness is considered as one of the most important factors influencing pavement conditions. Park et al. (2007) concluded in their research that IRI has a great influence on the Pavement Condition Index (PCI). Many agencies have used pavement roughness to estimate the Present Serviceability Index (PSI), which is another indicator of pavement performance (Yoder and Witczak, 1975; Roberts et al., 1991).

PSI was used in the American Association of State Highway Officials (AASHO) road test to measure ride quality through longitudinal profile variation data (Sun, 2001). Later, a quantitative measure for estimating pavement performance, known as PCI, was developed by the US Army Corps of Engineers (Shahnazari, et al. 2012). The two components of PCI are the riding comfort rating for roughness and the distress manifestation index for pavement surface distresses (Hajek et.al., 1986). Besides PSI and PCI, there are other performance indicators developed by different state highway agencies, such as the Pavement Condition Rating (PCR) and the Pavement Quality Index (PQI). PCR is an index reflecting the combined effects of various distress types, severities, and extents on general pavement conditions (Highway Preservation Systems, Ltd., 2001). PQI indicates the overall condition of a pavement regarding both present and future service to users. It ranges from 2 to 10 with 2 representing the poorest pavement, and 10 representing the best possible pavement (Lashlee, 2004). Currently, NCDOT uses PCR as the pavement performance indicator.

2.1.1 Pavement Condition Survey

A pavement condition survey is usually conducted to determine the condition of a pavement (Wilburn, 1976). The data collected in a pavement condition survey can assist in the decision-making process regarding pavement maintenance, rehabilitation, and reconstruction (Hicks and Mahoney, 1981). Four basic types of data are included in a typical survey: physical distress, structural capacity, friction measurements, and ride quality or roughness (Gramling, 1994).

Physical distress measures deterioration of road surface and subsurface caused by traffic, environment, and aging (American Association of State Highway and Transportation Officials, 1985). Distress types can be generally classified as cracking, surface deterioration, and distortion. Additionally, distress information is usually collected based on the extent and severity of the distress. Structural capacity indicates the pavement capacity to carry traffic loads with minimum distress or deformation (Gramling, 1994). Pavement friction, also known as skid resistance, is defined as the horizontal force generated when a tire that is prevented from rotating slides with the pavement surface (Meyer and Goodwin, 1972). An adequate level of friction is required by the FHWA to provide safe operating conditions for all vehicles. Roughness or ride quality is another important type of performance data, and is described in the following section.

2.1.2 Roughness

Roughness is the predominate measure of pavement service quality, and generally, the equipment developed to measure pavement roughness falls into two classifications: response type road roughness measuring system (RTRRMS) and profilers (Gramling, 1994). Gramling (1994) indicated that for a RTRRMS, roughness is calculated by measuring the movements of a vehicle or a wheel against pavements; whereas, profilers were designed to measure the true profile of the pavement surface.

In the 1980s, the World Bank sponsored the International Road Roughness Experiment (IRRE) to develop guidelines for conducting roughness measurement consistently worldwide. This experiment resulted in an international standard for measuring and reporting pavement roughness, which is the International Roughness Index (IRI). According to Thomas (1992), there are several factors that should be considered when selecting IRI as the standard scale of roughness. First, IRI has to relate to the vibration response of motor vehicles. Second, in order to achieve a time-stable measurement of roughness, the scale has to be mathematically related to the road profile. Third, a wide range of hardware has to be available to measure this index. Fourth, the measuring procedure and equipment have to be predefined to be widely used all over the world. Currently, IRI has become the industry standard to measure pavement roughness (Thomas, 1992).

Although technologies of measuring longitudinal profiles have existed for decades, they have not been fully developed. Karamiha et al. (1999) stated that a prevailing sense exists in highway communities that if the same road is measured by different communities with their own equipment, the results will be different. They also indicated that errors may be caused by variations of equipment, inappropriate conducting procedures, pavement surfaces, and surrounding environments. Five categories of influencing factors were identified, including profiler design, surface shape, measurement environment, profiler operation, and profiler driver and operator.

2.2 Pavement Management System

IRI is an important component of a pavement management system (PMS). The Organization for Economic Co-operation and Development (OECD) defined pavement management as “a process of coordinating and controlling a comprehensive set of activities in order to maintain pavements, as to make the best possible use of resources available” (OCDE, 1987). Hudson et al. (1979) defined pavement management as “the involvement of the identification and implementation of optimum strategies, which serve all those activities ranging from initial information acquisition to planning and programming of maintenance, rehabilitation and new construction at all levels.” Although there is no universally accepted definition of pavement management, the common point of pavement management definitions is that they involve multiple activities to preserve pavement in mint condition.

A pavement management system (PMS), as defined by the American Association of State Highway and Transportation Officials (AASHTO), is “…the effective and efficient directing of the various activities involved in providing and sustaining pavements in a condition acceptable to the traveling public at the least life-cycle cost" (AASHTO, 1985). In other words, a PMS is an integral system that can be used to manage entire activities of pavements, including design, construction, maintenance, and rehabilitation. The main purpose of a PMS is to maintain the pavements for public use.

Based on different scopes of pavement administration, a PMS can be classified into two administrative levels: network and project. The network level analysis concentrates on decision-making and overall budgeting for network pavements, which involves the activities of "ranking and identifying candidate pavements for improvements, estimating the network-level budget, forecasting the long-range budget, assessing the network-level pavement condition, and forecasting future conditions." The project level analysis focuses more on "solving technical problems, including the cause assessment of deterioration, the potential solution determination, the benefit assessment of alternatives, and the ultimate selection and design of the desired solutions" (OCDE, 1987). The NCDOT PMS can perform analyses at both levels.

2.2.1 The Information Subsystem of a Pavement Management System

A typical PMS has three basic components, including the information, the analysis, and the implementation subsystems (Hudson, et al., 1979). The information of pavement roughness is included in the information subsystem. The essential function of the information subsystem is to collect data, such as inventory, pavement condition, pavement history, traffic loads, and costs. Pavement condition data include pavement roughness, surface distress, rutting, skid resistance, and structural capacity (Vitillo, n. d.).

The methods of data collection vary based on the categories of pavement. For example, visual inspection for a small town or rural county can be recorded in Microsoft Excel or

Access, which is more than sufficient, while a state road network needs a more complex data system (Pavement Interactive, August 2007). Usually pavement data are collected every one or two years. The data collected are not only used to evaluate the current condition of pavements, but also to predict future pavement conditions. The IRI information used in this research is stored in the information subsystem of the NCDOT PMS.

2.3 Previous Studies on IRI

Many studies have been conducted to explore the applications of IRI in pavement management.

2.3.1 Pavement Performance Models

Several factors can affect the roughness of pavements. According to Kargah-Ostadi et al. (2010), these factors include initial roughness, pavement age, traffic, climatic conditions, pavement structural properties, subgrade properties, drainage types, drainage conditions, maintenance, and rehabilitation treatments. Previous studies (Prozzi and Madanat, 2003; Chou and Pellinen, 2005) have been conducted to investigate how these factors influence pavement performance.

In 2003, Prozzi and Madanat (2003) demonstrated that the original pavement performance model developed by the American Association of State Highways Officials (AASHO) had some issues when it was developed, “such as inconsistencies of statistical approach, improper treatment of observations, and mis-specified regression equation because of units.” In their research, they developed a new model to predict the Present Serviceability Index (PSI), which encompassed the factors of traffic volume, initial serviceability, time, structure, and climate. They used nonlinear regression and joint estimation of factor parameters. However, this model also had some limitations. According to their description, the data resources were insufficient and encompassed the information of pavements under similar environmental conditions.

In 2005, Chou and Pellinen used the artificial neural network (ANN) technology to develop the time-dependent roughness prediction model for three types of pavements: polyester polymer concrete (PPC), asphalt overlay on concrete, and hot-mix asphalt (HMA). The inputs considered were initial IRI, age, freeze index, temperature, annual Proximity-Based Neural Network (PPN), and traffic load. The output was targeted time-series IRI, which is the network IRI. After the prediction models were developed, they were used to calculate the service lives of pavements. It was concluded that the initial IRI and annual precipitation significantly influenced the performance of pavements; for PPC pavement, initial IRI was the most important factor that affected the roughness. The limitation of this study came from the source of the data. Because the data was collected in the state of Indiana, the models were considered only as local models (Chou and Pellinen, 2005). Another limitation in this studies is that most of the models developed included more than one independent variable, which is not applicable to some state DOT's PMSs. Because in these PMSs, pavement age should be the only independent variable used to develop the performance models. This is the case for the NCDOT PMS.

2.3.2 Initial IRI and the Service Lives of Pavements

Previous studies stated that initial IRI values impacted the performance of the pavement during its life time and that pavements with lower initial IRI values would serve the public longer (Janoff, 1990; Corley-Lay and Mastin, 2009; Crowe, 2002). However, few studies have been conducted to validate the relationship between initial IRI and the service lives of pavements.

In 1997, the Smoothness Specification for Pavement (Smith et al., 1997) reported that initial smoothness significantly impacted the future smoothness of pavements. In this research, the significance of initial roughness was studied by examining the coefficient of the initial IRI in the developed model, which included a network IRI as the dependent variable and initial roughness and pavement age as independent variables. Coefficients of the initial IRI were studied, and the significance of initial roughness was verified. The results indicated that the initial IRI has a significant influence on the network IRI. It should be noted that the data used in the research was only obtained from asphalt concrete (AC), Portland cement concrete (PCC), and AC overlay projects.

In the same study, nonlinear regression models were developed to describe the relationship between long-term roughness and initial roughness, age, and interaction between initial roughness and age. The threshold value of roughness and the initial roughness value were used to calculate the service lives of pavements. Then, a linear relationship between service lives and initial roughness was developed. It was concluded that pavements with smaller initial IRI have a longer service lives. In their research, other measurements of pavement roughness were also studied, including ones measured by the Bureau of Public Road (BPR) rough meter and the Portland Cement Association (PCA) road meter. Additionally, the research also indicated that other factors could impact the predicted pavement service lives, such as traffic level, pavement thickness, climate, and quality of construction.

In 2005, Perera et al. (2005) indicated in their research that, compared to pavements having a greater initial IRI, pavements that were built smoother would provide a longer service lives before reaching a terminal roughness threshold. In this research, the dataset was subdivided into subdatasets based on the IRI change rates of the roadways. By estimating the intercepts of each scatter plot of subdatasets, the initial IRI values were determined. Then, the service lives of pavements were estimated. It was concluded that pavements with smaller initial IRI deteriorated at a relative slower pace over time. The limitation of this study is that only concrete pavements were studied.

2.4 Linear Regression Analysis

Linear regression analysis can be used to either estimate the mean of the populations or predict the future trend of a variable. In this research, linear regression analysis was used to predict network IRI, using initial IRI and other factors. There are primarily three objectives of the linear regression analysis. The first objective is general study, which aims to test the correlation between variables; the second one is prediction, which predicts the future values according to the information provided by the independent variables; the third objective is to remove an unwanted factor by replacing one variable with another variable converted by parameters (Dunn and Clark, 1987).

A dependent variable is explained mathematically by a model. Independent variables are considered as predictors that provide information for prediction of the dependent variable. If there is one dependent variable and one independent variable, simple linear regression models can be used to predict the dependent variable. If there is more than one independent variable, multiple regression models can be applied to predict the dependent variable. A multiple regression model can be written as:

$$y = b_0 + b_1x_1 + b_2x_2 + \cdots + b_nx_n$$

where,

y is the dependent variable,

x_n is independent variable,

n is the total number of independent variables.

2.5 F-test

An F-test is used to test the hypotheses that if there is a difference among the means of more than two groups. The typical null and alternative hypotheses for F-test are given by,

H_0: all the means of groups are the same;

H_a: at least two of the means of groups are different.

In this research, the F-test was used to investigate the difference among rates of change in different initial IRI groups. Analysis of variance (ANOVA) was used to achieve this goal, which is described in the next section. To conduct an F-test, the mean square error within the groups (MSE) and the mean square error between the groups (MSB) need to be calculated. The ratio of MSE to MSB is called the F ratio, which is named after the original creator, R. Fisher (Lane, n.d.). The formula can be given by:

$$F - ratio = \frac{MSB}{MSE}$$

MSB and *MSE* can be calculated using the following equations:

$$MSB = \frac{n_1(\bar{x}_{1.} - \bar{x}_{..})^2 + n_2(\bar{x}_{2.} - \bar{x}_{..})^2 + \cdots + n_k(\bar{x}_{k.} - \bar{x}_{..})^2}{k - 1}$$

where,

n_k is the number of observations for the group of k,

$\bar{x}_{k.}$ is the mean of the group of k,

$\bar{x}_{..}$ is the mean of the total observations from all the groups,

k is the number of groups.

$$MSE = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2 + \cdots + (n_k - 1)s_k^2}{n_{tot} - k}$$

where,

s_k^2 is the standard deviation of group of k,

n_k is the number of observations for the group of k,

n_{tot} is the total number of observations from all the groups,

k is the number of groups.

s^2 can be calculated using the equation below:

$$s^2 = \frac{\sum(x - \bar{x})^2}{n - 1}$$

where,

$\bar{x}$ is the mean of a group,

s^2 is standard deviation,

n is the number of observations for a group.

If MSE is equal to MSB, it indicates that the means of groups are equal. If MSE is not equal to MSB and the F ratio is larger than the F critical value, then it indicates that at least two of the means are different, so the null hypothesis should be rejected. To compare the F ratio to the appropriate F critical value, a control factor called the level of significance should be determined. If the calculated p-value is smaller than the level of significance, the null hypothesis is rejected.

2.6 Analysis of Variance

"Analysis of Variance (ANOVA) refers broadly to a collection of experimental situations and statistical procedures for the analysis of quantitative responses from experimental units" (Devore, 2008). In this research, ANOVA was used to examine whether or not rates of change in different initial IRI groups are different.

The simplest ANOVA problem is a single-factor ANOVA and only involves one factor that differentiate the treatment or population. "Single-factor ANOVA focuses on a comparison of more than two population or treatment means" (Devore, 2008). In this type of analyses, the null hypothesis is that all the means of different groups are the same. To test the hypothesis, an F- test is used. If the null hypothesis is rejected, the conclusion would be that, among the means, at least two of them are different. Based on the rejection of a null hypothesis, further study focusing on which means are different from the others can be performed using t-tests or contrasts, as described in the next section.

2.7 T-test

A t-test is a statistical method to test whether or not the means of two sample groups are different. There are typically two types of t-tests: one-sided and two sided. They are shown as followings,

Two sided:

H_0: the means of two groups are the same;

H_a: the means of two groups are not the same.

One sided:

H_0: the mean of group A is larger than or equal to that of group B;

H_a: the mean of group A is smaller than that of group.

One sided:

H_0: the mean of group A is smaller than or equal to that of group B;

H_a: the mean of group A is larger than that of group B.

In this research, the t-test was used to investigate the specific differences of changes in IRI over time between two different initial IRI groups. This can also be achieved using contrasts, as described in the next section. To conduct a t-test, a t score needs to be calculated and compared to a critical t value. A t score can be calculated as:

$$\boldsymbol{t} = \frac{\bar{\boldsymbol{x}}_{\mathbf{1}} + \bar{\boldsymbol{x}}_{\mathbf{2}}}{\sqrt{\frac{{\boldsymbol{S}_{\mathbf{1}}}^{\mathbf{2}}}{\boldsymbol{n}_{\mathbf{1}}} + \frac{{\boldsymbol{S}_{\mathbf{2}}}^{\mathbf{2}}}{\boldsymbol{n}_{\mathbf{2}}}}}$$

where,

$\bar{\boldsymbol{x}}_{\mathbf{1}}$ is the mean of the first sample group,

$\bar{\boldsymbol{x}}_{\mathbf{2}}$ is the mean of the second sample group,

$\boldsymbol{S}_{\mathbf{1}}$ is the standard deviation of the first sample group,

$\boldsymbol{S}_{\mathbf{2}}$ is the standard deviation of the second sample group,

$\boldsymbol{n}_{\mathbf{1}}$ is the total number of values in the first sample group,

$\boldsymbol{n}_{\mathbf{2}}$ is the total number of values in the second sample group.

The formula for the standard deviation is given by:

$$\boldsymbol{S} = \sqrt{\frac{\sum(\boldsymbol{x} - \bar{\boldsymbol{x}})^{\mathbf{2}}}{\boldsymbol{n} - \mathbf{1}}}$$

where,

x is the value given by the sample group,

$\bar{\boldsymbol{x}}$ is the mean,

n is the total number of values.

A critical t value can be obtained from a t table, according to the degree of freedom and the level of significance. The degree of freedom is determined by sample sizes. Different levels of significance can be used in a t-test, but eventually the strictest level of significance based on the comparison with the critical t value will be used to draw a conclusion.

The selection of a two-tailed t-test or a one-tailed t-test is determined by the null hypothesis. If a direction in relationship between the two groups is hypothesized, then a one-tailed t-test will be chosen. If no direction is hypothesized, then a two-tailed t-test will be used.

2.8 Contrast

A contrast is usually used to test the significance of differences among levels of variables. In this research, contrasts are used to examine whether or not the difference between means of two groups exist and also used to estimate the specific differences between two groups. The simplest contrast compares two levels of a variable, and a contrast can also be used to test the differences between combinations of variables.

Contrast defined by Everitt (2002) is “a linear function of parameters or statistics in which the coefficients sum to zero.” For example, if an application include two treatment groups (x_a and x_b) and a control group (with mean x_c), the following contrast is used to compare the mean of control group and the average of the treatment groups;

$$x_c - \frac{1}{2}x_a - \frac{1}{2}x_b$$

For this research project, there are only two levels of treatment groups (x_a and x_b). The contrast can be written as:

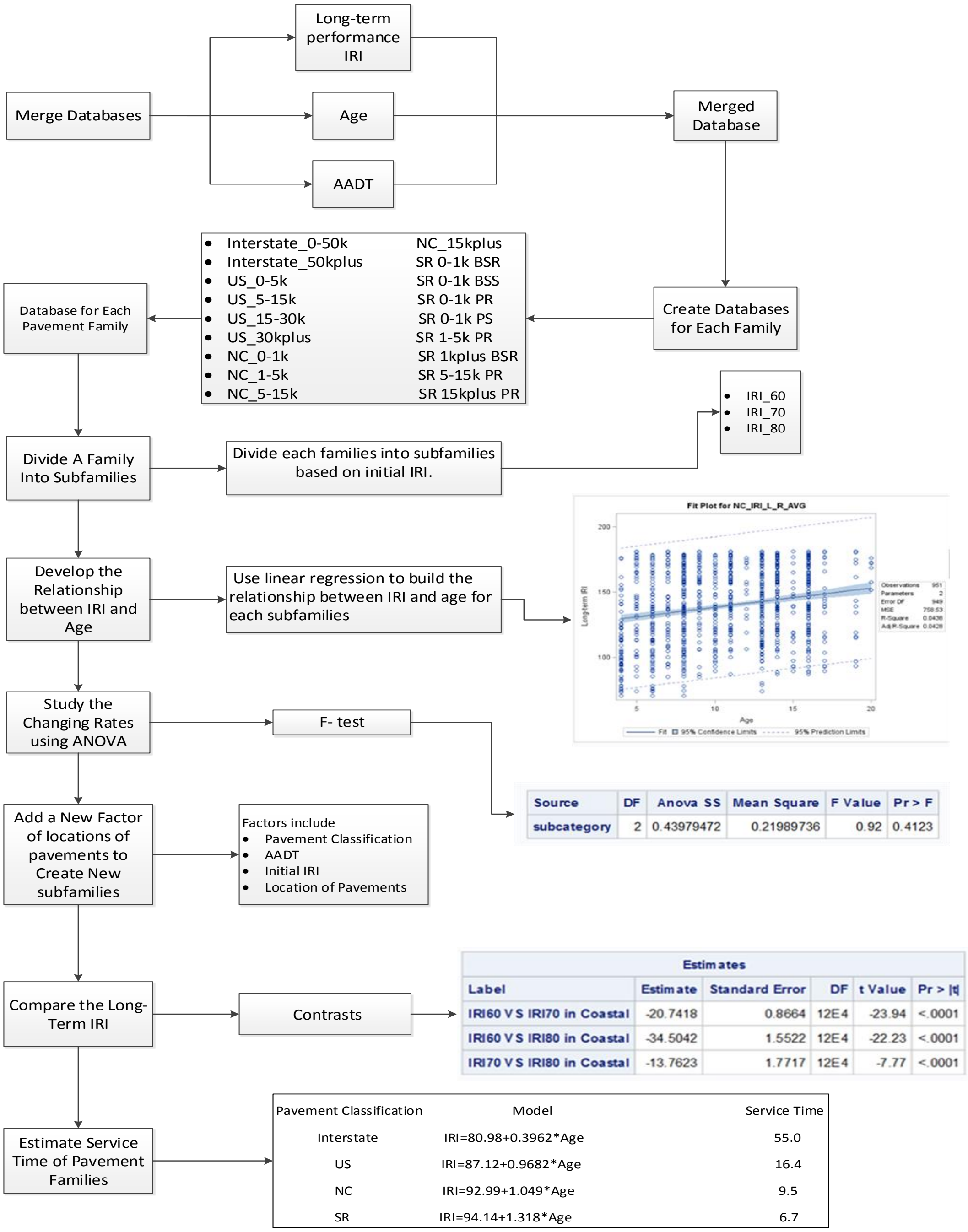
$$x_a - x_b$$

CHAPTER 3: RESEARCH METHODOLOGIES

3.1 Summary

To achieve the research objectives, initial IRI, network performance IRI, age, AADT, and locations of pavements need to be analyzed for every roadway section. In this research, network performance IRI and age were used to develop linear regression models that described the change in IRI over time, which could be used to investigate if smoother pavements deteriorated slower. Initial IRI, AADT, and locations of pavements were the factors that can influence pavement roughness. They were considered in this research and were used to categorize roadway sections into pavement families and subfamilies.

The pavement family databases were developed by merging three individual databases that contain network IRI, age, and AADT, respectively. The data merging process was described in the next section. After the family database was created, each family was divided into subfamilies based on pre-defined initial IRI ranges, including IRI_60 (initial IRI between 0~60 inch/mile), IRI_70 (initial IRI between 60~70 inch/mile), and IRI_80 (initial IRI between 70~80 inch/mile). Then, linear regression analysis was performed to develop the relationship between network performance IRI and age for each subfamily. The results provided the rates of changes in IRI of pavements in each subfamily, which represented how fast the IRI value increases over time. Then, ANOVA was conducted to examine whether or not the deterioration rates of different initial IRI subfamilies are significantly different. The results showed no significant differences among initial IRI groups. To further the study, a new factor, locations of pavements, was included in the analyses. Contrasts were used to examine the differences of the network IRI for subfamilies again. In addition, the service lives of roadway families were studied. The flow chart of research methodologies was shown in Figure 1.



Source	DF	Anova SS	Mean Square	F Value	Pr > F
subcategory	2	0.43979472	0.21989736	0.92	0.4123

Estimates					
Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Coastal	-20.7418	0.8664	12E4	-23.94	<.0001
IRI60 VS IRI80 in Coastal	-34.5042	1.5522	12E4	-22.23	<.0001
IRI70 VS IRI80 in Coastal	-13.7623	1.7717	12E4	-7.77	<.0001

Pavement Classification	Model	Service Time
Interstate	IRI=80.98+0.3962*Age	55.0
US	IRI=87.12+0.9682*Age	16.4
NC	IRI=92.99+1.049*Age	9.5
SR	IRI=94.14+1.318*Age	6.7

Figure 1: Flowchart of research methodologies

3.2 Development of Pavement Families and Subfamilies

The procedure of developing pavement families and subfamilies is described in the following section.

3.2.1 Roadway Families

In this research, the initial IRI and network performance IRI data were collected by NCDOT. In North Carolina, pavements are classified as Interstate, US, NC and SR (Secondary Roads). According to roadways' traffic volume, i.e., Annual Average Daily Traffic (AADT), and their classifications, roadways are divided into different families, as shown in Table 1. In this table, Interstate_0-50k represents Interstate roadways with an AADT value between 0 and 50,000 veh/day. BSR represents Bituminous Rural Subdivision routes, BSS represents Bituminous Slurry Subdivision routes, PS represents Plant Mix Subdivision routes, and PR represents Plant Mix Rural routes.

Table 1: Roadway families in NCDOT PMS

No.	Family	No.	Family
1	Interstate_0-50k	10	NC_15kplus
2	Interstate_50kplus	11	SR_BSR_0-1k
3	US_0-5k	12	SR_BSR_1kplus
4	US_5-15k	13	SR_BSS_0-1k
5	US_15-30k	14	SR_PR_0-1k
6	US_30kplus	15	SR_PR_1-5k
7	NC_0-1k	16	SR_PR_5-15k
8	NC_1-5k	17	SR_PR_15kplus
9	NC_5-15k	18	SR_ PS_0-1k

3.2.2 Development of the Merged Database

Databases that contain the network IRI, age, and AADT data were obtained from NCDOT. In this research, the relationship between initial IRI and network performance

IRI over time was developed for every pavement family, therefore the respective database for each pavement family should be created. To this end, the databases provided by NCDOT need to be merged.

NCDOT has surveyed all the asphalt pavements and 20% concrete pavements every two years since 1982, and has maintained several databases to store the collected data. NCDOT provided three databases to be used in this research. The first one is NCDOT_Construction_Data, which includes construction information for roadways, such as construction date, the begin mile post and the end mile post of each specific pavement project, the construction materials, and the thicknesses of pavements. Among these information, construction completion year was used to calculate pavement age. The second database is NCDOT_IRI, which encompasses IRI information, such as county names and route numbers of roadway sections, the start and the end mile posts, and the date of the IRI survey. In this database, measured IRI values were used in statistical analyses as network IRI, and initial IRI if the corresponding pavement age is zero. The third database is NCDOT_Asphalt_Ratings. This database contains the pavement information for asphalt pavements, such as county names and route numbers, AADT, the start and end mile posts, and the dates of surveys. In this database, AADT was used to subdivide roadways into families.

Merging the above mentioned three databases involved several steps. Each of the provided databases has different start and end mile posts and often times these mile posts intersect with each other. In addition, the network performance IRI has been collected in 0.1 mile increments, while pavement age and AADT were collected for pavements that are longer than 0.1 miles, making this data merging process a challenging task. The following procedures describe how to merge the provided databases into the final database which includes age, AADT, and IRI for further analyses. The tool used in this process is Microsoft Access 2010.

(1) Extracting data

This step is to extract the following needed data from following databases.

- NCDOT_IRI: COUNTY, ROUTE, OFFSET_FROM, OFFSET_TO, EFF_YEAR and NC_IRI_L_R_AVG
    - COUNTY: the county name
    - ROUTE: the route number
    - OFFSET_FROM: the start mile post of an IRI survey
    - OFFSET_TO: the end mile post of an IRI survey
    - EFF_YEAR: the date of an IRI survey
    - NC_IRI_L_R_AVG: the measured IRI value
- NCDOT_Construction_Data: County (COUNTY), Route (ROUTE), Begin MP (BEGIN_FROM), End MP (END_TO), and Year Comp (YEARCOMP)
    - County: the county name.
    - Route: the route number.
    - Begin MP: the start mile post of construction. For programing convenience, this item was written as BEGIN_FROM in the following description
    - End MP: the end mile post of construction. For programing convenience, this item was written as END_TO in the following description

  - Year Comp: the completion date of construction. For programing convenience, this item was written as YEARCOMP
- NCDOT_Asphalt_Ratings: COUNTY, ROUTE, OFFSET_FROM (BEGINE_POINT), OFFSET_TO (END_POINT), EFF_YEAR (AADTYEAR) and AADT
  - COUNTY: the county name
  - ROUTE: the route number
  - OFFSET_FROM: the start mile post of the AADT survey. To distinguish the start mile posts from the data in the NCDOT_IRI database, this item was written as BEGIN_FROM
  - OFFSET_TO: the end mile post of AADT survey. To distinguish the end mile posts from the data in the NCDOT_IRI database, this item was written as END_POINT
  - EFF_YEAR: dates of AADT surveys. To distinguish EFF_YEAR from the NCDOT_IRI database, it was written as AADTYEAR

(2) Merging Age and the IRI into One Database, IRI_AGE

The purpose of this step was to create a new database, IRI_AGE, which includes IRI and age information of roadway sections. NC_IRI_L_R_AVG in the NCDOT_IRI database was collected for every 0.1-mile roadway section, and roadway sections were merged using this length. In this research, NC_IRI_L_R_AVG is referred to as IRI. Corresponding age and AADT value were extracted and assigned to each roadway section. In this process, roadway sections were identified by “COUNTY”, “ROUTE”, “OFFSET_FROM”, “OFFSET_TO”.

The connection was built between the NCDOT_IRI database and the NCDOT_Construction_Data database in Access by defining county and route attributes as “primary keys”. Specifically, “BEGIN_FROM”, “END_TO”, and “Year Comp” from NCDOT_Construction_Data and “OFFSET_FROM”, “OFFSET_TO”, “EFF_YEAR”, and “NC_IRI_L_R_AVG” from NCDOT_IRI were used for merging the IRI and age data into a new database, IRI_AGE. An example is shown below in Figure 2 and actual merged database is shown in Figure 3. It should be noticed that the new databases contains many unreasonable entries that need to be removed, as described in the next section.

NCDOT_IRI_and_RUTTING_DATA
(IRI Database)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI
1_10000040	0.0	0.1	1998	67
1_10000040	0.1	0.2	2000	78

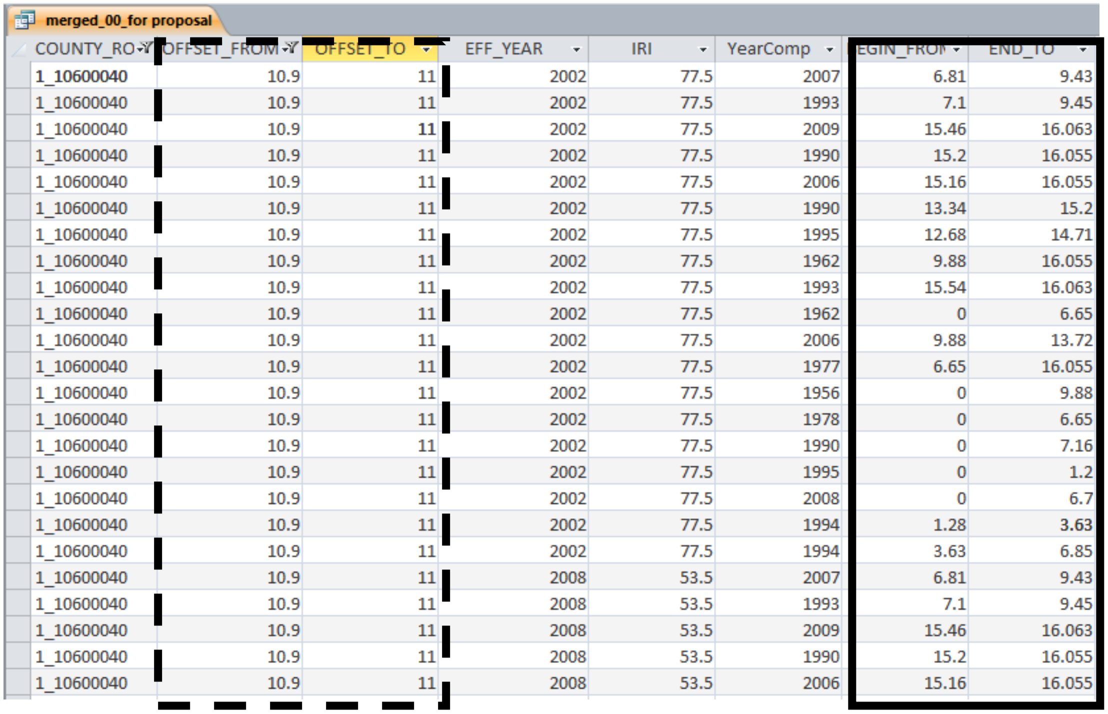
NCDOT_Construction_Data
(Age Database)

County_Route	BEGIN_FROM	END_TO	Year Comp
1_10000040	0.0	2.1	1980
1_10000040	0.0	2.1	1997
1_10000040	2.1	3.4	2000
1_10000040	2.1	3.4	2002

Merged Table (1)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	BEGIN_FROM	END_TO	Year Comp
1_10000040	0.0	0.1	1998	67	0.0	2.1	1980
1_10000040	0.0	0.1	1998	67	0.0	2.1	1997
1_10000040	0.0	0.1	1998	67	2.1	3.4	2000
1_10000040	0.0	0.1	1998	67	2.1	3.4	2002
1_10000040	0.1	0.2	2000	78	0.0	2.1	1980
1_10000040	0.1	0.2	2000	78	0.0	2.1	1997
1_10000040	0.1	0.2	2000	78	2.1	3.4	2000
1_10000040	0.1	0.2	2000	78	2.1	3.4	2002

Figure 2: The example process of merging databases (1)

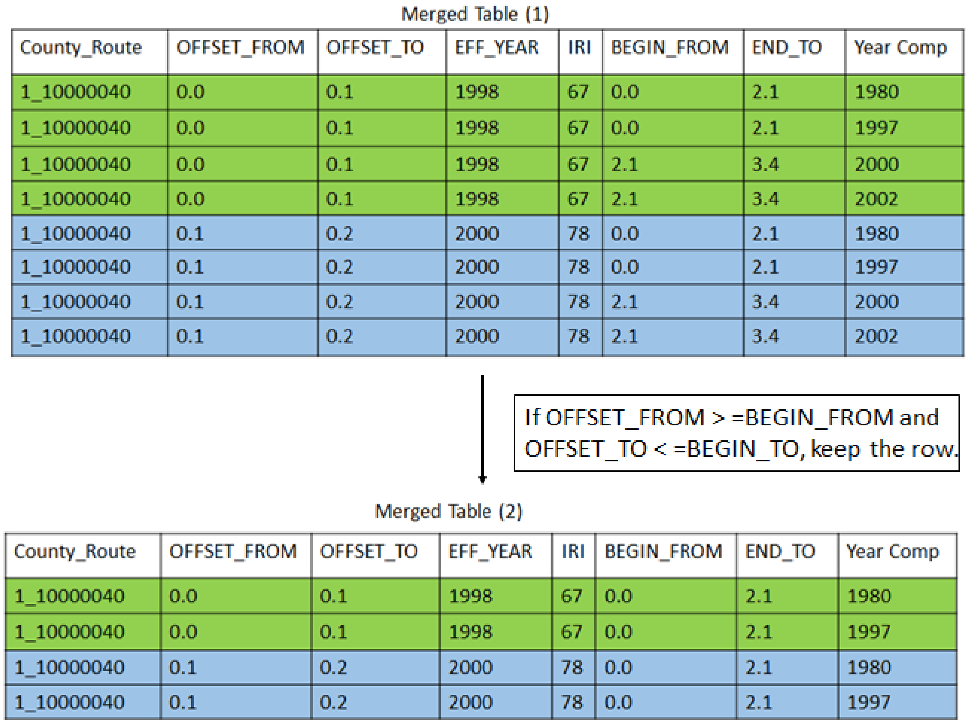


COUNTY_RO	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	YearComp	EGIN_FRO	END_TO
1_10600040	10.9	11	2002	77.5	2007	6.81	9.43
1_10600040	10.9	11	2002	77.5	1993	7.1	9.45
1_10600040	10.9	11	2002	77.5	2009	15.46	16.063
1_10600040	10.9	11	2002	77.5	1990	15.2	16.055
1_10600040	10.9	11	2002	77.5	2006	15.16	16.055
1_10600040	10.9	11	2002	77.5	1990	13.34	15.2
1_10600040	10.9	11	2002	77.5	1995	12.68	14.71
1_10600040	10.9	11	2002	77.5	1962	9.88	16.055
1_10600040	10.9	11	2002	77.5	1993	15.54	16.063
1_10600040	10.9	11	2002	77.5	1962	0	6.65
1_10600040	10.9	11	2002	77.5	2006	9.88	13.72
1_10600040	10.9	11	2002	77.5	1977	6.65	16.055
1_10600040	10.9	11	2002	77.5	1956	0	9.88
1_10600040	10.9	11	2002	77.5	1978	0	6.65
1_10600040	10.9	11	2002	77.5	1990	0	7.16
1_10600040	10.9	11	2002	77.5	1995	0	1.2
1_10600040	10.9	11	2002	77.5	2008	0	6.7
1_10600040	10.9	11	2002	77.5	1994	1.28	3.63
1_10600040	10.9	11	2002	77.5	1994	3.63	6.85
1_10600040	10.9	11	2008	53.5	2007	6.81	9.43
1_10600040	10.9	11	2008	53.5	1993	7.1	9.45
1_10600040	10.9	11	2008	53.5	2009	15.46	16.063
1_10600040	10.9	11	2008	53.5	1990	15.2	16.055
1_10600040	10.9	11	2008	53.5	2006	15.16	16.055

Figure 3: Merged database with IRI and age

To remove the unreasonable roadway sections, only the roadway sections of which “OFFSET_FROM” is greater than or equal to “BEGIN_FROM” and “OFFSET_TO” is smaller than and equal to “END_TO” (Figure 4) remained in the IRI_AGE database. Otherwise, roadway sections in the two databases are not matching spatially, and thus are considered unreasonable and removed. This process is illustrated in Figure 4.

The roadway sections were further purged using a condition, which is that a roadway section was kept in the database only if its “Year Comp” is smaller than or equal to “EFF_YEAR” and is closest to “EFF_YEAR” (Figure 5). This is because for the same roadway section, it may be treated for several times and have several “Year Comps”. This step is to select the reasonable construction year for each IRI record.



Merged Table (1)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	BEGIN_FROM	END_TO	Year Comp
1_10000040	0.0	0.1	1998	67	0.0	2.1	1980
1_10000040	0.0	0.1	1998	67	0.0	2.1	1997
1_10000040	0.0	0.1	1998	67	2.1	3.4	2000
1_10000040	0.0	0.1	1998	67	2.1	3.4	2002
1_10000040	0.1	0.2	2000	78	0.0	2.1	1980
1_10000040	0.1	0.2	2000	78	0.0	2.1	1997
1_10000040	0.1	0.2	2000	78	2.1	3.4	2000
1_10000040	0.1	0.2	2000	78	2.1	3.4	2002

If OFFSET_FROM > =BEGIN_FROM and OFFSET_TO < =BEGIN_TO, keep the row.

Merged Table (2)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	BEGIN_FROM	END_TO	Year Comp
1_10000040	0.0	0.1	1998	67	0.0	2.1	1980
1_10000040	0.0	0.1	1998	67	0.0	2.1	1997
1_10000040	0.1	0.2	2000	78	0.0	2.1	1980
1_10000040	0.1	0.2	2000	78	0.0	2.1	1997

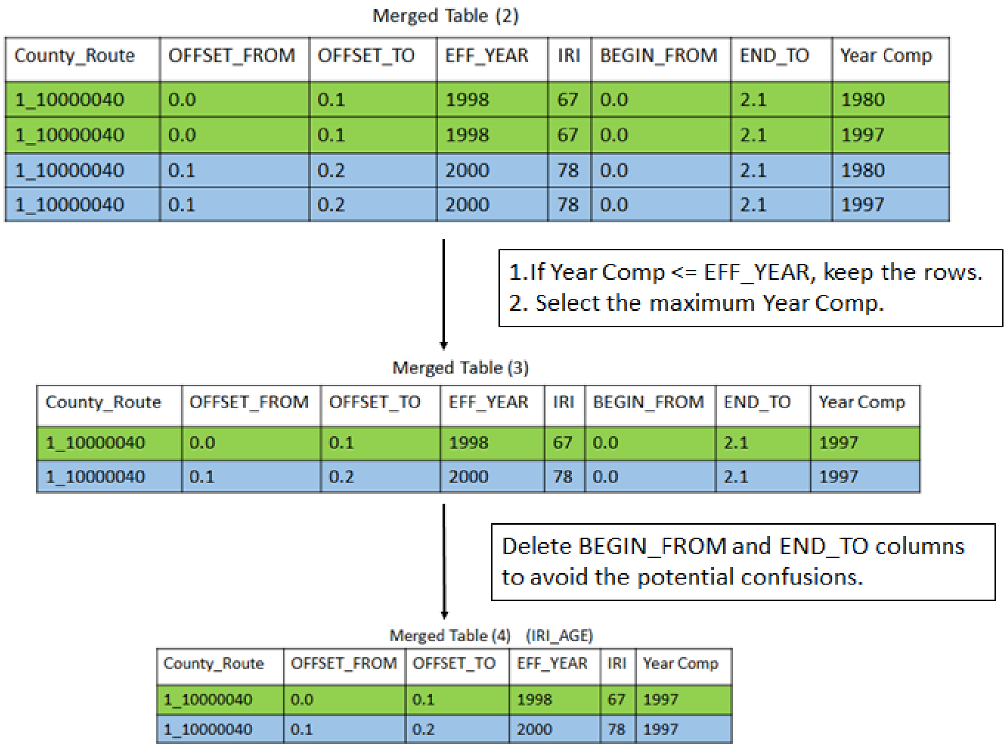
Figure 4: The example process of merging databases (2)

The code used in Access to achieve this goal is:

"SELECT COUNTY_ROUTE, OFFSET_FROM, OFFSET_TO, EFF_YEAR, IRI, MAX(YearComp) FROM IRI_AGE

GROUP BY COUNTY_ROUTE, OFFSET_FROM, OFFSET_TO, EFF_YEAR, IRI;"

The last step is to derive age for each IRI record. It is calculated by subtracting "Year Comp" from "EFF_YEAR"



Merged Table (2)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	BEGIN_FROM	END_TO	Year Comp
1_10000040	0.0	0.1	1998	67	0.0	2.1	1980
1_10000040	0.0	0.1	1998	67	0.0	2.1	1997
1_10000040	0.1	0.2	2000	78	0.0	2.1	1980
1_10000040	0.1	0.2	2000	78	0.0	2.1	1997

1.If Year Comp <= EFF_YEAR, keep the rows.
2. Select the maximum Year Comp.

Merged Table (3)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	BEGIN_FROM	END_TO	Year Comp
1_10000040	0.0	0.1	1998	67	0.0	2.1	1997
1_10000040	0.1	0.2	2000	78	0.0	2.1	1997

Delete BEGIN_FROM and END_TO columns
to avoid the potential confusions.

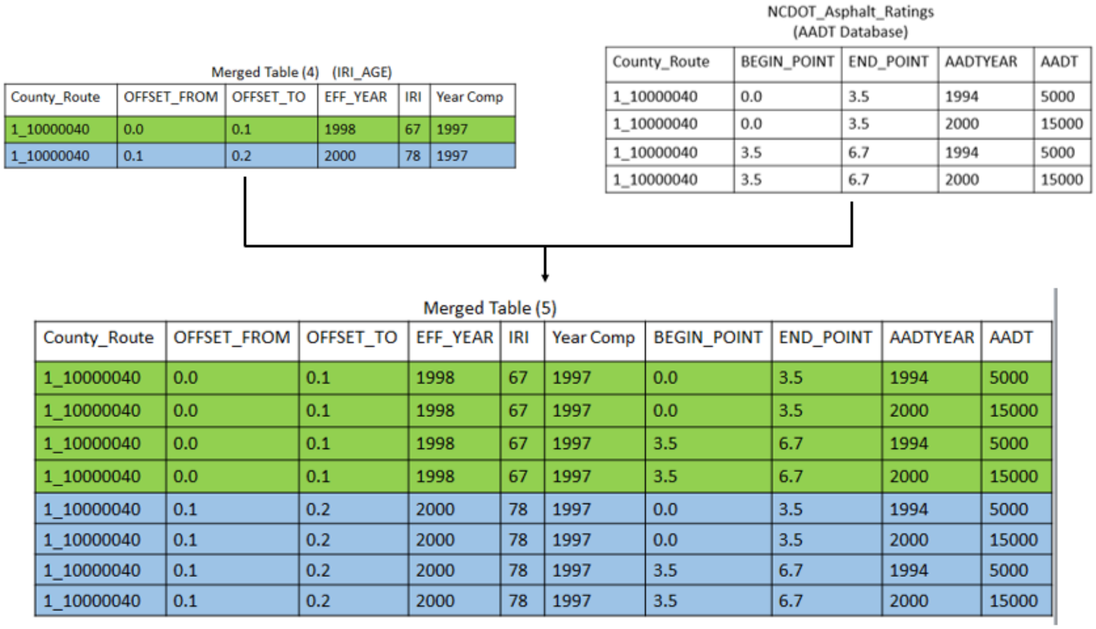
Merged Table (4) (IRI_AGE)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	Year Comp
1_10000040	0.0	0.1	1998	67	1997
1_10000040	0.1	0.2	2000	78	1997

Figure 5: The example process of merging databases (3)

(3) Merging the AADT and the IRI_ AGE databases into a new database, IRI_AGE_AADT

The purpose of this step is to create a new database, IRI_AGE_AADT, which includes IRI, age, and AADT of roadway sections. This process involved several steps. Similar to the previous section, the connection of the "IRI_AGE" database and the NCDOT_Asphalt_Ratings database was built in Access by defining county and route attributes as "primary keys". "OFFSET_FROM", "OFFSET_TO", "EFF_YEAR", "NC_IRI_L_R_AVG" and "Year Comp" from IRI_AGE (merged database including IRI and age), and "BEGINE_POINT", "END_POINT", "EFF_YEAR1", "AADT" from the NCDOT_Asphalt_Ratings database were selected in order to merge AADT values into the IRI_AGE database (Figure 6).



Merged Table (4) (IRI_AGE)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	Year Comp
1_10000040	0.0	0.1	1998	67	1997
1_10000040	0.1	0.2	2000	78	1997

NCDOT_Asphalt_Ratings
(AADT Database)

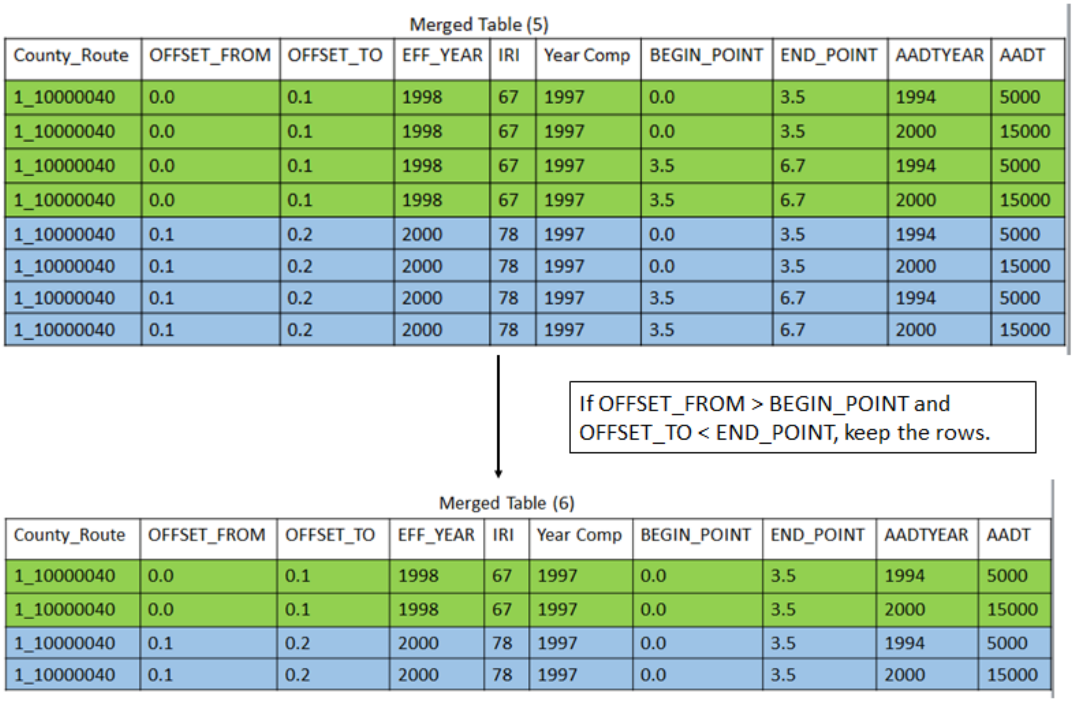
County_Route	BEGIN_POINT	END_POINT	AADTYEAR	AADT
1_10000040	0.0	3.5	1994	5000
1_10000040	0.0	3.5	2000	15000
1_10000040	3.5	6.7	1994	5000
1_10000040	3.5	6.7	2000	15000

Merged Table (5)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	Year Comp	BEGIN_POINT	END_POINT	AADTYEAR	AADT
1_10000040	0.0	0.1	1998	67	1997	0.0	3.5	1994	5000
1_10000040	0.0	0.1	1998	67	1997	0.0	3.5	2000	15000
1_10000040	0.0	0.1	1998	67	1997	3.5	6.7	1994	5000
1_10000040	0.0	0.1	1998	67	1997	3.5	6.7	2000	15000
1_10000040	0.1	0.2	2000	78	1997	0.0	3.5	1994	5000
1_10000040	0.1	0.2	2000	78	1997	0.0	3.5	2000	15000
1_10000040	0.1	0.2	2000	78	1997	3.5	6.7	1994	5000
1_10000040	0.1	0.2	2000	78	1997	3.5	6.7	2000	15000

Figure 6: The example process of merging databases (4)

Roadway sections were kept in the final database, if their AADT “OFFSET_FROM” is greater than “BEGINE_POINT” and “OFFSET_TO” is smaller than “END_POINT” to ensure spatial matching (Figure 7).



Merged Table (5)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	Year Comp	BEGIN_POINT	END_POINT	AADTYEAR	AADT
1_10000040	0.0	0.1	1998	67	1997	0.0	3.5	1994	5000
1_10000040	0.0	0.1	1998	67	1997	0.0	3.5	2000	15000
1_10000040	0.0	0.1	1998	67	1997	3.5	6.7	1994	5000
1_10000040	0.0	0.1	1998	67	1997	3.5	6.7	2000	15000
1_10000040	0.1	0.2	2000	78	1997	0.0	3.5	1994	5000
1_10000040	0.1	0.2	2000	78	1997	0.0	3.5	2000	15000
1_10000040	0.1	0.2	2000	78	1997	3.5	6.7	1994	5000
1_10000040	0.1	0.2	2000	78	1997	3.5	6.7	2000	15000

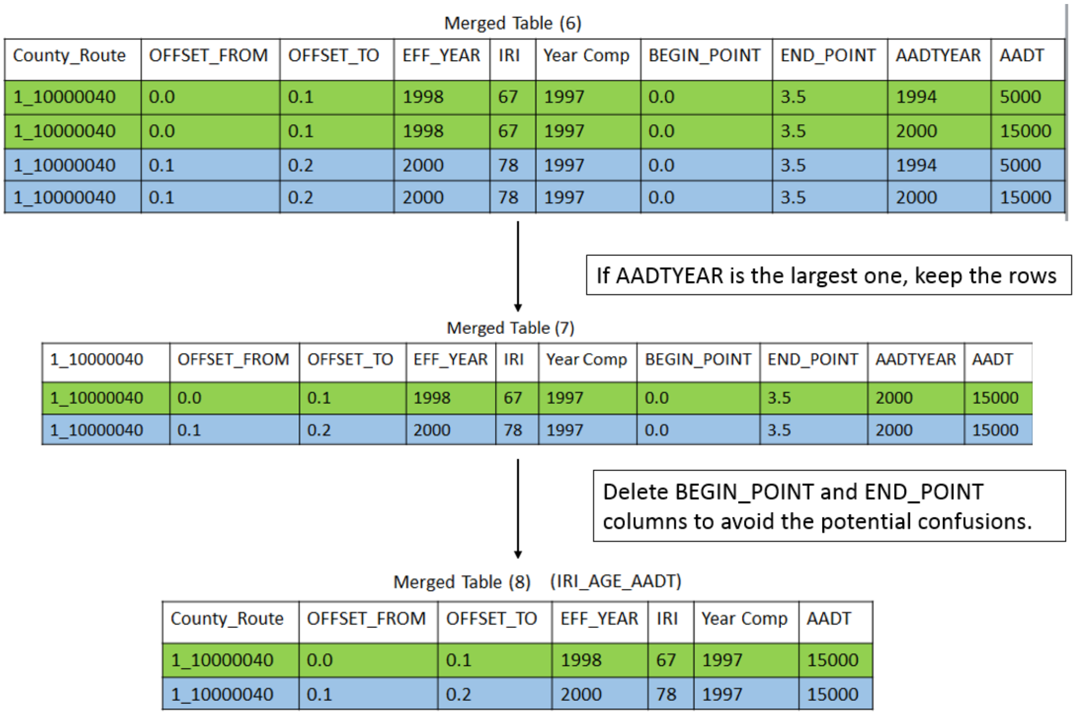
If OFFSET_FROM > BEGIN_POINT and OFFSET_TO < END_POINT, keep the rows.

Merged Table (6)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	Year Comp	BEGIN_POINT	END_POINT	AADTYEAR	AADT
1_10000040	0.0	0.1	1998	67	1997	0.0	3.5	1994	5000
1_10000040	0.0	0.1	1998	67	1997	0.0	3.5	2000	15000
1_10000040	0.1	0.2	2000	78	1997	0.0	3.5	1994	5000
1_10000040	0.1	0.2	2000	78	1997	0.0	3.5	2000	15000

Figure 7: The example process of merging databases (5)

The next step is to select the sections that have the most recent AADT values (Figure 9). This is because for each IRI record section, it may have more than one AADT record collected at different times. In this step, it was assumed that the most reasonable AADT value for each IRI record section is the most recent one. For a practical example, as shown in Figure 8, the AADT effective year selected for the IRI in year 1998 was year 2000, and the AADT effective year selected for the IRI in year 2000 was year 2000 as well. Figure 9 shows the practical process of merging databases. As shown in this figure, the IRI value in 2001 has various AADT values collected in different years, and the most recent year, 2010, was used.



Merged Table (6)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	Year Comp	BEGIN_POINT	END_POINT	AADTYEAR	AADT
1_10000040	0.0	0.1	1998	67	1997	0.0	3.5	1994	5000
1_10000040	0.0	0.1	1998	67	1997	0.0	3.5	2000	15000
1_10000040	0.1	0.2	2000	78	1997	0.0	3.5	1994	5000
1_10000040	0.1	0.2	2000	78	1997	0.0	3.5	2000	15000

If AADTYEAR is the largest one, keep the rows

Merged Table (7)

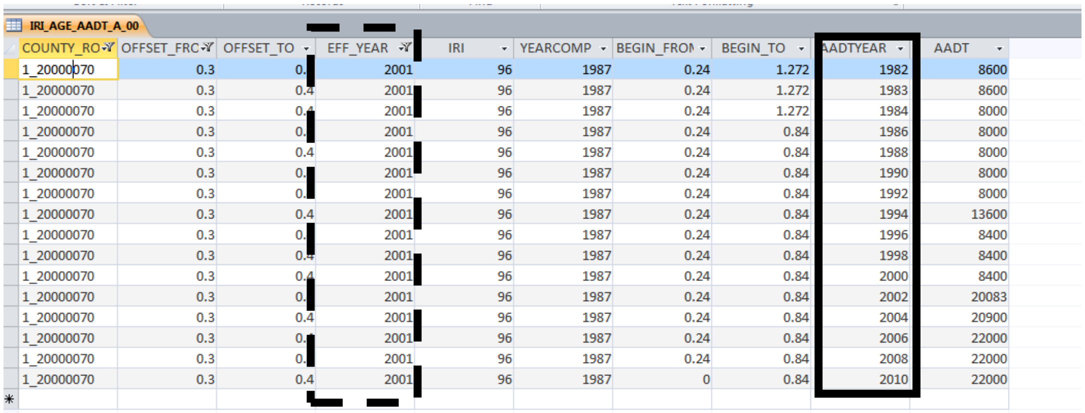
1_10000040	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	Year Comp	BEGIN_POINT	END_POINT	AADTYEAR	AADT
1_10000040	0.0	0.1	1998	67	1997	0.0	3.5	2000	15000
1_10000040	0.1	0.2	2000	78	1997	0.0	3.5	2000	15000

Delete BEGIN_POINT and END_POINT columns to avoid the potential confusions.

Merged Table (8) (IRI_AGE_AADT)

County_Route	OFFSET_FROM	OFFSET_TO	EFF_YEAR	IRI	Year Comp	AADT
1_10000040	0.0	0.1	1998	67	1997	15000
1_10000040	0.1	0.2	2000	78	1997	15000

Figure 8: The sample process of merging databases (6)



COUNTY_RO	OFFSET_FRC	OFFSET_TO	EFF_YEAR	IRI	YEARCOMP	BEGIN_FROM	BEGIN_TO	AADTYEAR	AADT
1_20000070	0.3	0.	2001	96	1987	0.24	1.272	1982	8600
1_20000070	0.3	0.4	2001	96	1987	0.24	1.272	1983	8600
1_20000070	0.3	0.4	2001	96	1987	0.24	1.272	1984	8000
1_20000070	0.3	0.	2001	96	1987	0.24	0.84	1986	8000
1_20000070	0.3	0.4	2001	96	1987	0.24	0.84	1988	8000
1_20000070	0.3	0.	2001	96	1987	0.24	0.84	1990	8000
1_20000070	0.3	0.	2001	96	1987	0.24	0.84	1992	8000
1_20000070	0.3	0.4	2001	96	1987	0.24	0.84	1994	13600
1_20000070	0.3	0.	2001	96	1987	0.24	0.84	1996	8400
1_20000070	0.3	0.4	2001	96	1987	0.24	0.84	1998	8400
1_20000070	0.3	0.4	2001	96	1987	0.24	0.84	2000	8400
1_20000070	0.3	0.	2001	96	1987	0.24	0.84	2002	20083
1_20000070	0.3	0.4	2001	96	1987	0.24	0.84	2004	20900
1_20000070	0.3	0.	2001	96	1987	0.24	0.84	2006	22000
1_20000070	0.3	0.	2001	96	1987	0.24	0.84	2008	22000
1_20000070	0.3	0.4	2001	96	1987	0	0.84	2010	22000

Figure 9: Merged database with IRI, age, and AADT values

The code used in Access to achieve these goals is:

/Selecting the most recent AADT values for each roadway sections/

"SELECT COUNTY_ROUTE, OFFSET_FROM, OFFSET_TO, EFF_YEAR, IRI, YearComp, MAX(AADTYEAR) FROM IRI_AGE_AADT

GROUP BY COUNTY_ROUTE, OFFSET_FROM, OFFSET_TO, EFF_YEAR, IRI, YearComp;"

As a result, the roadway section database including IRI, age and AADT is obtained, namely IRI_AGE_AADT.

3.2.3 Creating Roadway Families

After obtaining the merged database IRI_AGE_AADT, it was divided into families based on the roadway classification (Interstate, US, NC, or SR) and its most recent AADT value. A list of all the families is shown in Table 1.

3.2.4 Dividing a Family into Subfamilies

Because this research is to develop the relationship between initial IRI and network performance IRI, network performance IRI will be studied based on different initial IRI ranges. Thus, each family is divided into subfamilies in term of initial IRI values as shown in Table 2.

Table 2: Subfamilies of pavement family definition

Subfamily	Subfamily_60	Subfamily_70	Subfamily_80
Initial IRI Range (inch/mile)	0 ~ 60	60 ~ 70	70 ~ 80

Roadways which have initial IRI values greater than 80 inch/mile were not included in this research. This is because an initial IRI value greater than 80 inch/mile is very close to an IRI value of 103 inch/mile that was identified as the threshold of acceptable ride quality achieved in a previous study (Chen, et al., 2014), which means the pavements will need be repaired soon after they are treated or constructed. Outliers were excluded in this process. The extremely large IRI values at age of 0, 1, 2, and 3 were considered as outliers, as shown in the SAS code in Figure 10.

3.3 The Relationship between Initial IRI and Network IRI

In this study, if roadway sections in all subfamilies with smaller initial IRI values have smaller rates of change in network IRI, it can be concluded that pavements with smaller initial IRI, meaning smoother surface, will have slower IRI deterioration rates. In other words, if the pavement is constructed with a high quality (indicated by a small initial IRI value), this pavement would stay in good condition for a longer time (indicated by the slower IRI deterioration rates). Linear regression was conducted to investigate this relationship, as described in the next section.

3.3.1 Relationship between Network IRI and Age

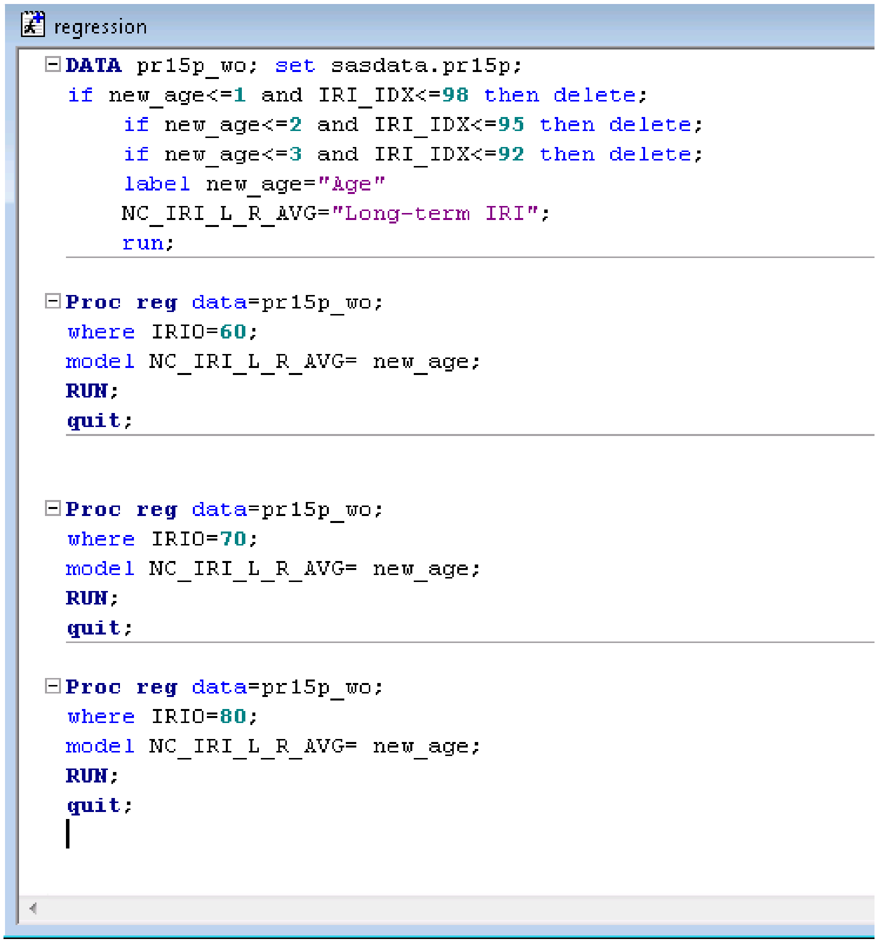
Linear regression analysis was conducted to investigate the relationship between network IRI and age for each subfamily. Based on the way the subfamilies were developed, roadways' classification, AADT, and initial IRI were already considered in the analysis.

The model used is,

$$IRI = \alpha + \beta * AGE$$

where AGE is age of pavement, IRI is network IRI, α and β are parameters,

The resulting β values indicate the rates of deterioration of IRI for a specific subfamily. The code used in SAS is shown in Figure 10. "New_age" indicates the age of the pavements, "NC_IRI_L_R_AVG" indicates the network IRI, and "IRI_IDX" represents the IRI index, which ranges from 0 to 100, with 100 representing the perfect smooth condition. "IRI_IDX" was used to identify outliers in this study. The thresholds, "IRI_IDX" values of 98, 95, and 92, were determined by the researchers, to remove the most extreme IRI ratings, while preserving the majority of the observations.



```
DATA pr15p_wo; set sasdata.pr15p;
if new_age<=1 and IRI_IDX<=98 then delete;
    if new_age<=2 and IRI_IDX<=95 then delete;
    if new_age<=3 and IRI_IDX<=92 then delete;
    label new_age="Age"
    NC_IRI_L_R_AVG="Long-term IRI";
    run;

Proc reg data=pr15p_wo;
where IRIO=60;
model NC_IRI_L_R_AVG= new_age;
RUN;
quit;


Proc reg data=pr15p_wo;
where IRIO=70;
model NC_IRI_L_R_AVG= new_age;
RUN;
quit;

Proc reg data=pr15p_wo;
where IRIO=80;
model NC_IRI_L_R_AVG= new_age;
RUN;
quit;
```

Figure 10: SAS Code for linear regression

Table 4 shows β values for all the subfamilies. “N/A” in this table indicates the data is not available, because of the insufficient data for some subfamilies. The results of regression analysis are included in appendix A.

To examine β values for each subfamily, descriptive statistics were obtained and summarized in Table 5. The outliers were defined as the value lying outside of two times of the standard deviation. According to the descriptive statistics, the outliers of subfamily_60, subfamily_70, and subfamily_80 fall outside of ranges of (-4.044, 7.34), (0.0937, 1.5889), and (-0.2208, 2.5724), respectively. The final reasonable β values are included in Table 5.

Table 3: Rates of change in IRI values

Family	Subfamily		
	Subfamily _60	Subfamily _70	Subfamily _80
Interstate 0-50k	0.37010	N/A	N/A
Interstate 50kplus	0.28608	N/A	N/A
US 0-5k	0.53576	1.00126	1.46503
US 5-15k	0.99852	1.16400	0.62123
US 15-30k	0.97747	0.44515	1.49026
US 30kplus	0.49645	0.29572	0.58778
NC 0-1k	0.92099	0.69980	N/A
NC 1-5k	0.83556	N/A	N/A
NC 5-15k	0.72083	N/A	0.58660
NC 15kplus	0.44381	0.68594	0.54262
SR 0-1k BSR	1.85725	N/A	0.74153
SR 0-1k BSS	N/A	N/A	N/A
SR 0-1K PR	2.19287	0.92448	1.96254
SR 0-1K PS	N/A	N/A	N/A
SR 1-5k PR	1.13650	0.38560	0.68261
SR 1kplus BSR	11.75481	1.47318	2.70794
SR 5-15k PR	1.18662	0.96319	0.96519
SR 15kplus PR	N/A	1.21551	1.75598

Table 4: Descriptive statistics of β Values

Subfamily_60		Subfamily_70		Subfamily_80	
Minimum	0.286	Minimum	0.2957	Minimum	0.5426
Maximum	11.755	Maximum	1.4732	Maximum	2.7079
Mean	1.648	Mean	0.8413	Mean	1.1758
Mode	≈0.911	Mode	≈0.3755	Mode	≈0.5723
Median	0.921	Median	0.9245	Median	0.7415
Std Dev	2.846	Std Dev	0.3738	Std Dev	0.6983
Skewness	3.6507	Skewness	0.0449	Skewness	1.0546
Kurtosis	16.7376	Kurtosis	2.1027	Kurtosis	3.3524
Sum	24.71362	Sum	9.25383	Sum	14.10931
Count	15	Count	11	Count	12

3.3.2 ANOVA for Deteriorate Rates

ANOVA was conducted to determine if β values of subfamily_60, subfamily_70, and subfamily_80 are equal to each other. The hypotheses are:

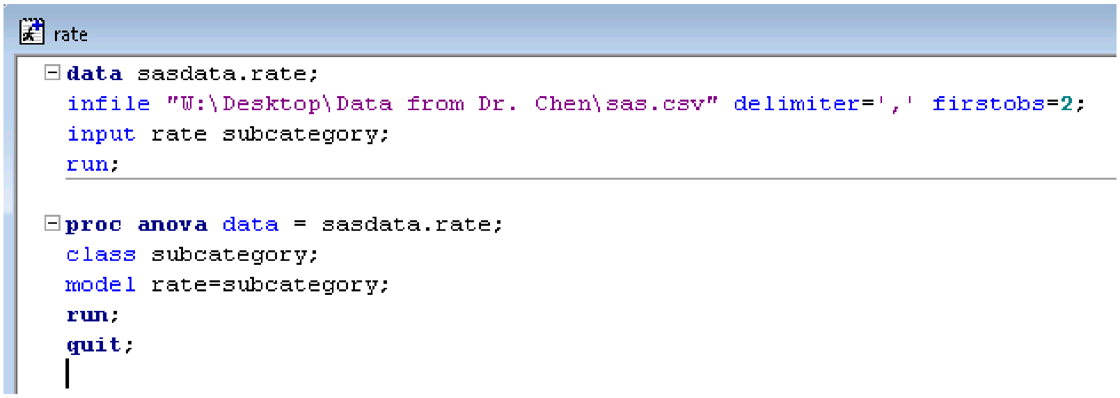
H$_0$: the average rates of change in IRI (the mean β values) are the same for these three subfamilies.

Ha: at least two of the means are different from each other.

Table 5: Final β Values

Family	Subfamily		
	Subfamily _60	Subfamily _70	Subfamily _80
US 0-5k	0.53576	1.00126	1.46503
US 5-15k	0.99852	1.16400	0.62123
US 15-30k	0.97747	0.44515	1.49026
US 30kplus	0.49645	0.29572	0.58778
NC 15kplus	0.44381	0.68594	0.54262
SR 0-1K PR	2.19287	0.92448	1.96254
SR 1-5k PR	1.13650	0.38560	0.68261
SR 5-15k PR	1.18662	0.96319	0.96519

The code used in SAS is shown in Figure 11.

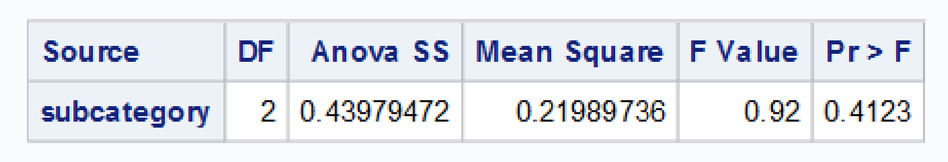


```
data sasdata.rate;
infile "W:\Desktop\Data from Dr. Chen\sas.csv" delimiter=',' firstobs=2;
input rate subcategory;
run;

proc anova data = sasdata.rate;
class subcategory;
model rate=subcategory;
run;
quit;
```

Figure 11: Code of ANOVA

Table 7 shows the test results. The p-value of the ANOVA is 0.4123, indicating that it was failed to reject the null hypothesis at the 0.05 significant level. This means that there is no significant difference between these three subfamilies.

Table 6: ANOVA results



Source	DF	Anova SS	Mean Square	F Value	Pr > F
subcategory	2	0.43979472	0.21989736	0.92	0.4123

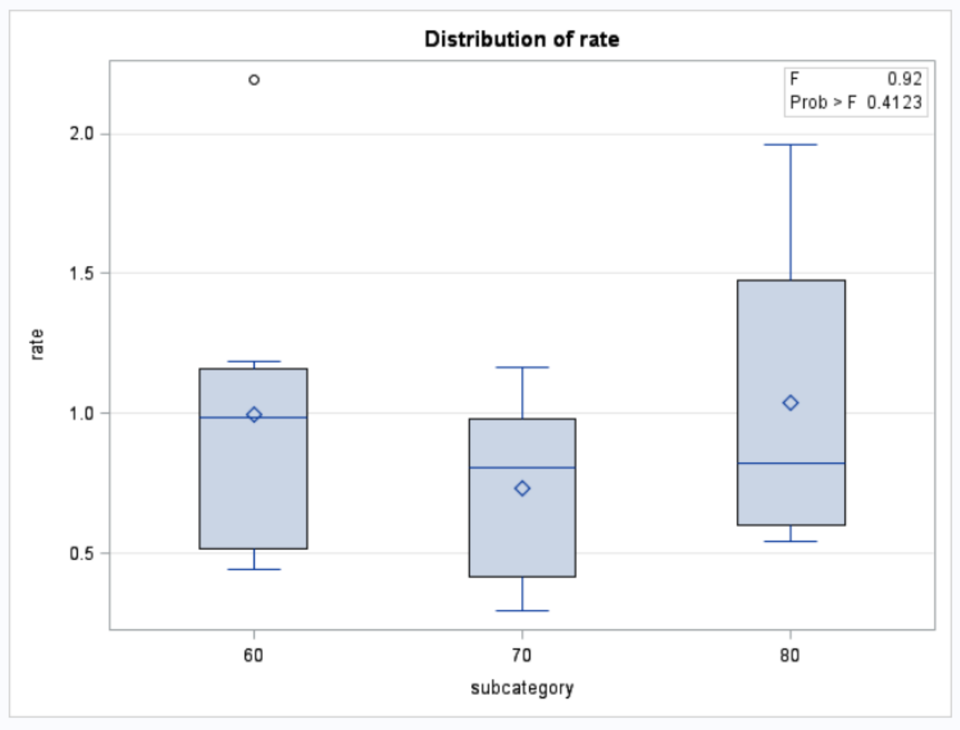


Figure 12: Boxplots of β values for three subfamilies

The boxplot (Figure 12) also shows that the average deteriorate rates of IRI for subfamily_60, subfamily_70, and subfamily_80 are not significantly different. It should be noted that, in this regression analysis, the factors which have been considered are roadway classifications, initial IRI, and age. Based on the literature review, other factors can also affect pavement roughness, including environmental factors, pavement structures, and pavement materials. Therefore, the next step was to include an additional factor, locations of roadway sections that has been collected by NCDOT in the further analysis, as described in the next section.

3.3.3 Contrasts for analyzing Network IRI Using Different Initial IRI

To further investigate the relationship between initial IRI and long term network performance IRI, the locations of roadway sections were included in the analyses. As shown in Table 7, when considering the location factor, each pavement family has 9 subfamilies. The location factor has three levels, i.e., Coastal, Mountains, and Piedmont, representing three geographical regions in North Carolina. AADT was already considered when creating initial roadway families. Therefore, the factors that were included in the analyses were roadway classification, IRI, age, AADT, and location. As an example shown in Table 7, the pavement family of Interstate_0-50k has nine subfamilies with different initial IRI, in each of the locations (the coastal, mountains, and piedmont regions).

Table 7: Sub categories of pavement family with region

Pavement Family	Region	Initial IRI
Interstate_0-50k	Coastal	IRI_{60}
		IRI_{70}
		IRI_{80}
	Mountains	IRI_{60}
		IRI_{70}
		IRI_{80}
	Piedmont	IRI_{60}
		IRI_{70}
		IRI_{80}

Since locations of pavements are considered as an additional factor, if the subfamilies are divided based on all the factors, the data for each subfamily will be insufficient to conduct the regression analysis. To address this issue, condition data were grouped for pavement families. The multiple regression equation describing the relationship between those factors and network IRI is:

$$
\begin{aligned}
IRI = {} & \alpha + \beta_1 * Region_C + \beta_2 * Region_M + \beta_3 * Region_P + \beta_4 * IRI_{60} + \beta_5 * IRI_{70} \\
& + \beta_6 * IRI_{80} + \beta_7 * (Region_C * IRI_{60}) + \beta_8 * (Region_C * IRI_{70}) + \beta_9 \\
& * (Region_C * IRI_{80}) + \beta_{10} * (Region_M * IRI_{60}) + \beta_{11} \\
& * (Region_M * IRI_{70}) + \beta_{12} * (Region_M * IRI_{80}) + \beta_{13} \\
& * (Region_P * IRI_{60}) + \beta_{14} * (Region_P * IRI_{70}) + \beta_{15} \\
& * (Region_P * IRI_{80}) + \beta_{16} * Age
\end{aligned}
$$

where,

α is constant,

$\beta_1, \beta_2, \ldots, \beta_{16}$ are coefficients,

$Region_c$ is the Coastal region,

$Region_m$ is the Mountains region,

$Region_p$ is the Piedmont region,

IRI_{60} includes roadway sections with initial IRI between 0 and 60,

IRI_{70} includes roadway sections with initial IRI between 60 and 70,

IRI_{80} includes roadway sections with initial IRI between 70 and 80,

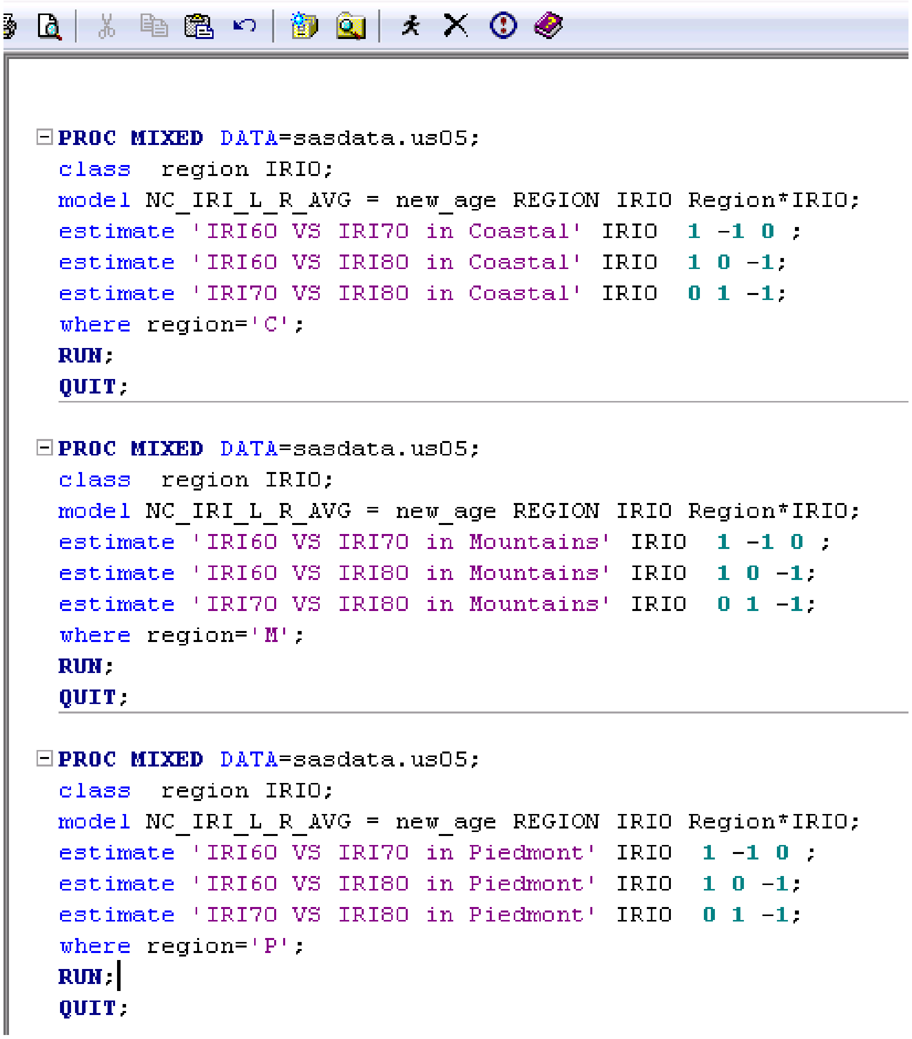
Age is the age of the pavement.

It should be noticed that in this model, β_{16}, which is the coefficient of age, is the same for all regions and initial IRI values. Therefore, β_{16} represents the overall IRI deterioration rate. To investigate how individual subfamily's IRI values would change over time, the following contrasts were analyzed to test the corresponding null hypotheses:

- H_0: $IRI_{60} - IRI_{70} = 0$ in the Coastal region (the network IRI values of subfamily_60 and subfamily_70 at the same age are the same in the coastal region)
- H_0: $IRI_{60} - IRI_{80} = 0$ in the Coastal region (the network IRI values of subfamily_60 and subfamily_80 at the same age are the same in the coastal region)
- H_0: $IRI_{70} - IRI_{80} = 0$ in the Coastal region (the network IRI values of subfamily_70 and subfamily_80 at the same age are the same in the coastal region)
- H_0: $IRI_{60} - IRI_{70} = 0$ in the Mountains region (the network IRI values of subfamily_60 and subfamily_70 at the same age are the same in the Mountains region)
- H_0: $IRI_{60} - IRI_{80} = 0$ in the Mountains region (the network IRI values of subfamily_60 and subfamily_80 at the same age are the same in the Mountains region)
- H_0: $IRI_{70} - IRI_{80} = 0$ in the Mountains region (the network IRI values of subfamily_70 and subfamily_80 at the same age are the same in the Mountains region)
- H_0: $IRI_{60} - IRI_{70} = 0$ in the Piedmont region (the network IRI values of subfamily_60 and subfamily_70 at the same age are the same in the Piedmont region)

- H_0: $IRI_{60} - IRI_{80} = 0$ in the Piedmont region (the network IRI values of subfamily_60 and subfamily_80 at the same age are the same in the Piedmont region)
- H_0: $IRI_{70} - IRI_{80} = 0$ in the Piedmont region (the network IRI values of subfamily_70 and subfamily_80 at the same age are the same in the Piedmont region)

The code used in SAS is shown in Figure 13.

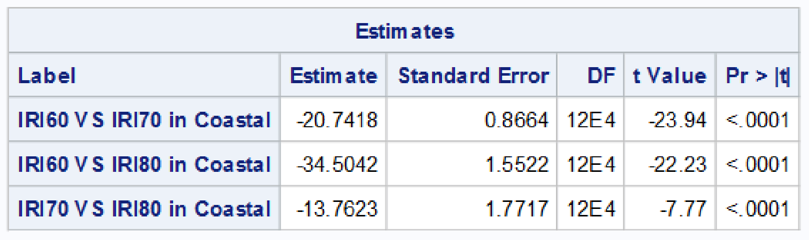


```
PROC MIXED DATA=sasdata.us05;
class  region IRIO;
model NC_IRI_L_R_AVG = new_age REGION IRIO Region*IRIO;
estimate 'IRI60 VS IRI70 in Coastal' IRIO  1 -1 0 ;
estimate 'IRI60 VS IRI80 in Coastal' IRIO  1 0 -1;
estimate 'IRI70 VS IRI80 in Coastal' IRIO  0 1 -1;
where region='C';
RUN;
QUIT;

PROC MIXED DATA=sasdata.us05;
class  region IRIO;
model NC_IRI_L_R_AVG = new_age REGION IRIO Region*IRIO;
estimate 'IRI60 VS IRI70 in Mountains' IRIO  1 -1 0 ;
estimate 'IRI60 VS IRI80 in Mountains' IRIO  1 0 -1;
estimate 'IRI70 VS IRI80 in Mountains' IRIO  0 1 -1;
where region='M';
RUN;
QUIT;

PROC MIXED DATA=sasdata.us05;
class  region IRIO;
model NC_IRI_L_R_AVG = new_age REGION IRIO Region*IRIO;
estimate 'IRI60 VS IRI70 in Piedmont' IRIO  1 -1 0 ;
estimate 'IRI60 VS IRI80 in Piedmont' IRIO  1 0 -1;
estimate 'IRI70 VS IRI80 in Piedmont' IRIO  0 1 -1;
where region='P';
RUN;
QUIT;
```

Figure 13: Code of ANOVA contrast

Because of the unbalanced sample sizes of the Interstate families, not all contrasts of Interstate_0-50k and Interstate_50kplus were performed. Because of insufficient data, contrasts of SR_BSS_0-1k, SR_BSR_0-1k, SR_PR_0-1k, and SR_PS_0-1k were not analyzed. As two examples, the results of US_0-5k and NC_1-5k are shown in the Table 8 to Table 13. Detailed results are included in Appendix B.

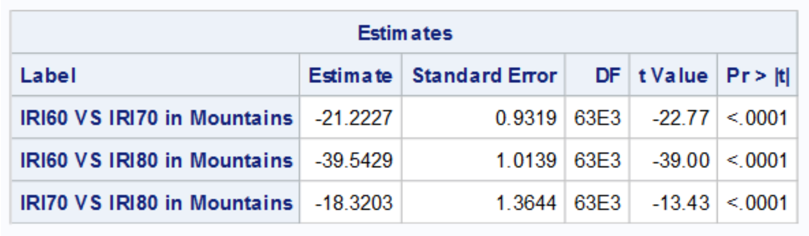
Table 8: Estimates of contrasts: US 0-5k in coastal



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Coastal	-20.7418	0.8664	12E4	-23.94	<.0001
IRI60 VS IRI80 in Coastal	-34.5042	1.5522	12E4	-22.23	<.0001
IRI70 VS IRI80 in Coastal	-13.7623	1.7717	12E4	-7.77	<.0001

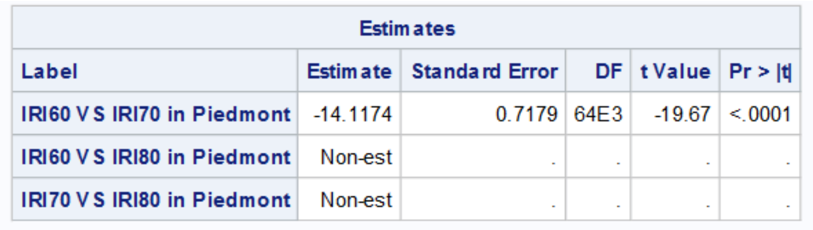
Table 9: Estimates of contrasts: US 0-5k in mountains



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Mountains	-21.2227	0.9319	63E3	-22.77	<.0001
IRI60 VS IRI80 in Mountains	-39.5429	1.0139	63E3	-39.00	<.0001
IRI70 VS IRI80 in Mountains	-18.3203	1.3644	63E3	-13.43	<.0001

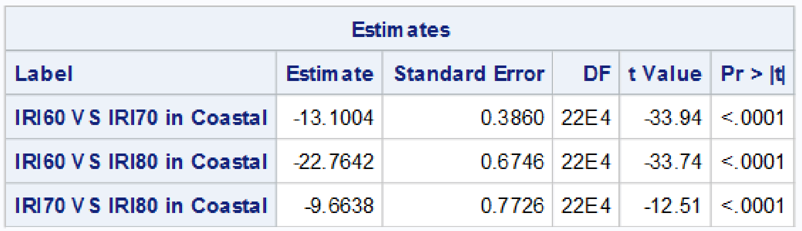
Table 10: Estimates of contrasts: US 0-5k in piedmont



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Piedmont	-14.1174	0.7179	64E3	-19.67	<.0001
IRI60 VS IRI80 in Piedmont	Non-est	.	.	.	.
IRI70 VS IRI80 in Piedmont	Non-est	.	.	.	.

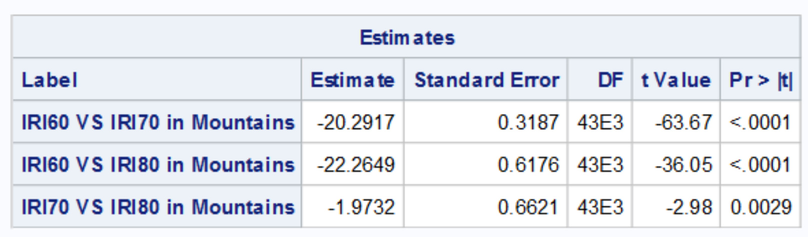
Table 11: Estimates of contrasts: NC 1-5k in coastal



Estimates

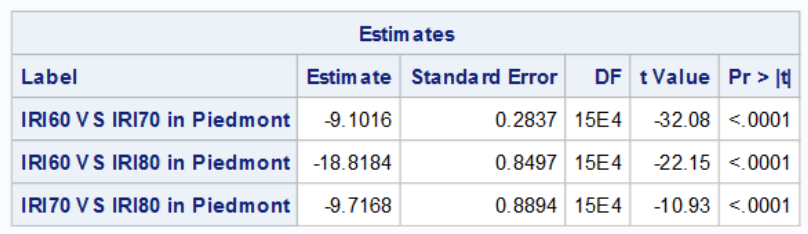
Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Coastal	-13.1004	0.3860	22E4	-33.94	<.0001
IRI60 VS IRI80 in Coastal	-22.7642	0.6746	22E4	-33.74	<.0001
IRI70 VS IRI80 in Coastal	-9.6638	0.7726	22E4	-12.51	<.0001

Table 12: Estimates of contrasts: NC 1-5k in mountains



Estimates					
Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Mountains	-20.2917	0.3187	43E3	-63.67	<.0001
IRI60 VS IRI80 in Mountains	-22.2649	0.6176	43E3	-36.05	<.0001
IRI70 VS IRI80 in Mountains	-1.9732	0.6621	43E3	-2.98	0.0029

Table 13: Estimates of contrasts: NC 1-5k in piedmont



Estimates					
Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Piedmont	-9.1016	0.2837	15E4	-32.08	<.0001
IRI60 VS IRI80 in Piedmont	-18.8184	0.8497	15E4	-22.15	<.0001
IRI70 VS IRI80 in Piedmont	-9.7168	0.8894	15E4	-10.93	<.0001

Table 14: Summary of contrast results

Pavement Family	Location of Pavement	Order
Interstate_0-50k	Coastal	N/A
	Mountains	$IRI_{60} < IRI_{70}$
	Piedmont	N/A
Interstate_50kplus	Coastal	N/A
	Mountains	N/A
	Piedmont	$IRI_{70} < IRI_{60}$
US_0-5k	Coastal	$IRI_{60} < IRI_{70} < IRI_{80}$
	Mountains	$IRI_{60} < IRI_{70} < IRI_{80}$
	Piedmont	$IRI_{60} < IRI_{70}$
US_5-15k	Coastal	$IRI_{60} < IRI_{80} < IRI_{70}$
	Mountains	$IRI_{60} < IRI_{70} < IRI_{80}$
	Piedmont	$IRI_{60} < IRI_{80} < IRI_{70}$
US_15-30k	Coastal	$IRI_{60} < IRI_{80} < IRI_{70}$
	Mountains	$IRI_{60} < IRI_{70} < IRI_{80}$
	Piedmont	$IRI_{60} < IRI_{70} < IRI_{80}$
US_30kplus	Coastal	$IRI_{60} < IRI_{70} < IRI_{80}$
	Mountains	$IRI_{70} < IRI_{60} < IRI_{80}$
	Piedmont	$IRI_{60} < IRI_{70}$
NC_0-1k	Coastal	$IRI_{60} < IRI_{70} < IRI_{80}$
	Mountains	$IRI_{60} < IRI_{70} < IRI_{80}$

	Piedmont	$IRI_{60} < IRI_{70} < IRI_{80}$
NC_1-5k	Coastal	$IRI_{60} < IRI_{70} < IRI_{80}$
	Mountains	$IRI_{60} < IRI_{70} < IRI_{80}$
	Piedmont	$IRI_{60} < IRI_{70} < IRI_{80}$
NC_5-15k	Coastal	$IRI_{60} < IRI_{70} < IRI_{80}$
	Mountains	$IRI_{60} < IRI_{70} < IRI_{80}$
	Piedmont	$IRI_{60} < IRI_{70} < IRI_{80}$
NC_15kplus	Coastal	$IRI_{60} < IRI_{70} < IRI_{80}$
	Mountains	$IRI_{70} < IRI_{60} < IRI_{80}$
	Piedmont	$IRI_{60} < IRI_{70} < IRI_{80}$
SR_BSR_1kplus	Coastal	$IRI_{60} < IRI_{70} < IRI_{80}$
	Mountains	N/A
	Piedmont	$IRI_{70} < IRI_{60}$
SR_PR_1-5k	Coastal	$IRI_{60} < IRI_{70} < IRI_{80}$
	Mountains	$IRI_{70} < IRI_{60} < IRI_{80}$
	Piedmont	$IRI_{70} < IRI_{60} < IRI_{80}$
SR_PR_5-15k	Coastal	$IRI_{60} < IRI_{70} < IRI_{80}$
	Mountains	$IRI_{60} < IRI_{70} < IRI_{80}$
	Piedmont	$IRI_{70} < IRI_{60} < IRI_{80}$
SR_PR_15kplus	Coastal	$IRI_{60} < IRI_{80} < IRI_{70}$
	Mountains	N/A
	Piedmont	$IRI_{60} < IRI_{70} < IRI_{80}$

From the analysis results, for most of the subfamilies (25 out of 36, approximately 70%), the null hypotheses were rejected at the 0.05 significant level, as shown in the Table 14, and an ascending order, $IRI_{60} < IRI_{70} < IRI_{80}$, can be concluded. For example, the estimates of contrasts for US_0-5k in Coastal are shown as: $IRI_{60}-IRI_{70}= -20.7$, $IRI_{60}-IRI_{80}= -34.5$, and $IRI_{70}-IRI_{80}= -13.8$, which can be written as $IRI_{80}= IRI_{70} +13.8= IRI_{60} + 34.5$. Therefore, for the US_0-5k family, $IRI_{60} < IRI_{70} < IRI_{80}$. The contrasts of other pavement families are attached to Appendix B. This finding proved that smoother pavements (smaller initial IRI) have longer service lives.

3.4 Prediction of Pavement Service Lives

Linear regression analysis was conducted to predict the service lives of roadways using the following expression:

$$IRI = \alpha + \beta * Age$$

Where,

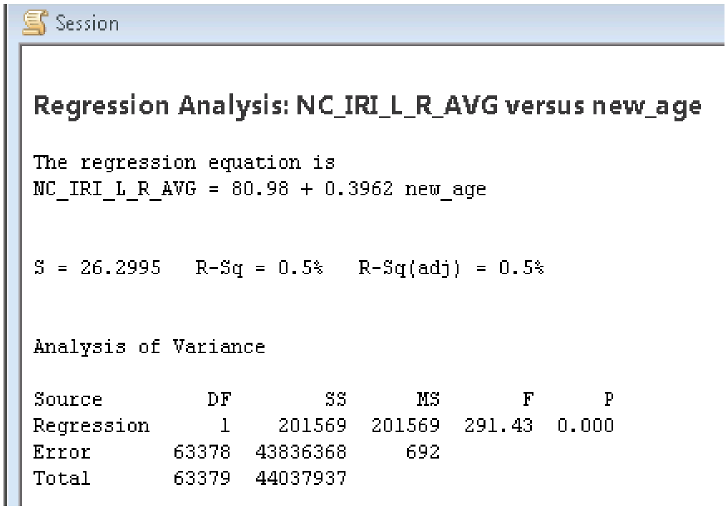
α is constant,

β is the coefficient,

age is the age of pavements

The service lives are estimated for 4 roadway classifications: Interstate, US, NC, and SR. This was based on the assumption that roadways in the same pavement classification perform similarly, therefore, having the same service lives. Minitab was used for this analysis.

The parameter estimates for four pavement classifications are shown in Figure 14 to 21.



```
Regression Analysis: NC_IRI_L_R_AVG versus new_age

The regression equation is
NC_IRI_L_R_AVG = 80.98 + 0.3962 new_age


S = 26.2995   R-Sq = 0.5%   R-Sq(adj) = 0.5%


Analysis of Variance

Source         DF        SS      MS       F      P
Regression      1    201569  201569  291.43  0.000
Error       63378  43836368     692
Total       63379  44037937
```

Figure 14: Regression analysis for Interstate

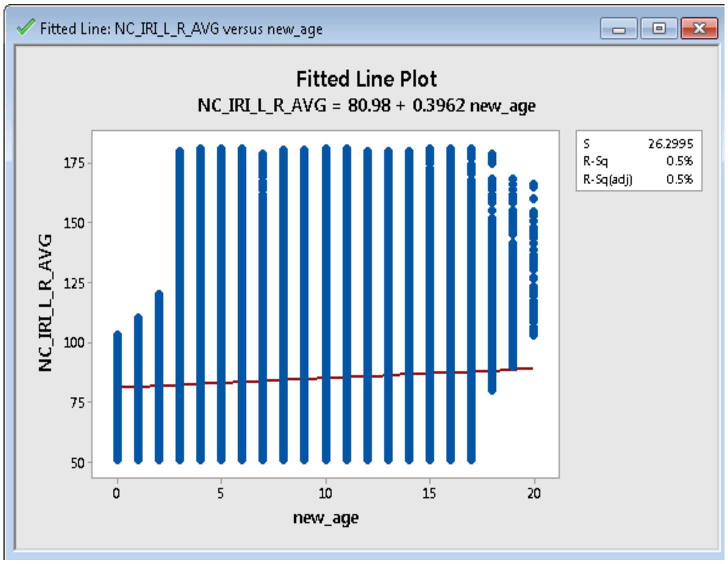
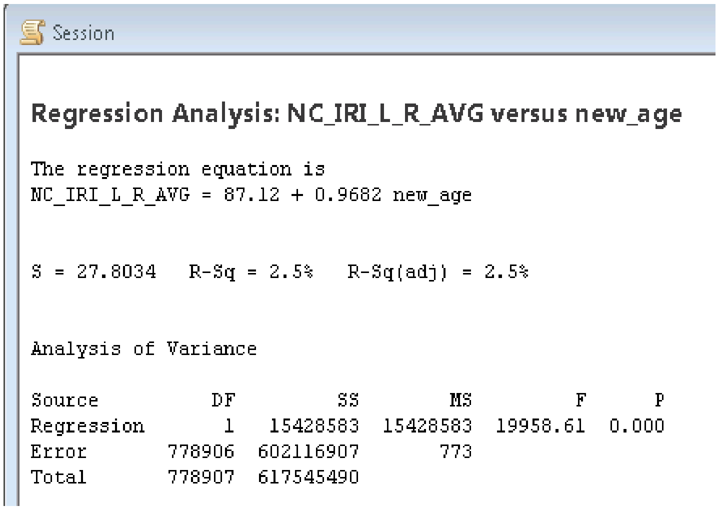


Figure 15: Fitted line plot for Interstate



Regression Analysis: NC_IRI_L_R_AVG versus new_age

```
The regression equation is
NC_IRI_L_R_AVG = 87.12 + 0.9682 new_age


S = 27.8034   R-Sq = 2.5%   R-Sq(adj) = 2.5%


Analysis of Variance

Source          DF         SS         MS         F      P
Regression       1   15428583   15428583  19958.61  0.000
Error       778906  602116907        773
Total       778907  617545490
```

Figure 16: Regression analysis for US

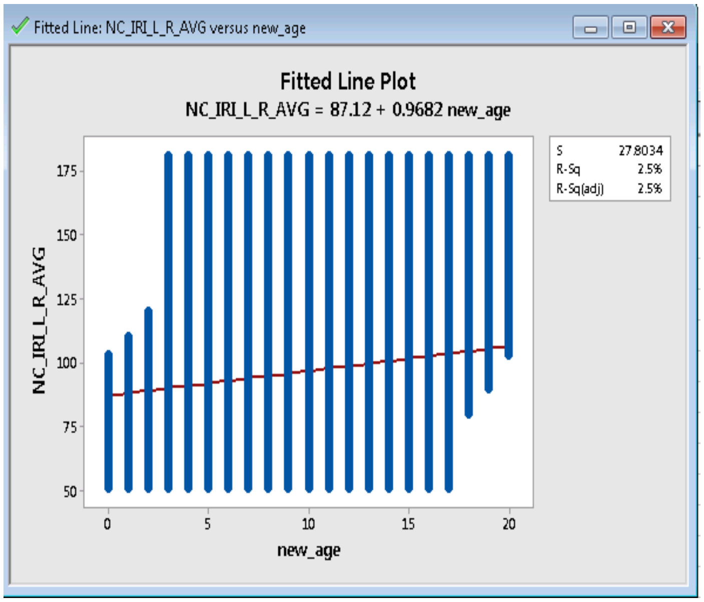
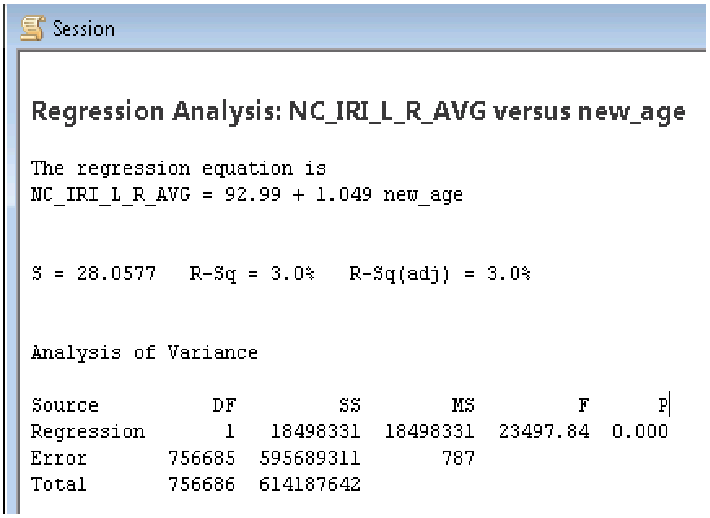


Figure 17: Fitted line plot for US



Session

Regression Analysis: NC_IRI_L_R_AVG versus new_age

```
The regression equation is
NC_IRI_L_R_AVG = 92.99 + 1.049 new_age


S = 28.0577   R-Sq = 3.0%   R-Sq(adj) = 3.0%


Analysis of Variance

Source          DF         SS         MS         F      P
Regression       1   18498331   18498331  23497.84  0.000
Error       756685  595689311        787
Total       756686  614187642
```

Figure 18: Regression analysis result for NC

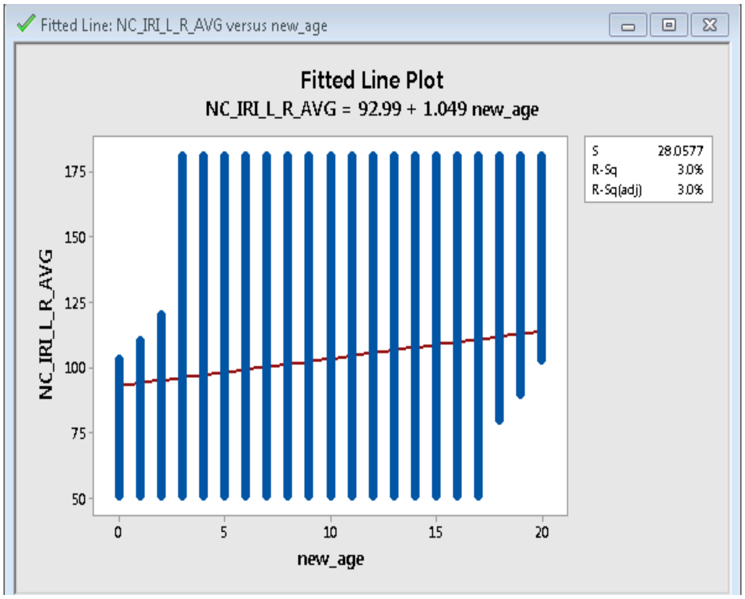
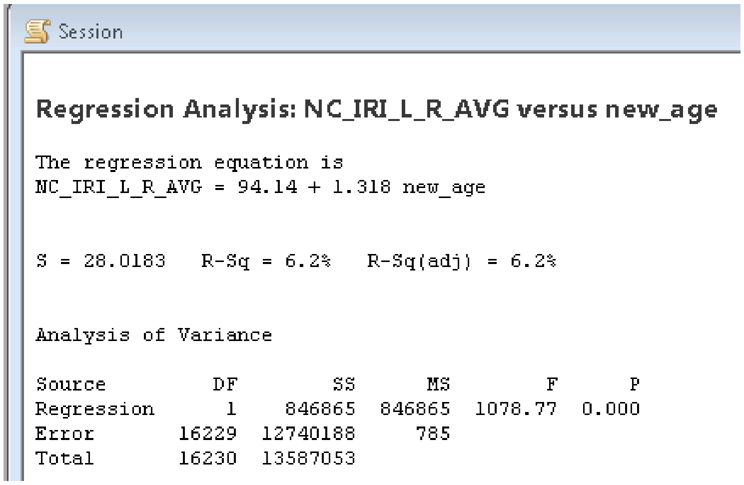


Figure 19: Fitted line plot for NC



```
Regression Analysis: NC_IRI_L_R_AVG versus new_age

The regression equation is
NC_IRI_L_R_AVG = 94.14 + 1.318 new_age


S = 28.0183   R-Sq = 6.2%   R-Sq(adj) = 6.2%


Analysis of Variance

Source         DF        SS      MS        F      P
Regression      1    846865  846865  1078.77  0.000
Error       16229  12740188     785
Total       16230  13587053
```

Figure 20: Regression analysis for SR

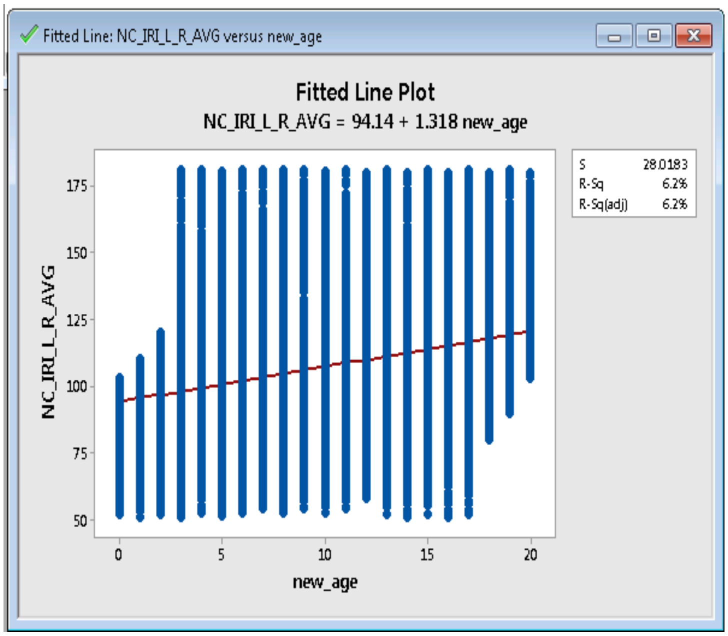


Figure 21: Fitted line plot for SR

The final models for each pavement family are shown in Table 15. The service lives before roadways reach the threshold of 103 in. /mi. are also calculated.

Table 15: Polynomial Models for IRI and age

Pavement Classification	Model	Service Life
Interstate	IRI=80.98+0.3962*Age	55
US	IRI=87.12+0.9682*Age	16.4
NC	IRI=92.99+1.049*Age	9.5
SR	IRI=94.14+1.318*Age	6.7

From Table 15, the estimated service lives for Interstate, US, NC, and SR roadways are 55, 16.4, 9.5, and 6.7 years, respectively. NCDOT recommends that asphalt pavements to be treated in year 12 and 23 (NCDOT, 2014). Compared to the NCDOT recommendations, the service life for Interstate is much longer, and the service lives for US, NC, and SR are comparable. The service life for Interstate is not realistic. The contour plot (Figure 22) and the distribution of age vs. IRI for Interstate (Figure 23) show that there are a large number of IRI values of 75 inch/mile clustering at ages of 6 and 11. This is probably because of survey equipment errors occurred in these two years. These two highly dense groups of IRI values make the service life of Interstate to be a large number. It was decided to exclude this service life from further analyses, and recommend a future study to investigate the possible causes and develop a reasonable solution. Because service lives derived in this study were solely based on IRI, and NCDOT recommendations were obtained based on various different distress and the overall pavement performance, the estimated service lives of US, NC, and SR roadway classifications are reasonable.

The models developed for US, NC, and SR can be used to calculate the acceptance IRI criterion for corresponding pavement constructions or treatments. If NCDOT expects to treat the pavement in the year of 12, initial IRI value at the age of 0 can be calculated using the defined threshold and the expected service life (Table 15). This initial IRI value provides a reference IRI criterion for NCDOT to accept the contractors' performance. The calculated initial IRI values are included in Table 16.

Table 16: Initial IRI values for US, NC, and SR

Pavement Classification	Initial IRI Value (inch/mile)
US	91
NC	90
SR	87

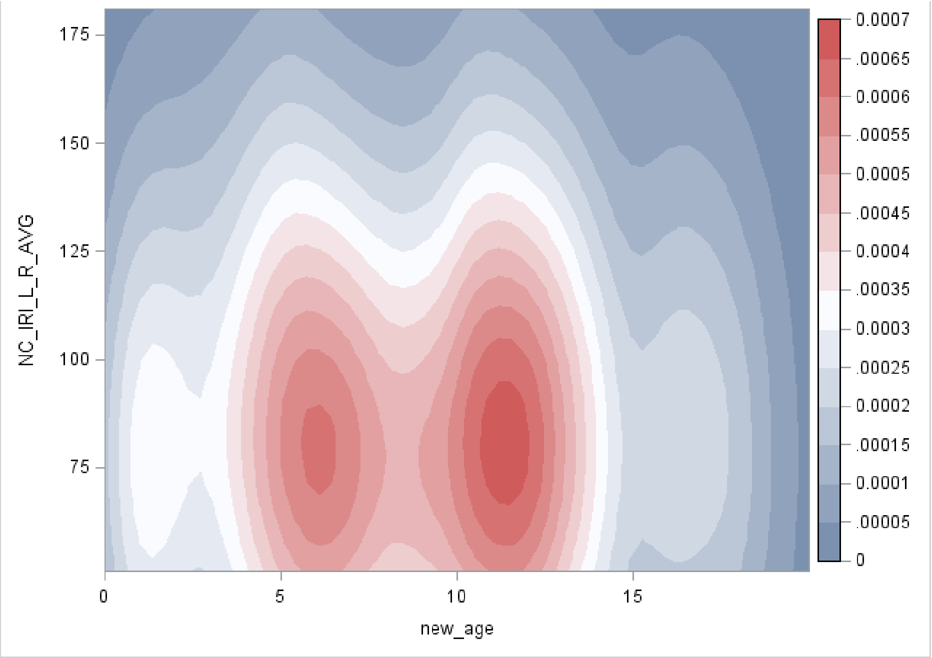


Figure 22: Contour plot of age vs. IRI for Interstate

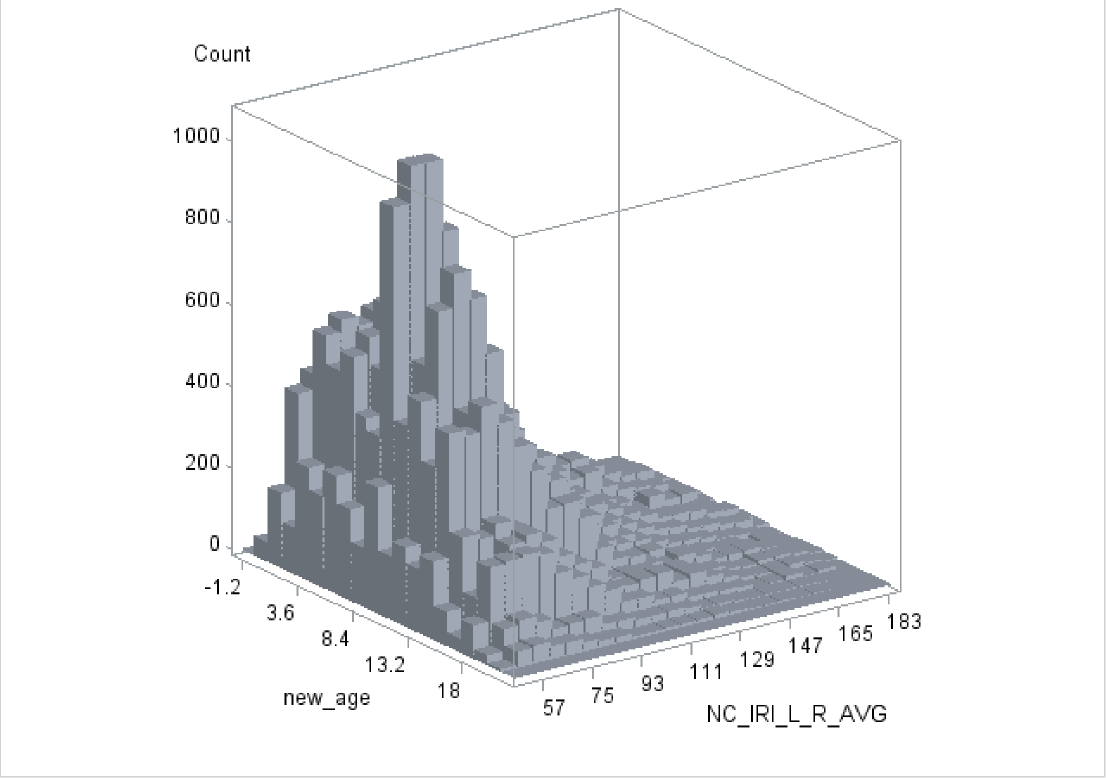


Figure 23: Distribution of age vs. IRI for Interstate

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

The objectives of this research are to develop the relationship between initial IRI and network IRI and to predict the service lives of pavement. To achieve these objectives, three databases provided by NCDOT were merged, linear regression and contrasts were conducted to develop the relationship between initial IRI and network IRI, and to predict the service lives of pavements.

It can be concluded that roadway initial IRI values have influence on the network IRI performance. When roadway classification, AADT, and initial IRI were included as independent variables in this study, the roadways' IRI deterioration rates of pavements families with different initial IRIs were not significantly different. Thus, locations of roadways were included as an additional factor to further analyze the relationship between initial IRI and network IRI, and the results indicated that pavements with smaller initial IRI last longer.

In this study, reasonable service lives were estimated for each pavement classification. The IRI threshold used in the analyses is 103 inch/mile, which was obtained from the previous study and is the threshold of acceptable/ unacceptable ride quality. The results indicated that the average service lives for the Interstate, the US, the NC, and the SR pavements are 55, 16.4, 9.5, and 6.7 years, respectively. NCDOT recommends that asphalt pavements to be treated in year 12 and 23 (NCDOT, 2014). Compared to NCDOT recommendations, the results in this study indicated that service life for Interstate is much longer and was not used in further analyses, US roadways last longer than 12 years, and NC and SR roadways last shorter than 12 years. The estimated service lives for US, NC, and SR are reasonable because service lives derived in this study were based on IRI only, and NCDOT recommendations were obtained based on various different distress and the overall pavement performance. The possible reason for the unrealistic service life for Interstate was survey equipment errors. Using the derived regression equation (Table 15), the initial IRI values for Interstate, US, NC, and SR were calculated, assuming these roadways would reach the IRI threshold of 103 inch/mile in year 12. These initial IRI values can be used as construction acceptance criteria for the NCDOT construction unit. The initial IRI values are:

Recommendations are provided for the future studies.

It is recommended to allocate the resources to collect condition data in a more balanced way: when conducting the contrast analysis, it was noticed that the data for some of the pavements (for example, Interstate_0-50k and Intersate_50kplus) was unbalanced (for example, for Interstate_0-50k in location of Mountains, there are 30 records out of 13,930 for IRI_70, 13,900 records for IRI_60, and there is no records for IRI_80), resulting in insufficient data for some subfamilies and the contrast analysis could not continue.

It is recommended to store pavement information in one comprehensive database: merging databases in this research was very complicate and time consuming. In addition, during the merging process, some data were removed in order to achieve reasonable combinations of IRI, age, and AADT, which means those data were not used even though they contain useful information. A centralized, geo-referenced database can efficiently address this issue.

It is recommended to improve the data quality of future data collection efforts: it was observed that for some roadway sections, the IRI data collected changes dramatically and inconsistently over time. This is probably because different vendors, using different surveying equipment, were selected to survey the roadways in different years. It is recommended that future IRI data should be collected by one vendor who can make a long-term commitment or by the NCDOT surveying crew.

It is recommended to use multiple IRI thresholds for pavements. The IRI threshold used in this study, 103 inch/mile, is the overall threshold for all roadway classifications. However, each pavement classification has its own service purpose and should be built with its corresponding criterion. Therefore, it is recommended to use different thresholds for different pavement classifications to estimate more reasonable service lives, and initial IRI values for the construction acceptance purpose.

It is recommended to further study the service life for Interstate. Possible reasons for the IRI value of 75 inch/mile to be clustered at ages of 6 and 11 need to be investigated. Once the issue is addressed, a reasonable regression equation should be developed to derive an appropriate service life for Interstate.

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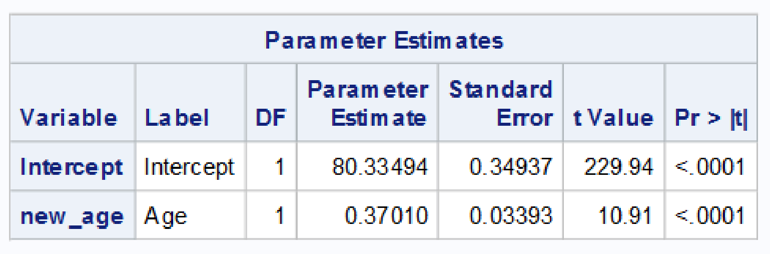
APPENDIX A: RESULTS OF REGRESSION ANALYSIS

Interstate_0-50k subcategory_60



Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
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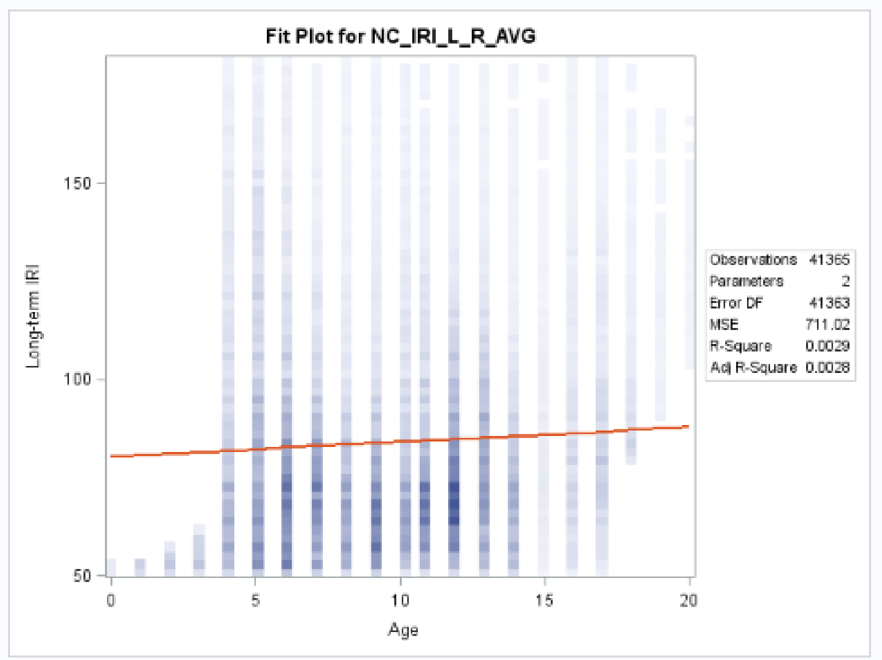
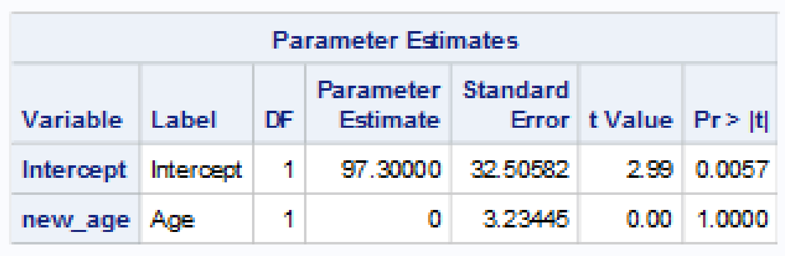
new_age	Age	1	0.37010	0.03393	10.91	<.0001



Interstate_0-50k subcategory_70

(NOT AVAILABLE)

Interstate_0-50k subcategory_80



Parameter Estimates

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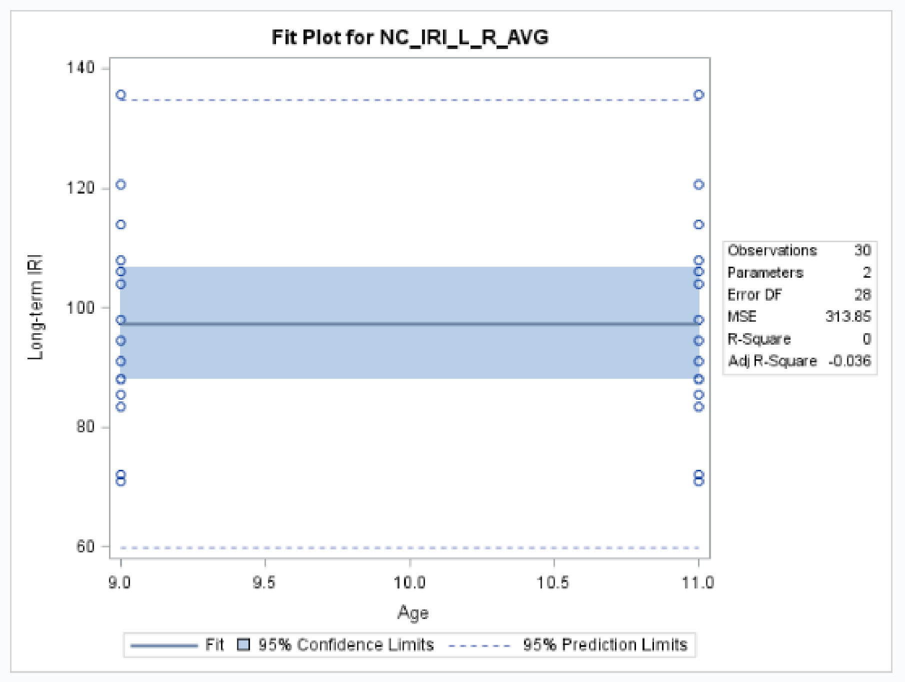
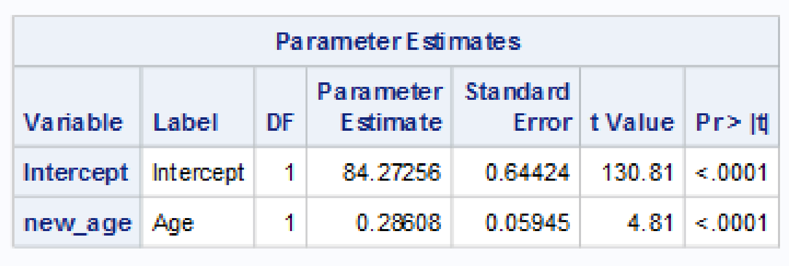


Interstate_50kplus subcategory_60



Parameter Estimates

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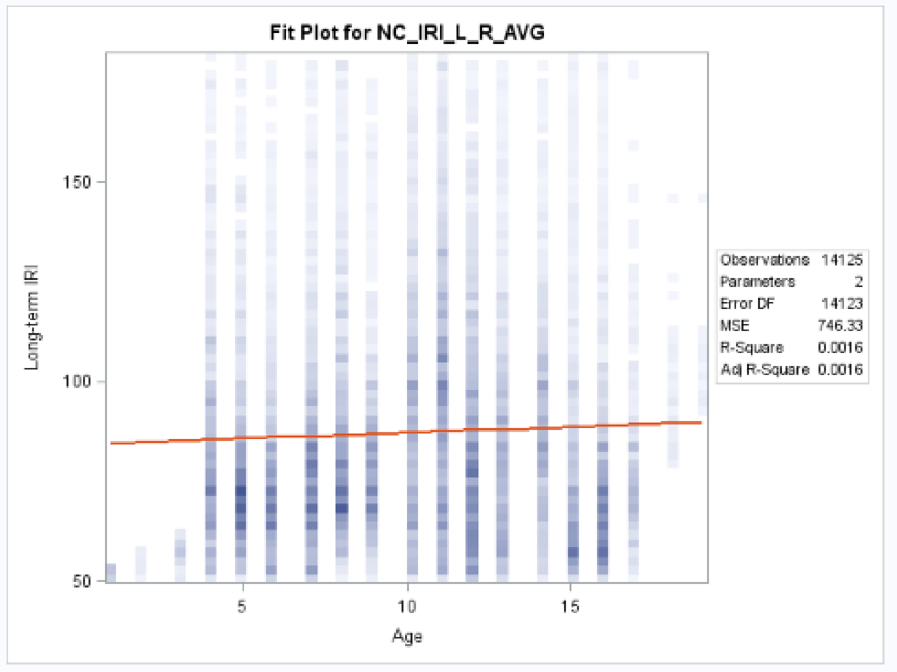

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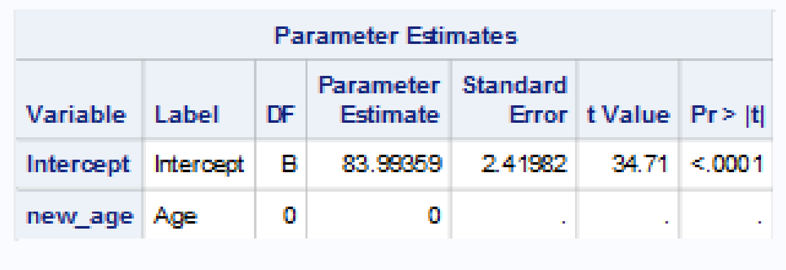
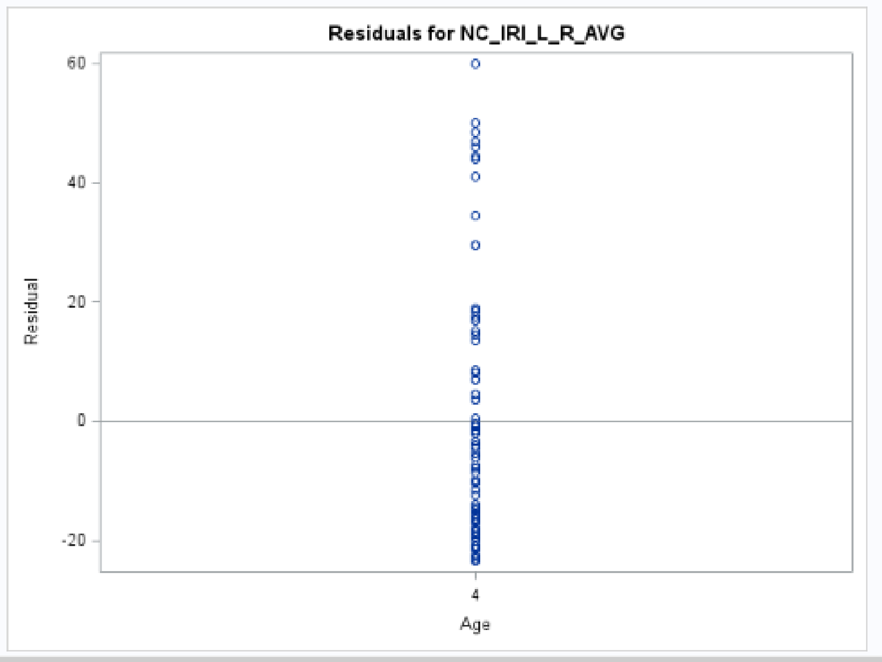
Error DF	14123
MSE	746.33
R-Square	0.0016
Adj R-Square	0.0016

Interstate_50kplus subcategory_70



Parameter Estimates

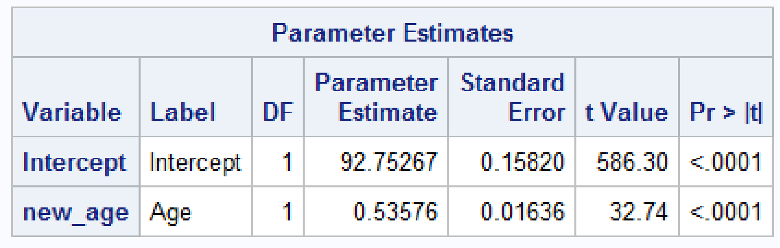
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	B	83.99359	2.41982	34.71	<.0001
new_age	Age	0	0	.	.	.



Interstate_50kplus subcategory_80

(NOT AVAILBALE)

US_0-5k subcategory_60



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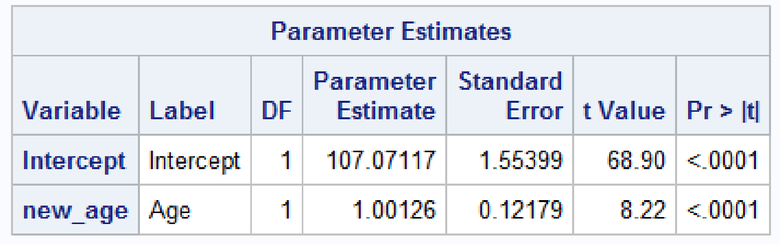
Intercept	Intercept	1	92.75267	0.15820	586.30	<.0001
new_age	Age	1	0.53576	0.01636	32.74	<.0001

US_0-5k subcategory_70



Parameter Estimates

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Intercept	Intercept	1	107.07117	1.55399	68.90	<.0001
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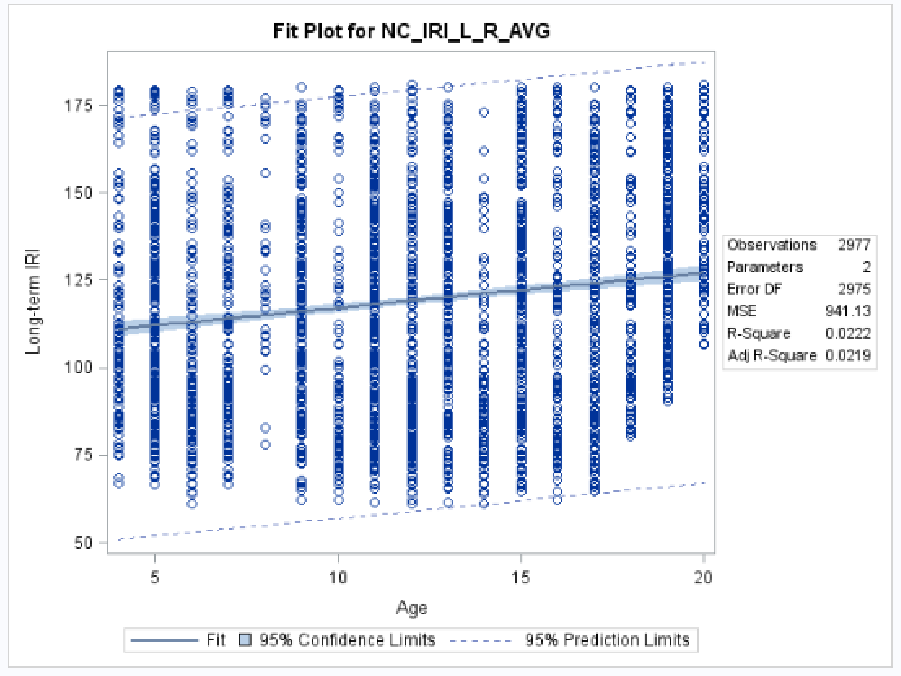
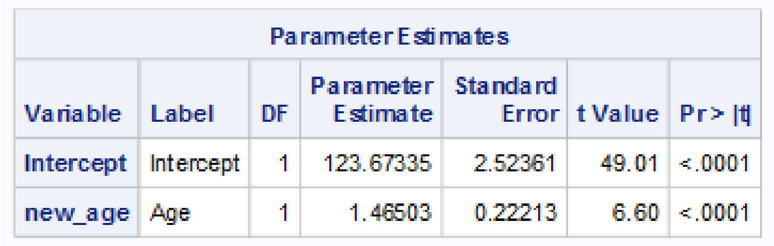


US_0-5k subcategory_80



Parameter Estimates						
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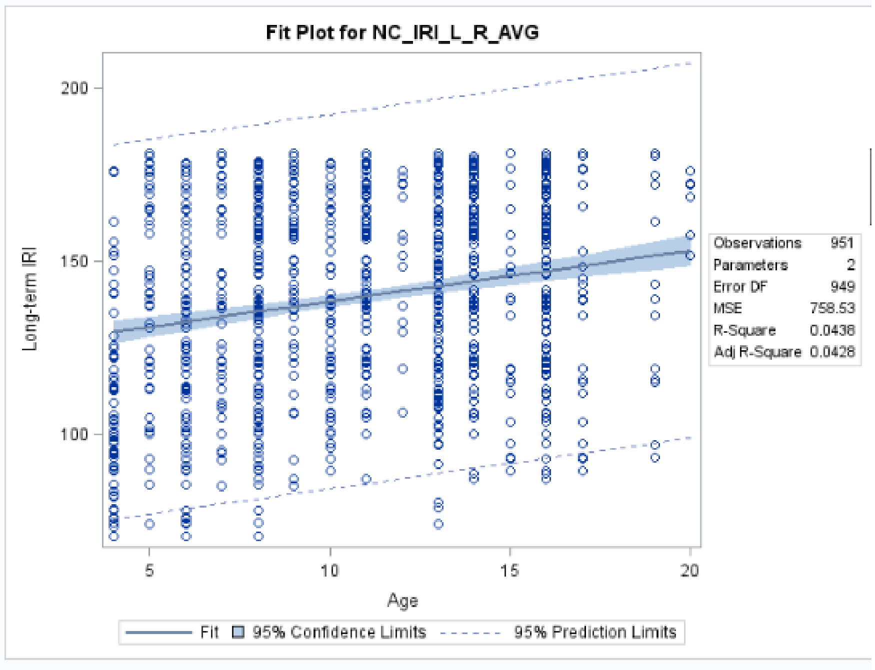
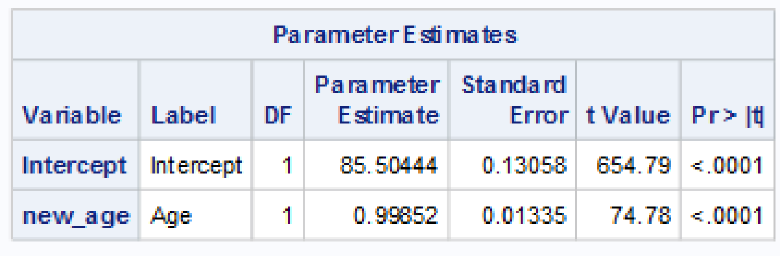
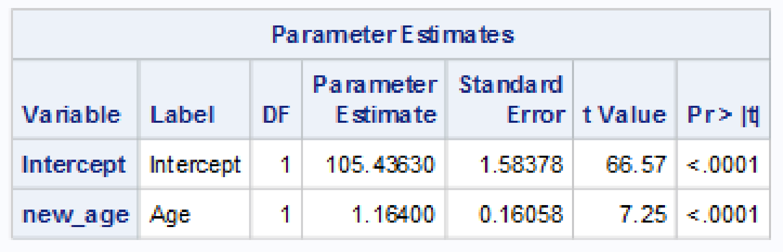


US_5-15k subcategory_60



Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	85.50444	0.13058	654.79	<.0001
new_age	Age	1	0.99852	0.01335	74.78	<.0001

US_5-15k subcategory_70



Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
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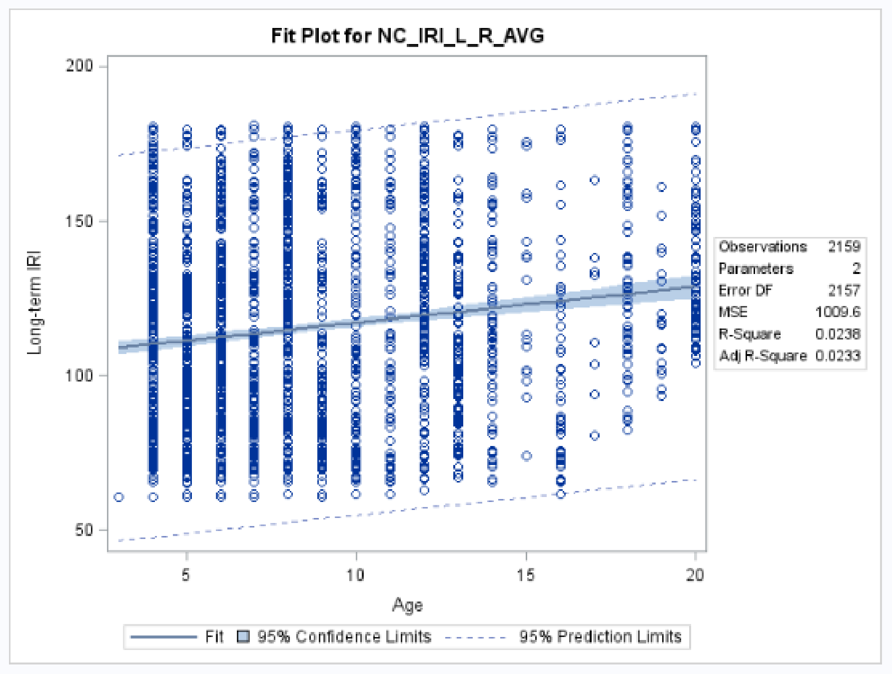
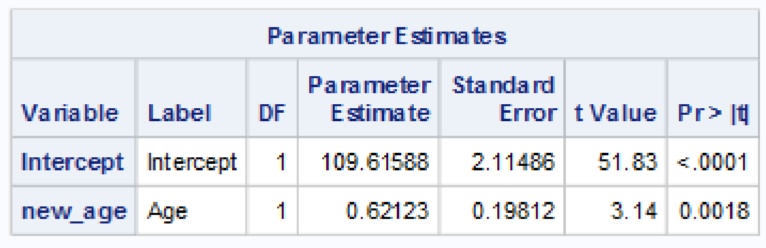


US_5-15k subcategory_80



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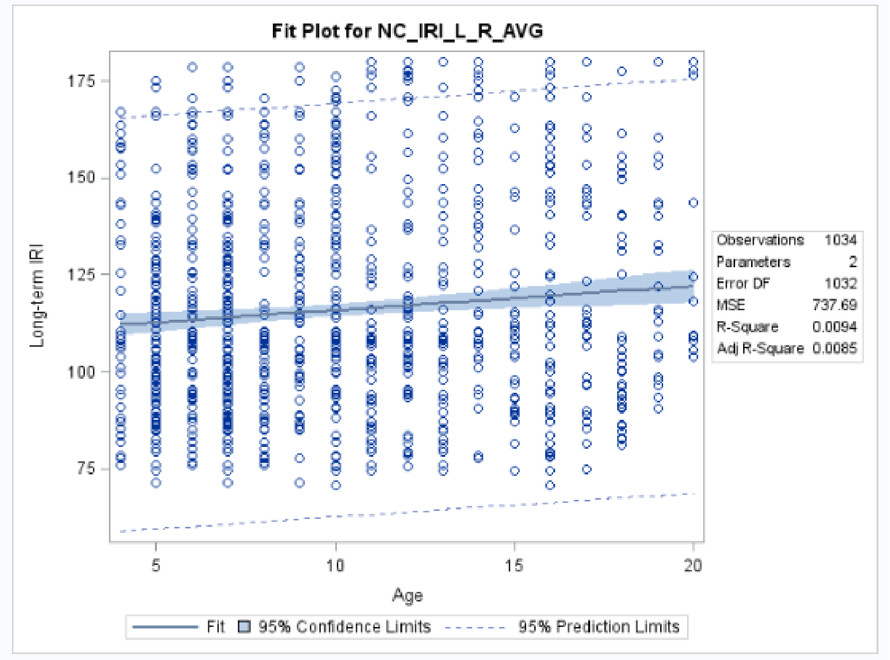

Observations	1034
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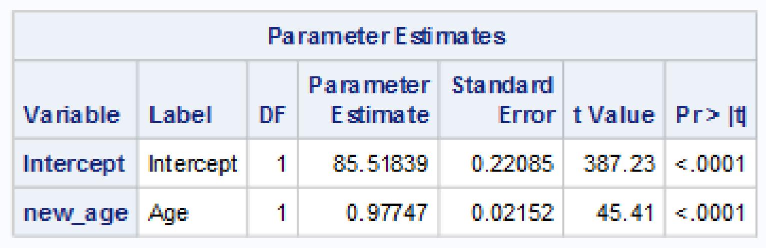
Error DF	1032
MSE	737.69
R-Square	0.0094
Adj R-Square	0.0085

US_15-30k subcategory_60



Parameter Estimates						
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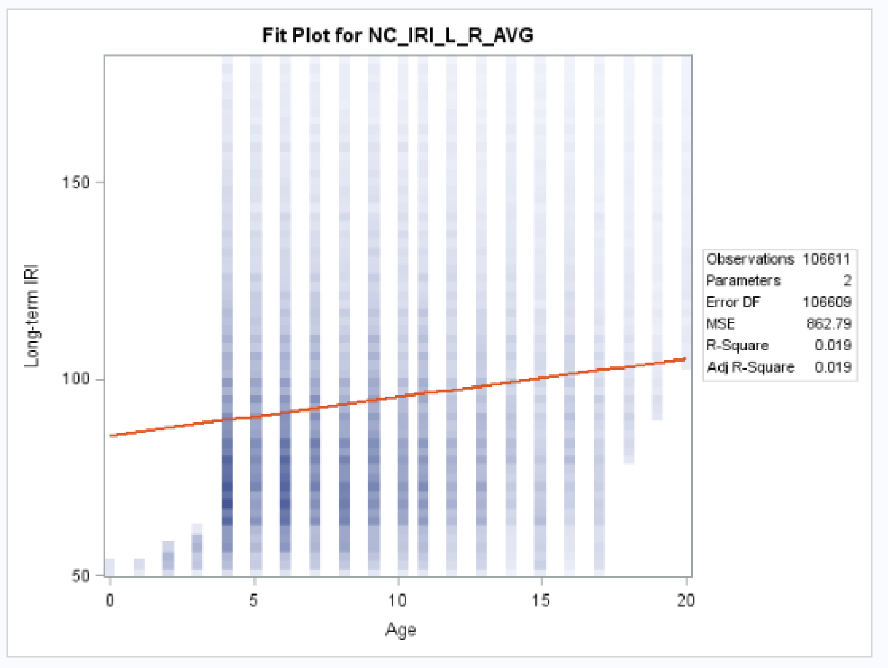
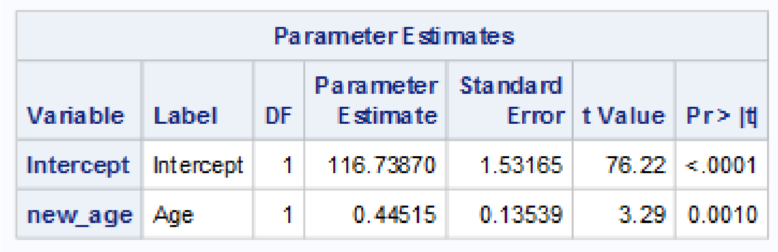


Observations	106611
Parameters	2
Error DF	106609
MSE	862.79
R-Square	0.019
Adj R-Square	0.019

US_15-30k subcategory_70



Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	116.73870	1.53165	76.22	<.0001
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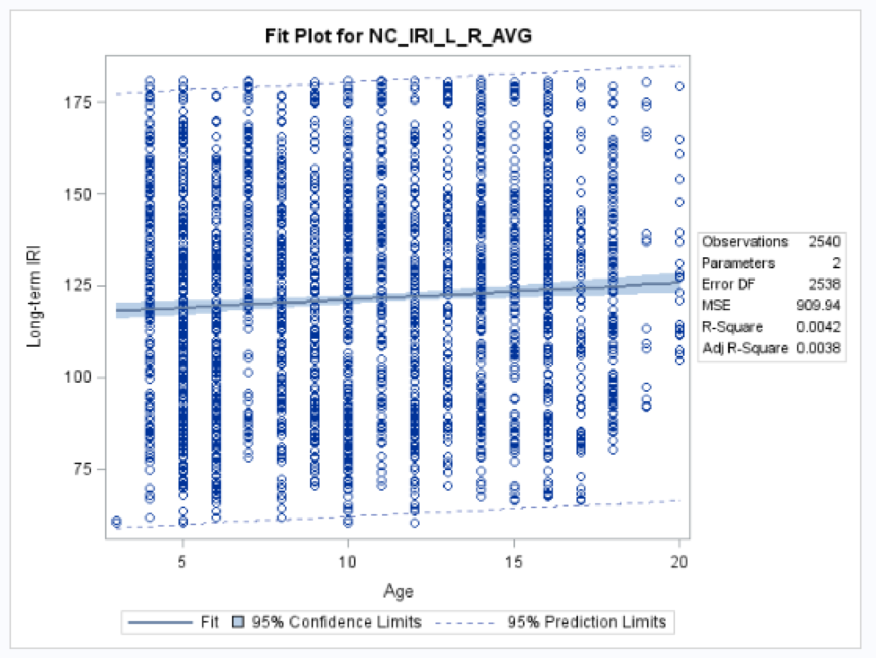

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Parameters	2
Error DF	2538
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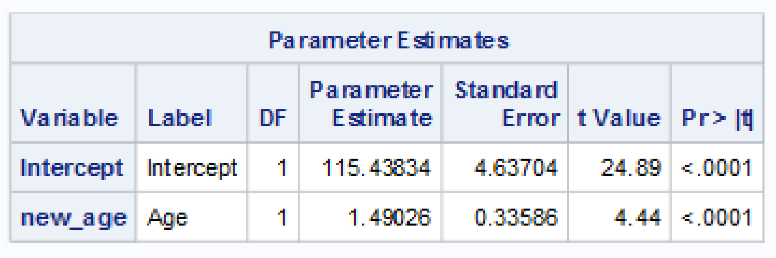
Adj R-Square	0.0038

US_15-30k subcategory_80



Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
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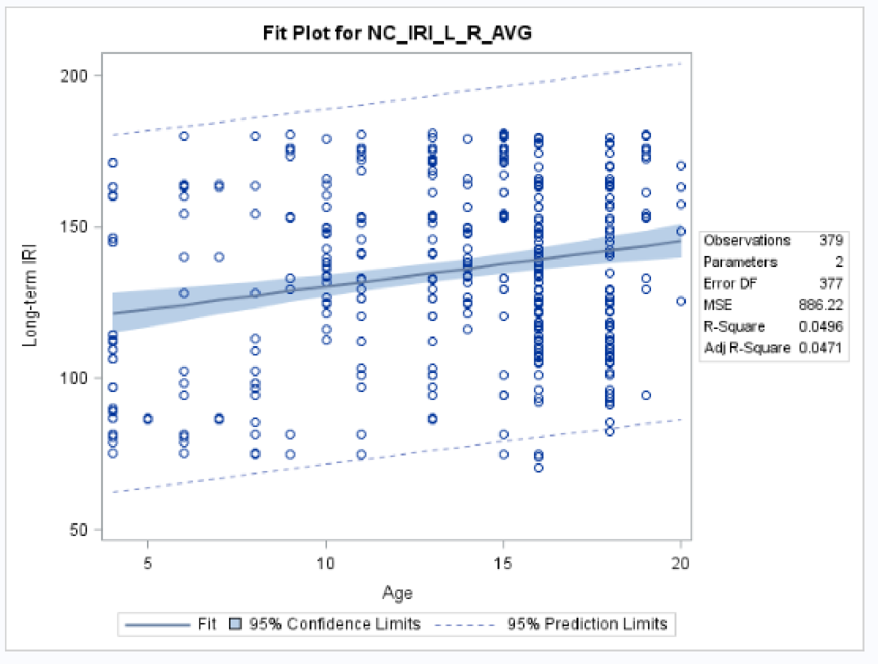
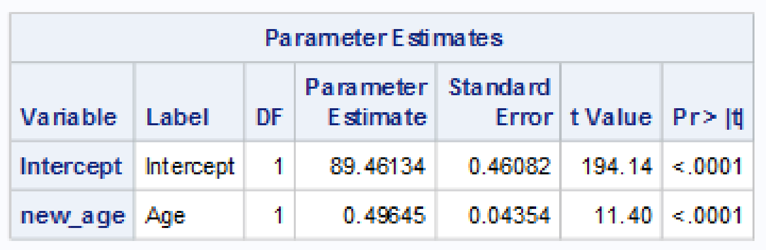


US_30kplus subcategory 60



Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
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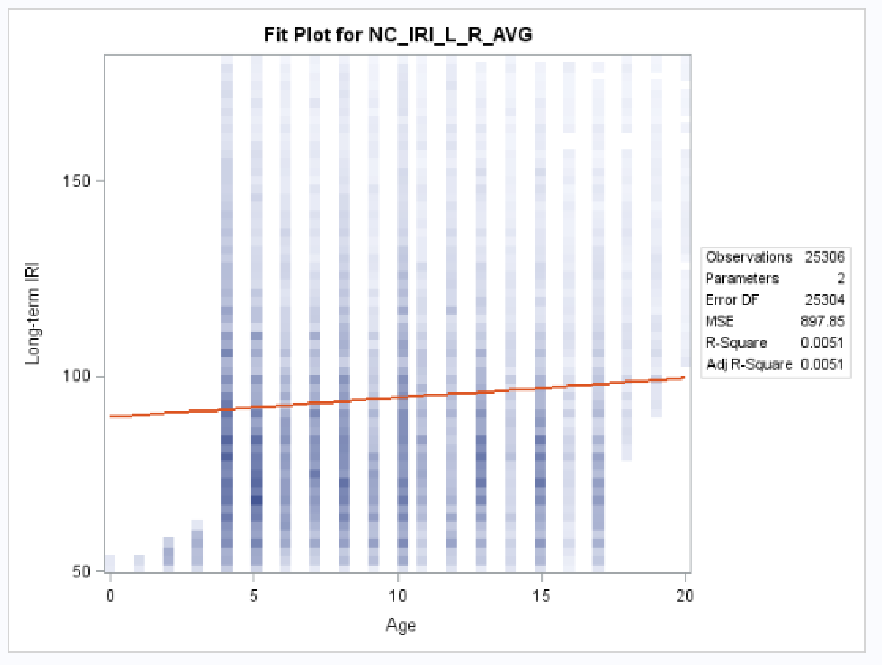
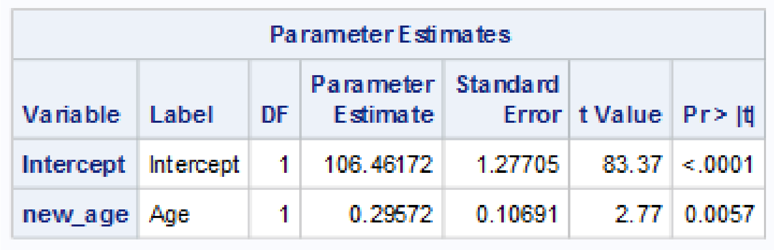


US_30kplus subcategory 70



Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
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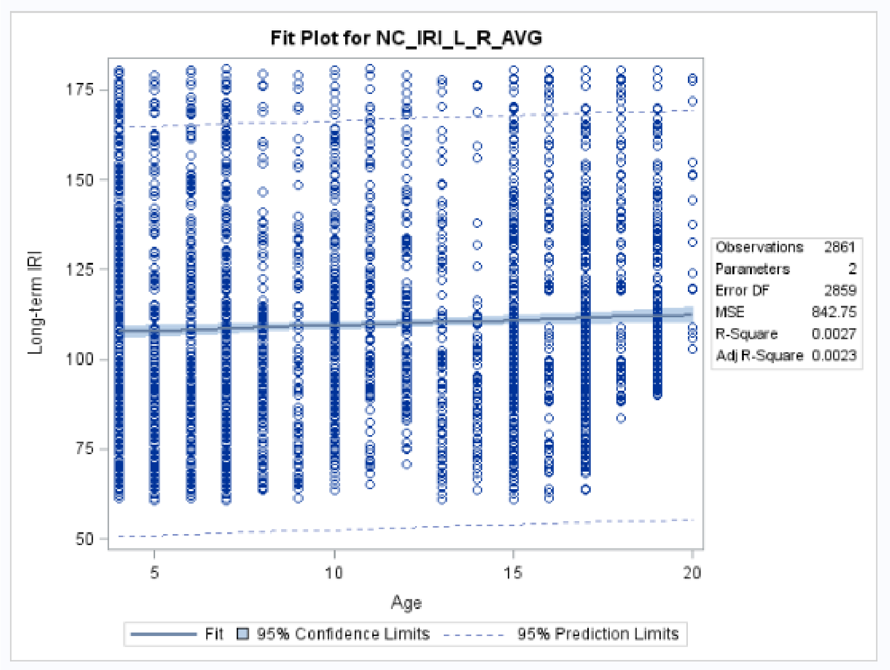
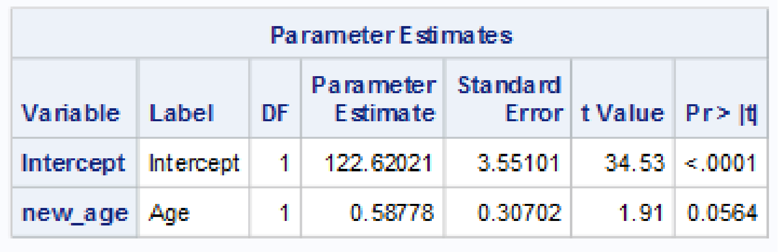


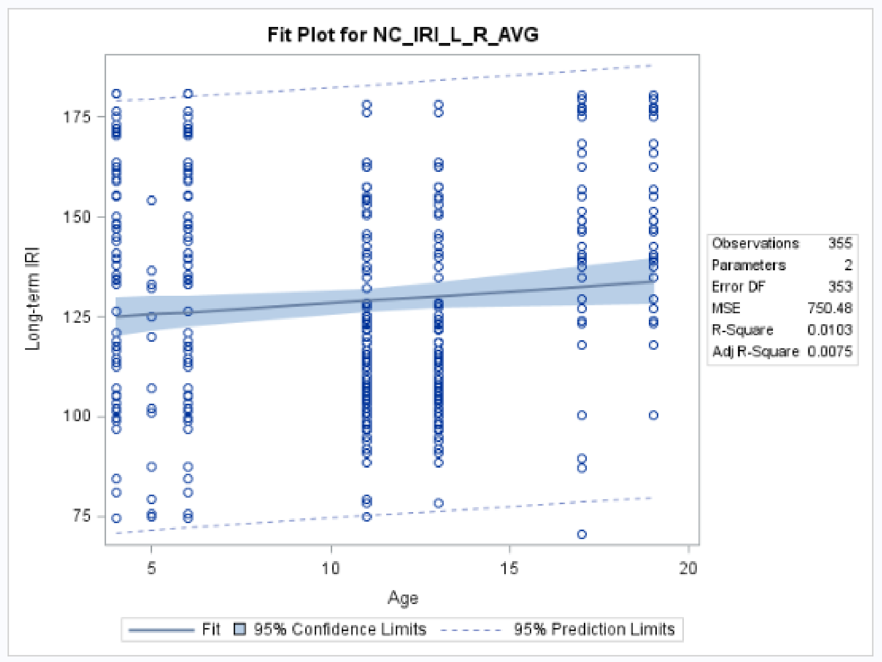
Fit Plot for NC_IRI_L_R_AVG

Observations	2861
Parameters	2
Error DF	2859
MSE	842.75
R-Square	0.0027
Adj R-Square	0.0023

US_30kplus subcategory 80



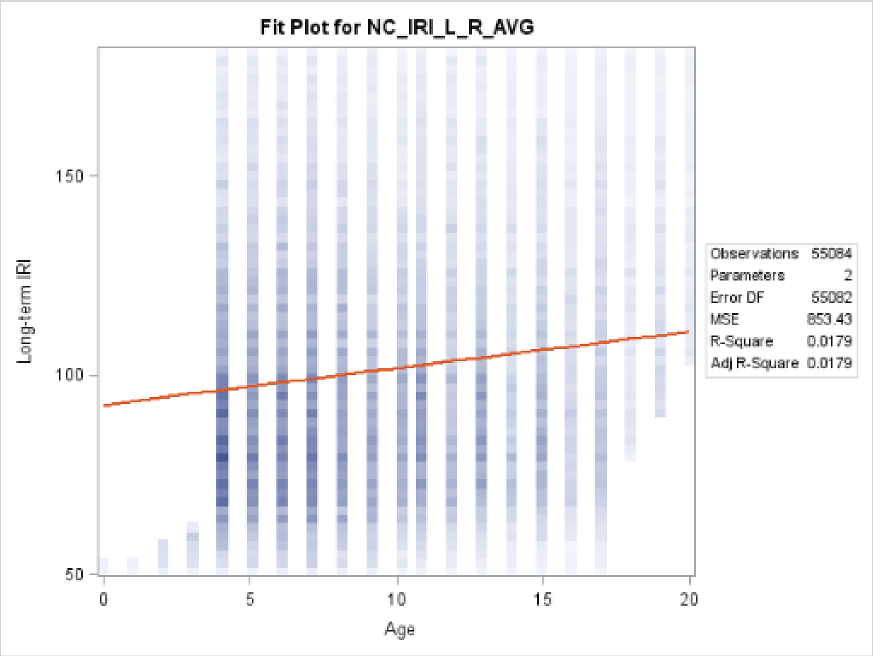
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	122.62021	3.55101	34.53	<.0001
new_age	Age	1	0.58778	0.30702	1.91	0.0564



Observations	355
Parameters	2
Error DF	353
MSE	750.48
R-Square	0.0103
Adj R-Square	0.0075

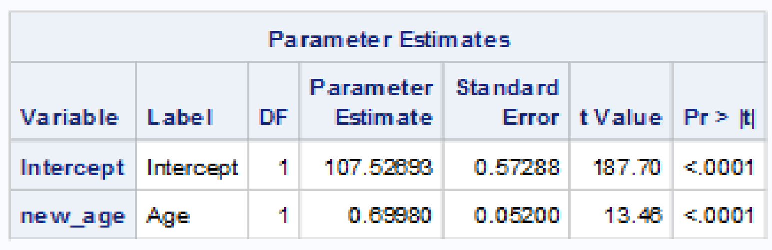
NC_0-1K subcategory 60

Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	92.47552	0.30717	301.06	<.0001
new_age	Age	1	0.92099	0.02908	31.67	<.0001

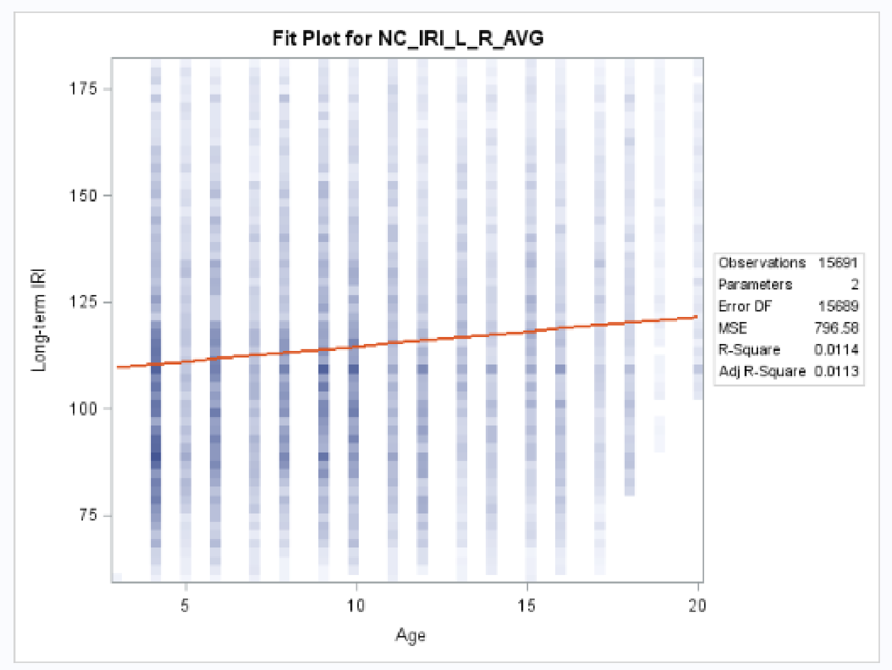


Observations	55084
Parameters	2
Error DF	55082
MSE	853.43
R-Square	0.0179
Adj R-Square	0.0179

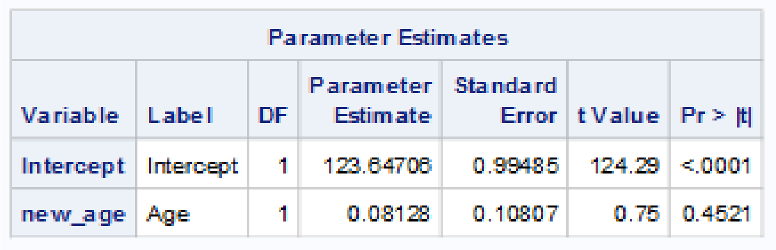
NC_0-1K subcategory 70



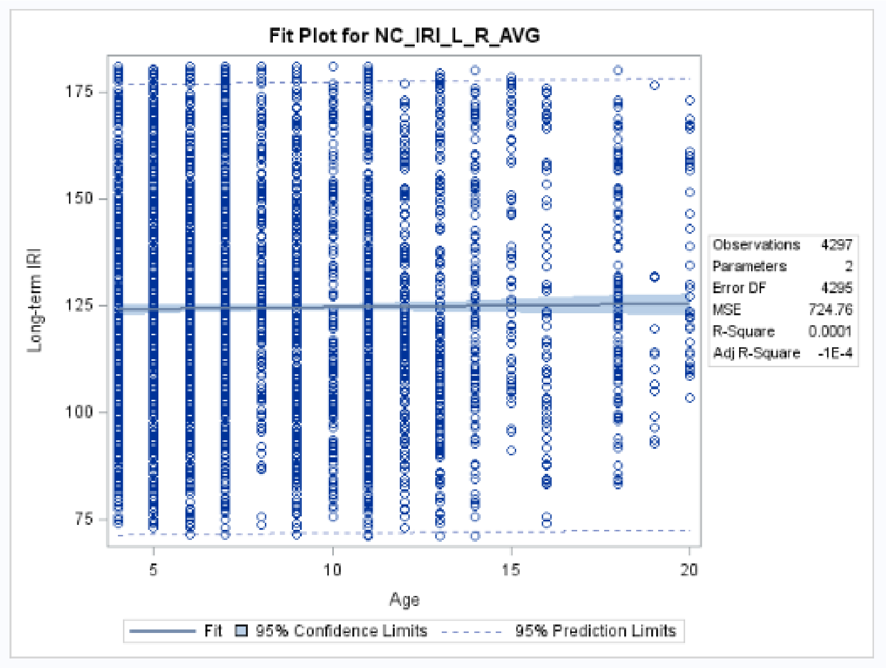
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	107.52693	0.57288	187.70	<.0001
new_age	Age	1	0.69980	0.05200	13.46	<.0001



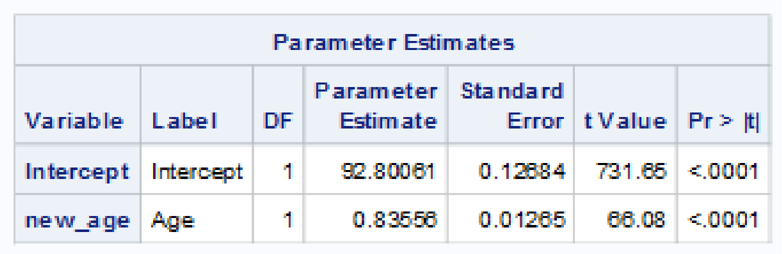
NC_0-1K subcategory 80



Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	123.64706	0.99485	124.29	<.0001
new_age	Age	1	0.08128	0.10807	0.75	0.4521

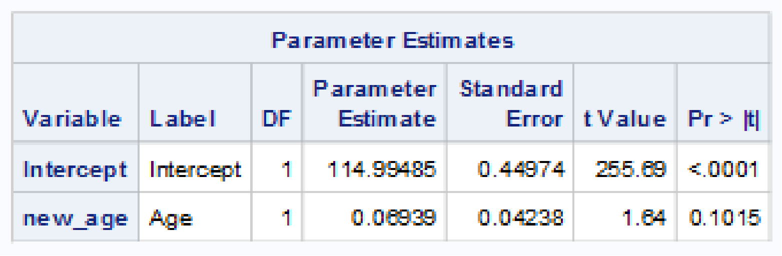


NC_1-5k subcategory 60

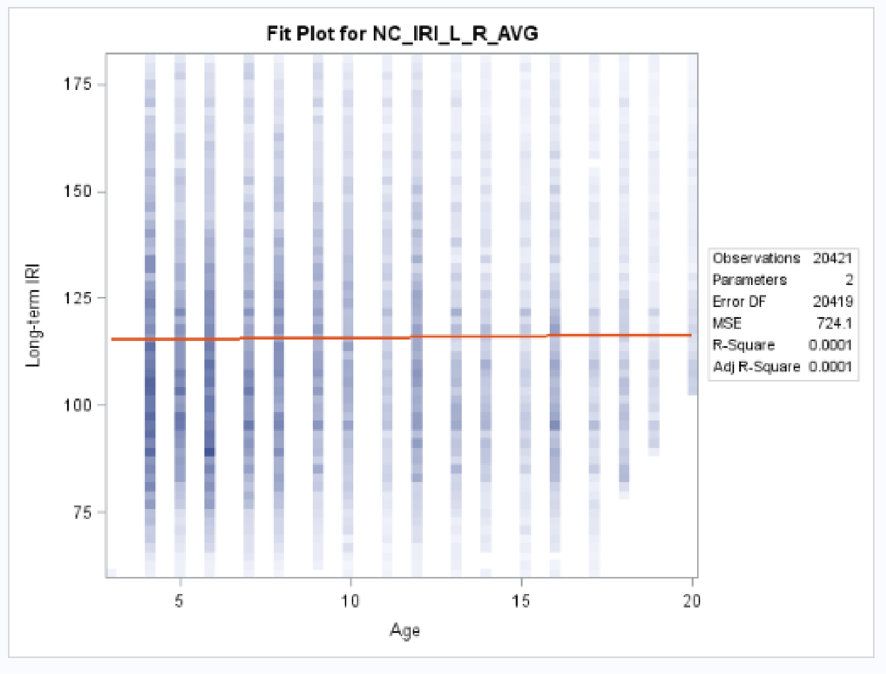


Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	92.80061	0.12684	731.65	<.0001
new_age	Age	1	0.83556	0.01265	66.08	<.0001

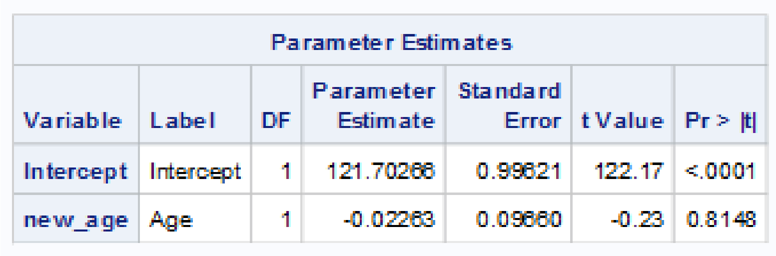
NC_1-5k subcategory 70



Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	114.99485	0.44974	255.69	<.0001
new_age	Age	1	0.06939	0.04238	1.64	0.1015

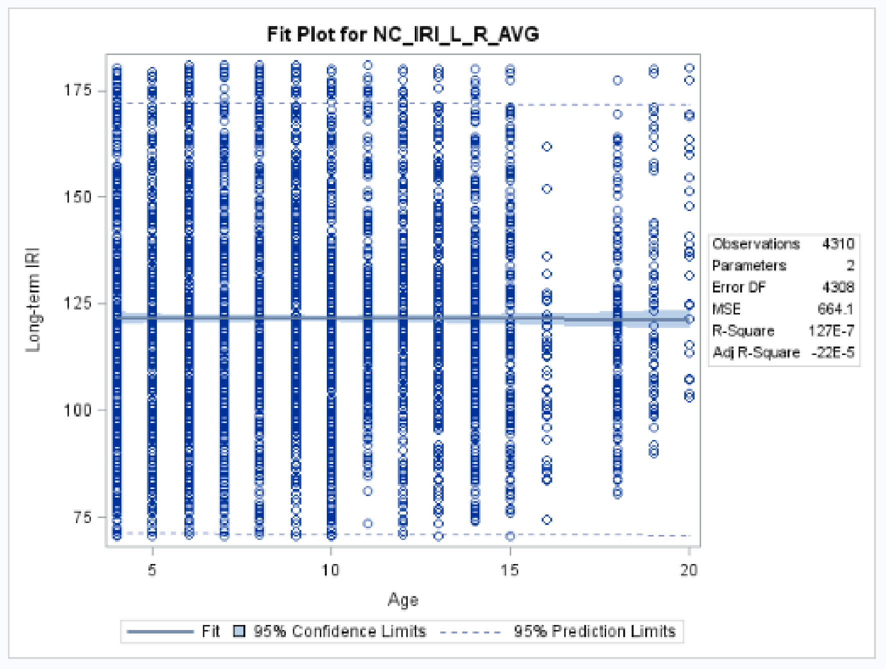


NC_1-5k subcategory 80

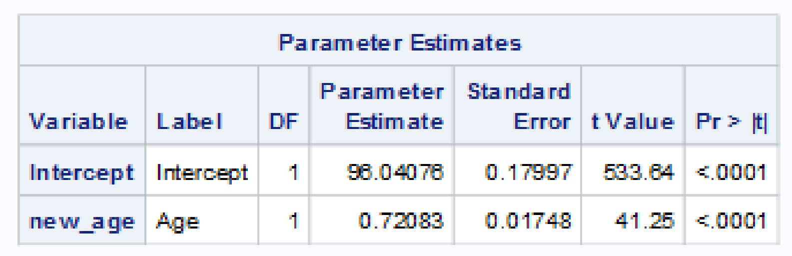


Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	121.70266	0.99621	122.17	<.0001
new_age	Age	1	-0.02263	0.09660	-0.23	0.8148

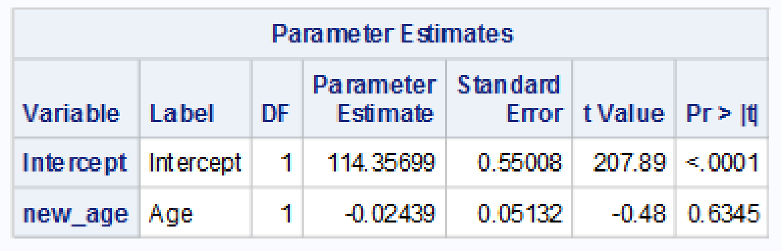


NC_5-15k subcategory 60

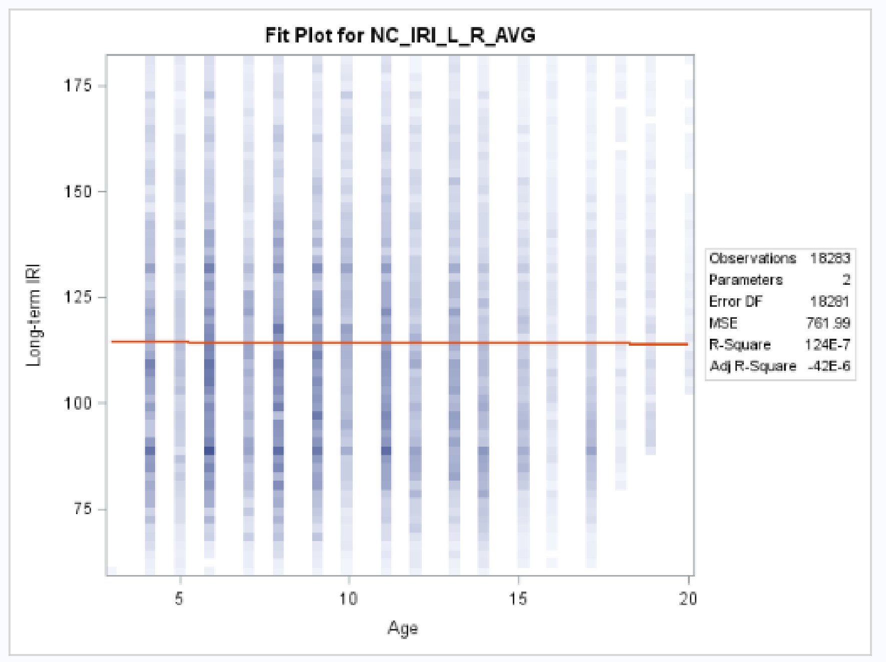


Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	96.04076	0.17997	533.64	<.0001
new_age	Age	1	0.72083	0.01748	41.25	<.0001

NC_5-15k subcategory 70

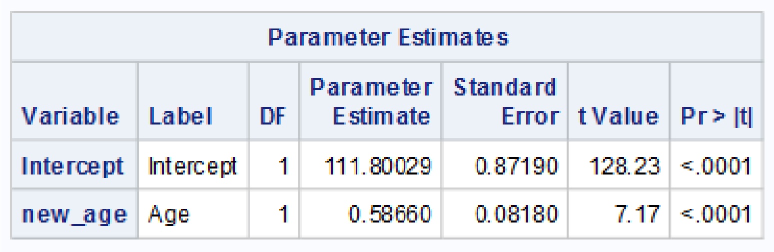


Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	114.35699	0.55008	207.89	<.0001
new_age	Age	1	-0.02439	0.05132	-0.48	0.6345

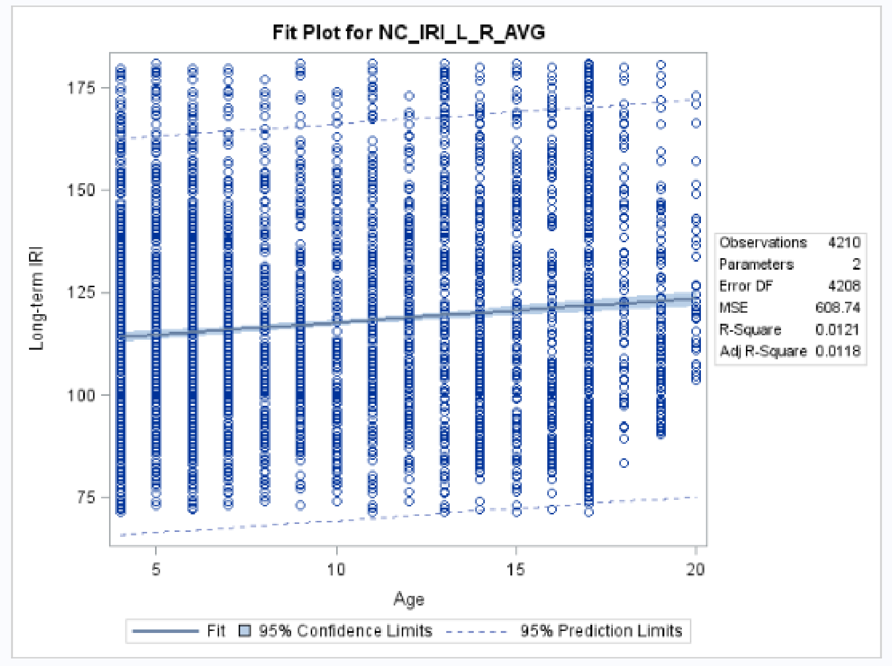


Observations	18283
Parameters	2
Error DF	18281
MSE	761.99
R-Square	124E-7
Adj R-Square	-42E-6

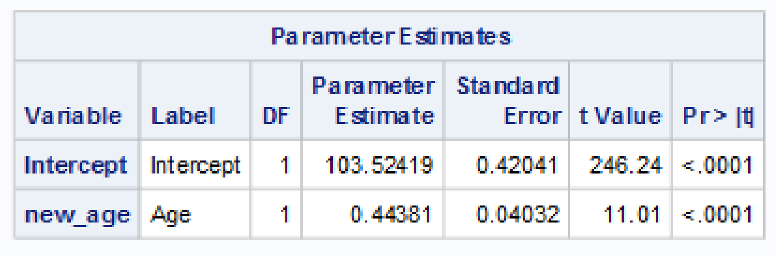
NC_5-15k subcategory 80



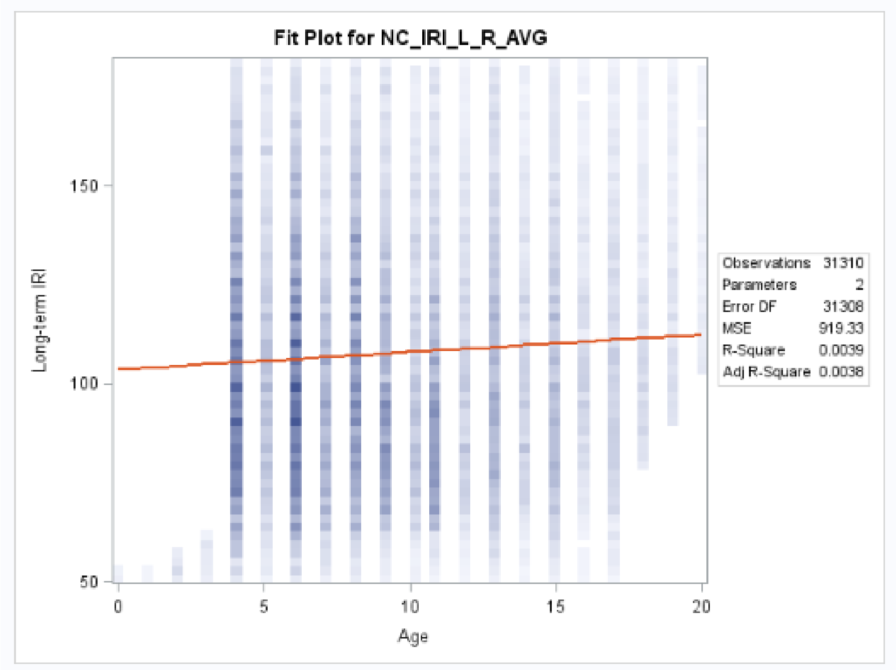
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	111.80029	0.87190	128.23	<.0001
new_age	Age	1	0.58660	0.08180	7.17	<.0001



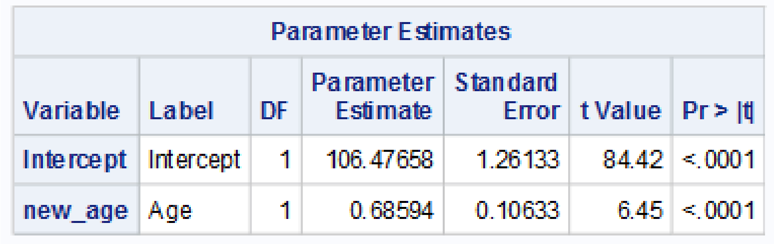
NC_15kplus subcategory 60



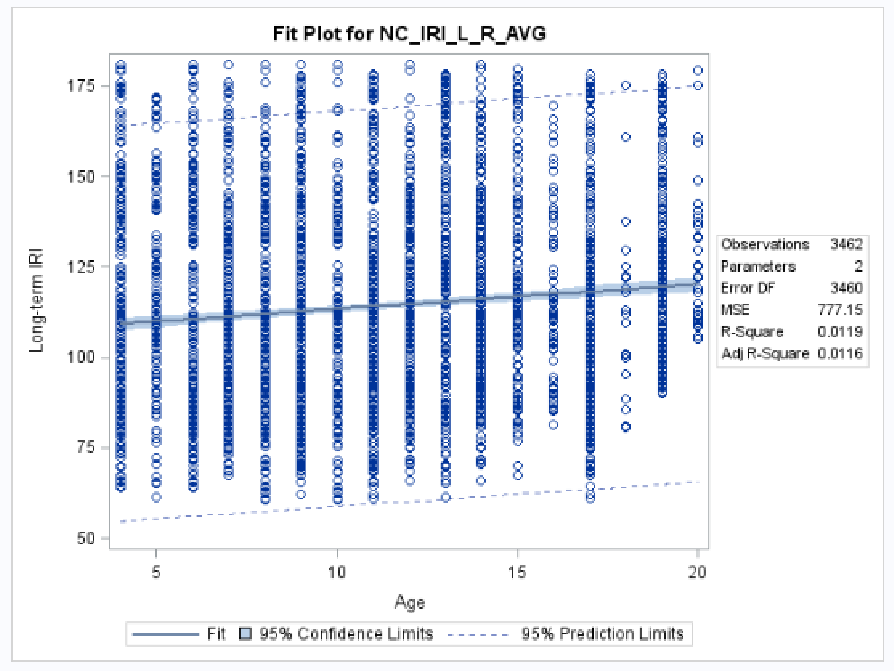
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	103.52419	0.42041	246.24	<.0001
new_age	Age	1	0.44381	0.04032	11.01	<.0001



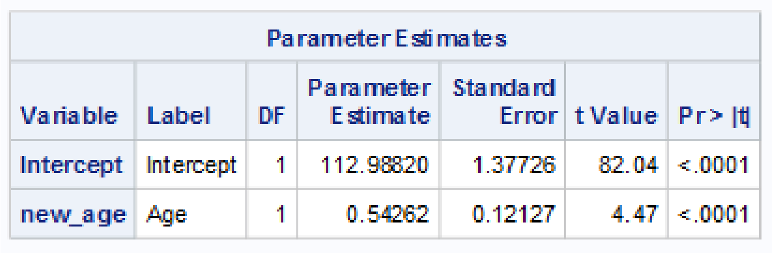
NC_15kplus subcategory 70



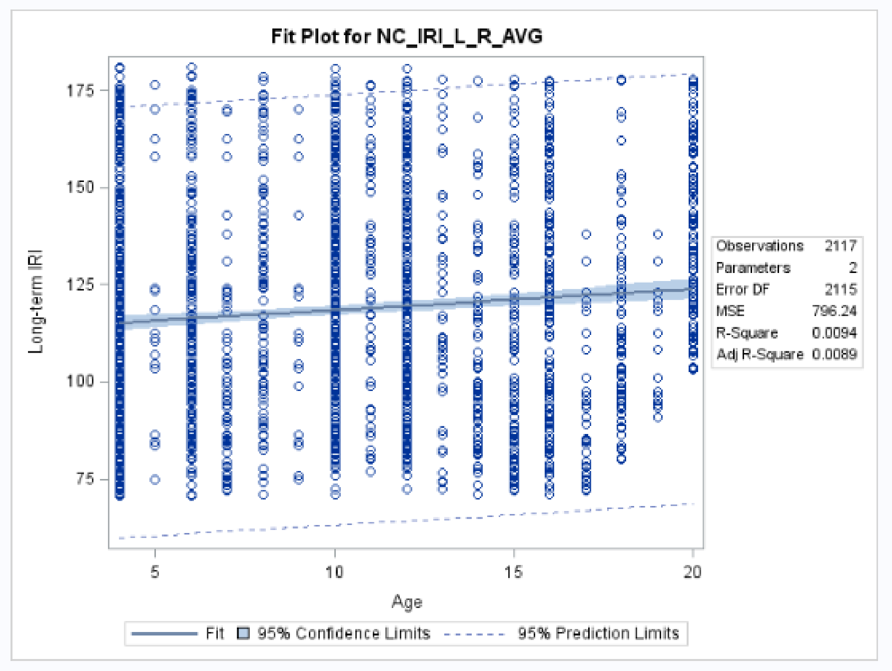
Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	106.47658	1.26133	84.42	<.0001
new_age	Age	1	0.68594	0.10633	6.45	<.0001



NC_15kplus subcategory 80

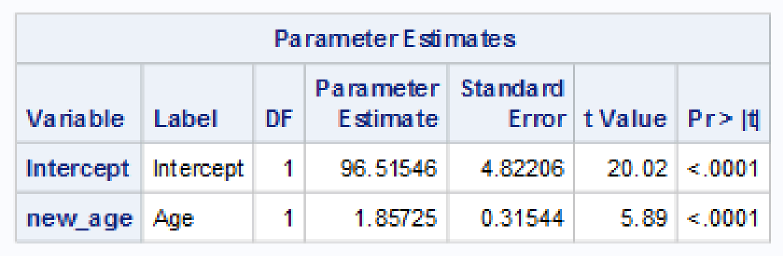


Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	112.98820	1.37726	82.04	<.0001
new_age	Age	1	0.54262	0.12127	4.47	<.0001

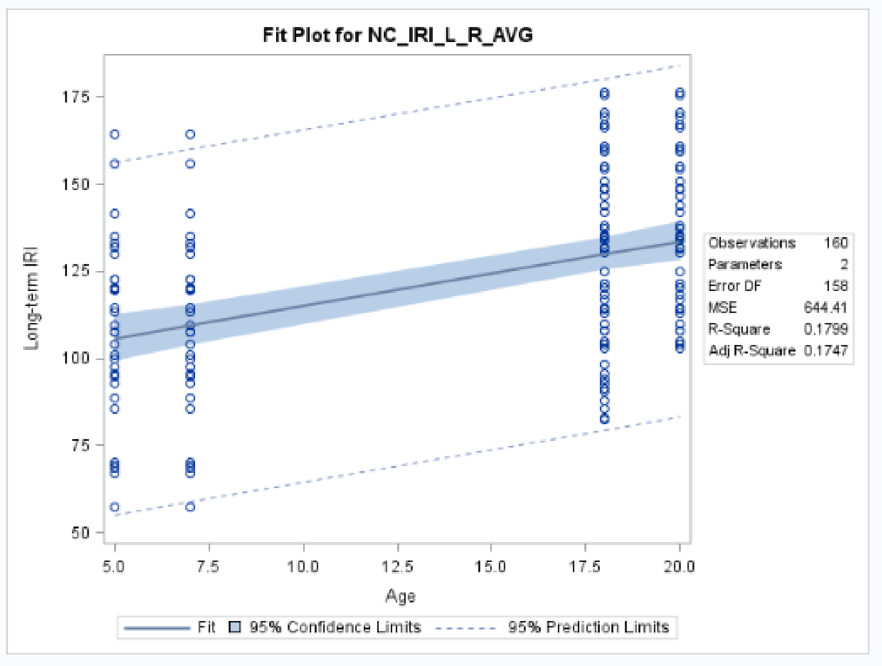


Observations	2117
Parameters	2
Error DF	2115
MSE	796.24
R-Square	0.0094
Adj R-Square	0.0089

RS_ BSR_0-1k subcategory 60



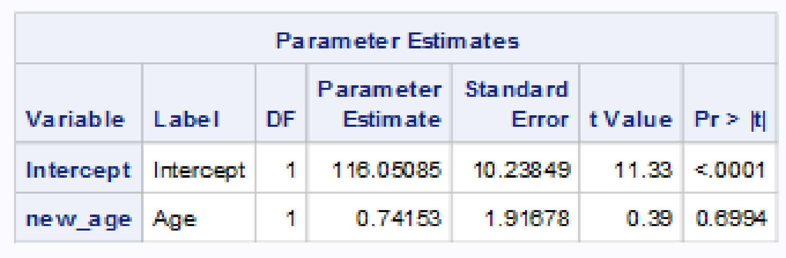
Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	96.51546	4.82206	20.02	<.0001
new_age	Age	1	1.85725	0.31544	5.89	<.0001



RS_BSR_0-1k subcategory 70

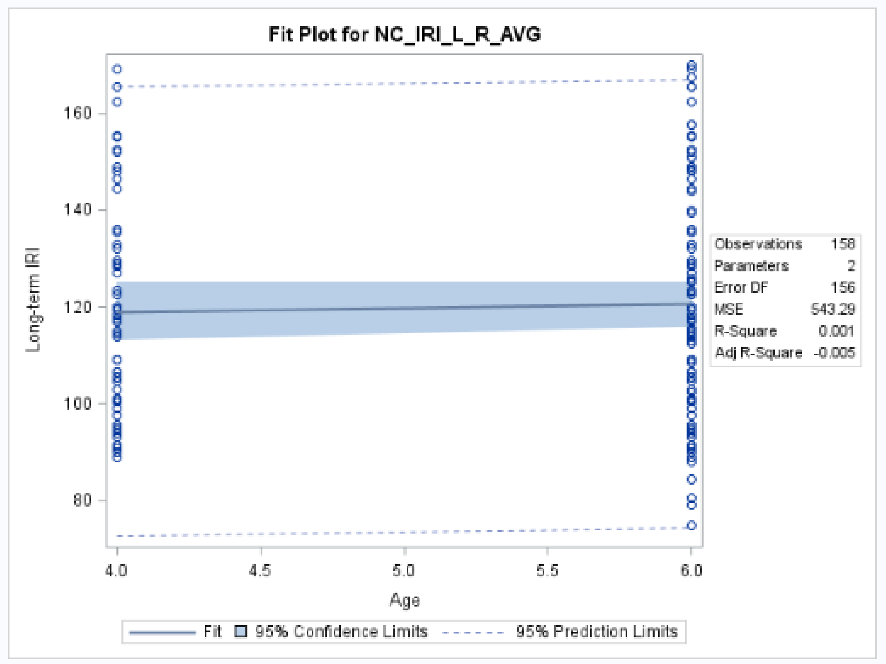
(NOT AVAILABLE)

RS_BSR_0-1k subcategory 80

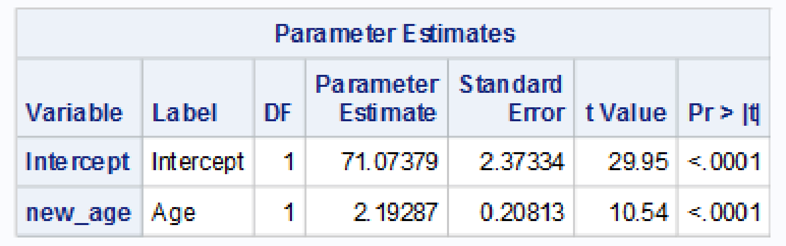


Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	116.05085	10.23849	11.33	<.0001
new_age	Age	1	0.74153	1.91678	0.39	0.6994

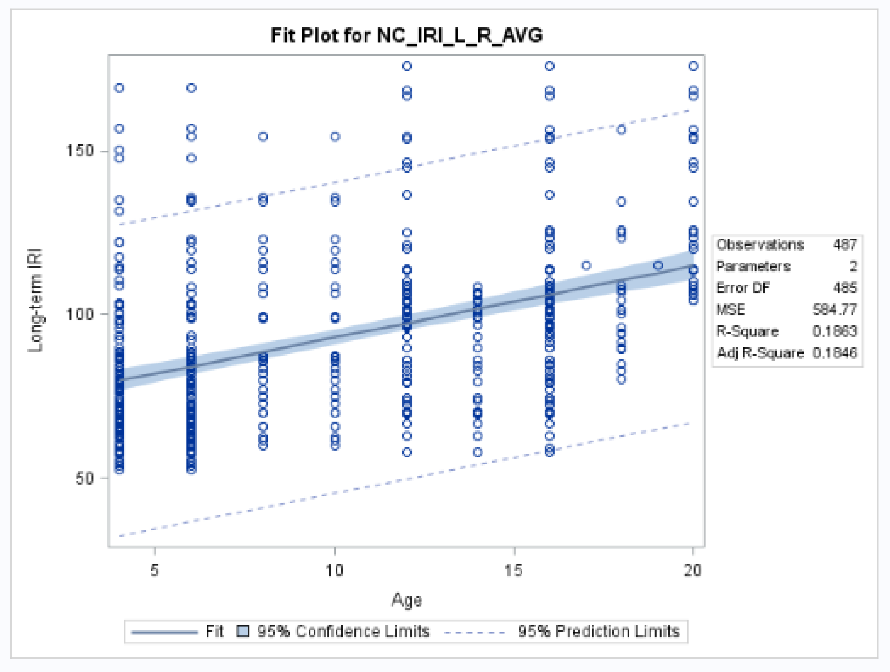


SR_PR_0-1k subcategory 60

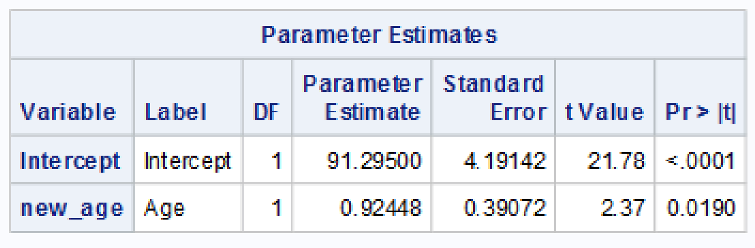


Parameter Estimates

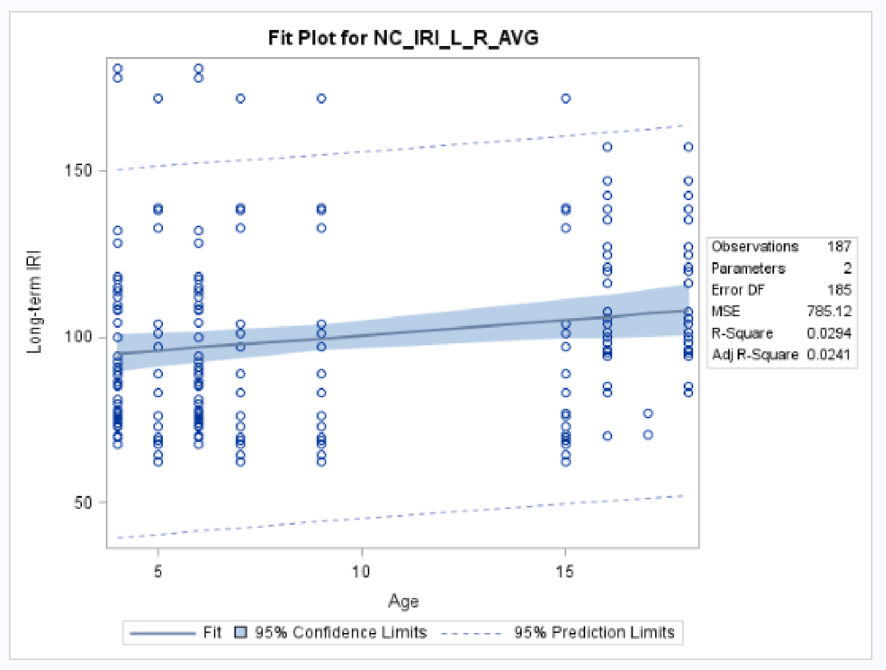
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	71.07379	2.37334	29.95	<.0001
new_age	Age	1	2.19287	0.20813	10.54	<.0001



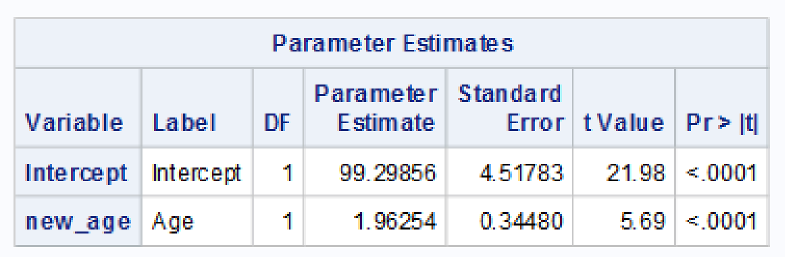
SR_ PR_0-1k subcategory 70



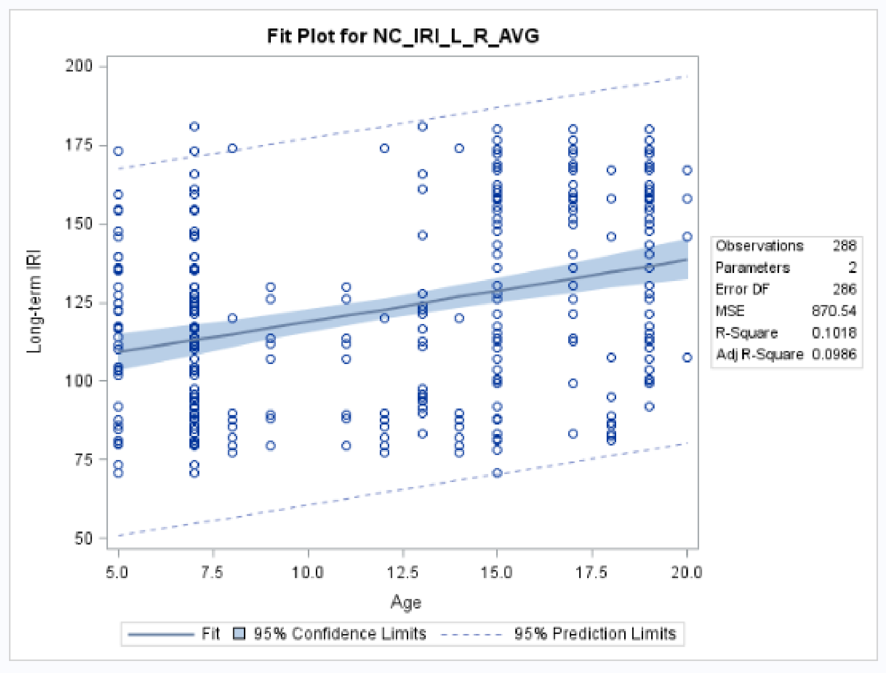
Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	91.29500	4.19142	21.78	<.0001
new_age	Age	1	0.92448	0.39072	2.37	0.0190



SR_PR_0-1k subcategory 80

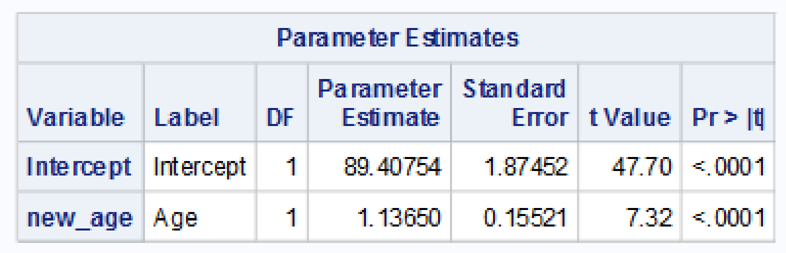


Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	99.29856	4.51783	21.98	<.0001
new_age	Age	1	1.96254	0.34480	5.69	<.0001

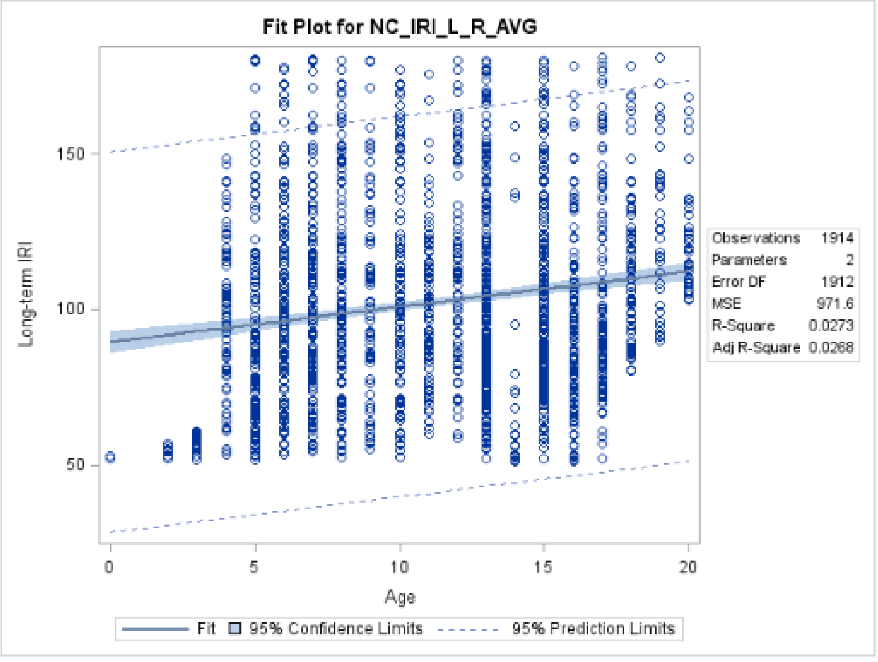


Observations	288
Parameters	2
Error DF	286
MSE	870.54
R-Square	0.1018
Adj R-Square	0.0986

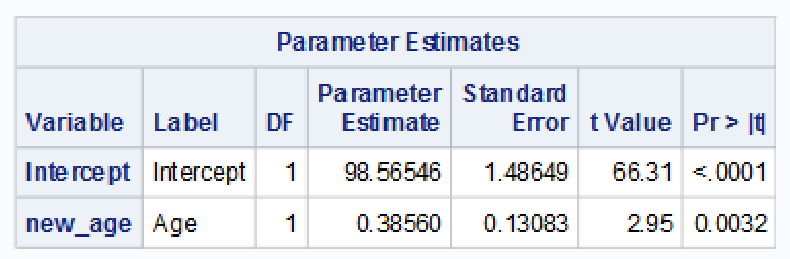
SR_PR_1-5k subcategory 60



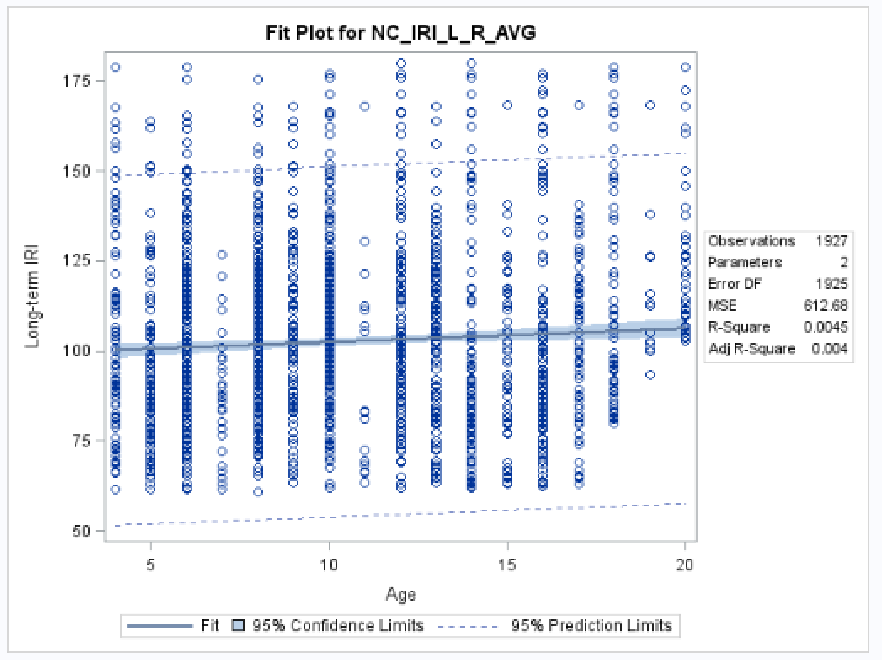
Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	89.40754	1.87452	47.70	<.0001
new_age	Age	1	1.13650	0.15521	7.32	<.0001



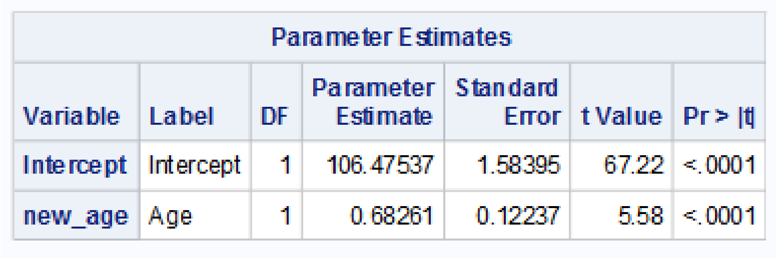
SR_PR_1-5k subcategory 70



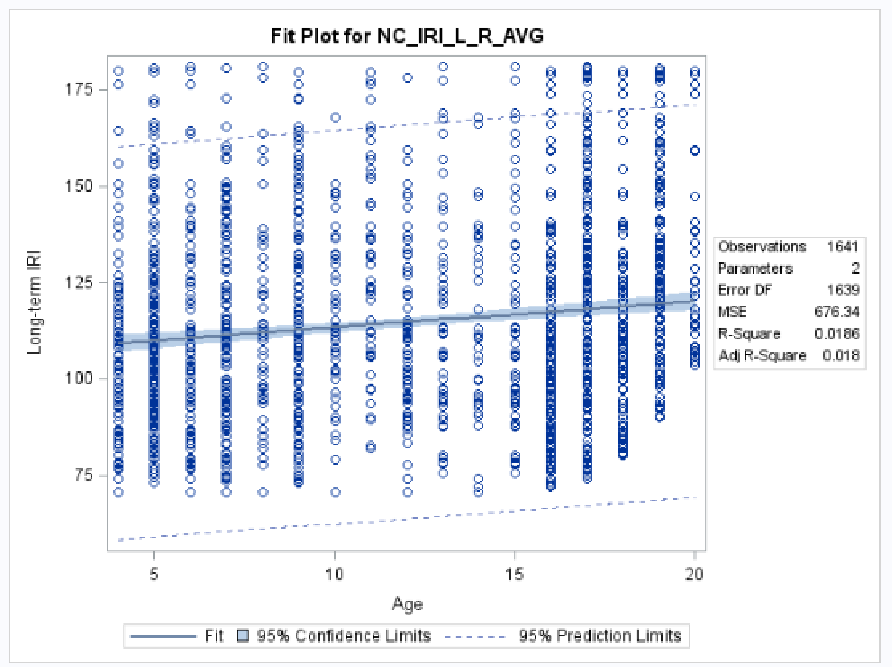
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	98.56546	1.48649	66.31	<.0001
new_age	Age	1	0.38560	0.13083	2.95	0.0032



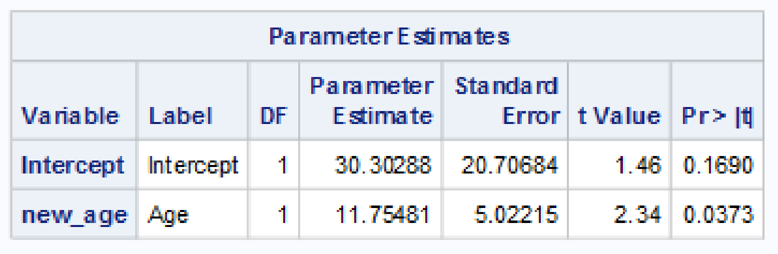
SR_PR_1-5k subcategory 80



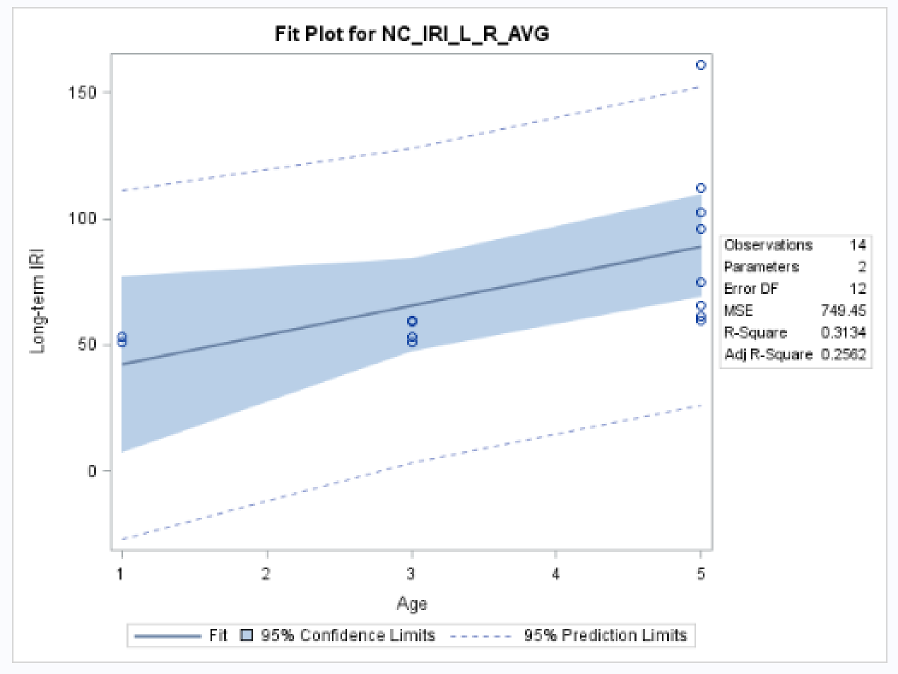
Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	106.47537	1.58395	67.22	<.0001
new_age	Age	1	0.68261	0.12237	5.58	<.0001



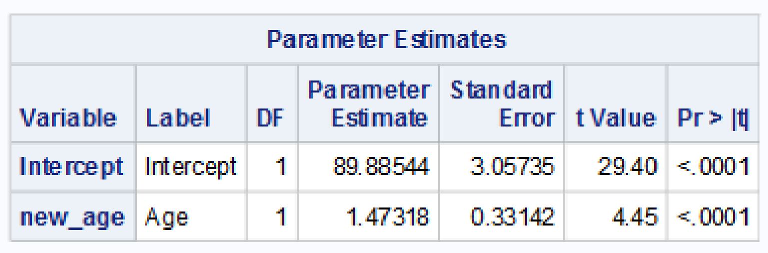
SR_BSR_1kplus subcategory 60



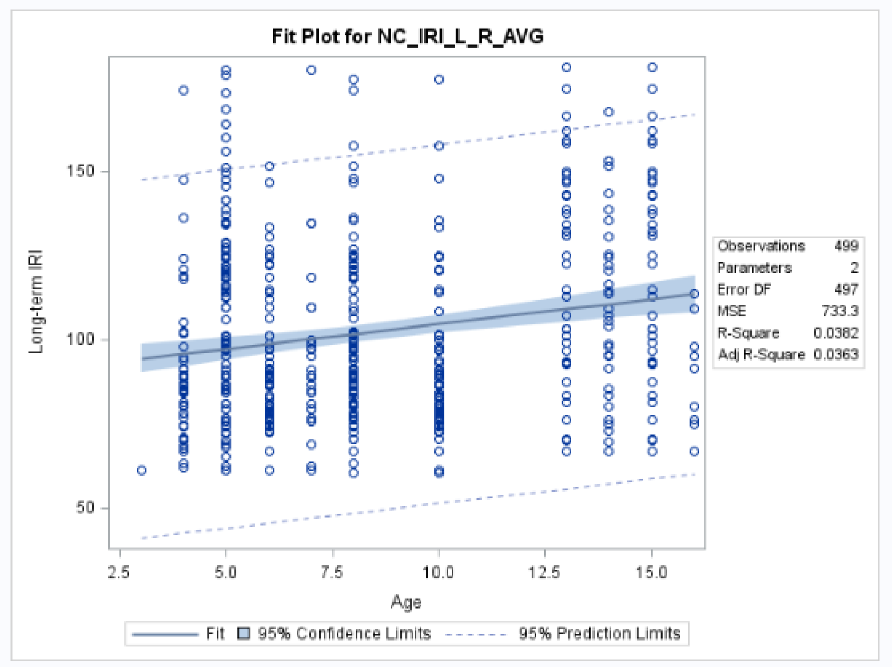
Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	30.30288	20.70684	1.46	0.1690
new_age	Age	1	11.75481	5.02215	2.34	0.0373



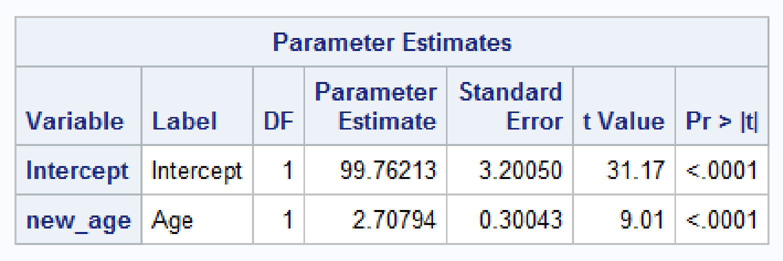
SR_BSR_1kplus subcategory 70



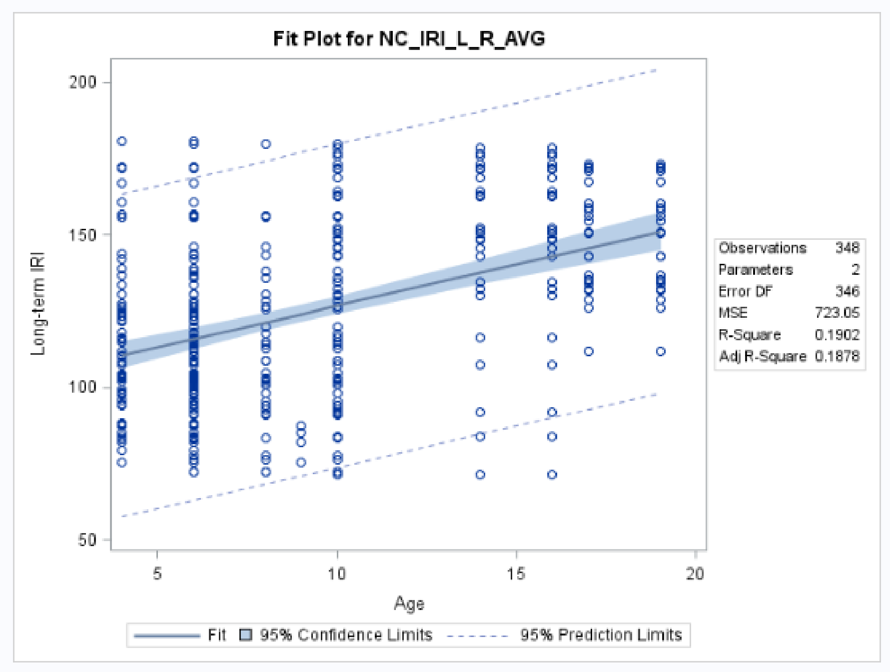
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	89.88544	3.05735	29.40	<.0001
new_age	Age	1	1.47318	0.33142	4.45	<.0001



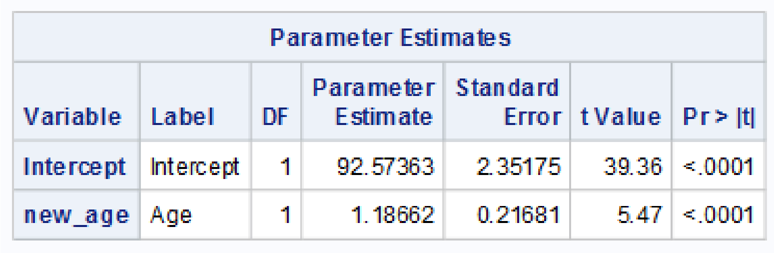
SR_BSR_1kplus subcategory 80



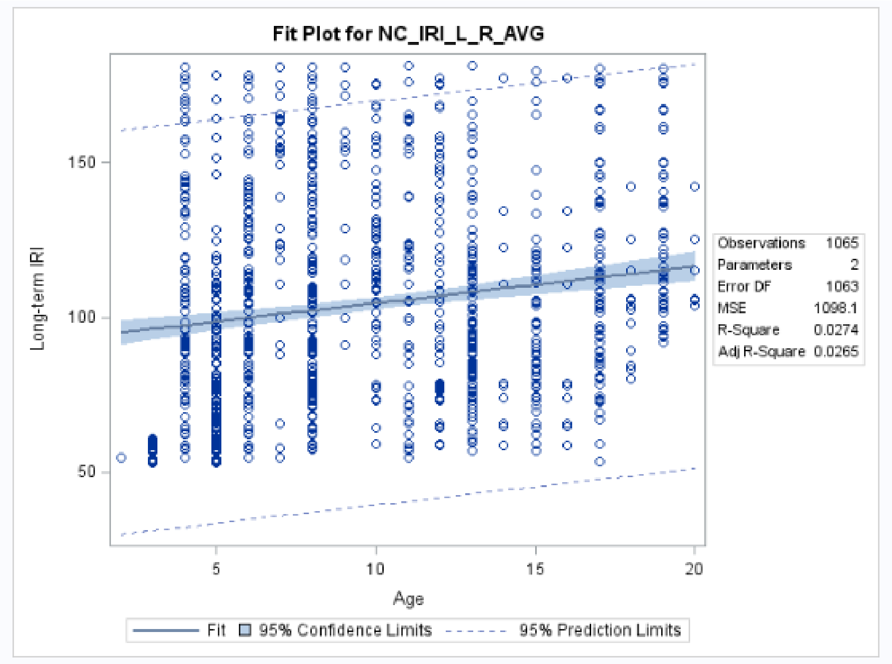
Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	99.76213	3.20050	31.17	<.0001
new_age	Age	1	2.70794	0.30043	9.01	<.0001



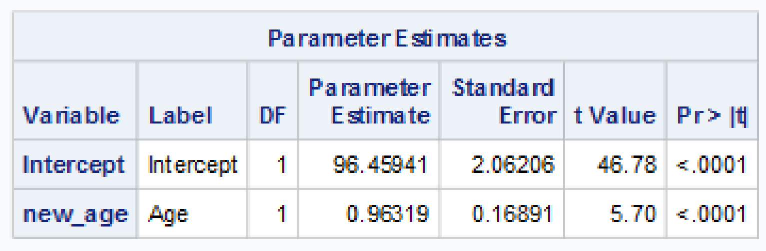
SR_PR_5-15k subcategory 60



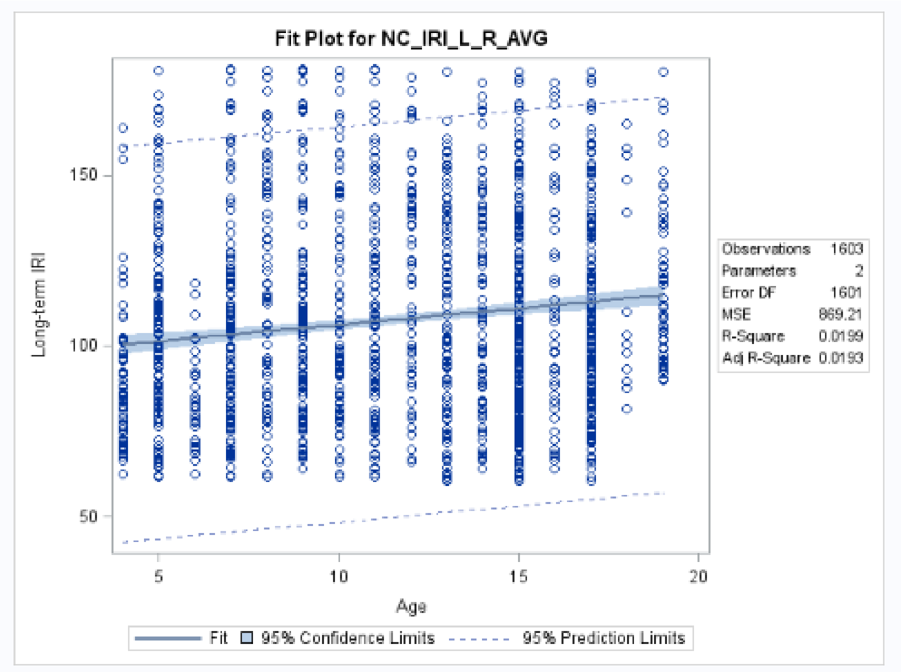
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	92.57363	2.35175	39.36	<.0001
new_age	Age	1	1.18662	0.21681	5.47	<.0001



SR_PR_5-15k subcategory 70

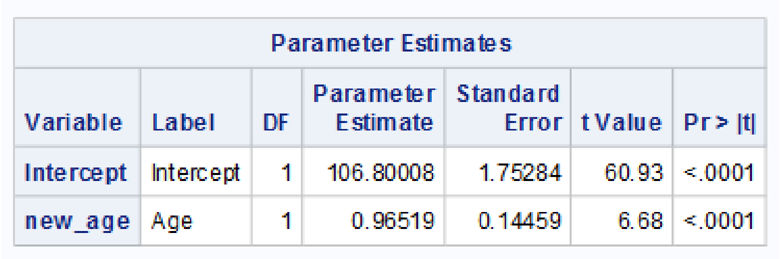


Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	96.45941	2.06206	46.78	<.0001
new_age	Age	1	0.96319	0.16891	5.70	<.0001

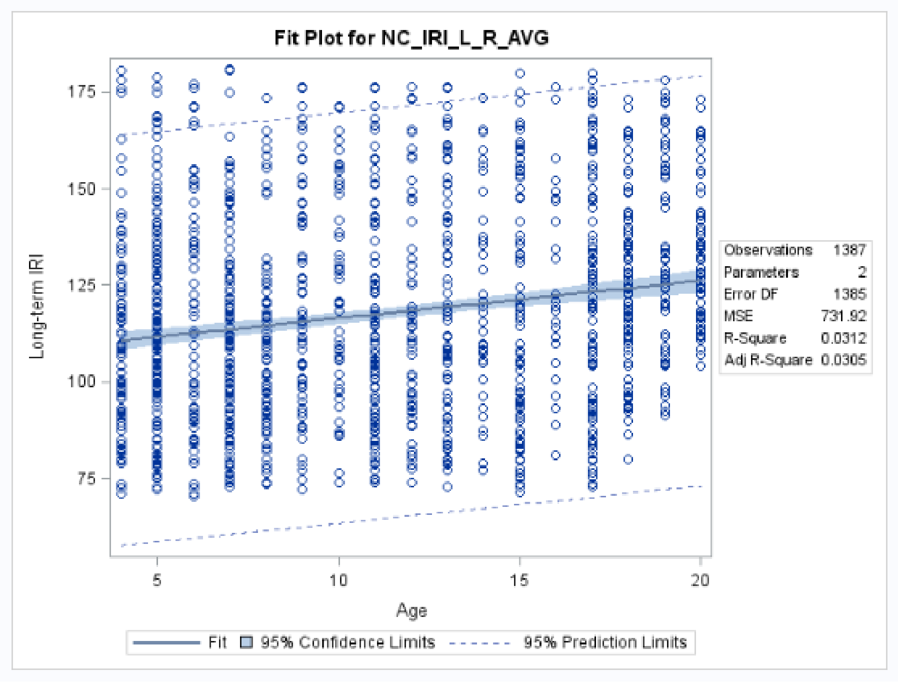


Observations	1603
Parameters	2
Error DF	1601
MSE	869.21
R-Square	0.0199
Adj R-Square	0.0193

SR_PR_5-15k subcategory 80

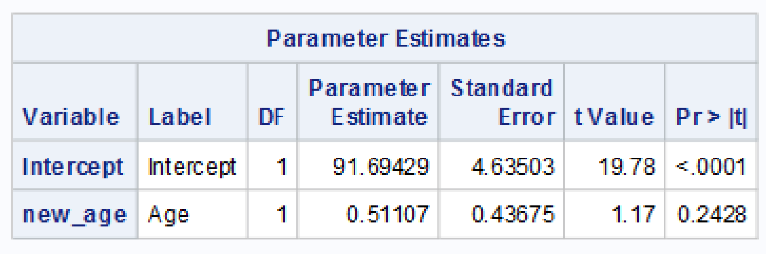


Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	106.80008	1.75284	60.93	<.0001
new_age	Age	1	0.96519	0.14459	6.68	<.0001

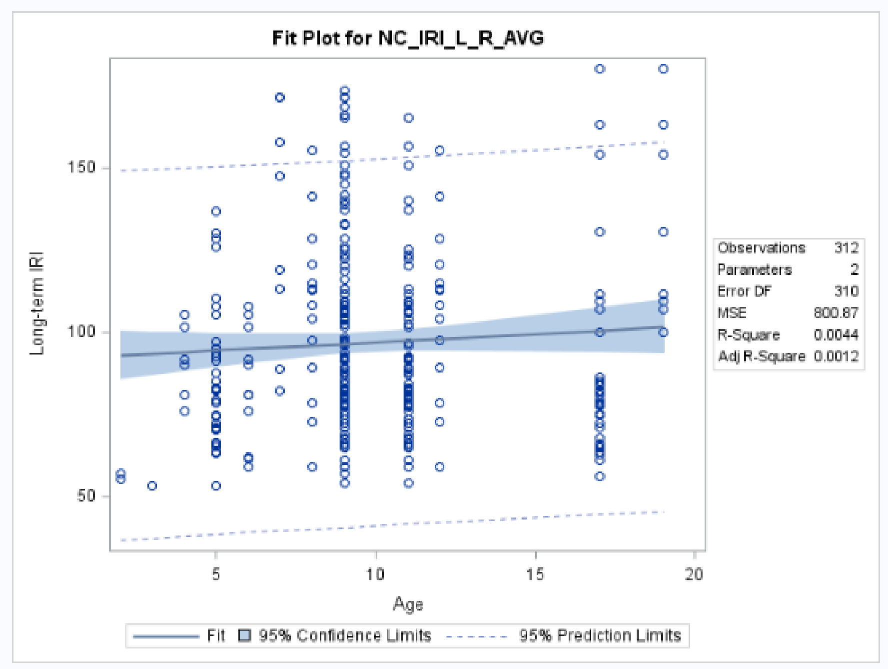


Observations	1387
Parameters	2
Error DF	1385
MSE	731.92
R-Square	0.0312
Adj R-Square	0.0305

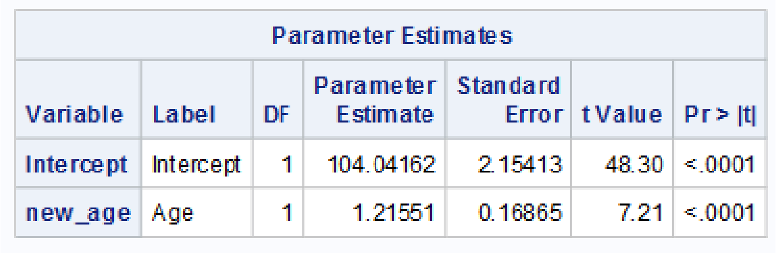
SR_PR_15kplus subcategory 60



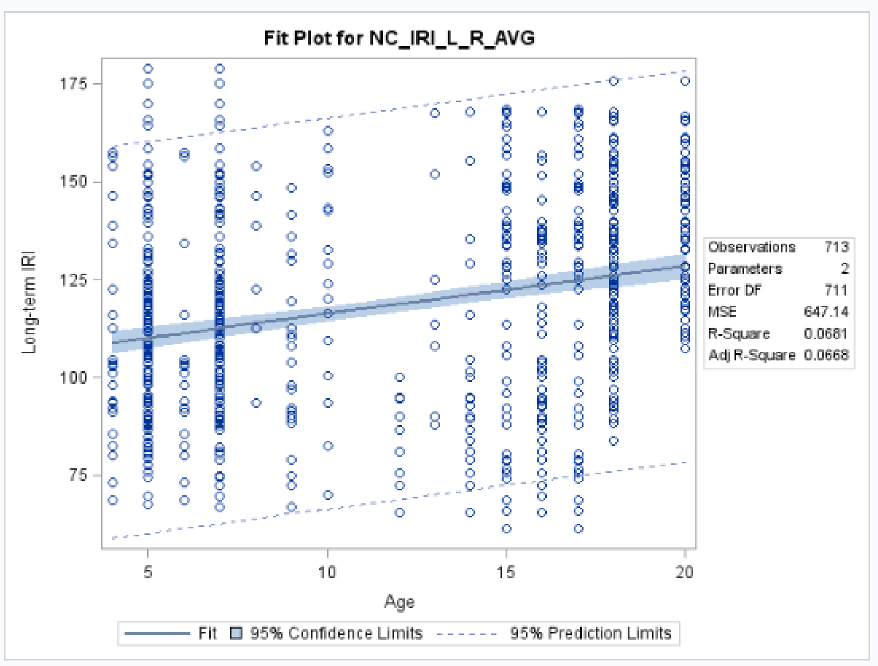
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	91.69429	4.63503	19.78	<.0001
new_age	Age	1	0.51107	0.43675	1.17	0.2428



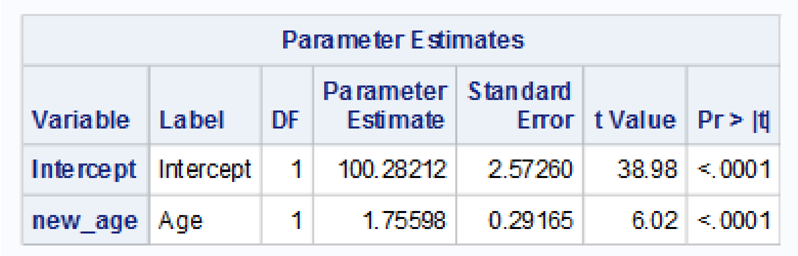
SR_PR_15kplus subcategory 70



Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	104.04162	2.15413	48.30	<.0001
new_age	Age	1	1.21551	0.16865	7.21	<.0001

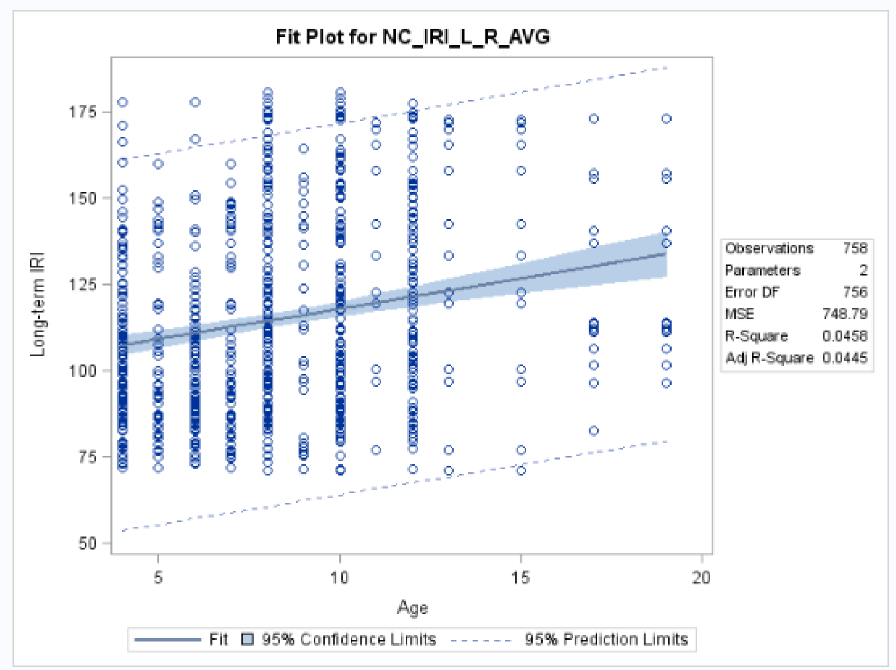


SR_PR_15kplus subcategory 80



Parameter Estimates

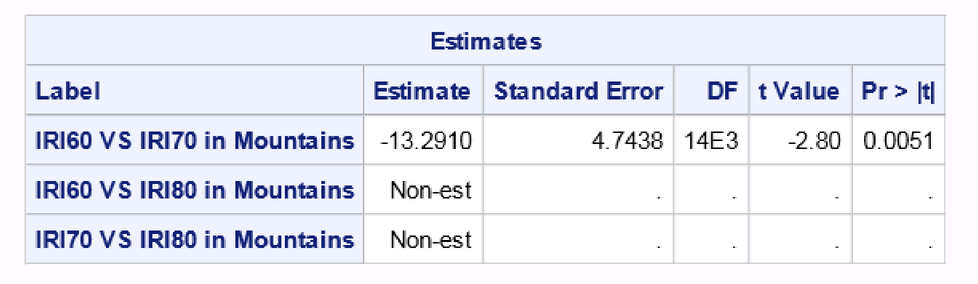
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	100.28212	2.57260	38.98	<.0001
new_age	Age	1	1.75598	0.29165	6.02	<.0001



Observations	758
Parameters	2
Error DF	756
MSE	748.79
R-Square	0.0458
Adj R-Square	0.0445

APPENDIX B: CONTRAST RESULTS

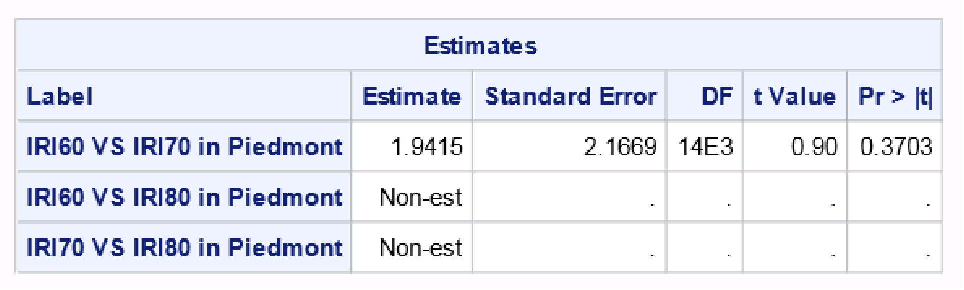
Interstate_0-50k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Mountains	-13.2910	4.7438	14E3	-2.80	0.0051
IRI60 VS IRI80 in Mountains	Non-est	.	.	.	.
IRI70 VS IRI80 in Mountains	Non-est	.	.	.	.

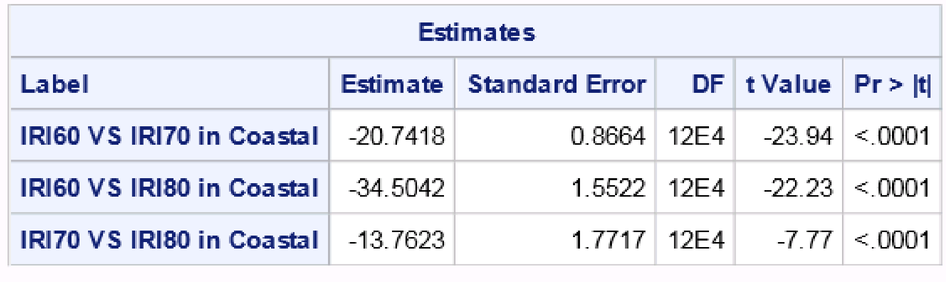
Interstate_50kplus



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Piedmont	1.9415	2.1669	14E3	0.90	0.3703
IRI60 VS IRI80 in Piedmont	Non-est	.	.	.	.
IRI70 VS IRI80 in Piedmont	Non-est	.	.	.	.

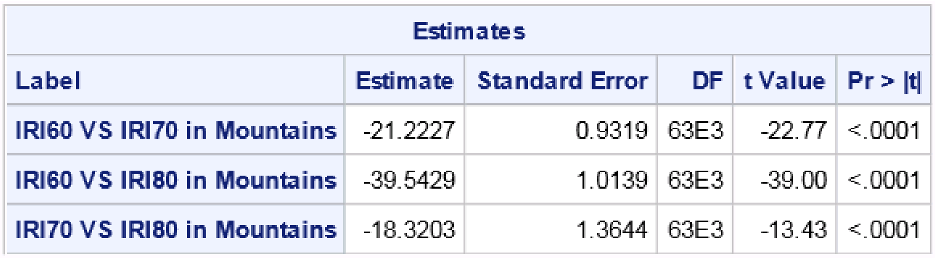
US_0-5k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Coastal	-20.7418	0.8664	12E4	-23.94	<.0001
IRI60 VS IRI80 in Coastal	-34.5042	1.5522	12E4	-22.23	<.0001
IRI70 VS IRI80 in Coastal	-13.7623	1.7717	12E4	-7.77	<.0001

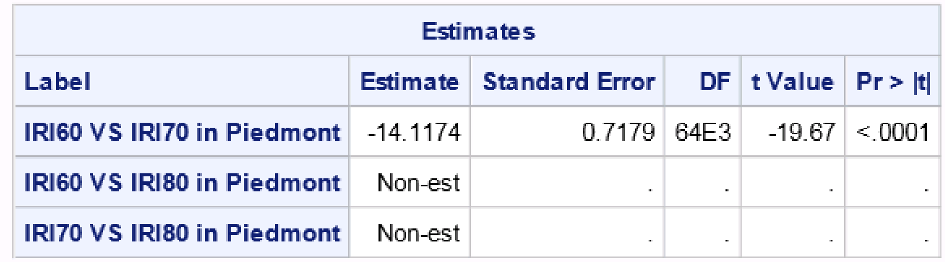
US_0-5k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Mountains	-21.2227	0.9319	63E3	-22.77	<.0001
IRI60 VS IRI80 in Mountains	-39.5429	1.0139	63E3	-39.00	<.0001
IRI70 VS IRI80 in Mountains	-18.3203	1.3644	63E3	-13.43	<.0001

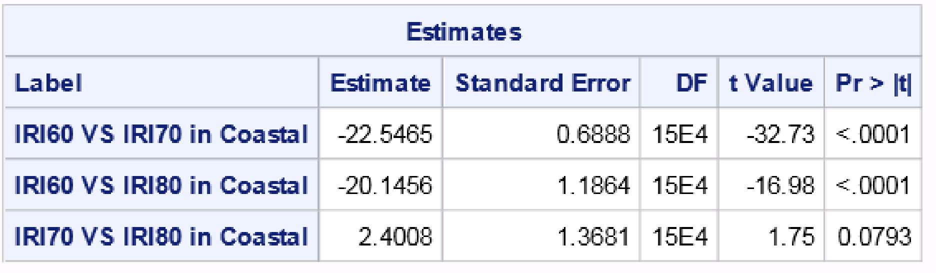
US_0-5k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Piedmont	-14.1174	0.7179	64E3	-19.67	<.0001
IRI60 VS IRI80 in Piedmont	Non-est	.	.	.	.
IRI70 VS IRI80 in Piedmont	Non-est	.	.	.	.

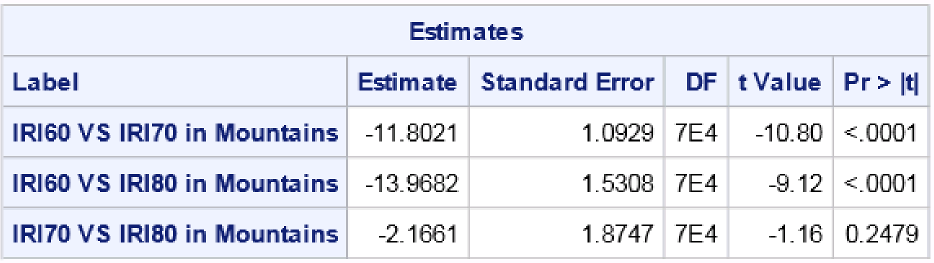
US_5-15k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Coastal	-22.5465	0.6888	15E4	-32.73	<.0001
IRI60 VS IRI80 in Coastal	-20.1456	1.1864	15E4	-16.98	<.0001
IRI70 VS IRI80 in Coastal	2.4008	1.3681	15E4	1.75	0.0793

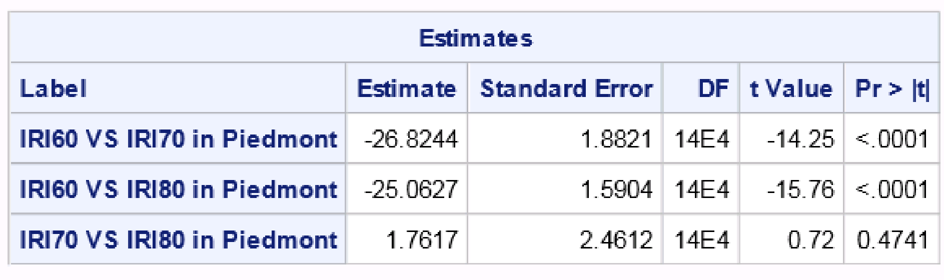
US_5-15k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Mountains	-11.8021	1.0929	7E4	-10.80	<.0001
IRI60 VS IRI80 in Mountains	-13.9682	1.5308	7E4	-9.12	<.0001
IRI70 VS IRI80 in Mountains	-2.1661	1.8747	7E4	-1.16	0.2479

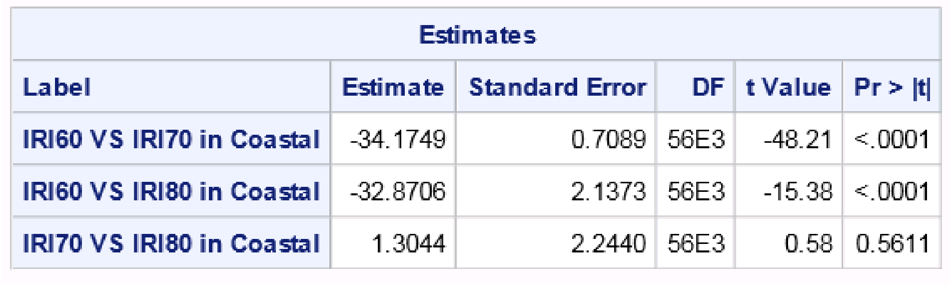
US_5-15k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Piedmont	-26.8244	1.8821	14E4	-14.25	<.0001
IRI60 VS IRI80 in Piedmont	-25.0627	1.5904	14E4	-15.76	<.0001
IRI70 VS IRI80 in Piedmont	1.7617	2.4612	14E4	0.72	0.4741

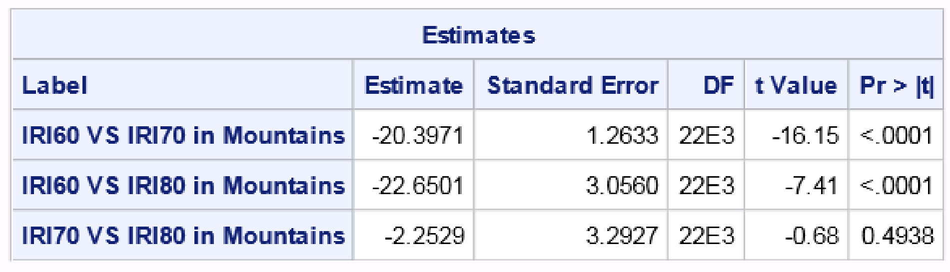
US_15-30k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Coastal	-34.1749	0.7089	56E3	-48.21	<.0001
IRI60 VS IRI80 in Coastal	-32.8706	2.1373	56E3	-15.38	<.0001
IRI70 VS IRI80 in Coastal	1.3044	2.2440	56E3	0.58	0.5611

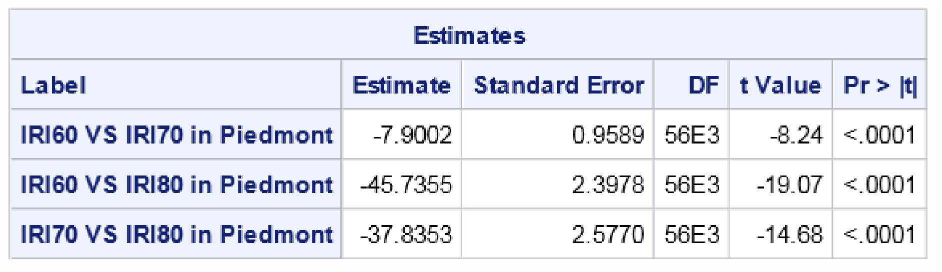
US_15-30k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Mountains	-20.3971	1.2633	22E3	-16.15	<.0001
IRI60 VS IRI80 in Mountains	-22.6501	3.0560	22E3	-7.41	<.0001
IRI70 VS IRI80 in Mountains	-2.2529	3.2927	22E3	-0.68	0.4938

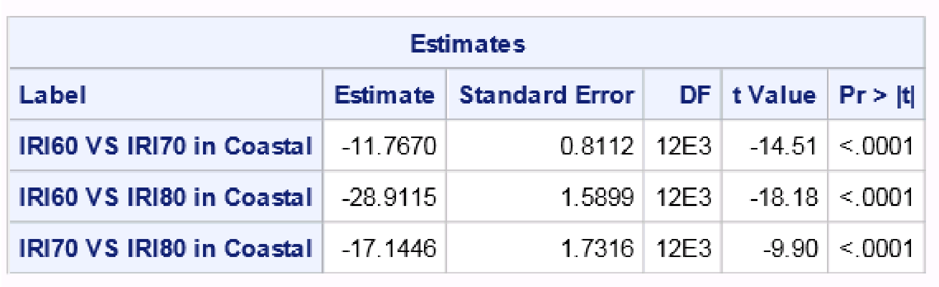
US_15-30k



Estimates

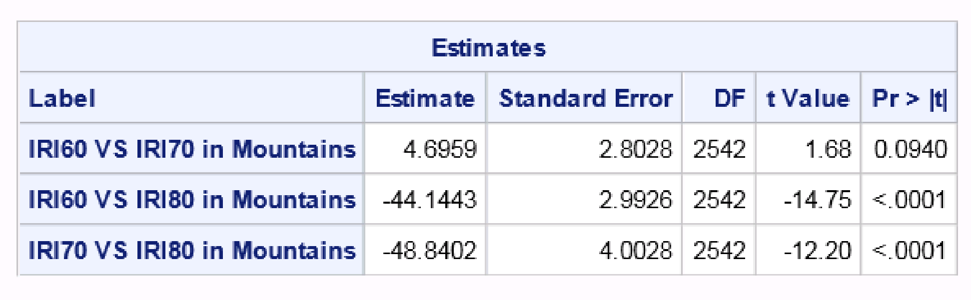
Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Piedmont	-7.9002	0.9589	56E3	-8.24	<.0001
IRI60 VS IRI80 in Piedmont	-45.7355	2.3978	56E3	-19.07	<.0001
IRI70 VS IRI80 in Piedmont	-37.8353	2.5770	56E3	-14.68	<.0001

US_30kp



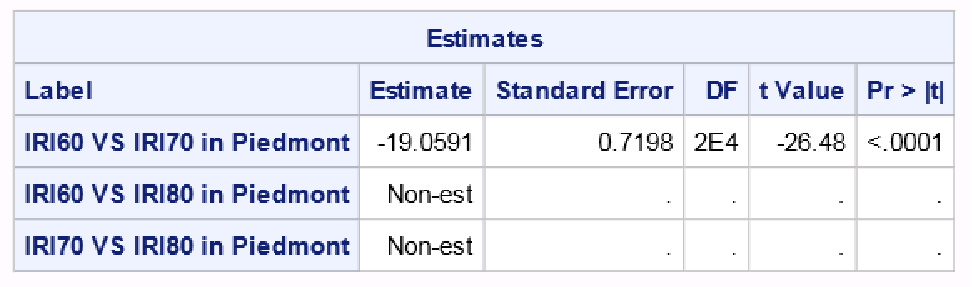
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Coastal	-11.7670	0.8112	12E3	-14.51	<.0001
IRI60 VS IRI80 in Coastal	-28.9115	1.5899	12E3	-18.18	<.0001
IRI70 VS IRI80 in Coastal	-17.1446	1.7316	12E3	-9.90	<.0001

US_30kp



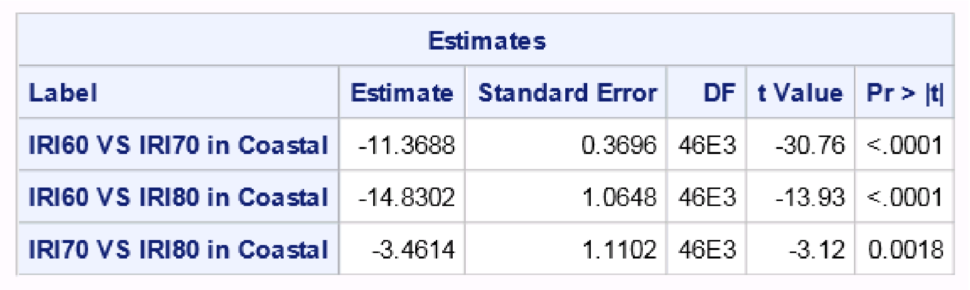
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Mountains	4.6959	2.8028	2542	1.68	0.0940
IRI60 VS IRI80 in Mountains	-44.1443	2.9926	2542	-14.75	<.0001
IRI70 VS IRI80 in Mountains	-48.8402	4.0028	2542	-12.20	<.0001

US_30kp



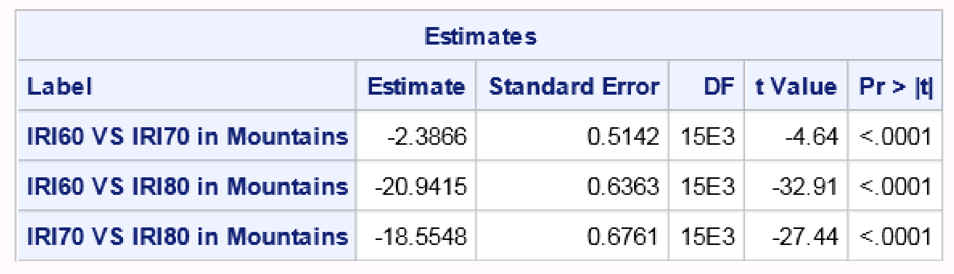
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Piedmont	-19.0591	0.7198	2E4	-26.48	<.0001
IRI60 VS IRI80 in Piedmont	Non-est	.	.	.	.
IRI70 VS IRI80 in Piedmont	Non-est	.	.	.	.

NC_0-1k



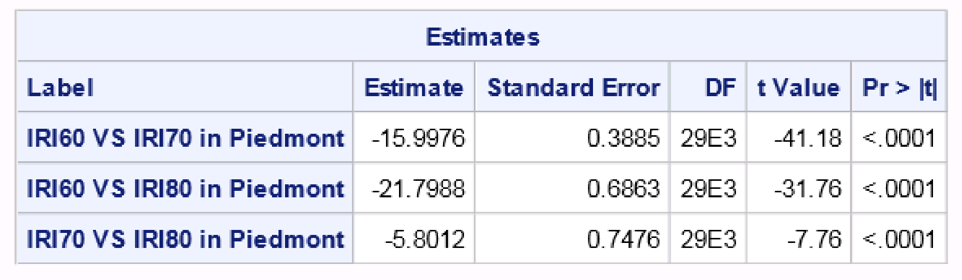
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Coastal	-11.3688	0.3696	46E3	-30.76	<.0001
IRI60 VS IRI80 in Coastal	-14.8302	1.0648	46E3	-13.93	<.0001
IRI70 VS IRI80 in Coastal	-3.4614	1.1102	46E3	-3.12	0.0018

NC_0-1k



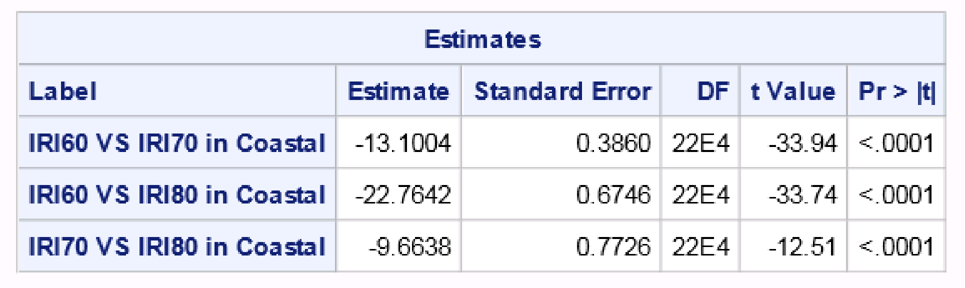
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Mountains	-2.3866	0.5142	15E3	-4.64	<.0001
IRI60 VS IRI80 in Mountains	-20.9415	0.6363	15E3	-32.91	<.0001
IRI70 VS IRI80 in Mountains	-18.5548	0.6761	15E3	-27.44	<.0001

NC_0-1k



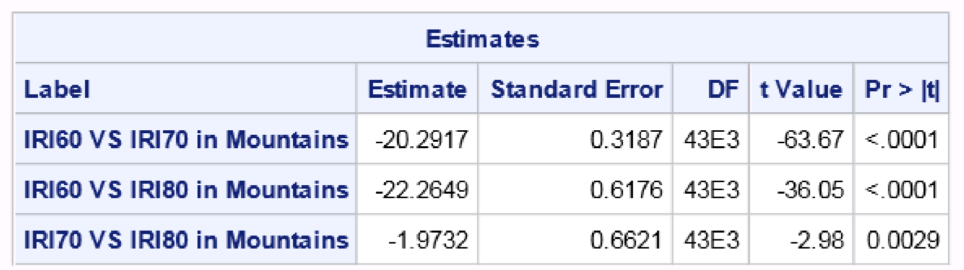
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Piedmont	-15.9976	0.3885	29E3	-41.18	<.0001
IRI60 VS IRI80 in Piedmont	-21.7988	0.6863	29E3	-31.76	<.0001
IRI70 VS IRI80 in Piedmont	-5.8012	0.7476	29E3	-7.76	<.0001

NC_1-5k



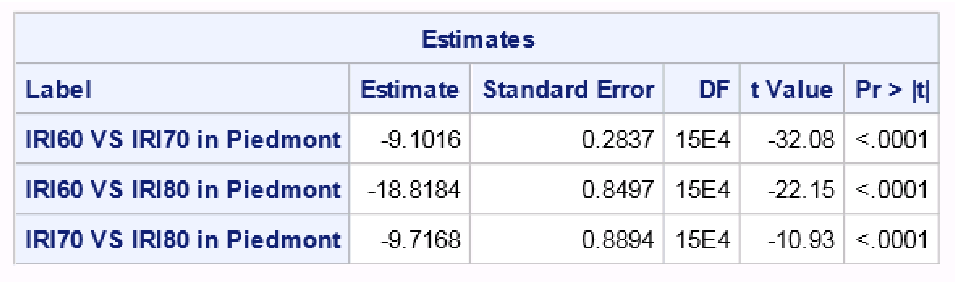
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Coastal	-13.1004	0.3860	22E4	-33.94	<.0001
IRI60 VS IRI80 in Coastal	-22.7642	0.6746	22E4	-33.74	<.0001
IRI70 VS IRI80 in Coastal	-9.6638	0.7726	22E4	-12.51	<.0001

NC_1-5k



Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Mountains	-20.2917	0.3187	43E3	-63.67	<.0001
IRI60 VS IRI80 in Mountains	-22.2649	0.6176	43E3	-36.05	<.0001
IRI70 VS IRI80 in Mountains	-1.9732	0.6621	43E3	-2.98	0.0029

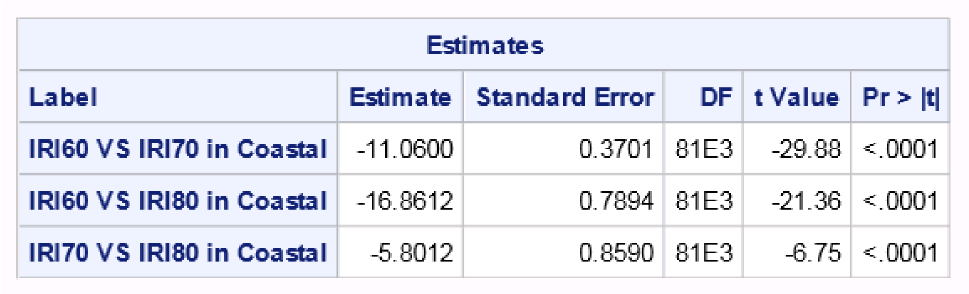
NC_1-5k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Piedmont	-9.1016	0.2837	15E4	-32.08	<.0001
IRI60 VS IRI80 in Piedmont	-18.8184	0.8497	15E4	-22.15	<.0001
IRI70 VS IRI80 in Piedmont	-9.7168	0.8894	15E4	-10.93	<.0001

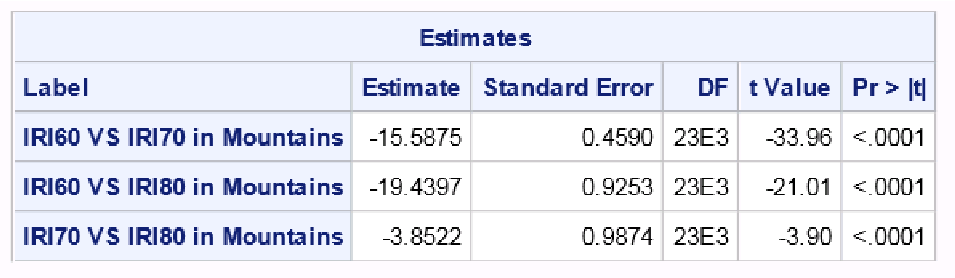
US_5-15k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Coastal	-11.0600	0.3701	81E3	-29.88	<.0001
IRI60 VS IRI80 in Coastal	-16.8612	0.7894	81E3	-21.36	<.0001
IRI70 VS IRI80 in Coastal	-5.8012	0.8590	81E3	-6.75	<.0001

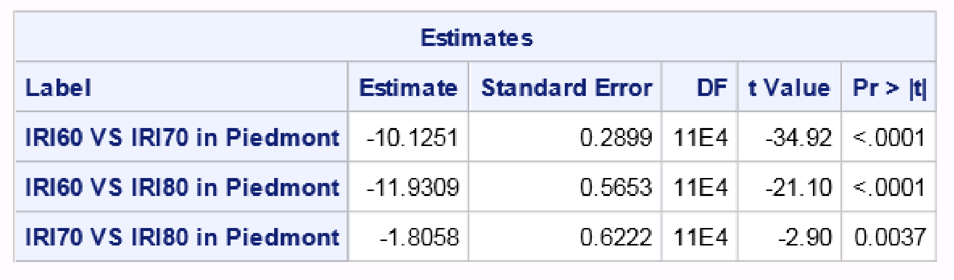
US_5-15k



Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Mountains	-15.5875	0.4590	23E3	-33.96	<.0001
IRI60 VS IRI80 in Mountains	-19.4397	0.9253	23E3	-21.01	<.0001
IRI70 VS IRI80 in Mountains	-3.8522	0.9874	23E3	-3.90	<.0001

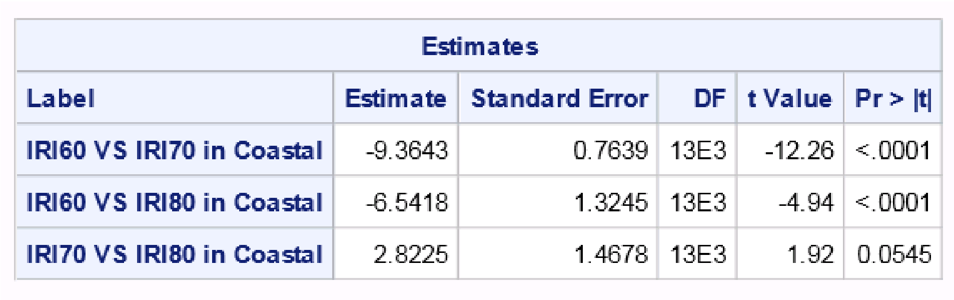
US_5-15k



Estimates

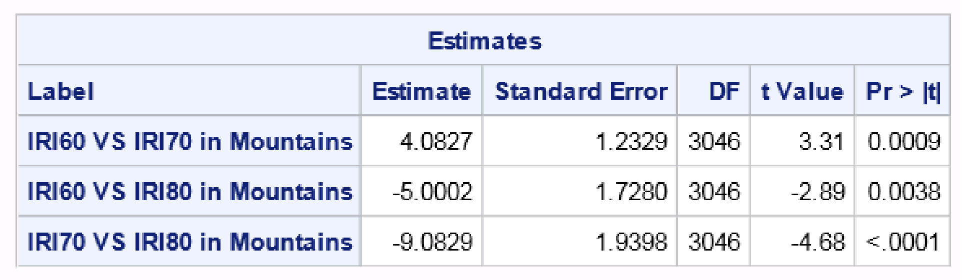
Label	Estimate	Standard Error	DF	t Value	Pr > |t|
IRI60 VS IRI70 in Piedmont	-10.1251	0.2899	11E4	-34.92	<.0001
IRI60 VS IRI80 in Piedmont	-11.9309	0.5653	11E4	-21.10	<.0001
IRI70 VS IRI80 in Piedmont	-1.8058	0.6222	11E4	-2.90	0.0037

NC_15kp



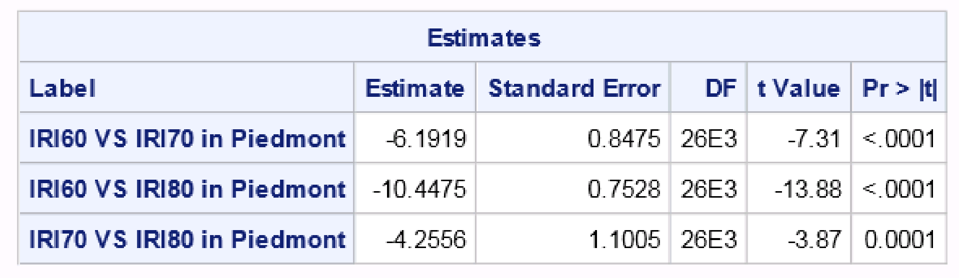
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Coastal	-9.3643	0.7639	13E3	-12.26	<.0001
IRI60 VS IRI80 in Coastal	-6.5418	1.3245	13E3	-4.94	<.0001
IRI70 VS IRI80 in Coastal	2.8225	1.4678	13E3	1.92	0.0545

NC_15kp



Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Mountains	4.0827	1.2329	3046	3.31	0.0009
IRI60 VS IRI80 in Mountains	-5.0002	1.7280	3046	-2.89	0.0038
IRI70 VS IRI80 in Mountains	-9.0829	1.9398	3046	-4.68	<.0001

NC_15kp

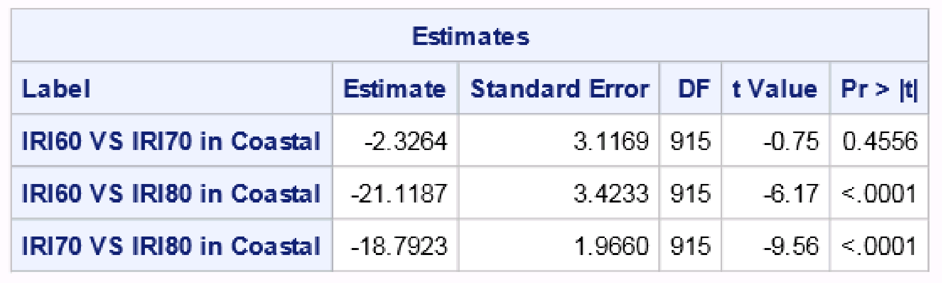


Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Piedmont	-6.1919	0.8475	26E3	-7.31	<.0001
IRI60 VS IRI80 in Piedmont	-10.4475	0.7528	26E3	-13.88	<.0001
IRI70 VS IRI80 in Piedmont	-4.2556	1.1005	26E3	-3.87	0.0001

SR_BSR_0-1k

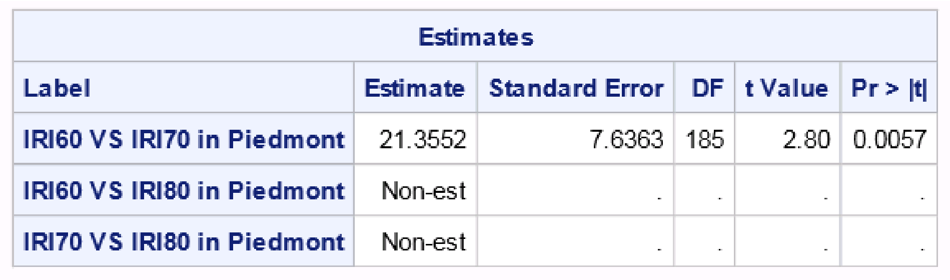
(NOT AVAILABLE)

SR_BSR_1kp



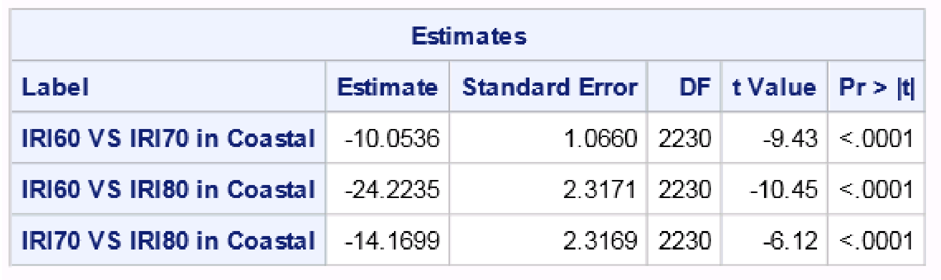
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Coastal	-2.3264	3.1169	915	-0.75	0.4556
IRI60 VS IRI80 in Coastal	-21.1187	3.4233	915	-6.17	<.0001
IRI70 VS IRI80 in Coastal	-18.7923	1.9660	915	-9.56	<.0001

SR_BSR_1kp



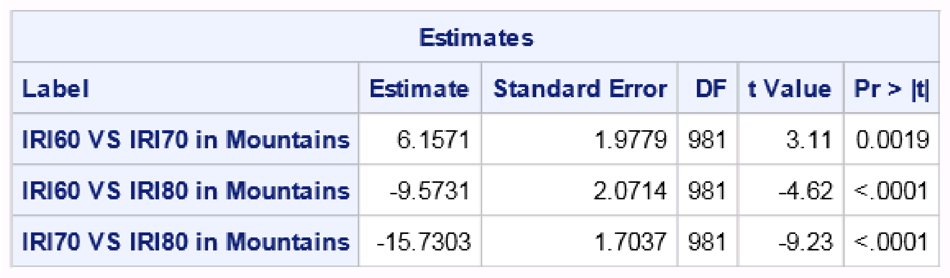
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Piedmont	21.3552	7.6363	185	2.80	0.0057
IRI60 VS IRI80 in Piedmont	Non-est	.	.	.	.
IRI70 VS IRI80 in Piedmont	Non-est	.	.	.	.

SR_PR_1-5k



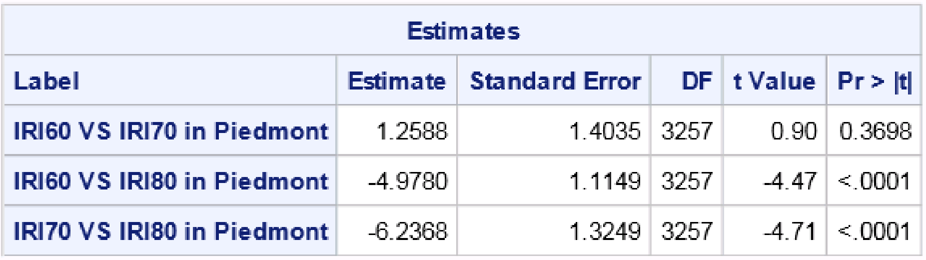
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Coastal	-10.0536	1.0660	2230	-9.43	<.0001
IRI60 VS IRI80 in Coastal	-24.2235	2.3171	2230	-10.45	<.0001
IRI70 VS IRI80 in Coastal	-14.1699	2.3169	2230	-6.12	<.0001

SR_PR_1-5k



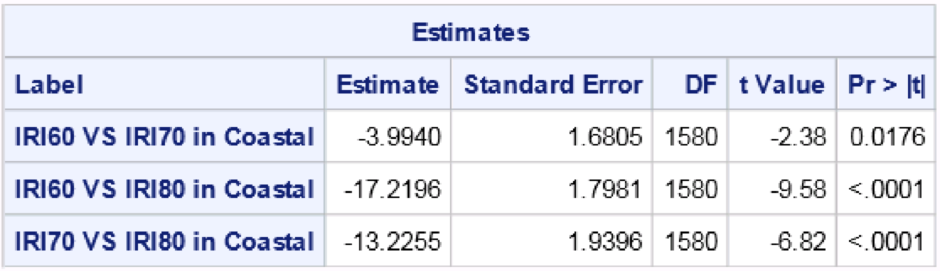
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Mountains	6.1571	1.9779	981	3.11	0.0019
IRI60 VS IRI80 in Mountains	-9.5731	2.0714	981	-4.62	<.0001
IRI70 VS IRI80 in Mountains	-15.7303	1.7037	981	-9.23	<.0001

SR_PR_1-5k



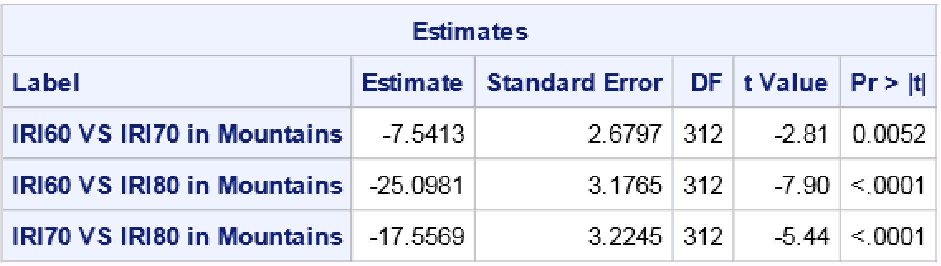
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Piedmont	1.2588	1.4035	3257	0.90	0.3698
IRI60 VS IRI80 in Piedmont	-4.9780	1.1149	3257	-4.47	<.0001
IRI70 VS IRI80 in Piedmont	-6.2368	1.3249	3257	-4.71	<.0001

SR_PR_5-15k



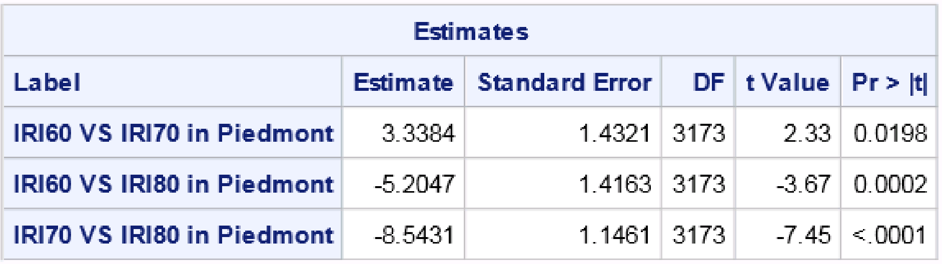
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Coastal	-3.9940	1.6805	1580	-2.38	0.0176
IRI60 VS IRI80 in Coastal	-17.2196	1.7981	1580	-9.58	<.0001
IRI70 VS IRI80 in Coastal	-13.2255	1.9396	1580	-6.82	<.0001

SR_PR_5-15k



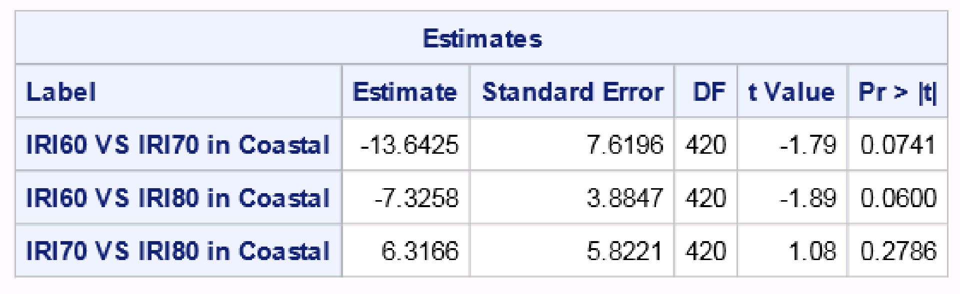
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Mountains	-7.5413	2.6797	312	-2.81	0.0052
IRI60 VS IRI80 in Mountains	-25.0981	3.1765	312	-7.90	<.0001
IRI70 VS IRI80 in Mountains	-17.5569	3.2245	312	-5.44	<.0001

SR_PR_5-15k



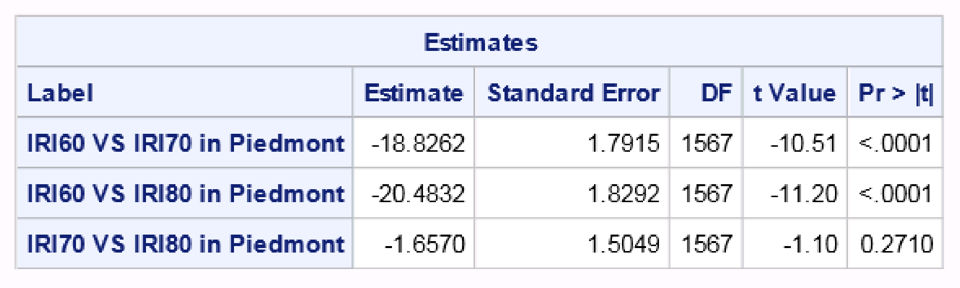
Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Piedmont	3.3384	1.4321	3173	2.33	0.0198
IRI60 VS IRI80 in Piedmont	-5.2047	1.4163	3173	-3.67	0.0002
IRI70 VS IRI80 in Piedmont	-8.5431	1.1461	3173	-7.45	<.0001

SR_PR_15kplus



Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Coastal	-13.6425	7.6196	420	-1.79	0.0741
IRI60 VS IRI80 in Coastal	-7.3258	3.8847	420	-1.89	0.0600
IRI70 VS IRI80 in Coastal	6.3166	5.8221	420	1.08	0.2786

SR_PR_15kplus



Estimates					
Label	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
IRI60 VS IRI70 in Piedmont	-18.8262	1.7915	1567	-10.51	<.0001
IRI60 VS IRI80 in Piedmont	-20.4832	1.8292	1567	-11.20	<.0001
IRI70 VS IRI80 in Piedmont	-1.6570	1.5049	1567	-1.10	0.2710