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ROUGHNESS PROGRESSION ON KDOT ASPHALT PAVEMENTS

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16 Abstract

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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ABSTRACT

Pavement smoothness is a major factor affecting performance. Since the introduction of the Superpave system in Kansas, bonus payment for asphalt pavement construction has increased significantly, indicating that these pavements are smoother initially. However, roughness (or lack of smoothness) progression on these pavements is yet to be determined. In this study, roughness of 17 pavement sections, built between 1998 and 2001, was analyzed. These sections were constructed over different subgrade and base types, and different asphalt binder grades were used. Annual roughness data was collected from the Pavement Management Information System database of the Kansas Department of Transportation. In addition, five new sections, built over last three years, were also monitored. Roughness data on these sections were collected periodically. International Roughness Index (IRI) was used as the roughness statistic for analyzing both types of sections.

The results show that Cold-In-Place Recycled (CIPR) bases produce smoother Superpave pavements over time compared to crushed aggregate and asphalt concrete bases. Properties of the surface course mixture and the subgrade are the major factors that influence as-constructed roughness of Superpave pavements. Roughness progression trends show that there is a linear relationship between the short-term roughness and the as-constructed roughness. For the Superpave pavements that did not receive early maintenance intervention, the short-term roughness would be influenced by age the pavement and binder course mixture properties. The short-term roughness of a Superpave pavement is very sensitive to age and the surface course dust content.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Pavement smoothness can simply be defined as a lack of roughness. This is a more optimistic view of the road condition. Pavement roughness can be described by the magnitude of longitudinal profile irregularities and their distribution over the measurement interval. It consists of random multi-frequency waves of different wavelengths and amplitudes. ASTM (1998) defines roughness as “the deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage, for example, longitudinal profile, transverse profile and cross slope.” Janoff (1985) defines longitudinal roughness as “the deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, and dynamic pavement load.”

Pavement profiles and detailed recordings of surface elevations are frequently used to characterize smoothness. Different wavelengths will have different effects on ride quality depending upon vehicle characteristics and driving speed. Thus smoothness is an important indicator of pavement riding comfort and safety. Rough roads also result in potential vehicle damage and increased operating costs. Monitoring pavement smoothness has been a hallmark of pavement management system.

There is a growing concern in the highway industry for smoother and smoother pavements. In a 1990 NCHRP study, it was shown that out of the 36 states reporting, 80 percent specified smoothness criteria on new pavement construction (Woodstrom, 1990). Just two years later, in another NCHRP study, it was found that of the 22 states reporting, 91 percent utilized smoothness criteria on construction of new pavements (Scofield, 1992). A 2005 NCHRP study has shown that 16 agencies are using ride quality for quality control for asphalt pavements and 39 agencies use ride quality in acceptance (Hughes, 2005).

Although smoothness specifications with profilograph measurements were implemented on the Portland Cement Concrete (PCC) pavements in 1985 in Kansas, new bituminous pavements had surface tolerance requirements as measured by a 10 ft straight edge or 25 ft string line at selected locations. The maximum variation of the surface for 10 ft was not allowed to exceed 3/16 inch and the maximum for 25 ft was 5/16 inch. Evidently, these requirements were not sufficient for constructing smooth riding bituminous pavements, and public complaints about the rides on the newly paved bituminous pavements were rampant. By 1990, the Kansas Department of Transportation (KDOT) was successful in controlling concrete pavement smoothness in the state of Kansas. This success of smoothness specifications on PCC pavements led to the development of profilograph-based specifications for Asphalt Concrete (AC) pavements in 1990 (Hossain and Parcells, 1995).

1.2 PROBLEM STATEMENT

Pavement smoothness is probably the single most important indicator of performance from the stand point of the traveling public. The road surface smoothness on newly constructed bituminous pavement is a major concern for the highway industry. This “smoothness” or riding comfort is a measure of the quality of the newly constructed pavements since it affects the road users directly. According to Hudson (1981), the primary purpose for smoothness measurement is to maintain the construction quality control.

After the introduction of Superpave pavements in Kansas, smoothness bonus payment has increased significantly, indicating that Superpave pavements are smoother initially. However, very few studies have been done on the roughness progression of Superpave pavements. Thus, there is a need to determine whether the roughness progression has slowed down or not.

1.3 RESEARCH OBJECTIVES

The objectives of this study are:

- To evaluate short-term roughness progression on Superpave pavements built in Kansas;
- To find the significant factors that contribute to as-constructed and short-term roughness on Superpave pavements; and
- To establish the functional relationships between roughness and the significant factors that influence it.

1.4 SYNOPSIS

This report is divided into six chapters. Chapter one is an introduction to the problem. Chapter two is a literature review on asphalt pavement roughness. This chapter also discusses roughness evaluation equipment and roughness summary statistics. Chapter three identifies the projects and the different data used in the study. Chapter four is an analysis of the roughness data showing the roughness trends. Chapter five presents the statistical analyses that were done in this study. Results of analysis of variance and multiple regression are presented in this chapter. Finally, chapter six offers some conclusions and recommendations.

CHAPTER 2

REVIEW OF PREVIOUS ASPHALT ROUGHNESS RESEARCH

2.1 OVERVIEW

Many in the asphalt pavement industry believe that initial pavement smoothness is directly related to the pavement service life. Very few studies have been conducted which directly relate pavement smoothness to actual pavement performance. A previous study for the National Asphalt Pavement Association (NAPA) examined the relationship between initial roughness and roughness after 8 to10 years of service (Janoff, 1985). The results showed that pavements with increased initial smoothness had lower roughness levels, fewer cracks levels, and lower average annual maintenance costs after 8 to 10 years following construction. The results also indicated that approximately 110 percent of initial roughness was present after 8 to 10 years of service. The study was conducted based on roughness measurements form Arizona and Pennsylvania obtained with a Mays ride meter. The same relationship should be present for the International Roughness Index (IRI) measurements, as Mays ride meter measurements have been shown to have a linear relationship with IRI.

A research study was conducted by the University of Waterloo (Raymond, 2000) using the Canadian Long Term Pavement Performance (C-LTPP) and the Federal Highway Administration (FHWA) Long Term Pavement Performance (LTPP) data to examine the effect of initial smoothness on long-term roughness progression in asphalt overlays placed over existing asphalt pavements. Roughness data was collected from Specific Pavement Study (SPS) section SPS-5, General Pavement Study (GPS) section GPS-6, and C-LTPP sites. Results indicate that for the C-LTPP sites, 68 percent of the initial roughness remains after 8 years of service. These values are 57, 85, and 84 percent for SPS-5, GPS-6, and combination of these three sites, respectively. Removing outliers in the combined analysis it showed that almost all of initial roughness remains after eight years of service life for the overlaid asphalt pavements.

A recent NCHRP study (Perera and Kohn, 2001) using LTPP data examined different factors that might affect pavement smoothness. For GPS-1 (AC pavements on granular base) sections, results showed that on 13 percent of the sections, IRI at last profile date was less than the IRI at the first profile date, while on 15 percent of the sections the difference in IRI between the last and the first profile date was less than 6.4 in/mile. The average time interval between the first and the last measurement was six years. For GPS-2 (AC pavements on stabilized base) sections, results showed that on 11 percent of the test sections, the IRI at the last profile date was less than the IRI at the first profile date, and the difference between the IRI values for these measurements was less than 6.3 in/mile. This difference is very small and can result from the variations in the profiled path (Perera and Kohn, 2001). A model was developed for each site, which predicts long-term IRI in terms of IRI at first profile data (not as-constructed), time between consecutive profile measurements, cumulative traffic, structural number of the section, plastic limit of subgrade, percent materials of base passing No. 200 sieve (for GPS-1 site), and moisture content of subgrade soil (for GPS-2 site). As expected, it was found for both sites that a smoother pavement remained smoother during the next measurement.

Perera and Kohn (2001) also studied an LTPP SPS site in Kansas. The SPS-1 site (strategic study of structural factors for flexible pavements) shows that initial average IRI of 12 test sections in Kansas was 51 inches per mile. However, significant smoothness loss occurred with time for most of these sections. The roughness of some of these sections increased by 100 inches per mile over a 5 year time period. This study did not identify the factors that lead to this rapid increase in roughness.

2.2 ROUGHNESS TRENDS IN FLEXIBLE PAVEMENTS

The LTPP program recently completed a study to investigate the changes in roughness of flexible pavements over time and their relationship to design factors, subgrade conditions, and climatic conditions. After observing the roughness trends, the conclusion was that most of the flexible pavement sections studied showed little change in roughness over time (FHWA, 1997). Other key findings from this study included (FHWA, 1997):

- Flexible pavement roughness remains relatively constant over the early life of the pavement. Then, after a certain point, it shows a rapid increase.
- Roughness of the pavements over fine-grained soils was related to the plasticity index and the percentage of subgrade passing the US No. 200 sieve. Pavements on fine-grained soils having higher plasticity indices and a higher percentage passing the US No. 200 sieve have higher International Roughness Index (IRI) values.
- Pavements in areas that have a high freezing index or a high number of freeze/thaw cycles had higher roughness values. This would suggest

that adequate frost protection is an important factor for good pavement performance in freezing regions.

Most of the test sections studied in that project were more than 15 years old, but had low roughness values. A preliminary analysis of these sections indicated that they had carried a low cumulative traffic volume when compared to the theoretical cumulative traffic volume that can be supported by the pavement structure (FHWA, 1997). Furthermore, most of the sections that were showing a high increase in roughness over the years were close to or had exceeded their design life based on the equivalent single-axle loads and the 1993 AASHTO pavement design equation. Another general observation noted from this study was that pavements with IRI in excess of 126 in/mile generally exhibited larger increases in roughness over time when compared to the other test sections.

The time-sequence roughness values at a section can vary due to the following factors: variations in the profiled path, seasonal effects, and maintenance activities. Variations in the profiled wheelpath for different years can cause changes in the measured profile and, therefore, the computed roughness. Considerable transverse variability may also occur in some pavements which may cause considerable variations in roughness, depending on the wheel path that is followed. If a section is profiled during different seasons of the year, changes in roughness can occur. For instance, the profile of a pavement can change due to moisture effects on a subgrade that cause the subgrade soil to swell or shrink. Frost heave of the subgrade and base layers during the winter months can cause variations in the pavement profile. Consequently, thawing action of the subgrade and base in spring can cause variations in the pavement profile.

Maintenance activities such as repair of distressed areas can lead to a reduction of pavement roughness. The variable roughness patterns that were observed at some of the test sections in this study were attributed to these causes.

2.3 ATTAINMENT OF ASPHALT CONCRETE (AC) PAVEMENT SMOOTHNESS

The smoothness of an asphalt pavement is primarily a function of its as-constructed smoothness. However, other factors such as distresses occurring in the pavement can adversely affect the smoothness. Major distresses in AC pavements that affect smoothness include fatigue cracking, deteriorated transverse cracking, corrugations, and shoving. Subgrade properties, such as, expansive and frost susceptible soils, may also contribute to the roughness of an AC pavement.

2.3.1 Profile Measurements during Construction

As-built roughness is very critical and necessary measures need to be taken to reduce it. Daily measurement of the completed pavement profile is necessary to best achieve the desired pavement profile (FHWA, 2002). This helps in detecting defects and minimizes the cumulative effect of such anomalies that might occur in the construction process. This can detect where roughness is developing and what factors may be leading to these defects, such as, paving equipment operation. Daily profile traces should be reviewed for compliance with the specifications, the effect of the results on the incentive payments, and the identification of opportunities for improvement should be part of the measurement and tracking process.

Equipment used for profile measurements should be properly calibrated and should be in good working order too. Equipment should provide results which are precise, repeatable, and reproducible. Repeatability is the ability of the same equipment to repeat itself on the same length of roadway. Reproducibility is the ability of two pieces of equipment to produce the same true profile. In addition to the precision of the equipment, the specification writer should keep in mind that profilographs are not capable of measuring long wavelength roughness that may be present in an AC pavement. It is also important to consider how the contractor will be allowed to correct defects in the pavement profile. Some contractors suggest rolling out bumps before resorting to grinding. Some owners prefer to leave the bump and only extract the monetary penalty. Their feeling is that rolling or grinding the pavement is more damaging to the pavement than leaving the bump in the pavement.

2.3.2 Factors Affecting As-Constructed Smoothness in an AC Pavement

Some studies have shown that AC pavements that are smooth initially stay smoother for a longer time. In general, good planning and communication, proper mix production and delivery, correct placement techniques, and accurate end-product evaluation are required during construction of either a new pavement or an overlay to achieve a smooth AC pavement. Projects analyzed in this study are rehabilitated (overlay), reconstructed or new pavements sections. Factors that may lead to a smooth as-constructed pavement are discussed below.

Planning and Communication

Good planning is required before the construction process begins. Effective communication starts with the pre-paving meeting and it has to be continued through out the project if a smooth pavement is to be constructed.

Subgrade Preparation

The purpose of the subgrade is to provide a stable platform so that the base can be placed without deforming. Generally, a subgrade with an in-place California Bearing Ratio (CBR) of 6 or higher is considered sufficiently stable for the construction of base course (FHWA, 2002). Expansive soils need to be stabilized after which the subgrade is trimmed to provide the grade necessary for placement of the base.

Base Preparation

Roughness in the base will be reflected in the surface. Therefore, it is important to ensure that a smooth base is constructed. Again, stability of the base is an issue of concern toward constructing a smooth pavement. If need be, reworking or stabilizing the base can be done to provide the proper support.

Surface Preparation for AC overlay

Removal and repair of distressed areas using proper patching techniques is required. Cracks need to be routed and sealed. Milling or a leveling course can be used where appropriate depending on the extent of rutting or in cases where the existing pavement is very rough. After these repairs are done, proper brooming of the surface is required followed by application of a tack coat to ensure a good bond between the underlying pavement structure and the overlay.

Mix Production and Material Delivery

Consistency of the mix is vital in that, the mix must be produced with a consistent temperature in order to prevent negative effects on the paver dynamics as the viscosity of the mix changes with temperature. Improper handling of the mixture can lead to segregation. Segregation makes the mixture non-uniform due to separation of the coarse and fine aggregates. Segregation hinders proper compaction leading to a rough pavement. A segregated mix also results in varying viscosity, changing the forces on the screed and the mat thickness.

When delivering the material using an end dump truck, the paver should be allowed to make a gentle contact with the delivery truck and then push it. This will avoid the creation of a bump or marks in the pavement. However, use of a bottom dump truck (conveyer or belly) eliminates this bumping effect although some other precaution should be taken when belly dumping. A new development in the delivery of the mix that completely eliminates this bumping effect is the use of a Material Transfer Vehicle (MTV). The MTV acts as a surge bin on wheels that has the ability to take mix from a truck, remix it (reducing the potential of temperature segregation), and then deliver the mixture to the paver via a conveyer.

Placing

In order to construct a smooth AC pavement, paving needs to be done at a slow and steady pace. A constant supply of material is required in order to ensure continuous paver operation. Thus, it is important to coordinate plant production, delivery, and paver speed.

Grade Control

This is required to ensure the desired pavement profile is met. The three traditional types of grade reference methods used in AC pavement construction are stringline, mobile reference, and joint matching shoe (FHWA, 2002). Laser technology is also being employed today but it becomes difficult where there are numerous changes in grade. A combination of these methods can also be used. A stringline is theoretically the best method but it is expensive and there are chances that it might get bumped by workers or equipment. The state of the practice for constructing smooth AC pavements is to use a long mobile referencing system, usually a 30 ft or longer ski (FHWA, 2002). A joint-matching shoe is a short ski (1 ft) that simply duplicates the grade of the surface on which it is riding. Therefore, it should only be used when the grade being sensed is very smooth.

Compaction

A test strip needs to be constructed at the start of any new paving project to determine the proper type and number of rollers needed for the given project. Wheels or drums of the rollers need to be clean and straight. Generally, proper roller operation techniques such as operating the roller at a continuous speed and keeping the roller on the newly placed mat need to be practiced to ensure a smooth pavement.

Joint Construction

Transverse joints can be used in AC pavements when construction is suspended, such as at the end of the day and longitudinal joints are established when a lane of AC is constructed adjacent to a previously paved lane. When constructing joints, it is important to ensure that pavement thickness is not reduced which might affect the initial smoothness and also it might cause the weakness of the joint to be accentuated.

CHAPTER 3

TEST SECTIONS AND DATA COLLECTION

3.1 TEST SECTIONS

3.1.1 Introduction

Project specific information for different test sections analyzed in this study is presented here. These sections can broadly be classified into two groups: existing and new Superpave sections. These selected projects were conventionally built as illustrated in Figure 3.1. Conventional AC pavements are layered systems with superior materials at the top where the intensity of stress is high and inferior materials at the bottom where the stress intensity is low. This allows the use of local materials and usually results in an economical design. The test sections were Superpave projects and are located in different parts of the state as shown in Figure 3.2.

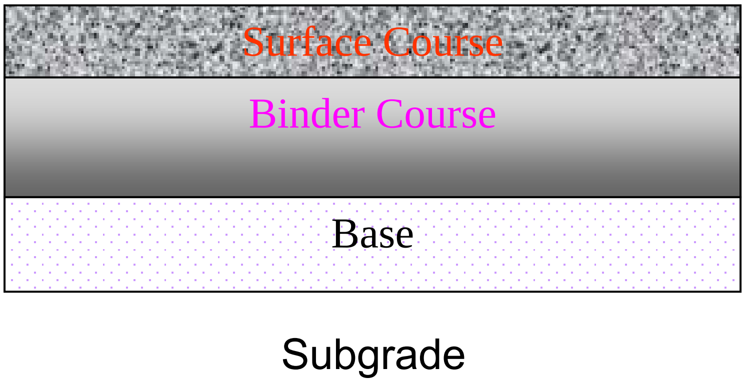


Figure 3.1 Typical Cross Section of a Conventional Flexible Pavement

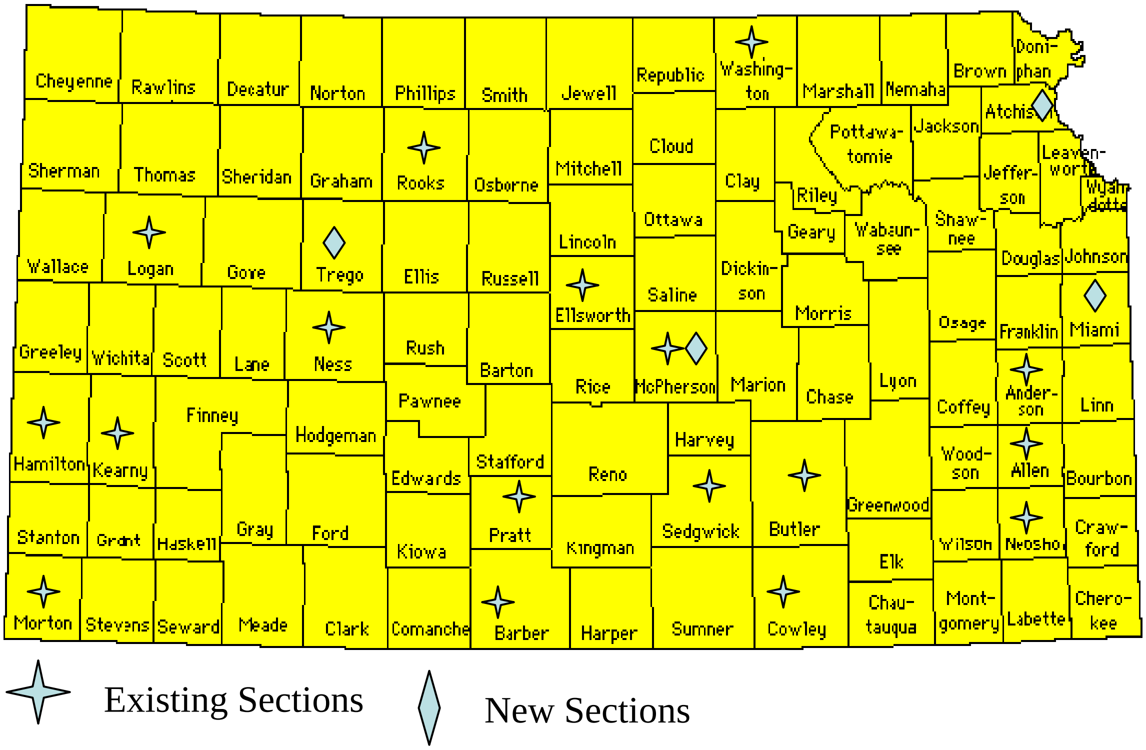


Figure 3.2 Project Locations

3.1.2 Existing Superpave Sections

A total of seventeen projects were selected for analysis as shown in Table 3.1. These projects were built between 1998 and 2001. All of these sections are major modification projects, i.e., they are either reconstructed or rehabilitated sections. Table 3.2 shows the layer thickness data for these projects. Most of the sections are two-lane undivided highways with 8 to 10-ft wide shoulders. The K-254 sections are four-lane divided highways. Project lengths vary and so do the thicknesses of different layers.

Nine of these projects were built over six inch lime-treated subgrade, seven over eighteen inches of compacted soil, and one over six inches of fly-ash modified subgrade. A four to six inch Asphalt Concrete (AC) base is utilized in six of the projects while five other projects have an Aggregate Base (AB) with thicknesses varying from 13 to 17.5 inches. The rest of the projects have a Cold-in-Place Recycled (CIPR) base that is 3 to 4.5 inches thick except K-57 project which was built without any base layer. All projects have surface and binder courses of varying thicknesses as shown in Table 3.2. The asphalt mix used in the construction of both surface and binder courses was designed following the Superpave mix design method.

Table 3.1 Existing Superpave Sections

Project No.	Route	County	Project Length (mile)	Work Performed	Construction Year
169-1-K-4419-02	US-169	Allen	8.4	Reconstruction	1999
169-2-K-4420-02	US-169	Anderson	4.2	Reconstruction	1999
57-2-K-4421-02	K-57	Anderson	2.2	Reconstruction	1999
254-08-K-5060-02	K-254(NB)	Butler	4.7	Reconstruction	1998
	K-254(SB)			Rehabilitation	
70-27-K-5982-01	I-70	Ellsworth	16.9	Reconstruction	1999
50-38-K-5743-01	US-50	Hamilton	12.4	Reconstruction	1999
50-47-K-5744-01	US-50	Kearney	14.9	Rehabilitation	2001
83-55-K-5388-01	US-83	Logan	14.9	Reconstruction	1999
61-59-K-5386-01	K-61	McPherson	2.2	Reconstruction	1999
81B-59-K-5386-02	US-81B	McPherson	2.5	Reconstruction	1999
27-65-K-5382-01	K-27	Morton	14.4	Rehabilitation	1999
169-67-K-5387-02	US-169	Neosho	6.8	Reconstruction	1999
283-68-K-5391-01	US-283	Ness	16.5	Rehabilitation	1999
281-76-K-5390-01	US-281	Pratt	6.4	Rehabilitation	1998
183-82-K-5751-01	US-183	Rooks	2.8	Rehabilitation	1998
254-87-K-5060-02	K-254(NB)	Sedgwick	7.31	Reconstruction	1998
	K-254(SB)			Rehabilitation	
36-101-K-5383-01	US-36	Washington	9.2	Rehabilitation	2001

Table 3.2 Layer Type and Thickness of Existing Sections

	Subgrade		Base		Binder Course		Surface Course	
Project No.	Type	Thick (in)	Type	Thick (in)	Binder	Thick (in)	Binder	Thick (in)
169-1-K-4419-02	LT	6	AC	6	SM-2C (PG64-28)	4	SM-1T (PG64-28)	1
169-2-K-4420-02	LT	6	AC	6	SM-2C (PG64-28)	4	SM-1T (PG64-28)	1
57-2-K-4421-02	LT	6	N/A	N/A	SM-2C (PG64-28)	5.5	SM-1T (PG64-28)	1
254-08-K-5060-02	LT	6	AB+ UDB	7+ 6	SM-2C (PG58-28)	6.5	SM-1T (PG70-28)	1
	LT	6	CIPR	4	SM-2C (PG58-28)	8	SM-1T (PG70-28)	1
70-27-K-5982-01	COM	18	AC	4	SR-2C (PG58-34)	2	SM-1T (PG64-28)	1
50-38-K-5743-01	FA	6	AC	6	SM-19B (PG70-28)	2.5	SM-9.5T (PG70-28)	1.5
50-47-K-5744-01	COM	18	AC	10	SM-19B (PG70-28)	2.5	SM-9.5T (PG70-28)	1.5
83-55-K-5388-01	COM	18	CIPR	4	SM-2C (PG58-28)	9	SM-1T (PG58-28)	1
61-59-K-5386-01	LT	6	AB+ UDB	11+ 6.5	SR-2C (PG58-28)	5.5	SM-1T (PG64-28)	1
81B-59-5386-02	LT	6	AB+ UDB	11+ 6.5	SR-2C (PG58-34)	5.5	SM-1T (PG64-28)	1
27-65-K-5382-01	COM	18	CIPR	3	SM-2C (PG58-28)	6.5	SM-2A (PG58-28)	1.5
169-67-K-5387-02	LT	6	AC	8	SM-2C (PG58-28)	4	SM-1T (PG64-28)	1
283-68-K-5391-01	COM	18	CIPR	4.5	SR-2C (PG58-34)	6.5	SM-2A (PG58-28)	1.5
281-76-K-5390-01	COM	18	CIPR	4	SM-2C (PG58-28)	5	SM-1T (PG64-28)	1
183-82-K-5751-01	COM	18	CIPR	4	SM-2C (PG64-28)	4	SM-1T (PG64-28)	1
254-87-K-5060-02	LT	6	AB+ UDB	7+ 6	SM-2C (PG58-28)	4	SM-1T (PG70-28)	1
	LT	6	CIPR	4	SM-2C (PG58-28)	7	SM-1T (PG70-28)	1
36-101-K-5383-01	LT	6	AB	13	SR-2C (PG58-28)	7	SM-1T (PG58-28)	1

LT: Lime-treated
COM: Compaction Type AA-MR5-5
FA: Fly-ash
CIPR: Cold-in-place-recycled asphalt
AC: Asphalt concrete
AB: Aggregate base
UDB: Unbound-drainable-base

3.1.3 New Superpave Sections

Five newly constructed Superpave test sections were established for continuous monitoring. Each test section is 1,000 ft long. All but one of these test sections were built in the summer of 2003. Four of these sections are four-lane divided highways, while the fifth (US-73) is a two-lane undivided highway. Tables 3.3 and 3.4 present general information about these sections. The sections were built over either an AC or CIPR base of varying thicknesses. The surface course thickness for all new projects was the same.

Table 3.3 New Superpave Sections

Project No.	Route	County	Mile Post	Construction Year
135-59-K-8881-01	I-135	McPherson	63	2003
70-98K-7305-01	I-70	Trego	128	2003
73-3K-8433-01	US-73	Atchison	50	2002
69-61K-6402-01	US-69	Miami	123	2003
169-61K-7142-02	US-169	Miami	137	2003

Table 3.4 Layer Type and Thickness of New Sections

Project No.	Subgrade		Base		Binder Course		Surface Course	
	Type	Thick (in)	Type	Thick (in)	Binder	Thick (in)	Binder	Thick (in)
135-59-K-8881-01	LT	6	CIPR+AC	4+ 2.5	SM-19A (PG70-28)	2.5	SM-9.5T (PG70-28)	1.5
70-98K-7305-01	FA	6	CIPR	4	SM-19A (PG70-28)	6	SM-9.5T (PG70-28)	1.5
73-3K-8433-01	FA	6	AC	3	SM-12.5A (PG64-28)	1.5	SM-9.5A (PG64-28)	1.5
69-61K-6402-01	LT	6	AC	11	SM-19A (PG70-28)	2.5	SM-9.5T (PG70-28)	1.5
169-61K-7142-02	LT	6	AC	5	SM-19A (PG70-28)	2.5	SM-9.5T (PG70-28)	1.5

3.2 DATA COLLECTION

Data collected for this study can be classified into four different categories:

- Layer property data,
- Traffic data,
- Climatic data, and
- Profile or roughness data.

Each of these categories is discussed in the subsequent sections.

3.2.1 Layer Property Data

This category includes properties of subgrade soil as well as Superpave mixture data.

3.2.1.1 Subgrade Data

Subgrade data was obtained from the design files. Table 3.5 shows different subgrade properties of the existing and new study sections. These properties include: optimum moisture content, maximum dry density, percent plasticity index and percent soil passing US No. 200 sieve. According to the Unified Soil Classification system, most of these projects were located in areas with silty clay soil. The percent Plasticity Index (PI) values for most of these projects are very high. PI varies between 10 and 31 percent indicating that the soil is potentially expansive. For this reason, subgrade directly beneath the pavement required modification for most of the projects. Some sections had subgrade soil modified using lime or using fly-ash to reduce shrink and swell potential of subgrade soil. In other cases, subgrade soil was compacted to a deeper depth.

Table 3.5 Subgrade Soil Properties

Project No.	Unified Soil Classification	Max. Dry	Optimum Moisture Content (%)	Liquid Limit (%)	Plasticity Index (%)	Subgrade Materials Passing US No. 200 Sieve (%)
Existing Sections						
169-1-K-4419-02	ML-CL	99	21	45	24	91
169-2-K-4420-02	ML-CL	97	18	36	10	93
57-2-K-4421-02	ML-CL	97	18	36	10	93
254-08-K-5060-02	CH	92	23	55	31	99
70-27-K-5982-01	CL	100	19	49	25	88
50-38-K-5743-01	ML-CL	100	21	36	13	96
50-47-K-5744-01	ML-CL	103	21	42	18	89
83-55-K-5388-01	ML-CL	101	19	39	17	99
61-59-K-5386-01	CL	97	18	35	11	98
81B-59-5386-02	CL	103	22	38	18	95
27-65-K-5382-01	CL	102	20	35	13	91
169-67-K-5387-02	CL	99	22	44	19	89
283-68-K-5391-01	CL	103	19	45	24	85
281-76-K-5390-01	SC	115	13	23	8	85
254-87-K-5060-02	CL	99	19	38	17	96
183-82-K-5751-01	CL	N/A	N/A	36	16	81
36-101-K-5383-01	CH	N/A	N/A	60	35	88
New Sections						
135-59-K-8881-01	CL	99	20	35	11	98
70-98K-7305-01	CL-ML	102	20	31	11	93
73-3K-8433-01	CL-ML	99	17	42	19	86
69-61K-6402-01	CL	95	18	39	15	87
169-61K-7142-02	CL	96	19	36	13	88

For both existing and new sections, more than 85 percent or more subgrade material passed through US No. 200 sieve. The range of optimum moisture content was 13 to 23 percent. Dry density of subgrade soil exceeded 90 lb/ft^3 for all sections.

3.2.1.2 Superpave Mixture Data

This section discusses the properties of the asphalt mix used in the construction of both binder and surface courses. As mentioned earlier, Superpave mix design procedure was used to design the asphalt mix.

Superpave Mix Design

Superpave mix design is a structured approach consisting of the following four steps: selection of materials, selection of design aggregate structure, selection of design asphalt binder content, and evaluation of moisture susceptibility. Selecting materials involves selection of a Performance Grade (PG) asphalt binder for the project climate and traffic conditions (traffic speed and traffic level), and selection of aggregates for use. A Superpave binder can be designated as PG 64-22. In this example, “64” is the 7-day average maximum pavement design temperature in ^{0}C and “-22” is the minimum pavement design temperature in ^{0}C. Five asphalt mixture types are specified in Superpave according to nominal maximum aggregate size: 3/8 inch, 1/2 inch, 3/4 inch, 1 inch, and 11/2 inches.

After the materials are selected, trial blends are established for the aggregates. Trial asphalt binder content is selected for each blend. Two specimens are produced for each trial blend and the volumetric and densification properties are analyzed for each one of them. Any trial blend that meets the Superpave mix design criteria can be selected as the design aggregate structure. After this, test specimens composed of the selected design aggregate structure, but at four different asphalt contents are fabricated. The asphalt content that results in 4 percent air voids at the design number of gyrations is the design asphalt binder content. The final step is to determine the Tensile Strength Ratio (TSR) which is a measure of the temperature susceptibility of the mix.

The designation of the binder and surface course mixtures shown in Tables 3.2 and 3.4 follows the KDOT nomenclature for the Superpave mixes. In Kansas, a Superpave mix is designated as “SM.” The numeric following SM indicates the nominal maximum aggregate size in the mix in mm. The alphabet immediately after that specifies the aggregate gradation i.e. it indicates that the gradation passed above (A) or below (B, C or T) the maximum density line in the finer sand sizes. Gradation above the maximum density line is finer and it allows inclusion of more sandy materials in the mix as compared to the gradation below the maximum density line which is coarser. In some instances, KDOT uses recycled mixes. In such a case, “SM” would be replaced by “SR” to stand for Surface Recycle.

The AC binder course thickness for the existing projects varies from 2.5 to 9 inches. The binder course mixture type was 3/4 inch nominal maximum aggregate size Superpave mixture with coarser gradation, designated as SM-2C or SM-19B by KDOT. Five of those projects had recycled materials used in the binder course. The thickness of the surface course varies in between 1 and 11/2 inches. The mix designation of the majority of the surface course mixes is SM-1T. SM-1T is actually a 3/8 inch nominal maximum size Superpave mixture with coarse gradation (Siddique *et al*., 2005).

However, in Kansas, this mixture requires a minimum 40 percent primary aggregate (by weight of total aggregate) to ensure higher friction resistance. Such primary aggregates include chat (a waste from zinc mining), crushed sandstone, crushed gravel, crushed steel slag, and crushed porphyry (rhyolite, basalt, granite, etc). Three different PG binder grades were used in the wearing course: 70-28, 64-28, and 58-28.

The AC surface course thickness was the same for all new sections unlike the binder course thickness that varied from 1.5 to 6 inches. Most projects were built with fine graded mixes for the binder course with a nominal maximum aggregate size of 3/4 inches. Coarse graded mixes were more dominant in the surface courses that were built with either PG 70-28 or PG 64-28.

Superpave mix properties for the binder and surface courses for the existing sections are shown in Tables 3.7 and 3.8, respectively, whereas those for the new sections are shown in Table 3.9. These values represent the average of the values taken for all sublots on these projects and were obtained from the Quality Control/Quality Assurance (QC/QA) database. Table 3.6 lists the required volumetric mixture properties for different mixes.

Table 3.6 KDOT Superpave Volumetric Mixture Design Requirements

Parameter	**SM-9.5A**	**SM-12.5A/SM-2A**	**SM-19A**	**SM-1T/SM-9.5T**	**SM-19B/SM-2C/SR-2C**
Air Voids (%)	4.0±2.0	4.0±2.0	4.0±2.0	4.0±2.0	4.0±2.0
Min. VMA (%)	15	14	13	15	13
Dust to Binder Ratio	0.6-1.2	0.6-1.2	0.6-1.2	0.8-1.6	0.8-1.6

The surface course asphalt content for existing sections varied between 4.6 and 6.2 percent, whereas new sections had a surface course asphalt content that was a little bit higher compared to existing sections. Air voids of the mixes for all projects met KDOT specifications, (4±2 %). There was a large variability in Voids in the Mineral Aggregate (VMA) values; they ranged from 12 to 16.4 percent depending upon mixture type. Voids Filled with Asphalt (VFA) for all of the projects were very close to 70 percent. Fine aggregate angularity and sand equivalent values did not change significantly from project to project.

Table 3.7 Binder Course Mixture Properties of Existing Sections

Section	Asphalt Content (%)	Air Voids (%)	VMA (%)	VFA (%)	Aggregate Passing No. 200 Sieve (%)	Fine Aggregate Angularity	Sand Equivalent (%)	Mixture Type
US-169 (1)	4.6	3.8	13.8	72.5	5.1	44	79	SM-2C (PG64-28)
US-169 (2)	4.8	3.9	13.4	70.9	5.5	44	78	SM-2C (PG64-28)
K-57	5	4	13.6	70.6	4.9	44	78	SM-2C (PG64-28)
K-254 (1)	5.2	4.2	13.7	69.3	4.2	43	75	SM-2C (PG58-28)
I-70	5.3	4.4	13.6	67.6	4.9	44	78	SM-2C (PG58-28)
US-50 (1)	4.9	3.5	13.2	73.5	3.6	44	86	SR-2C (PG58-34)
US-50 (2)	4.8	4.3	12.8	66.4	3.4	44	86	SM-19B (PG70-28)
US-83	4.7	3.7	13.9	73.4	4	48	80	SM-19B (PG70-28)
K-61	5	4.2	13.3	68.4	4.7	43	88	SM-2C (PG58-28)
US-81B	5	4	13.1	69.5	5.3	44	89	SR-2C (PG58-28)
K-27	5.8	3.3	14.2	76.7	4.9	46	69	SR-2C (PG58-34)
US-169 (3)	3.7	4.3	13.5	68.1	3.6	47	95	SM-2C (PG58-28)
US-283	4.4	4.3	13.7	68.6	3.3	42	90	SM-2C (PG58-28)
US-281	4.9	4.4	13.9	68.3	3	43	88	SR-2C (PG58-34)
K-254 (2)	5.3	4.3	14.1	69.5	4.5	44	78	SM-2C (PG58-28)
US-183	5.1	3.7	13.4	72.2	4.1	43	84	SM-2C (PG64-28)
US-136	5.4	4.2	13.3	68.4	4.9	42	76	SM-2C (PG58-28)

Table 3.8 Surface Course Mixture Properties of Existing Sections

Section	Asphalt content (%)	Air Voids (%)	VMA (%)	VFA (%)	Aggregate Passing No. 200 Sieve (%)	Fine Aggregate Angularity	Sand Equivalent (%)	Mixture Type
US-169 (1)	4.6	3.4	13.8	75.4	4.7	44	80	SM-1T (PG64-28)
US-169 (2)	5	3.8	13.6	72.1	4.8	44	80	SM-1T (PG64-28)
K-57	5.6	4	14.7	72.8	4.5	44	78	SM-1T (PG64-28)
K-254 (1)	6	4.7	15.3	69.3	3.5	44	83	SM-1T (PG70-28)
I-70	6.3	4.3	15	70.6	4.8	46	79	SM-1T (PG70-28)
US-50 (1)	5.1	3.9	15.1	74.2	4.1	47	88	SM-1T (PG64-28)
US-50 (2)	5	4.2	15.1	72.2	4.2	46	78	SM-9.5T (PG70-28)
US-83	6.1	4	16.2	75	4.2	42	92	SM-9.5T (PG70-28)
K-61	5.9	5.9	15.8	62.7	4.1	42	77	SM-1T (PG58-28)
US-81B	6.1	5.2	15.6	66.7	3.8	41	65	SM-1T (PG64-28)
K-27	5.9	5	15.3	68.7	4.8	48	67	SM-1T (PG64-28)
US-169 (3)	6.2	3.9	15.6	75	3.6	45	93	SM-2A (PG58-28)
US-283	5.4	4.6	15.8	70.9	3.4	43	92	SM-1T (PG64-28)
US-281	5.4	4.6	15.8	70.9	4.6	43	87	SM-2A (PG58-28)
K-254 (2)	5.6	4.5	14.9	69.8	4.3	44	79	SM-1T (PG64-28)
US-183	5.48	4.45	15.08	70.5	5.8	43	99	SM-1T (PG64-28)
US-36	5.29	4.81	15.72	69.4	4.6	42	76	SM-1T (PG70-28)

Table 3.9 Mixture Properties for New Sections

Section	Asphalt content (%)	Air Voids (%)	VMA (%)	VFA (%)	Aggregate Passing No. 200 Sieve (%)	Fine Aggregate Angularity	Sand Equivalent (%)	Mixture Type
Binder Course								
I-135	4.2	4.2	13.7	69.3	4.8	45	78	SM-19A (PG70-28)
I-70	3.8	4.4	13.1	65.9	5.1	44	79	SM-19A (PG70-28)
US-73	4.9	4.4	14.3	66.9	4.8	44	86	SM-12.5A (PG64-28)
US-69	4.6	4.2	13.8	69.6	3.9	44	79	SM-19A (PG70-28)
US-169	5.2	3.9	14.3	72.7	4.9	48	88	SM-19A (PG70-28)
Surface Course								
I-135	6.8	4.4	15.6	73	4	45	83	SM-9.5T (PG70-28)
I-70	5.8	4.8	16.4	70.8	4.2	46	79	SM-9.5T (PG70-28)
US-73	6.5	4.7	15.6	67.5	4.8	46	88	SM-9.5A
US-69	6.9	4.1	16.2	77	4.6	49	93	SM-9.5T (PG70-28)
US-169	6.8	4.4	15.6	72	4.6	47	73	SM-9.5T (PG70-28)

3.2.2 Traffic Data

Depending on the type of highway, traffic data varied from section to section. Types of highway sections for this study included: Interstate, State, and US highways. Figure 3.3 presents the design year Equivalent Single Axle Loads (ESALs) per day for existing sections. Equivalent Single Axle Load is a standard load that is taken to be equal to 18,000 lbs (18 kip) on a single axle with dual tires. Daily ESAL values for these sections vary from about 25 for K-57 to over 490 for K-254 section.

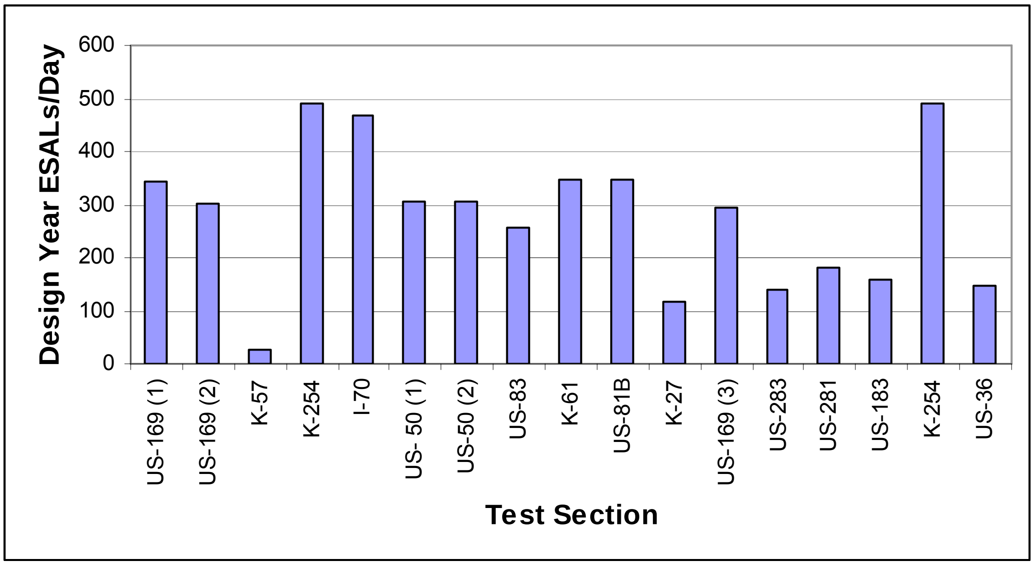


Figure 3.3 Design Year Traffic for Existing Sections

Figure 3.4 presents the design year Equivalent Single Axle Loads (ESALs) per day for the new sections. Daily ESAL values vary from about 100 to over 900 per day. It is important to note that the new I-70 section was a major modification project so the traffic loading shown in this figure was the additional traffic load that was experienced on this highway after reconstruction. The other projects were newly constructed.

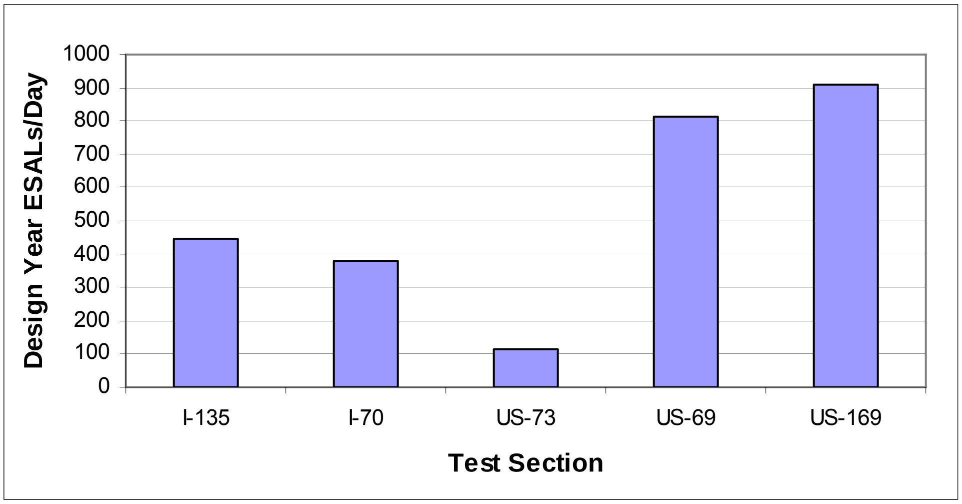


Figure 3.4 Design Year Traffic for New Sections

3.2.3 Climatic Data

Climatic data collected for the study include: average annual precipitation, number of days with temperature below 32^0F in a year, number of days with temperature above 90^0F in a year, number of wet days in a year, and number of freeze-thaw cycles per year. These data were obtained from the weather stations located nearest to the test sections. Climatic data for the existing projects is shown in Table 3.10. Average annual precipitation varies between 18 and 42 inches per year. Climatic data was not considered in the analysis of new sections.

Table 3.10 Climatic Data for Existing Projects

Project No.	Avg. Annual Precipitation (in)	Days Below 32° F	Days Above 90° F	Wet Days Per Yr	No. of Freeze Thaw Cycles	Mean Annual Temp. (0° F)
169-1-K-4419-02	42	100	36	49	83	56.3
169-2-K-4420-02	41	91	44	46	77	57.5
57-2-K-4421-02	41	91	44	46	77	57.5
254-08-K-5060-02	41	102	52	46	89	57.5
70-27-K-5982-01	30	114	55	36	94	55.5
50-38-K-5743-01	18	155	65	20	140	54.1
50-47-K-5744-01	20	130	79	24	114	55.5
83-55-K-5388-01	21	154	59	25	130	52.1
61-59-K-5386-01	36	115	58	30	78	55.7
81B-59-5386-02	36	115	58	30	78	55.7
27-65-K-5382-01	18	139	69	21	122	54.5
169-67-K-5387-02	41	91	44	46	75	57.5
283-68-K-5391-01	22	149	74	23	121	54.8
281-76-K-5390-01	28	107	72	32	94	57.5
183-82-K-5751-01	26	129	57	34	94	68
254-87-K-5060-02	35	93	61	41	76	57.7
36-101-K-5383-01	31	114	59	44	95	68

3.2.4 Roughness Data

Roughness data in terms of International Roughness Index (IRI) were obtained from KDOT Pavement Management Information System (PMIS) database. KDOT performs an annual inventory of its highway network and records this information in county-route-milepost format in PMIS. The PMIS database was built in 1985. Up to 1992, statewide roughness was determined using Mays ride meters (cars) traveling at 50 mph. This method of roughness determination obtained continuous readings between mileposts, which were summarized in inches per mile and assigned to the milepost location where the readings began. From 1982 to 1988, KDOT used a correlation to bump track as per NCHRP Report No. 288 to determine Profile Index (PI) for each 0.1 mile section. From 1989 to 1990, KDOT based correlation on average bump track data from 1982 to 1988. Beginning in 1991, the IRI was computed using a correlation. The IRI was further corrected by correlation to the dipstick. Since 1992, KDOT has been using the South Dakota-type profilers.

The profile data for this study was collected by a South Dakota-type high-speed inertial profiler, which is an International Cybernetics Corporation (ICC) profiler with laser sensors, shown in Figure 3.5. The KDOT profiler collects profile data at approximately 3-inch intervals from the Selcom 220 laser shots taken at a rate of 3,200/sec. The profiler is operated at a highway speed of 50 mph. The test sections were built under the smoothness specifications based on the California-type profilograph.

For the existing sections, 3 to 6 years of roughness data were available from PMIS up to 2005. The initial profile measurements were done six to eight months after construction during the PMS condition survey in the spring following the year of construction. Previous analyses have indicated that the roughness on the Kansas Superpave pavements remains unchanged for about this time period barring premature distresses, such as, premature rutting. Thus, although no profile measurements were available on these sections immediately after construction, the first set of profile measurements can be considered as the as-constructed roughness (Siddique *et al.*, 2005). There after, profile measurements were done annually.

Figure 3.5 KDOT South-Dakota Type Profilometer (Hossain, 2005)

For the new sections, as-constructed profile data was collected right after construction before the sections were opened to traffic. These sections were selected with the intention that profile measurements would be done periodically, at about six-month intervals. However, due to logistical problems some data could not be collected. For example, profile measurements were not done at 12 and 18 months for I-135, I-70, US-169 and US-69. No data was available 6 months following the construction of US-69 as this section was used as work-zone around this time. All other profile data were available up to December 2005.

<u>3.2.5 Maintenance Intervention</u>

Some of the existing projects received early maintenance intervention due to a large increase in roughness. Table 3.11 tabulates the projects and the types of action taken. A majority of the sections were treated with a slurry seal or crack seal. One section, K-57, was resurfaced with a one-inch overlay after three years in service.

Table 3.11 Projects With Maintenance Intervention

Project	County	Const. Year	Work Type	Maintenance Type	Year of Maintenance
169-1-K-4419-02	Allen	1999	Reconstruction	Slurry Seal	2003
169-2-K-4420-02	Anderson	1999	Reconstruction	Slurry Seal	2003
57-2-K-4421-02	Anderson	1999	Reconstruction	Thin overlay	2003
27-65-K-5382-01	Morton	1999	Rehabilitation	Crack Seal	2002
169-67-K-5387-02	Neosho	1999	Reconstruction	Slurry Seal	2002
283-68-K-5391-01	Ness	1999	Rehabilitation	Seal	2004
254-08-K-5060-02	Butler (NB)	1998	Reconstruction	Slurry Seal	2004
	Butler (SB)		Rehabilitation		
254-87-K-5060-02	Sedgwick (NB)	1998	Reconstruction	Slurry Seal	2004
	Sedgwick (SB)		Rehabilitation		

CHAPTER 4

ROUGHNESS DATA ANALYSIS

4.1 INTRODUCTION

This study aimed at evaluating roughness progression of Superpave pavements built in Kansas and also at finding significant factors that influence roughness progression. The analysis results have been presented in this chapter.

4.2 ROUGHNESS ANALYSIS OF EXISTING SECTIONS

For the two-lane sections, roughness data was collected on both wheel paths (left and right). The average IRI was then computed and used in the analysis. For the four-lane divided sections, profile data was collected on the right wheel path of the driving lane, in each direction. It is important to note that seven of the existing sections received maintenance intervention at some point during their early years of service life. For this reason, the existing projects were divided into two sub-categories in the analysis process; with and without maintenance intervention.

4.2.1 As-Constructed Roughness

4.2.1.1 Projects With Maintenance Intervention

Figure 4.1 shows the as-constructed IRI values for the existing Superpave sections with maintenance intervention. The figure shows that most of these sections were built with low initial roughness that ranged from 32 to 64 in/mile with an average of about 49 in/mile. The K-254 section in Butler County had the lowest IRI. On the other hand, US-169 (2) section in Anderson County had the highest IRI value. The section without a base course (K-57) also had a high as-constructed IRI value that was almost 64 in/mile.

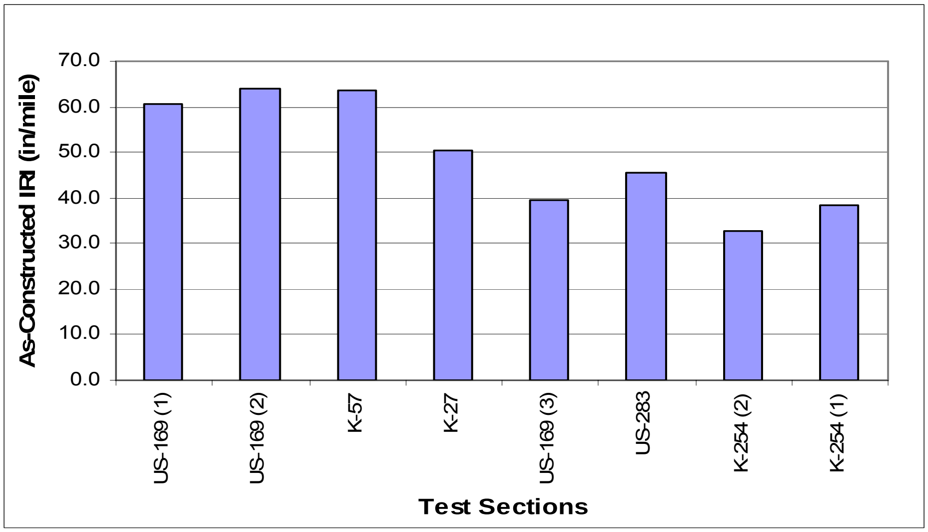


Figure 4.1 As-constructed IRI Values for Sections with Maintenance Intervention

4.2.1.2 Projects Without Maintenance Intervention

As-constructed IRI values for the existing Superpave sections without maintenance intervention are shown in Figure 4.2. Compared to the sections with maintenance intervention, these sections were built with a lower average initial roughness of about 38 in/mile. The as-constructed IRI values ranged from 32 to 47 in/mile. The US-81B section in McPherson County had the lowest IRI value. The other project located in this county, K-61, had the highest IRI value.

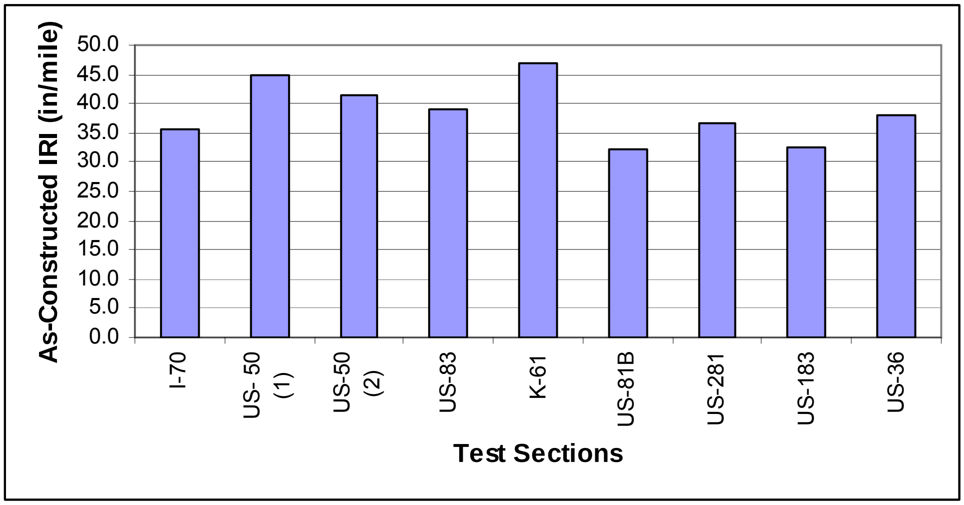


Figure 4.2 As-constructed IRI Values for Sections without Maintenance Intervention

4.2.2 Short-Term Roughness Progression

4.2.2.1 Projects With Maintenance Intervention

As shown in Figure 4.3, most of the sections exhibit a definite pattern of roughness progression where roughness increases with time. However, most projects showed some decrease in roughness with time. This was due to the maintenance intervention. A majority of the sections were treated with a slurry seal or crack seal. One of these sections was the K-57 project which was built without a base layer. It was resurfaced with a one-inch overlay after three years in service. Also, some variations in roughness pattern on some of the test sections can be attributed to the variations in the profiled paths for different years, and therefore, on the measured roughness.

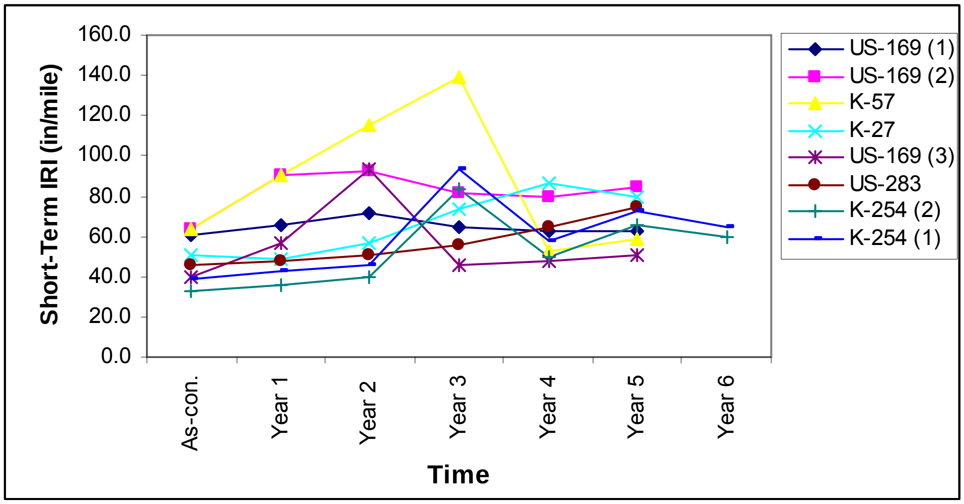


Figure 4.3 Roughness Progressions for Sections with Maintenance Intervention

4.2.2.2 Projects Without Maintenance Intervention

For most of these sections, roughness increased with time during the early years of service life but after some time, reduced roughness values can be observed as shown in Figure 4.4. This reduction in roughness values of sections without maintenance intervention can be attributed to smoothening effect of the roadway surface due to traffic action, localized maintenance, etc. As traffic traverses across a given section of roadway, tear and wear occurs on the roadway surface which smoothens the macrostructure of the pavement. As a result, the road surface becomes smoother with time. This phenomenon has also been observed for concrete pavements in Kansas (Akhter *et al.,* 2001). Some variations in roughness patterns can also be attributed to the variations in the profiled paths.

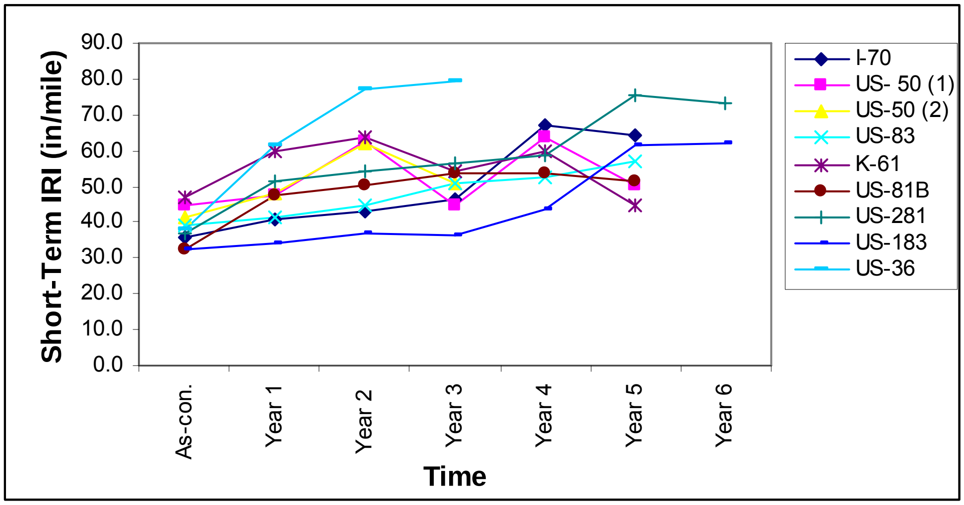


Figure 4.4 Roughness Progressions for Sections without Maintenance Intervention

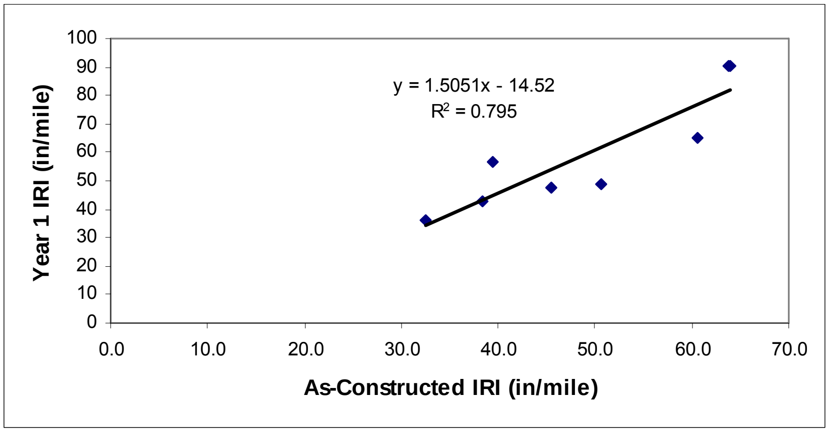
4.2.3 Relationship between Short-Term Roughness and As-Constructed Roughness

To establish the relationship between short-term roughness and as-constructed roughness, a scatter plot of the IRI values was produced. From this scatter plot, a simple linear regression model was developed for each year accompanied by the coefficient of determination, R^2 value. A linear regression model is defined by a dependent variable “y” expressed as a function of an independent variable “x”. The dependent variable in this case was the short-term roughness and the independent variable was the as-constructed roughness. It is clear from Figures 4.5 and 4.6 that short-term roughness of a Superpave pavement can be expressed as a function of its as-constructed roughness.

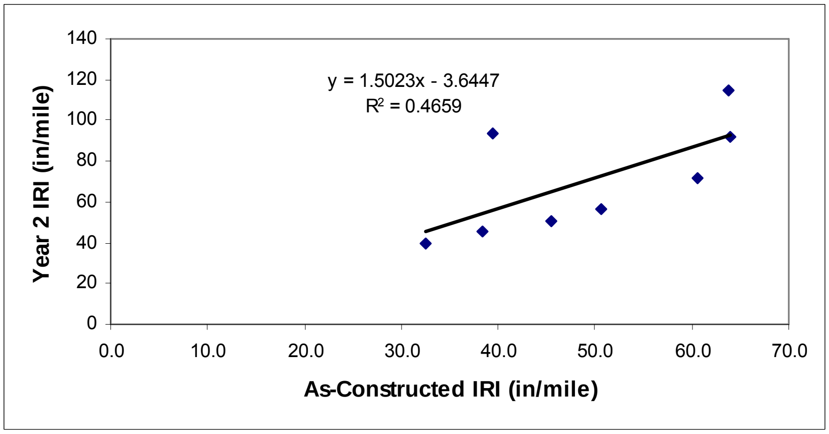
The R^2 value ranges from zero to one. The R^2 value reflects the amount of total variation of the data used to describe the model. A value of one indicates that all variation is represented and explained by the model while a value of zero indicates that none of the variation is represented or explained by the model. Variation not explained by the model could be as a result of missing data, errors in the data, or any number of uncontrollable effects.

4.2.3.1 Projects With Maintenance Intervention

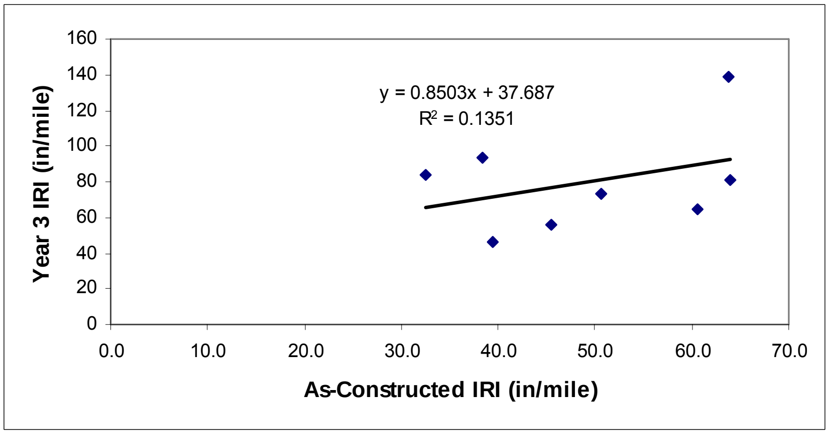
Figure 4.5 (a) shows that the relationship between the one-year and the as-constructed roughness can be expressed by a linear equation. The R^2 value of 0.79 means that 79 percent of the roughness variation after one year of pavement service is due to the as-constructed roughness. Relationships between as-constructed IRI and IRI values for the subsequent years were also linear although R^2 values decrease as the pavement ages. However, by removing a couple of outliers, better relationships can be obtained. Other factors such as, distresses occurring in the pavement also influence the roughness of the pavements as the pavement ages and this is another reason for the lower R^2 values. From Figure 4.5, we can also see that 150, 150, and 85 percent of as-constructed roughness remained after one, two and three years of service life, respectively. Another observation that can be made from these plots is that a pavement built with low initial roughness remains smoother over time.



(a) One-Year vs. As-Constructed IRI



(b) Two-Year vs. As-Constructed IRI

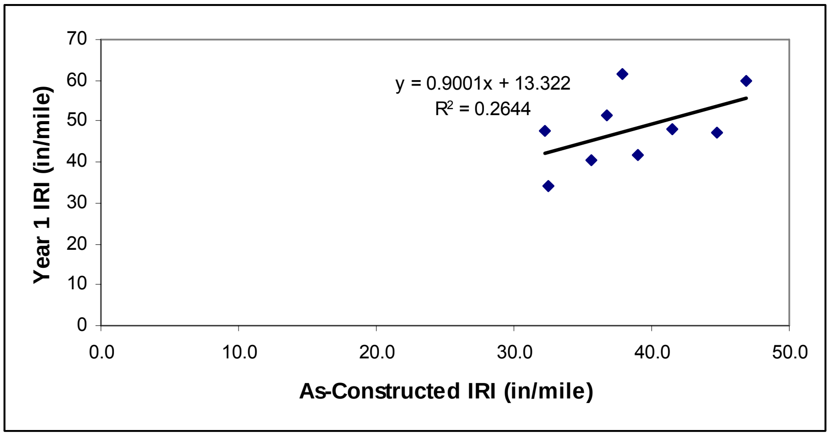


(c) Three-Year vs. As-Constructed IRI

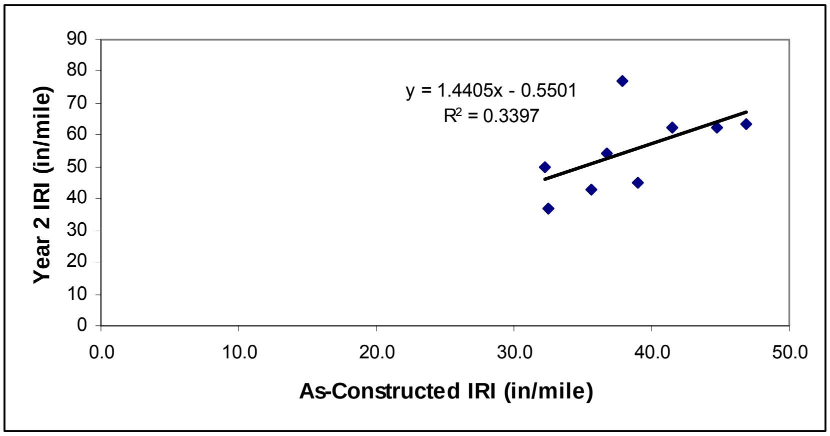
Figure 4.5 Relationships between Short-Term and As-Constructed IRI for Sections with Maintenance Intervention

4.2.3.2 Projects Without Maintenance Intervention

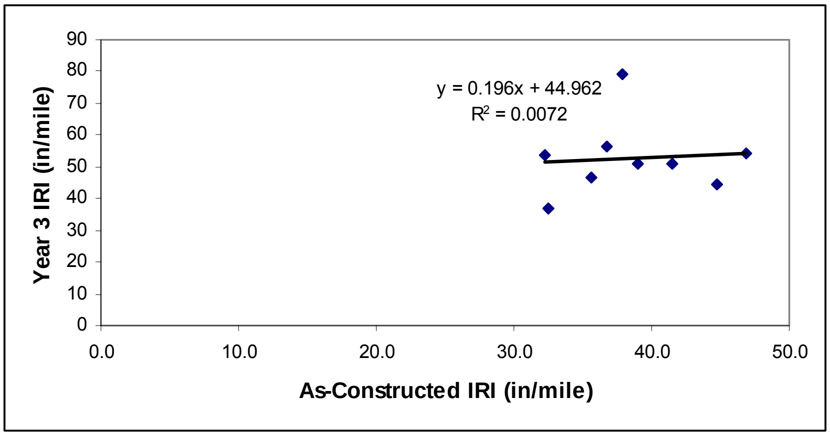
The relationships between the short-term and the as-constructed roughness for the sections without maintenance intervention were not as definite as those for the sections that received maintenance. From Figure 4.6 (a) it is seen that 90 percent of as-constructed roughness remained after one year. This value increased to 144 percent during the second year and then it decreased to 19 percent in the third year. The R^2 value also behaved in a similar manner where it increased from 0.26 for one-year IRI to 0.33 for two-year IRI. For the third year, this value was 0.007. This may indicate that after a few years in service, the roughness of these Superpave pavements is not highly influenced by the as-constructed roughness.



(a) One-Year vs. As-Constructed IRI



(b) Two-Year vs. As-Constructed IRI



(c) Three-Year vs. As-Constructed IRI

Figure 4.6 Relationships between Short-Term and As-Constructed IRI for Sections without Maintenance Intervention

4.3 ROUGHNESS ANALYSIS OF NEW SECTIONS

Profile data collection on the four-lane new sections was done on both wheel paths for both passing and driving lanes. Three replicate runs were made on each lane. The average IRI values were then computed and used in this analysis.

4.3.1 As-Constructed Roughness

The new pavement sections were also very smooth initially as illustrated in Figure 4.7. As-constructed IRI values ranged from 34 to 53 inch/mile. The section on US-169 had the lowest as-constructed IRI. This four-lane highway was designed for the highest traffic loading. The roughest section after construction was the one on US-73 highway. The average as-constructed IRI for all sections was about 41 inch/mile, which is very close to the average as-constructed IRI for the existing sections without maintenance intervention.

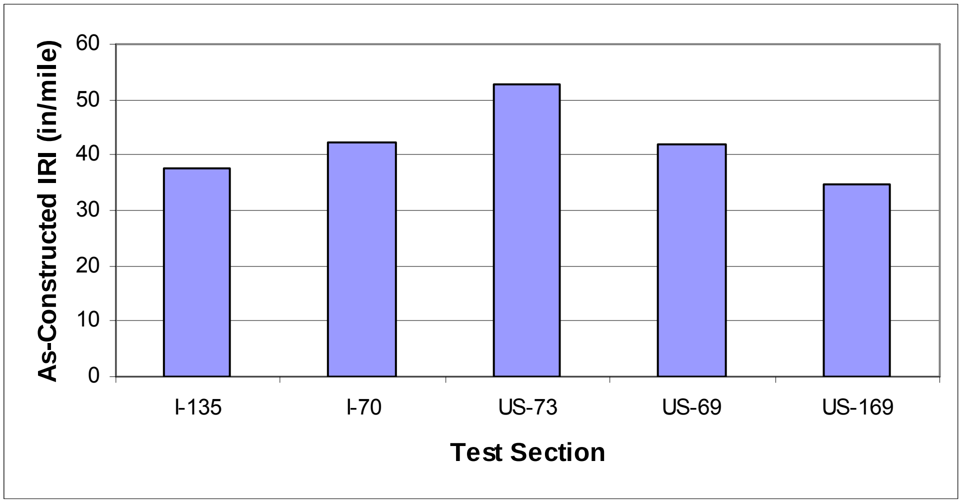


Figure 4.7 As-Constructed IRI Values for New Sections

4.3.2 Short-Term Roughness Progression

Since no profile measurements were taken on all new projects for 2004 due to logistical problems, this year was excluded from the analysis of short-term roughness.

Figure 4.8 presents the short-term roughness progression on the new sections. Only three sections have continuous data up to 30 months. For these three sections, roughness remained fairly low and gradually increased for the first 24 months of pavement service life. During this period, IRI values increased by approximately 16 percent for both I-70 and I-135 sections. These two sections are on four-lane highways. Although I-135 had lower as-constructed IRI, it carried higher traffic load than I-70. This probably explains why these two sections experienced an equal increase in roughness during their early years of service life. The US-169 section, which had the lowest as-constructed roughness, experienced an IRI increase of about 31 percent during the first 24 months. This section carried the highest traffic load.

Roughness on the I-135 project still remained fairly constant up to 30 months. Roughness on this section increased by 4 percent, from 24 to 30 months. Roughness on I-70 and US-169 sections increased by 28 and 26 percent, respectively, six months after their second year of service. Profile data on the US-73 section was available up to the first 18 months of service life. There after, data was collected when the pavement was 42 months old. To maintain parity with the other sections, the 12 and 18 month IRI values on this section were omitted. These values were 51 and 53 inch/mile for 12 and 18 months, respectively. However, we can observe from Figure 4.8 that roughness did not change much during the period between 6 and 42 months. It increased by about 10 percent during this period. This section also had the highest as-constructed IRI. There was a 95 percent increase in roughness for the US-69 section, 30 months after construction.

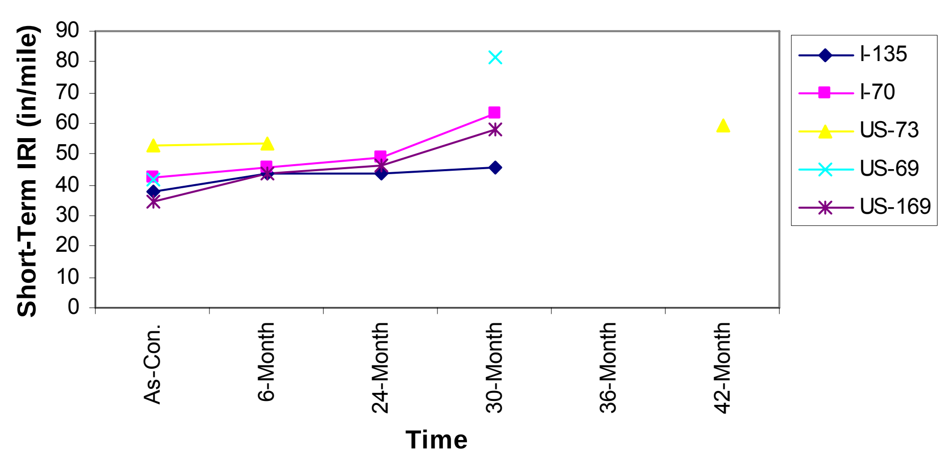
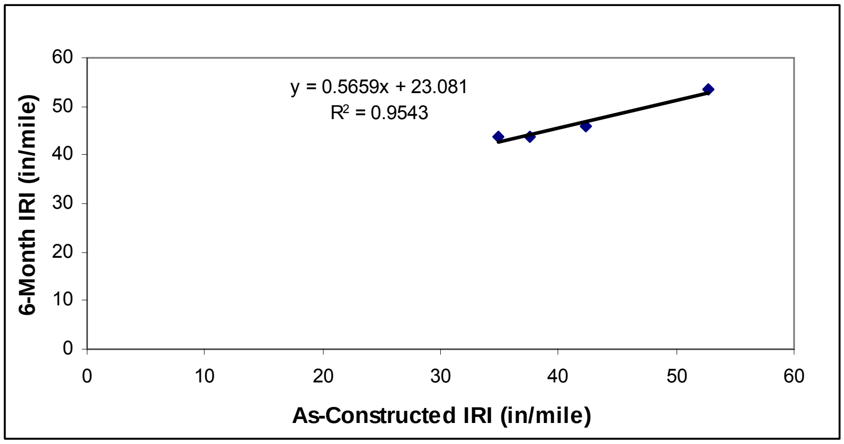


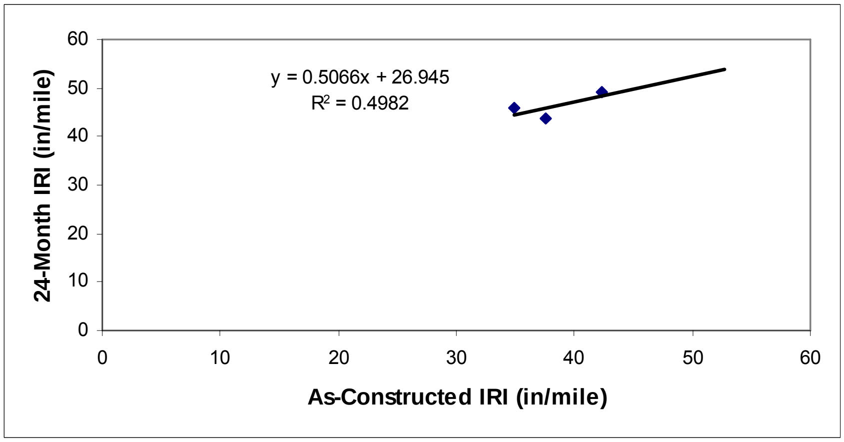
Figure 4.8 Short-Term Roughness Progressions of New Sections

4.3.3 Relationship between Short-Term Roughness and As-Constructed Roughness

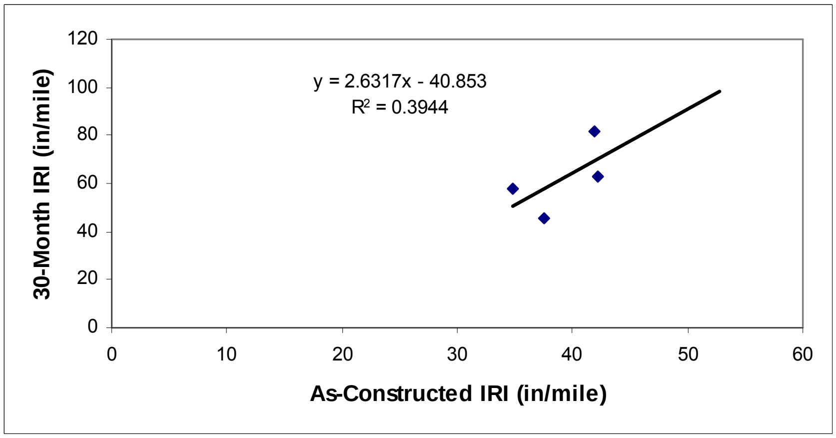
From Figure 4.9, we can observe that 95 percent of the variation in roughness after six months of pavement service life can be attributed to the as-constructed roughness. This R^2 value decreases to 49 and 39 percent after 24 and 30 months, respectively. The linear regression models also show that 56 and 50 percent of as-constructed roughness remained after 6 and 24 months of pavement service life, respectively. After 30 months, 263 percent of the as-constructed IRI remained. The relationships between short-term and as-constructed roughness of the new sections could have been improved by reducing the number of missing data values and also selecting a larger number of projects for study.



(a) 6-Month vs. As-Constructed IRI



(b) 24-Month vs. As-Constructed IRI



(c) 30-Month vs. As-Constructed IRI

Figure 4.9 Relationships between Short-Term and As-Constructed IRI for New Sections

CHAPTER 5

STATISTICAL ANALYSES

5.1 INTRODUCTION

Two types of statistical analyses were done. Analysis of Variance (ANOVA) was performed to examine the effect of different factors on the short-term roughness of Superpave pavement sections. Multiple regression analysis was performed to find the quantitative relationships between the roughness (in terms of IRI) and the significant factors. The Statistical Analysis System (SAS) software was used for these purposes. These analyses were done on both existing and new sections.

5.2 BACKGROUND

5.2.1 Analysis of Variance

Analysis of Variance (ANOVA) tests the difference between two or more population means. The process compares the variability that is observed between the two conditions (or groups) to the variability observed within each condition. Between groups variability is the variability among sample means as we go from one group to the other. It is caused by both random variability and by differences that may exist among population means. Since the groups are often formed by applying different treatments, between groups variability is also called variability due to treatments.

Within group variability is the random variations of the observations within groups. For instance, if roughness data are being analyzed, then the within group variability would be caused by random differences among treatment values within groups. The random variation within group is often called “experimental error”, so within group variability is also called error variability. When the variability that can be predicted (between the two groups) is much greater than the variability that cannot be predicted (within each group), it can be concluded that those population means are significantly different from each other.

5.2.2 Multiple Regression Analysis

The basic idea of regression analysis is to use data on a quantitative independent variable to predict or explain variation in a quantitative dependent variable. Multiple regression analysis is helpful in developing predictive equations consisting of a dependent variable and several independent variables. Mainly, it identifies and isolates those independent variables which have the largest impact on the dependent variable. Each variable is given an impact level (coefficient) which signifies the independent variable’s level of influence on the dependent variable. The greatest advantage of multiple regression analysis is its ability to analyze a large amount of data containing many variables.

The main use of multiple regression analysis is to find a correlation between the independent and dependent variables. In its elementary form, positive correlation between an independent and a dependent variable means that as the independent variable increases by unit, the dependent variable also increases by an amount equal to the coefficient of that variable. On the other hand, a negative correlation means that the dependent variable decreases as the independent variable increases by unit. These two conclusions assume that other variables are kept constant. An equation or a model is the result of multiple regression analysis.

5.2.3 SAS Software

The SAS program was used in this study to perform both analysis of variance and multiple regression analysis (SAS, 1979). The SAS program is a computer software for statistical analysis of data. The system is capable of storing and retrieving information, modifying and programming data, writing reports, statistical analysis and handling files. Researchers depend on SAS for reliable statistical algorithms. One of the reasons why the SAS program is widely used is because of its capability to handle linear model procedures. This gives SAS the ability to handle any problem that can be expressed in the traditional matrix form (Helwig *et al.,* 1979).

A very important aspect of SAS is that it can perform multiple regression analysis on extremely large data sets. SAS is designed to extract the maximum amount of information from the data set. It will determine the relationship between a dependent variable and one or more independent variables. With the information provided by SAS a model can be assembled. SAS can also (Helwig *et al.,* 1979):

- Distinguish independent variables which most significantly impact the dependent variable from those that do not (superfluous variables);
- Determine an operative relationship which quantifies how the significant independent variables impact the dependent variables;
- Determine the accuracy of the predicted variable;
- Determine the certainty of the linear coefficients;
- Determine the total variation of the data which is described by the model built (R^2); and
- Provide simple statistics of the data set.

5.3 ANALYSIS OF VARIANCE (ANOVA)

In this study, the response variable is the International Roughness Index (IRI). Seven treatment variables were considered: (a) Work type, (b) Profile age, (c) Subgrade type, (d) Base type, (e) Base course thickness, (f) Surface course PG binder type, and (g) Project number. Table 5.1 presents different levels for the categorical treatment variables for both existing and new sections.

Table 5.1 Levels of Different Factors for ANOVA

Factors	**Levels**	
	Existing Sections	***New Sections***
Work Type	Rehabilitation (R) and Reconstruction (H)	N/A
Subgrade Type	Lime-treated (LT), Fly-Ash (FA) and Compacted (CM)	Lime-treated and Fly ash-treated
Base Type	Aggregate (AB), Asphalt (AC), and CIPR (CR)	Asphalt (AC) and CIPR (CR)
PG Binder (Surface Course)	PG 58-28 (P1), PG 64-28 (P2), and PG 70-28 (P3)	PG 64-28 (P2) and PG 70-28 (P3)

Initially, the statistical model for the analysis of variance was;

$$IRI_{ijkljmno} = WORK_i + AGE_j + SG_k + BT_l + BTHICK_m + PG_n + PJN_o + Interactions + \varepsilon_{ijklmno} \qquad (5.1)$$

Where;

$IRI_{ijklmno}$ is the International Roughness Index (in/mile) obtained at the ith level of work type, jth level of profile age, kth level of subgrade type, lth level of base type, mth level of base thickness, nth level of PG binder type, and oth level of project number;

$WORK_i$ is an effect due to the ith level of work type;

AGE_j is an effect due to the jth level of profile age;

SG_k is an effect due to the kth level of subgrade type;

BT_l is an effect due to the lth level of base type;

$BTHICK_m$ is an effect due to the mth level of base course thickness;

PGn is an effect due to the nth level of PG binder type;

PJNo is an effect due to the oth level of project number;

ε_{ijklmn} is a random error associated with the response from each combination of different levels of the seven treatment variables. The εs are assumed to be independent, normally distributed with mean zero and have a constant variance;

and

Interactions are the effects due to the two-way interactions between the variables.

However, this model yielded non-estimable Least Square Means (LSMEANS). The LSMEANS would be required to compare the means of the response variable at different levels of a factor. Following this finding, it was concluded that this model was not suitable for analyzing this type of data because there were too few data points. A decision was thus reached to analyze only three variables at a time while maintaining the two discrete variables (age and base thickness) in each run as shown in Equation 5.2. The third variable (X) would be either one of the four categorical variables: work, subgrade, base type or binder grade.

$$IRI_{ijk} = AGE_i + BTHICK\,j + X_k \qquad (5.2)$$

The mixed procedure was used in these analyses because most of the variables are non-stochastic (fixed). A factor is a fixed factor if all of its values (categories) are measured, which was the case here. The Restricted Estimate Maximum Likelihood (REML) method of the mixed procedure was used. This method gives the best estimates for analyzing fixed effects. The project number was treated as the random variable. Interactions were not considered due to lack of sufficient data. The SAS code for this analysis is shown in the Appendix A.

All conclusions were made at a 0.05 error rate. The means of response variable at different levels of a factor were compared using the Least Square Means (LSMEANS) approach. This technique weights the estimates of each treatment or treatment combination effect equally, but not each observation (Milliken and Johnson, 1984). The LSMEANS model deals with the average of individual treatment measurements and for treatment combination, it gives unequal weight to each observation. The effects of one or more factors on treatments for comparison are eliminated since it estimates the average of the averages. Increased sample size increases the precision of the estimate of the treatment combination mean response (Milliken and Johnson, 1984).

The difference between MEANS and LSMEANS is that the former is the average or arithmetic mean and is computed by summing up all the data points and dividing by the total number of points whereas the later is a linear combination (sum) of the estimated effects (means, etc) from a linear model. MEANS is based on the data only but LSMEANS is based on the model used. In the cases where the data contains no missing values, the results of the MEANS and LSMEANS are identical. When missing values do occur, the two differ. In contrast to the MEANS statement, the LSMEANS statement performs multiple comparisons of interactions as well as main effects.

5.3.1 Existing Sections

Seventeen existing projects were selected for analysis. One of these projects, K-57, was built without a base layer. This project was excluded from the statistical analysis. But a total of eighteen sections were analyzed since each direction of travel for the 4-lane divided highway (K-254) was treated as a separate project. It is to be noted that profile data was collected separately in each direction.

5.3.1.1 Projects With Maintenance Intervention

ANOVA test results show that only pavement age has a statistically significant effect on the short-term IRI of existing pavements with maintenance intervention for two of the four combinations of factors analyzed. The other two combinations of factors showed age and base course thickness to have a significant influence on the short-term IRI. These analyses considered either base type or work type as the third treatment variable in the statistical model. As a result, plots against base course thickness were produced and shown in Figure 5.1. CIPR bases were evidently observed to be thinner compared to the other base types. Also, sections that were built over compacted subgrades were built with thinner bases than those built over lime-treated subgrades. Generally, reconstructed pavements were built with thicker bases compared to the rehabilitated ones.

```
                                   Legend: A = 1 obs, B = 2 obs, etc.
                                           BT = Base Type
BT |                                         cr = CIPR
   |                                       ac = Asphalt Concrete
cr +  F      N      F                          ab = Aggregate Base
   |
   |
   |
ac +                       L             F
   |
   |
ab +                                                                 N
   |
   ---+------+------+------+------+------+------+------+------+------+------+--
      3      4      5      6      7      8      9     10     11     12     13

                                     Base Thickness (inches)
```

(a) Plot of Base Type vs. Base Thickness

```
SG |
   |
lt +         N             L             F                           N
   |
   |
   |                               Legend: A = 1 obs, B = 2 obs, etc.
   |                                       SG = Subgrade Type
   |                                       lt = Lime-Treated
   |                                       cm = Compacted
cm +  F             F
   |
   ---+------+------+------+------+------+------+------+------+------+------+--
      3      4      5      6      7      8      9     10     11     12     13

                                     Base Thickness (inches)
```

(b) Plot of Subgrade Type vs. Base Thickness

```
                                   Legend: A = 1 obs, B = 2 obs, etc.
                                           Work = Work Type
Work |                                         r = Reconstruction
     |                                     h = Rehabilitation
  r +                       L             F                           N
     |
     |
     |
     |
     |
     |
  h +  F      N      F
     |
     --+------+------+------+------+------+------+------+------+------+------+--
       3      4      5      6      7      8      9     10     11     12     13

                                     Base Thickness (inches)
```

(c) Plot of Work Type vs. Base Thickness

Figure 5.1 Plots against Base Thickness for Existing Sections with Maintenance Intervention

Although none of the categorical variables was found to be statistically significant in influencing short-term roughness, some observations were made from the LSMEANS estimates from the different levels of these variables as shown in Table 5.2. From this table, we can observe that the short-term IRI values for the rehabilitated Superpave pavements are generally lower than those for reconstructed pavements. Also, Superpave pavements built over compacted subgrade are smoother than those built over lime-treated subgrade. It is clear from this table that the Superpave pavements built over aggregate bases are rougher compared to those built over other base types. Pavements built using binder type PG 64-28 are rougher compared to those built using other binder types.

Table 5.2 Least Square Means Estimates – With Maintenance Intervention

Level of Factor	**LSMEANS Estimate of IRI (in/mile)**
Factor: Work Type	
Rehabilitation	50.2
Reconstruction	68.7
Factor: Subgrade	
Lime Treated	60.9
Compacted	59.7
Factor: PG Binder Grade	
PG 58-28	61.2
PG 64-28	68.2
PG 70-28	55
Factor: Base Type	
Aggregate Base	106.3
Asphalt Base	65.8
CIPR	31.9

5.3.1.2 Projects Without Maintenance Intervention

Results obtained for the existing projects without maintenance intervention showed that only age was statistically significant in influencing short-term roughness for all of the four factor combinations. Once again, plots against base course thickness were done. From Figure 5.2 we can see that aggregate bases are thicker compared to the other base types. The rest of the plots did not have any distinct relationships that could be statistically interpreted.

```
                                   Legend: A = 1 obs, B = 2 obs, etc.
                                       BT = Base Type
BT |                                     cr = CIPR
   |                                   ac = Asphalt Concrete
cr +  T                                   ab = Aggregate Base
   |
   |
   |
ac +  F     F          D
   |
   |
ab +                         D           L
   |
 ---+---------+---------+---------+---------+---------+---------+---------+--
    4         6         8        10        12        14        16        18

                                Base Thickness (inches)
```

Figure 5.2 Plot of Base Type against Base Thickness for Existing Sections without Maintenance Intervention

Some inferences were also made from Table 5.3 which tabulates the least square means estimates for the projects without maintenance intervention. Reconstructed pavements are smoother than the rehabilitated pavements. Superpave pavements built over compacted subgrades and those built over CIPR bases are smoother than pavements built over other subgrade and base types. Superpave pavements built using binder type PG 64-28 were found to be smoother than those built using other binder grades. This is contrary to what was observed for the Superpave pavements with maintenance intervention.

Table 5.3 Least Square Means Estimates – Without Maintenance Intervention

Level of Factor	**LSMEANS Estimate of IRI (in/mile)**
Factor: Work Type	
Rehabilitation	53.6
Reconstruction	48.8
Factor: Subgrade	
Lime Treated	59.6
Compacted	46.7
Fly Ash Treated	48.7
Factor: PG Binder Grade	
PG 58-28	55.7
PG 64-28	48.8
PG 70-28	51.8
Factor: Base Type	
Aggregate Base	63.3
Asphalt Base	48.3
CIPR	42.9

5.3.2 New Sections

Five new Superpave projects were chosen for analysis. Six treatment factors were considered in the analyses since work type was not a variable.

Likewise, ANOVA results show that pavement age is the only factor that significantly affects short term roughness of the new Superpave pavements. Table 5.4 shows the LSMEANS estimates. The CIPR bases tend to produce smoother Superpave pavements with time. Lime-treated subgrades produce smoother pavements compared to subgrades treated with fly-ash. Superpave pavements built using PG 70-28 are smoother compared to those built using PG 64-28.

Table 5.4 Least Square Means Estimates – New Sections

Level of Factor	LSMEANS Estimate of IRI (in/mile)
Factor: Subgrade	
Lime Treated	43.9
Fly Ash Treated	59.8
Factor: Base Type	
Asphalt Base	54.3
CIPR	46.2
Factor: PG Binder Grade	
PG 64-28	64.4
PG 70-28	47.5

5.4 MULTIPLE REGRESSION ANALYSIS

Multiple regression analysis was used in this study to establish the functional relationships between the IRI values and the significant factors that influence roughness. Different models were developed for as-constructed IRI and short-term IRI. The general form of the regression model is:

$$IRI = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_n X_n + \varepsilon \qquad (5.3)$$

Where;

IRI is the International Roughness Index (in/mile) which is the dependent variable;

β_0 is the constant, where the regression line intercepts the y axis, representing the amount the dependent variable (IRI) will be when all the independent variables are 0;

β_1, β_2…βn are the regression coefficients, representing the amount the dependent variable IRI changes when the corresponding independent variable changes by a unit;

X_1, X_2…Xn are the independent variables; and

ε is the error term reflected in the residuals.

Table 5.5 presents a list of independent variables that were used to develop the models in this study. These variables include a variety of layer, geometric, traffic, as well as climatic factors.

Table 5.5 Parameters Used to Derive Models

Factors	**Variables**
Layer information	**Subgrade thickness, base thickness, binder course thickness, surface course thickness**
Subgrade properties	Subgrade Materials passing US No. 200 (75-micron) sieve, maximum dry density, optimum moisture content, plasticity index
Mixture properties (Binder and surface courses)	Aggregate passing 75-micron sieve (dust), asphalt content, air void, voids in mineral aggregates (VMA), voids filled with asphalt (VFA), fine aggregate angularity (FAA), and sand equivalent (SE).
Climatic data	Annual precipitation, number of days in a year with temperature below 32^0F, number of days in a year with temperature above 90^0F, number of wet days in a year, and number of freeze-thaw cycles.
Traffic	Daily Equivalent Single Axle Load (ESALs)

For the as-constructed IRI model, traffic and climatic variables were not used as independent variables. For the short-term IRI model, as-constructed IRI and age of the pavement at which the profile data was collected, were used as additional variables. Models were selected based on a number of statistical information, such as, R^2 value, p-value, as well as engineering judgment. Multi-colinearity test was also performed to check the correlation among the independent variables.

Different model selection methods are available to determine which model best explains the given data set. The forward selection method was used in this study. This model development process first selected the variable that has the highest correlation with the dependent variable. From this point, additional variables that increase the R^2 value were added to the model. With each addition of a variable, R^2 value, Residual standard deviation (Root MSE) and p-value were computed. The addition of variables was continued until such a point when any extra variable added would have a p-value greater than the Significant Level to Enter (SLE) which was equal to 0.5. At this point, the model had the highest R^2 value, and the standard deviation of the residuals was the lowest. The criterion for adding variables is that once a variable was entered, it could not be eliminated from the regression equation at a later stage (Ott and Longnecker, 2001).

5.4.1 Existing Sections

5.4.1.1 As-Constructed Roughness Model

Since as-constructed roughness is not affected by maintenance, all existing projects were analyzed together to develop the as-constructed roughness model. The resulting model is shown below:

$$IRI_{AC} = 168.917 - 7.061(SCAC) - 4.111(SCVMA) + 2.714(SCDUST) - 8.736(BCAV) \tag{5.4}$$

($R^2 = 0.68$; p-value = 0.009; Root MSE = 6.20; n = 16)

Where;

IRI_{AC} is the as-constructed IRI (in/mile);

SCAC is the surface course asphalt content (%);

SCVMA is the surface course voids in mineral aggregate (%);

SCDUST is the surface course dust content (aggregate percent passing No. 200 sieve); and

BCAV is the binder course air voids (%).

The model indicates that the as-constructed IRI of the existing Superpave pavements is only affected by the mixture properties of the surface and binder courses. As-constructed IRI will decrease with increase in surface course asphalt content, surface course VMA and binder course air voids. It appears that use of higher asphalt content in the surface course will help build smoother pavements. Higher VMA really translates into higher effective asphalt or film thickness on the aggregates and this also confirms that higher asphalt content is required for the surface course in order to lower initial roughness of the pavement. At the same time, a higher percent of air voids in the binder course is desirable in achieving higher smoothness in the newly constructed Superpave pavement. However, surface course dust content needs to be lowered if low as-constructed roughness is to be attained. Lower dust content requires lower asphalt content to have acceptable dust proportion and this increases the effective asphalt content. The Variance Inflation Factors (VIF) indicated that multi-colinearity does not exist between the independent variables. Also, the Cook's D values proved that none of the points plotted was highly influential. A point has high influence if omitting it from the data will cause the regression line to change substantially, i.e., the regression line will be twisted badly and the slope will also change.

5.4.1.2 Short-Term Roughness Model

Development of short-term roughness model was done separately for projects with and without maintenance intervention. As mentioned earlier, as-constructed IRI and age of the pavement at which the profile data was collected, were used as additional variables in these analyses.

Projects with Maintenance Intervention

The model describing short-term roughness of superpave pavements that received maintenance intervention is shown below:

$$IRI_{ST}=19.772+0.445(ASC)+5.899(SCDUST) \qquad (5.5)$$

(R^2 = 0.21; p-value = 0.006; Root MSE = 115.45; n = 9)

Where;

IRI_{ST} is the short-term IRI (in/mile);

ASC is the as-constructed IRI (in/mile); and

SCDUST is the surface course dust content (aggregate percent passing No. 200 sieve).

Equation 5.5 suggests that the short-term IRI of Superpave pavements that received early maintenance intervention is influenced by the as-constructed IRI and surface course properties. The positive coefficient of as-constructed IRI indicates that the smoother a Superpave pavement is built, the smoother it will remain over time. Higher dust content in the surface course will increase roughness of a Superpave pavement with time. Unlike the as-constructed model, no binder course parameter was found to influence the short-term roughness. There was no multi-colinearity between the different independent variables in this model and also, no point was highly influential.

Projects without Maintenance Intervention

Short-term roughness model for the pavements that did not receive early maintenance intervention is represented by the following equation:

$$IRI_{ST} = 4.347 + 2.753(AGE) + 0.490\,(BCSE) \tag{5.6}$$

(R^2 =0.29; p-value = 0.005; Root MSE = 7.53; n = 8)

Where;

IRI_{ST} is the short-term IRI (in/mile);

AGE is the time at which the profile data was taken; and

BCSE is the binder course sand equivalent (%).

Equation (5.6) shows that if a Superpave pavement did not receive early maintenance intervention, the short-term roughness will be affected by age and binder course properties. We can see from Equation (5.6) that these pavements become rougher with time. An increase in binder course sand equivalent will increase the short term roughness. Just like in the other two models, it was observed that multi-colinearity between the different independent variables did not exist and also no point was highly influential.

5.4.2 New Sections

In the development of short-term roughness model for the new sections, climatic data was not considered since most of the data collection happened over a two-year period. The forward selection method of statistical analysis was used as well for multiple regression.

5.4.2.1 As-Constructed Roughness Model

The resulting as-constructed roughness model for the new sections is shown in Equation (5.7):

$$IRI_{AC} = -131.385 + 2.571(PI) + 18.385(BCAV) + 3.201(OMC) \qquad (5.7)$$

(R^2 =0.99; p-value = 0.076; Root MSE = 0.82; n = 5)

Where;

IRI_{AC} is the as-constructed IRI (in/mile);

PI is the plasticity index (%);

BCAV is the binder course air voids (%); and

OMC is the optimum moisture content.

From this model, we can see that as-constructed IRI for the new sections is affected by subgrade properties. An increase in the plasticity index would increase the as-constructed roughness. This is due to increased swelling potential of the subgrade soils. Higher optimum moisture content would also increase as-constructed IRI. Apart from subgrade properties, only binder course percent air voids were found to have a significant influence on as-constructed roughness. New Superpave sections would show increased as-constructed roughness if the binder course percent air voids are increased. Unlike existing sections, none of the surface course properties were found to have a significant effect on as-constructed roughness. Although the results do not show existence of multi-colinearity, two of the observations have been shown to be highly influential.

5.4.2.2 Short-Term Roughness Model

Equation (5.8) represents the short-term roughness for new Superpave sections.

$$IRI_{ST} = 346.576 - 4.138\ (SCVFA) \tag{5.8}$$

(R^2 = 0.49; p-value = 0.016; Root MSE = 8.74; n = 5)

Where;

IRI_{ST} is the short-term IRI (in/mile); and

SCVFA is the surface course voids filled with asphalt (%).

The short-term IRI of new Superpave sections is only influenced by surface course voids filled with asphalt. Short-term IRI would decrease if the percent surface course voids filled with asphalt are increased. Two points were found to have high influence on the results. This might have affected the results a lot given that there were only a few data points. However, there was no multi-colinearity between the independent variables.

5.5 SENSITIVITY ANALYSIS

Sensitivity analysis was performed to examine the effect of different significant variables that influence the as-constructed and short-term roughness of the Superpave pavements. To accomplish this task, a section with average input values was chosen for each model. The assumption made in developing Figures 5.3 to 5.7 was that other variables remained constant while the variable being considered changed.

5.5.1 Existing Sections

5.5.1.1 As-Constructed Roughness

Figure 5.3 shows the sensitivity of as-constructed IRI to different variables for the existing sections. One percent increase in surface course asphalt content will result in about 13 percent reduction in as-constructed IRI. If surface course VMA and binder course air voids are increased by 1 percent, as-constructed IRI will be reduced by 8 and 16 percent, respectively. Contrary to this, as-constructed IRI will increase by 7 percent if surface course dust content is increased by 1 percent.

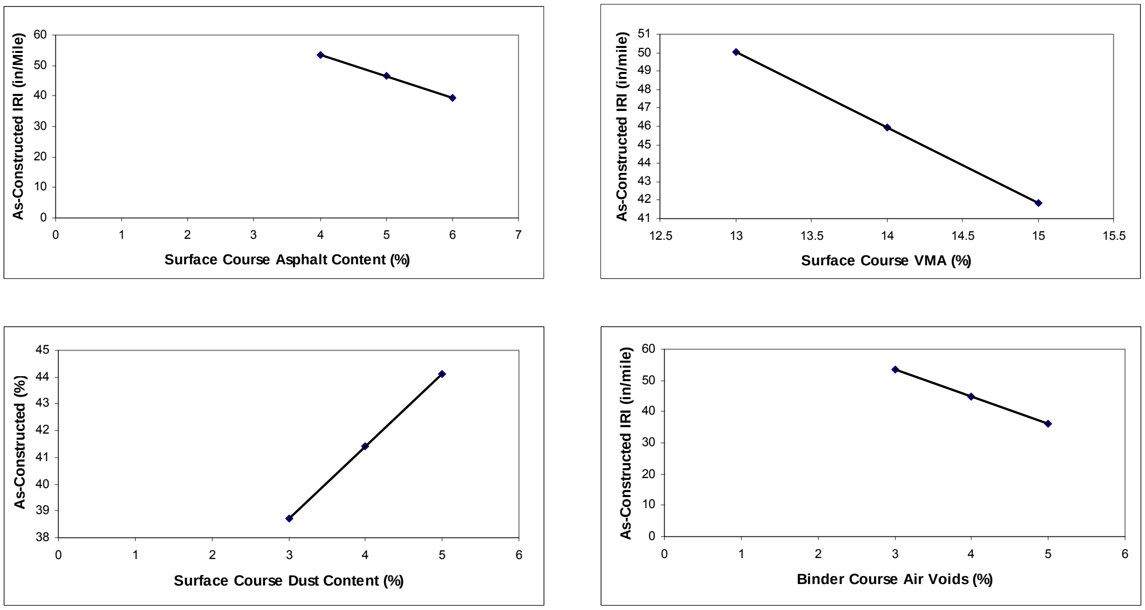


Figure 5.3 Sensitivity Analysis of As-Constructed IRI for Existing Sections

5.5.1.2 Short-Term Roughness

From Figures 5.4 and 5.5, we can see that short-term roughness of the existing sections will be quite sensitive to the age (service life) of the pavement and the surface course dust content. For the existing sections with maintenance intervention, if the surface course dust content is increased by 1 percent, short-term IRI will increase by 11 percent. If the difference between the as-constructed IRI of two sections is 1 in/mile, the rougher section will have higher short-term roughness of about 1.0 percent.

For the sections without maintenance intervention, a one percent increase in binder course sand equivalent will increase the short-term roughness by 1.1 percent. Approximately, four percent increase in short-term roughness would be expected yearly for the sections that did not receive early maintenance intervention.

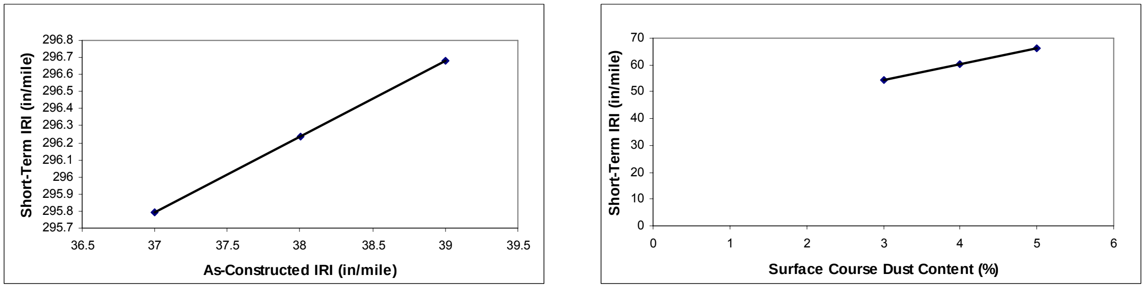


Figure 5.4 Sensitivity Analysis of Short-Term IRI for Existing Sections with Maintenance Intervention

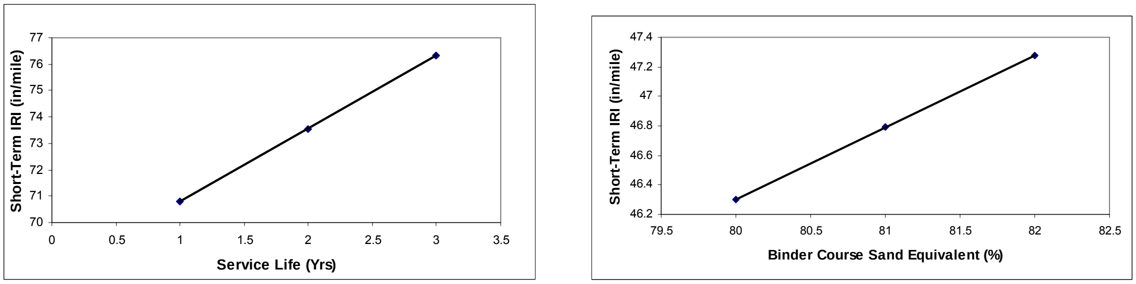


Figure 5.5 Sensitivity Analysis of Short-Term IRI for Existing Sections without Maintenance Intervention

5.5.2 New Sections

5.5.2.1 As-Constructed Roughness

The sensitivity of the as-constructed IRI to different variables for the new sections is shown in Figure 5.6. As-constructed IRI would be expected to increase by approximately 5 percent if plasticity index is increased by 1 percent. Binder course air voids have a very high impact on as-constructed IRI. One percent increase in binder course air voids would increase as-constructed IRI by 48 percent. Increasing optimum moisture content by 1 percent would increase as-constructed IRI by 14 percent.

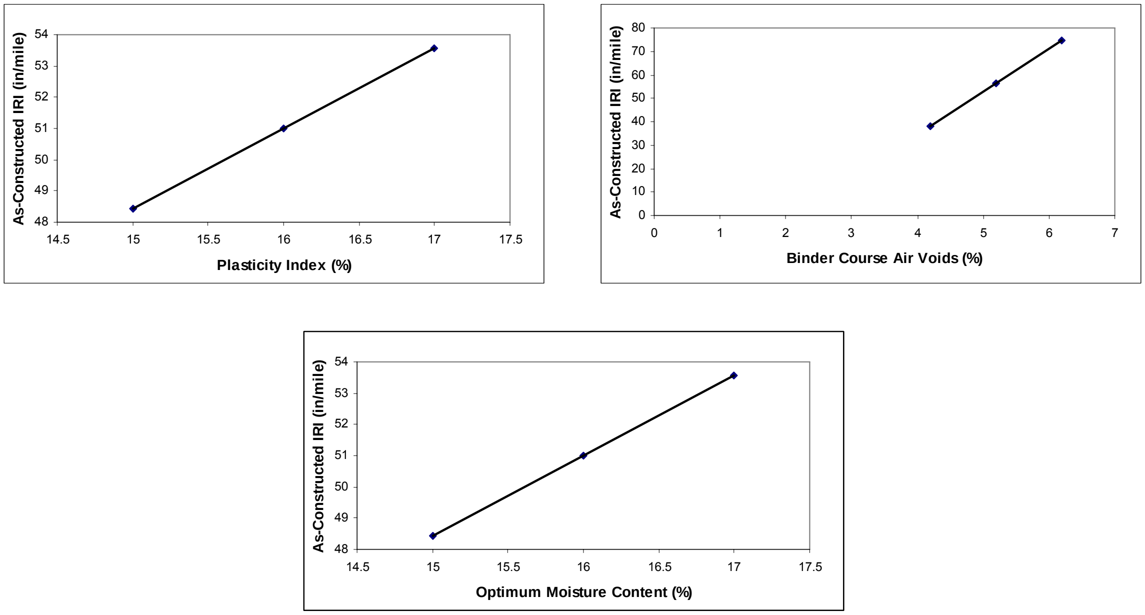


Figure 5.6 Sensitivity Analysis of As-Constructed IRI for New Sections

5.5.2.2 Short-Term Roughness

For the new sections, short-term roughness would be expected to reduce by 9 percent if the surface course voids filled with asphalt increase by 1 percent. This again indicates the influence of the effective asphalt content of the surface mixture on roughness.

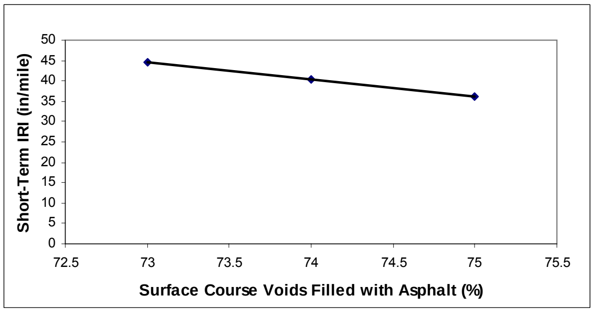


Figure 5.7 Sensitivity Analysis of Short-Term IRI for New Sections

CHAPTER 6

SUMMARY

6.1 CONCLUSIONS

The objectives of this study were to evaluate short-term roughness progression on the Superpave pavements built in Kansas and to find factors that significantly affect as-constructed and short-term roughness on Superpave pavements. Another goal was to establish the functional relationships between the roughness and the significant factors that influence it. Based on these goals and the results obtained, the following conclusions were made.

- Superpave pavements built over Cold-in-Place Recycled (CIPR) bases are smoother over time compared to the pavements built over Aggregate Bases (AB) and Asphalt Concrete (AC) bases. This was the case for all three scenarios considered in the analyses; existing sections with maintenance intervention, existing sections without maintenance intervention, and new sections. If base course thickness was the only factor to be considered in selecting the base type, CIPR bases would still be selected because they were also thinner than the other base types. However, Superpave pavements built over AC bases were smoother than those built over aggregate bases.
- Compacted subgrade produces smoother Superpave pavements over time than modified subgrade.
- It has been proven that as-constructed roughness of Superpave pavements is predominantly affected by the mixture properties of the surface course as well as subgrade properties. Such mixture properties include the

asphalt content, voids in mineral aggregate and aggregate materials passing No. 200 sieve or 75 micron sieve. Plasticity index of the subgrade soil and the optimum moisture content would affect the as-constructed roughness. Binder course air voids were found to influence as-built roughness too.

- The base thickness has some influence on the roughness of Superpave pavements. This effect is, however, tied to other factors like the type of sudgrade. It has been observed that pavements built over compacted subgrades had thinner bases and they were generally smoother than pavements built over other thicker bases.
- If a Superpave pavement did not receive early maintenance intervention, age and binder course sand equivalent will influence its short-term roughness.
- The short-term roughness of a Superpave pavement can be expressed in terms of its as-constructed roughness. A linear relationship exists between these two terms. In general, the smoother a Superpave pavement is built, the smoother it is over time.
- As-constructed roughness of Superpave pavements has been shown to be very sensitive to the surface course asphalt content, optimum moisture content and binder course air voids. A small change in these parameters would cause a big change in the as-constructed roughness.
- The short-term roughness of a Superpave pavement is very sensitive to age of the pavement and the surface course dust content.

6.2 RECOMMENDATIONS

Roughness is a very critical aspect of the as-constructed pavement and needs to be thoroughly and cautiously studied. For more conclusive results, the following recommendations are made:

- Roughness data for research needs to be improved. This study used summary IRI data from KDOT NOS survey, not raw profiles. A larger number of study sections should be selected for study and data should be collected continuously to minimize the number of missing values. Profile data should also be randomly collected in that it is not collected on the same sections repeatedly. It is recommended that researchers use “raw” profile data and an improved and representative summary statistics.
- For better comparisons of roughness progression, the projects selected should be of the same age to minimize variations due to climatic effects at different years.
- Consideration should be given to simulating this study in an accelerated testing laboratory where climatic effects and traffic loading can be controlled.

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APPENDIX A

Typical SAS Input and Output File for ANOVA

INPUT FILE

```
data s_pave; options ls=80;
input work $ age sg $ bt $ bthick pg $ pjn $ IRI;
title 'roughness progression with maintenance';
a = age;
cards;
;
proc print;
run;
proc plot; plot bt*bthick; plot sg*bthick; plot work*bthick; plot pg*bthick; plot bthick*age; plot bt*age; plot
IRI*age;
plot IRI*bthick; plot IRI*bt; plot work*bt plot sg*bt; plot sg*pg;
proc freq;
table work age bthick sg bt pg pjn work*sg;
run;
proc mixed;
class a work sg bt pg pjn;
model iri = age bthick bt / s;
repeated a /type = ar(1) sub = pjn(bt);
random pjn(bt);
lsmeans bt /pdiff;
run;
```

OUTPUT FILE

```
               The FREQ Procedure

                             Cumulative    Cumulative
work    Frequency     Percent     Frequency      Percent
-------------------------------------------------------
h           26       44.83           26        44.83
r           32       55.17           58       100.00


                             Cumulative    Cumulative
 age    Frequency     Percent     Frequency      Percent
 ------------------------------------------------------
   0         9       15.52            9       15.52
   1         9       15.52           18        31.03
   2         9       15.52           27        46.55
   3         9       15.52           36        62.07
   4         9       15.52           45        77.59
   5         9       15.52           54        93.10
   6         4        6.90           58       100.00
         roughness progression with maintenance              15
                                16:19 Sunday, May 7, 2006

               The FREQ Procedure

                             Cumulative    Cumulative
bthick    Frequency     Percent     Frequency      Percent
---------------------------------------------------------
    3         6       10.34            6       10.34
    4        14       24.14           20        34.48
  4.5         6       10.34           26        44.83
    6        12       20.69           38        65.52
    8         6       10.34           44       75.86
   13        14       24.14           58       100.00


                             Cumulative    Cumulative
 sg    Frequency     Percent     Frequency      Percent
 -----------------------------------------------------
 cm        12       20.69           12        20.69
 lt       46       79.31           58       100.00


         roughness progression with maintenance              16
                                16:19 Sunday, May 7, 2006

               The FREQ Procedure

                             Cumulative    Cumulative
 bt    Frequency     Percent     Frequency      Percent
 -----------------------------------------------------
 ab        14       24.14           14        24.14
 ac        18       31.03           32        55.17
 cr       26       44.83           58       100.00
```

```
                         Cumulative    Cumulative
 pg    Frequency     Percent    Frequency     Percent
 -------------------------------------------------------
 p1         12      20.69           12        20.69
 p2         18      31.03           30        51.72
 p3         28      48.28           58       100.00
       roughness progression with maintenance               17
                                   16:19 Sunday, May 7, 2006



                                         The FREQ Procedure

                           Cumulative    Cumulative
pjn        Frequency     Percent     Frequency      Percent
-----------------------------------------------------------
K254_1           7       12.07            7        12.07
K254_2           7       12.07           14        24.14
K254_3           7       12.07           21        36.21
K254_4           7       12.07           28        48.28
KS27            6       10.34           34       58.62
US169_1          6       10.34           40       68.97
US169_2          6       10.34           46       79.31
US169_3          6       10.34           52       89.66
US283           6       10.34           58      100.00


       roughness progression with maintenance               18
                                   16:19 Sunday, May 7, 2006

            The FREQ Procedure

           Table of work by sg

        work      sg

        Frequency|
        Percent  |
        Row Pct  |
        Col Pct  |cm      |lt      |  Total
        ---------+--------+--------+
        h        |     12 |     14 |     26
                 |  20.69 |  24.14 |  44.83
                 |  46.15 |  53.85 |
                 | 100.00 |  30.43 |
        ---------+--------+--------+
        r        |      0 |     32 |     32
                 |   0.00 |  55.17 |  55.17
                 |   0.00 | 100.00 |
                 |   0.00 |  69.57 |
        ---------+--------+--------+
        Total          12       46       58
                    20.69    79.31   100.00
       roughness progression with maintenance               19
                                   16:19 Sunday, May 7, 2006
```

```
              The Mixed Procedure

               Model Information

Data Set                  WORK.S_PAVE
Dependent Variable           IRI
Covariance Structures        Variance Components,
                          Autoregressive
Subject Effect               pjn(bt)
Estimation Method            REML
Residual Variance Method     Profile
Fixed Effects SE Method      Model-Based
Degrees of Freedom Method    Containment


            Class Level Information

 Class    Levels    Values

 a           7    0 1 2 3 4 5 6
 work         2    h r
 sg           2    cm lt
 bt           3    ab ac cr
 pg           3    p1 p2 p3
    roughness progression with maintenance                20
                                16:19 Sunday, May 7, 2006

              The Mixed Procedure

            Class Level Information

 Class    Levels    Values

 pjn          9    K254_1 K254_2 K254_3 K254_4
                   KS27 US169_1 US169_2 US169_3
                   US283


                  Dimensions

     Covariance Parameters            3
     Columns in X                  6
     Columns in Z                  9
     Subjects                    1
     Max Obs Per Subject            58
     Observations Used            58
     Observations Not Used            0
     Total Observations            58


    roughness progression with maintenance                21
                                16:19 Sunday, May 7, 2006

              The Mixed Procedure
```

```
                    Iteration History

     Iteration    Evaluations    -2 Res Log Like       Criterion

             0              1       449.38180509
             1              2       448.83305613      0.00000003
             2              1       448.83305103      0.00000000


                  Convergence criteria met.


                   Covariance Parameter Estimates

                  Cov Parm     Subject    Estimate

                  pjn(bt)                   9.2126
                  AR(1)       pjn(bt)      0.07080
                  Residual                  199.99


                roughness progression with maintenance                    22
                                              16:19 Sunday, May 7, 2006

                        The Mixed Procedure

                          Fit Statistics

                -2 Res Log Likelihood           448.8
                AIC (smaller is better)         454.8
                AICC (smaller is better)        455.3
                BIC (smaller is better)         455.4


                    Solution for Fixed Effects

                                Standard
Effect       bt        Estimate       Error      DF    t Value    Pr > |t|

Intercept               79.8432     14.1687       5       5.64      0.0024
age                      4.2047      1.0352      48       4.06      0.0002
bthick                  -8.5521      3.4784      48      -2.46      0.0176
bt           ab         74.3175     32.2087       5       2.31      0.0691
bt           ac         33.8953     10.9751       5       3.09      0.0272
bt           cr               0           .       .          .           .


                roughness progression with maintenance                    23
                                              16:19 Sunday, May 7, 2006

                        The Mixed Procedure

                  Type 3 Tests of Fixed Effects

                        Num     Den
           Effect         DF      DF    F Value    Pr > F
```

```
          age            1      48      16.50    0.0002
          bthick         1      48       6.04    0.0176
          bt             2       5       5.35    0.0572


                        Least Squares Means

                                Standard
 Effect    bt         Estimate       Error      DF    t Value    Pr > |t|

 bt       ab           106.27     21.5357       5       4.93      0.0043
 bt       ac          65.8432      4.0712       5      16.17      <.0001
 bt       cr          31.9479     11.1672       5       2.86      0.0354


            roughness progression with maintenance                  24
                                    16:19 Sunday, May 7, 2006

                        The Mixed Procedure

                Differences of Least Squares Means

                                   Standard
Effect   bt        _bt       Estimate       Error     DF   t Value   Pr > |t|

bt      ab        ac        40.4222    22.8390      5      1.77     0.1370
bt      ab        cr        74.3175    32.2087      5      2.31     0.0691
bt      ac        cr        33.8953    10.9751      5      3.09     0.0272
```

APPENDIX B

Typical SAS Input and Output File for Multiple Regression

INPUT FILE

1.0 Determination of Correlation Coefficients

```
data superpave; options ls=80;
input sgth bth bcth scth sg200 dd omc pi bcdust bcac bcav bcvma bcvfa bcfaa bcse scdust scac scav
scvma scvfa scfaa scse ppt tb ta
wdy ftc esals asc age iri;
title 'short term Reg with maintenance';
cards;


;
proc print;
run;
proc corr;
run;
proc reg;
model iri=sgth bth bcth scth sg200 dd omc pi bcdust bcac bcav bcvma bcvfa bcfaa bcse scdust scac scav
scvma scvfa scfaa scse ppt tb
ta wdy ftc esals asc age/r vif;
run;
```

2.0 Roughness Model Development

```
data superpave; options ls=80;
input iri asc scdust;
title 'short term Reg with maintenance';
cards;


;
proc print;
run;
proc corr;
run;
proc reg;
model iri=asc scdust/ r vif;
run;
```

OUTPUT FILE

1.0 Correlation Coefficients

```
                    The CORR Procedure

 31  Variables:   sgth     bth      bcth     scth     sg200    dd       omc
                pi      bcdust  bcac     bcav     bcvma    bcvfa    bcfaa
                bcse     scdust  scac     scav     scvma    scvfa    scfaa
                scse     ppt      tb       ta       wdy      ftc      esals
                asc      age      iri


                    Simple Statistics

Variable         N        Mean     Std Dev          Sum      Minimum      Maximum

sgth            49     8.44898     4.88647    414.00000      6.00000     18.00000
bth             49     6.96939     3.72549    341.50000      3.00000     13.00000
bcth            49     5.67347     1.53280    278.00000      4.00000      8.00000
scth            49     1.10204     0.20360     54.00000      1.00000      1.50000
sg200           49    93.57143     4.48144         4585     85.00000     99.00000
dd              49    99.63265     7.73707         4882     92.00000    120.00000
omc             49    20.48980     1.81570         1004     18.00000     23.00000
pi              49    20.93878     7.11046         1026     10.00000     31.00000
bcdust          49     4.41633     0.63880    216.40000      3.30000      5.50000
bcac            49     4.94898     0.57523    242.50000      3.70000      5.80000
bcav            49     4.08163     0.31733    200.00000      3.30000      4.30000
bcvma           49    13.80816     0.26207    676.60000     13.40000     14.20000
bcvfa           49    70.40000     2.45221         3450     68.10000     76.70000
                  short term Reg with maintenance                    11
                                   18:15 Monday, May 8, 2006

                    The CORR Procedure

                    Simple Statistics

Variable         N        Mean     Std Dev          Sum      Minimum      Maximum

bcfaa           49    44.06122     1.42021         2159     42.00000     47.00000
bcse            49    79.40816     7.33973         3891     69.00000     95.00000
scdust          49     4.08367     0.56249    200.10000      3.40000      4.80000
scac            49     5.60612     0.48236    274.70000      4.60000      6.20000
scav            49     4.36531     0.48285    213.90000      3.40000      5.00000
scvma           49    14.95714     0.70059    732.90000     13.60000     15.80000
scvfa           49    71.01429     2.33318         3480     68.70000     75.40000
scfaa           49    44.40816     1.30573         2176     43.00000     48.00000
scse            49    81.71429     7.05041         4004     67.00000     93.00000
ppt             49    35.34694     8.31803         1732     18.00000     42.00000
tb              49   105.91837    20.07261         5190     91.00000    149.00000
ta              49    55.04082    11.56316         2697     36.00000     74.00000
wdy             49    40.18367     9.63646         1969     21.00000     49.00000
ftc             49    89.18367    17.36336         4370     75.00000    122.00000
esals           49        4982        5186       244121    116.87000        17643
asc             49    43.90408    10.84022         2151     32.60000     64.00000
```

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age            49     3.24490     1.60118   159.00000     1.00000     6.00000
iri            49    63.41429    16.78732        3107    36.00000    93.50000
                      short term Reg with maintenance                     12
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                         The CORR Procedure

                   Pearson Correlation Coefficients, N = 49
                         Prob > |r| under H0: Rho=0

             sgth       bth      bcth      scth     sg200        dd       omc

 sgth     1.00000  -0.44212   0.27588   1.00000  -0.63605   0.78473  -0.27890
                     0.0015    0.0550    <.0001    <.0001    <.0001    0.0523

 bth     -0.44212   1.00000  -0.41860  -0.44212   0.36544  -0.42286   0.19783
           0.0015              0.0028    0.0015    0.0098    0.0025    0.1730

 bcth     0.27588  -0.41860   1.00000   0.27588   0.35225  -0.02174   0.34686
           0.0550    0.0028              0.0550    0.0131    0.8821    0.0146

 scth     1.00000  -0.44212   0.27588   1.00000  -0.63605   0.78473  -0.27890
           <.0001    0.0015    0.0550              <.0001    <.0001    0.0523

 sg200   -0.63605   0.36544   0.35225  -0.63605   1.00000  -0.53578   0.40014
           <.0001    0.0098    0.0131    <.0001              <.0001    0.0044

 dd       0.78473  -0.42286  -0.02174   0.78473  -0.53578   1.00000  -0.39623
           <.0001    0.0025    0.8821    <.0001    <.0001              0.0048
                      short term Reg with maintenance                     13
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                         The CORR Procedure

                   Pearson Correlation Coefficients, N = 49
                         Prob > |r| under H0: Rho=0

               pi    bcdust      bcac      bcav     bcvma     bcvfa     bcfaa

 sgth    -0.17548  -0.25335   0.13432  -0.45407   0.27689   0.46943  -0.02206
           0.2278    0.0790    0.3575    0.0010    0.0541    0.0007    0.8804

 bth      0.20480  -0.09652  -0.02991   0.39426  -0.05628  -0.37399  -0.07051
           0.1581    0.5094    0.8384    0.0051    0.7009    0.0081    0.6302

 bcth     0.49798  -0.31572   0.46982   0.06451   0.23756  -0.01580  -0.42128
           0.0003    0.0271    0.0007    0.6597    0.1003    0.9142    0.0026

 scth    -0.17548  -0.25335   0.13432  -0.45407   0.27689   0.46943  -0.02206
           0.2278    0.0790    0.3575    0.0010    0.0541    0.0007    0.8804

 sg200    0.35809   0.26739   0.58696   0.20384   0.16624  -0.14711  -0.24129
           0.0115    0.0633    <.0001    0.1601    0.2536    0.3131    0.0949

 dd      -0.57110   0.15088   0.27516  -0.72831   0.53578   0.78280   0.47797
           <.0001    0.3008    0.0557    <.0001    <.0001    <.0001    0.0005
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             short term Reg with maintenance                 14
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                  The CORR Procedure

            Pearson Correlation Coefficients, N = 49
                   Prob > |r| under H0: Rho=0

         bcse    scdust     scac      scav     scvma     scvfa     scfaa

sgth    0.00640   0.01485   0.04654   0.46059   0.43294  -0.26627   0.42781
        0.9652    0.9193    0.7508    0.0009    0.0019    0.0644    0.0022

bth     0.04428  -0.21349   0.17053  -0.02145   0.02822  -0.02979  -0.26505
        0.7626    0.1408    0.2414    0.8837    0.8474    0.8390    0.0657

bcth   -0.36104  -0.44609   0.46064   0.74157   0.52699  -0.69363   0.04196
        0.0108    0.0013    0.0009    <.0001    0.0001    <.0001    0.7747

scth    0.00640   0.01485   0.04654   0.46059   0.43294  -0.26627   0.42781
        0.9652    0.9193    0.7508    0.0009    0.0019    0.0644    0.0022

sg200  -0.63048  -0.08713   0.30482   0.30974  -0.10484  -0.52402  -0.11190
        <.0001    0.5516    0.0332    0.0303    0.4734    0.0001    0.4440

dd     -0.18220   0.49501  -0.00162   0.27256   0.14462  -0.12942   0.79878
        0.2102    0.0003    0.9912    0.0581    0.3215    0.3755    <.0001
             short term Reg with maintenance                 15
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                  The CORR Procedure

            Pearson Correlation Coefficients, N = 49
                   Prob > |r| under H0: Rho=0

         scse      ppt       tb        ta       wdy       ftc     esals

sgth   -0.16068  -0.94394   0.97064   0.72824  -0.96540   0.95221  -0.35236
        0.2701    <.0001    <.0001    <.0001    <.0001    <.0001    0.0130

bth     0.16940   0.38725  -0.41054  -0.18689   0.39100  -0.41022   0.22726
        0.2446    0.0060    0.0034    0.1985    0.0055    0.0034    0.1163

bcth   -0.10424  -0.27688   0.38372   0.49151  -0.30051   0.44105   0.13213
        0.4760    0.0541    0.0065    0.0003    0.0359    0.0015    0.3655

scth   -0.16068  -0.94394   0.97064   0.72824  -0.96540   0.95221  -0.35236
        0.2701    <.0001    <.0001    <.0001    <.0001    <.0001    0.0130

sg200  -0.31518   0.51545  -0.56596  -0.19022   0.54169  -0.46670   0.43645
        0.0274    0.0002    <.0001    0.1905    <.0001    0.0007    0.0017

dd     -0.54619  -0.84805   0.64572   0.51480  -0.81164   0.65432  -0.33568
        <.0001    <.0001    <.0001    0.0002    <.0001    <.0001    0.0184
             short term Reg with maintenance                 16
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                The CORR Procedure

          Pearson Correlation Coefficients, N = 49
                Prob > |r| under H0: Rho=0

                asc          age          iri

         sgth     0.19567     -0.07825      0.01389
                  0.1778       0.5930       0.9245

         bth     -0.34238      0.06415     -0.11743
                  0.0160       0.6615       0.4216

         bcth    -0.54928      0.07146     -0.24898
                  <.0001       0.6256       0.0845

         scth     0.19567     -0.07825      0.01389
                  0.1778       0.5930       0.9245

         sg200   -0.52504      0.13687     -0.10700
                  0.0001       0.3483       0.4643

         dd       0.36851     -0.08340      0.15048
                  0.0092       0.5689       0.3020
             short term Reg with maintenance                    17
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                The CORR Procedure

          Pearson Correlation Coefficients, N = 49
                Prob > |r| under H0: Rho=0

          sgth      bth      bcth      scth     sg200       dd       omc

omc     -0.27890   0.19783   0.34686  -0.27890   0.40014  -0.39623   1.00000
         0.0523    0.1730    0.0146    0.0523    0.0044    0.0048

pi      -0.17548   0.20480   0.49798  -0.17548   0.35809  -0.57110   0.80598
         0.2278    0.1581    0.0003    0.2278    0.0115    <.0001    <.0001

bcdust  -0.25335  -0.09652  -0.31572  -0.25335   0.26739   0.15088  -0.33754
         0.0790    0.5094    0.0271    0.0790    0.0633    0.3008    0.0177

bcac     0.13432  -0.02991   0.46982   0.13432   0.58696   0.27516  -0.10324
         0.3575    0.8384    0.0007    0.3575    <.0001    0.0557    0.4803

bcav    -0.45407   0.39426   0.06451  -0.45407   0.20384  -0.72831   0.11357
         0.0010    0.0051    0.6597    0.0010    0.1601    <.0001    0.4372

bcvma    0.27689  -0.05628   0.23756   0.27689   0.16624   0.53578  -0.25813
         0.0541    0.7009    0.1003    0.0541    0.2536    <.0001    0.0733
             short term Reg with maintenance                    18
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                The CORR Procedure
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```
              Pearson Correlation Coefficients, N = 49
                    Prob > |r| under H0: Rho=0

            pi    bcdust      bcac      bcav     bcvma     bcvfa     bcfaa

omc     0.80598  -0.33754  -0.10324   0.11357  -0.25813  -0.17453   0.02044
        <.0001    0.0177    0.4803    0.4372    0.0733    0.2304    0.8891

pi      1.00000  -0.49193  -0.06903   0.38636  -0.21103  -0.40720  -0.53601
                  0.0003    0.6374    0.0061    0.1455    0.0037    <.0001

bcdust  -0.49193   1.00000   0.44908  -0.62028   0.14230   0.61856   0.14584
        0.0003              0.0012    <.0001    0.3294    <.0001    0.3174

bcac    -0.06903   0.44908   1.00000  -0.38645   0.70624   0.51649  -0.19756
        0.6374    0.0012              0.0061    <.0001    0.0001    0.1736

bcav     0.38636  -0.62028  -0.38645   1.00000  -0.24867  -0.97533  -0.37651
        0.0061    <.0001    0.0061              0.0849    <.0001    0.0077

bcvma   -0.21103   0.14230   0.70624  -0.24867   1.00000   0.45482   0.09378
        0.1455    0.3294    <.0001    0.0849              0.0010    0.5215
                  short term Reg with maintenance                    19
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                         The CORR Procedure

              Pearson Correlation Coefficients, N = 49
                    Prob > |r| under H0: Rho=0

           bcse    scdust      scac      scav     scvma     scvfa     scfaa

omc     -0.04189  -0.59377   0.52934   0.12910   0.37715   0.02143   0.04573
        0.7750    <.0001    <.0001    0.3767    0.0076    0.8838    0.7550

pi       0.01167  -0.75346   0.27345   0.20083   0.39174  -0.11347  -0.41238
        0.9366    <.0001    0.0573    0.1665    0.0054    0.4376    0.0032

bcdust  -0.65285   0.88380  -0.56219  -0.33584  -0.87310   0.04024   0.27908
        <.0001    <.0001    <.0001    0.0183    <.0001    0.7837    0.0521

bcac    -0.92857   0.35344   0.11077   0.64831  -0.05413  -0.82526   0.37502
        <.0001    0.0127    0.4486    <.0001    0.7118    <.0001    0.0079

bcav     0.54713  -0.68334   0.24302  -0.00425   0.32624   0.01387  -0.78601
        <.0001    <.0001    0.0925    0.9769    0.0222    0.9247    <.0001

bcvma   -0.50323   0.35989   0.08529   0.50442   0.15853  -0.51229   0.41623
        0.0002    0.0111    0.5601    0.0002    0.2766    0.0002    0.0029
                  short term Reg with maintenance                    20
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                         The CORR Procedure

              Pearson Correlation Coefficients, N = 49
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```
                    Prob > |r| under H0: Rho=0

          scse      ppt       tb       ta      wdy      ftc     esals

omc      0.24225   0.42441  -0.13207  -0.37407   0.39244  -0.03860   0.15236
          0.0935    0.0024    0.3657    0.0081    0.0053    0.7923    0.2960

pi       0.40857   0.32443   0.05164  -0.13097   0.28050   0.08345   0.20490
          0.0036    0.0229    0.7246    0.3697    0.0509    0.5686    0.1579

bcdust  -0.74137   0.18750  -0.33053  -0.38791   0.24758  -0.26342   0.00319
          <.0001    0.1970    0.0204    0.0059    0.0863    0.0674    0.9826

bcac    -0.84562  -0.31669   0.12792   0.42535  -0.26136   0.21831   0.18002
          <.0001    0.0266    0.3811    0.0023    0.0697    0.1318    0.2158

bcav     0.74255   0.41052  -0.37965   0.02008   0.37652  -0.46899   0.27688
          <.0001    0.0034    0.0071    0.8911    0.0077    0.0007    0.0541

bcvma   -0.66958  -0.53365   0.21795   0.57737  -0.44690   0.22034   0.09425
          <.0001    <.0001    0.1325    <.0001    0.0013    0.1282    0.5195
                  short term Reg with maintenance                       21
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                      The CORR Procedure

                Pearson Correlation Coefficients, N = 49
                    Prob > |r| under H0: Rho=0

                      asc         age         iri

                omc     -0.53950     0.04387    -0.34615
                          <.0001      0.7647      0.0148

                pi      -0.57941     0.06722    -0.40858
                          <.0001      0.6463      0.0036

                bcdust   0.64563    -0.01621     0.40010
                          <.0001      0.9120      0.0044

                bcac    -0.16695     0.08171     0.04139
                          0.2516      0.5768      0.7776

                bcav    -0.61530     0.08284    -0.26808
                          <.0001      0.5715      0.0626

                bcvma   -0.20241     0.05471    -0.07892
                          0.1631      0.7089      0.5899
                  short term Reg with maintenance                       22
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                      The CORR Procedure

                Pearson Correlation Coefficients, N = 49
                    Prob > |r| under H0: Rho=0
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```
           sgth      bth     bcth     scth    sg200       dd      omc

bcvfa   0.46943  -0.37399  -0.01580   0.46943  -0.14711   0.78280  -0.17453
         0.0007    0.0081    0.9142    0.0007    0.3131    <.0001    0.2304

bcfaa  -0.02206  -0.07051  -0.42128  -0.02206  -0.24129   0.47797   0.02044
         0.8804    0.6302    0.0026    0.8804    0.0949    0.0005    0.8891

bcse    0.00640   0.04428  -0.36104   0.00640  -0.63048  -0.18220  -0.04189
         0.9652    0.7626    0.0108    0.9652    <.0001    0.2102    0.7750

scdust  0.01485  -0.21349  -0.44609   0.01485  -0.08713   0.49501  -0.59377
         0.9193    0.1408    0.0013    0.9193    0.5516    0.0003    <.0001

scac    0.04654   0.17053   0.46064   0.04654   0.30482  -0.00162   0.52934
         0.7508    0.2414    0.0009    0.7508    0.0332    0.9912    <.0001

scav    0.46059  -0.02145   0.74157   0.46059   0.30974   0.27256   0.12910
         0.0009    0.8837    <.0001    0.0009    0.0303    0.0581    0.3767
                short term Reg with maintenance                  23
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                     The CORR Procedure

                Pearson Correlation Coefficients, N = 49
                      Prob > |r| under H0: Rho=0

             pi    bcdust     bcac      bcav     bcvma     bcvfa     bcfaa

bcvfa  -0.40720   0.61856   0.51649  -0.97533   0.45482   1.00000   0.35713
         0.0037    <.0001    0.0001    <.0001    0.0010              0.0118

bcfaa  -0.53601   0.14584  -0.19756  -0.37651   0.09378   0.35713   1.00000
         <.0001    0.3174    0.1736    0.0077    0.5215    0.0118

bcse    0.01167  -0.65285  -0.92857   0.54713  -0.50323  -0.62146   0.15344
         0.9366    <.0001    <.0001    <.0001    0.0002    <.0001    0.2925

scdust -0.75346   0.88380   0.35344  -0.68334   0.35989   0.72362   0.35856
         <.0001    <.0001    0.0127    <.0001    0.0111    <.0001    0.0114

scac    0.27345  -0.56219   0.11077   0.24302   0.08529  -0.22773   0.27923
         0.0573    <.0001    0.4486    0.0925    0.5601    0.1155    0.0520

scav    0.20083  -0.33584   0.64831  -0.00425   0.50442   0.10223  -0.21254
         0.1665    0.0183    <.0001    0.9769    0.0002    0.4846    0.1426
                short term Reg with maintenance                  24
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                     The CORR Procedure

                Pearson Correlation Coefficients, N = 49
                      Prob > |r| under H0: Rho=0

           bcse    scdust      scac      scav     scvma     scvfa     scfaa
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```
bcvfa  -0.62146   0.72362  -0.22773   0.10223  -0.28655  -0.12089   0.80355
        <.0001    <.0001    0.1155    0.4846    0.0459    0.4080    <.0001

bcfaa   0.15344   0.35856   0.27923  -0.21254   0.01107   0.36690   0.71648
        0.2925    0.0114    0.0520    0.1426    0.9398    0.0095    <.0001

bcse    1.00000  -0.45554   0.03341  -0.41682   0.29032   0.63226  -0.39817
                  0.0010    0.8197    0.0029    0.0430    <.0001    0.0046

scdust -0.45554   1.00000  -0.59317  -0.33733  -0.74987   0.13845   0.43474
        0.0010              <.0001    0.0178    <.0001    0.3428    0.0018

scac    0.03341  -0.59317   1.00000   0.66643   0.80777  -0.45935   0.32673
        0.8197    <.0001              <.0001    <.0001    0.0009    0.0219

scav   -0.41682  -0.33733   0.66643   1.00000   0.69512  -0.92159   0.30380
        0.0029    0.0178    <.0001              <.0001    <.0001    0.0338
            short term Reg with maintenance                    25
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                     The CORR Procedure

              Pearson Correlation Coefficients, N = 49
                   Prob > |r| under H0: Rho=0

           scse       ppt       tb        ta       wdy       ftc     esals

bcvfa  -0.83844  -0.48842   0.38842   0.10205  -0.43640   0.46967  -0.23076
        <.0001    0.0004    0.0058    0.4853    0.0017    0.0007    0.1107

bcfaa  -0.20004  -0.04063  -0.20225  -0.22724  -0.00388  -0.16943  -0.16497
        0.1682    0.7816    0.1634    0.1164    0.9789    0.2445    0.2573

bcse    0.87914   0.09898  -0.00854  -0.10183   0.04752  -0.13040  -0.15566
        <.0001    0.4986    0.9536    0.4863    0.7458    0.3718    0.2855

scdust -0.74927  -0.13324  -0.13002  -0.15460  -0.05632  -0.11210  -0.12602
        <.0001    0.3614    0.3732    0.2888    0.7007    0.4432    0.3882

scac    0.13101  -0.09764   0.03728   0.30848  -0.12440   0.10309   0.12820
        0.3696    0.5045    0.7993    0.0310    0.3944    0.4809    0.3800

scav   -0.28754  -0.56960   0.48227   0.79691  -0.57708   0.53851   0.10515
        0.0451    <.0001    0.0004    <.0001    <.0001    <.0001    0.4721
            short term Reg with maintenance                    26
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                     The CORR Procedure

              Pearson Correlation Coefficients, N = 49
                   Prob > |r| under H0: Rho=0

                     asc          age          iri

              bcvfa    0.53406     -0.06367      0.23483
                       <.0001       0.6638       0.1043
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        bcfaa    0.16318     -0.06170      0.11260
                 0.2626       0.6736       0.4411

        bcse    -0.02356     -0.06186     -0.10833
                 0.8723       0.6728       0.4587

        scdust   0.74116     -0.05098      0.41192
                 <.0001       0.7279       0.0033

        scac    -0.80599      0.06276     -0.29717
                 <.0001       0.6684       0.0381

        scav    -0.62885      0.07589     -0.21195
                 <.0001       0.6043       0.1437
           short term Reg with maintenance                    27
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                  The CORR Procedure

          Pearson Correlation Coefficients, N = 49
                 Prob > |r| under H0: Rho=0

       sgth      bth     bcth     scth    sg200      dd      omc

scvma    0.43294   0.02822   0.52699   0.43294  -0.10484   0.14462   0.37715
         0.0019    0.8474    0.0001    0.0019    0.4734    0.3215    0.0076

scvfa   -0.26627  -0.02979  -0.69363  -0.26627  -0.52402  -0.12942   0.02143
         0.0644    0.8390    <.0001    0.0644    0.0001    0.3755    0.8838

scfaa    0.42781  -0.26505   0.04196   0.42781  -0.11190   0.79878   0.04573
         0.0022    0.0657    0.7747    0.0022    0.4440    <.0001    0.7550

scse    -0.16068   0.16940  -0.10424  -0.16068  -0.31518  -0.54619   0.24225
         0.2701    0.2446    0.4760    0.2701    0.0274    <.0001    0.0935

ppt     -0.94394   0.38725  -0.27688  -0.94394   0.51545  -0.84805   0.42441
         <.0001    0.0060    0.0541    <.0001    0.0002    <.0001    0.0024

tb       0.97064  -0.41054   0.38372   0.97064  -0.56596   0.64572  -0.13207
         <.0001    0.0034    0.0065    <.0001    <.0001    <.0001    0.3657
           short term Reg with maintenance                    28
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                  The CORR Procedure

          Pearson Correlation Coefficients, N = 49
                 Prob > |r| under H0: Rho=0

         pi    bcdust     bcac     bcav    bcvma    bcvfa    bcfaa

scvma    0.39174  -0.87310  -0.05413   0.32624   0.15853  -0.28655   0.01107
         0.0054    <.0001    0.7118    0.0222    0.2766    0.0459    0.9398

scvfa   -0.11347   0.04024  -0.82526   0.01387  -0.51229  -0.12089   0.36690
```

```
         0.4376    0.7837    <.0001    0.9247    0.0002    0.4080    0.0095

scfaa   -0.41238   0.27908   0.37502  -0.78601   0.41623   0.80355   0.71648
         0.0032    0.0521    0.0079    <.0001    0.0029    <.0001    <.0001

scse     0.40857  -0.74137  -0.84562   0.74255  -0.66958  -0.83844  -0.20004
         0.0036    <.0001    <.0001    <.0001    <.0001    <.0001    0.1682

ppt      0.32443   0.18750  -0.31669   0.41052  -0.53365  -0.48842  -0.04063
         0.0229    0.1970    0.0266    0.0034    <.0001    0.0004    0.7816

tb       0.05164  -0.33053   0.12792  -0.37965   0.21795   0.38842  -0.20225
         0.7246    0.0204    0.3811    0.0071    0.1325    0.0058    0.1634
              short term Reg with maintenance                    29
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                   The CORR Procedure

             Pearson Correlation Coefficients, N = 49
                  Prob > |r| under H0: Rho=0

           bcse    scdust     scac      scav    scvma     scvfa     scfaa

scvma    0.29032  -0.74987   0.80777   0.69512   1.00000  -0.39000   0.13339
         0.0430    <.0001    <.0001    <.0001              0.0056    0.3609

scvfa    0.63226   0.13845  -0.45935  -0.92159  -0.39000   1.00000  -0.17633
         <.0001    0.3428    0.0009    <.0001    0.0056              0.2255

scfaa   -0.39817   0.43474   0.32673   0.30380   0.13339  -0.17633   1.00000
         0.0046    0.0018    0.0219    0.0338    0.3609    0.2255

scse     0.87914  -0.74927   0.13101  -0.28754   0.35049   0.45023  -0.65466
         <.0001    <.0001    0.3696    0.0451    0.0135    0.0012    <.0001

ppt      0.09898  -0.13324  -0.09764  -0.56960  -0.43318   0.41474  -0.48326
         0.4986    0.3614    0.5045    <.0001    0.0019    0.0030    0.0004

tb      -0.00854  -0.13002   0.03728   0.48227   0.47189  -0.28765   0.29540
         0.9536    0.3732    0.7993    0.0004    0.0006    0.0451    0.0393
              short term Reg with maintenance                    30
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                   The CORR Procedure

             Pearson Correlation Coefficients, N = 49
                  Prob > |r| under H0: Rho=0

           scse      ppt       tb        ta       wdy       ftc     esals

scvma    0.35049  -0.43318   0.47189   0.60816  -0.47434   0.46495   0.00047
         0.0135    0.0019    0.0006    <.0001    0.0006    0.0008    0.9975

scvfa    0.45023   0.41474  -0.28765  -0.69609   0.40870  -0.35300  -0.19288
         0.0012    0.0030    0.0451    <.0001    0.0036    0.0129    0.1842
```

```
scfaa   -0.65466  -0.48326   0.29540   0.17825  -0.44485   0.39175  -0.20154
         <.0001    0.0004    0.0393    0.2204    0.0014    0.0054    0.1649

scse     1.00000   0.32038  -0.07672  -0.17235   0.24334  -0.16923  -0.01260
                   0.0248    0.6003    0.2363    0.0920    0.2451    0.9315

ppt      0.32038   1.00000  -0.87302  -0.85919   0.99386  -0.84790   0.27529
         0.0248              <.0001    <.0001    <.0001    <.0001    0.0556

tb      -0.07672  -0.87302   1.00000   0.69520  -0.90508   0.98532  -0.31201
         0.6003    <.0001              <.0001    <.0001    <.0001    0.0291
             short term Reg with maintenance                   31
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                   The CORR Procedure

              Pearson Correlation Coefficients, N = 49
                     Prob > |r| under H0: Rho=0

                       asc          age          iri

             scvma   -0.74340      0.03184     -0.38887
                      <.0001       0.8281       0.0058

             scvfa    0.51157     -0.09799      0.09812
                      0.0002       0.5030       0.5024

             scfaa    0.15295     -0.04881      0.10827
                      0.2941       0.7391       0.4590

             scse    -0.26317     -0.01582     -0.21628
                      0.0677       0.9141       0.1355

             ppt     -0.10054      0.04980     -0.02052
                      0.4918       0.7340       0.8887

             tb       0.11394     -0.06548     -0.06020
                      0.4357       0.6549       0.6812
             short term Reg with maintenance                   32
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                   The CORR Procedure

              Pearson Correlation Coefficients, N = 49
                     Prob > |r| under H0: Rho=0

            sgth      bth      bcth      scth     sg200       dd       omc

ta       0.72824  -0.18689   0.49151   0.72824  -0.19022   0.51480  -0.37407
         <.0001    0.1985    0.0003    <.0001    0.1905    0.0002    0.0081

wdy     -0.96540   0.39100  -0.30051  -0.96540   0.54169  -0.81164   0.39244
         <.0001    0.0055    0.0359    <.0001    <.0001    <.0001    0.0053

ftc      0.95221  -0.41022   0.44105   0.95221  -0.46670   0.65432  -0.03860
         <.0001    0.0034    0.0015    <.0001    0.0007    <.0001    0.7923
```

```
esals   -0.35236   0.22726   0.13213  -0.35236   0.43645  -0.33568   0.15236
         0.0130    0.1163    0.3655    0.0130    0.0017    0.0184    0.2960

asc      0.19567  -0.34238  -0.54928   0.19567  -0.52504   0.36851  -0.53950
         0.1778    0.0160    <.0001    0.1778    0.0001    0.0092    <.0001

age     -0.07825   0.06415   0.07146  -0.07825   0.13687  -0.08340   0.04387
         0.5930    0.6615    0.6256    0.5930    0.3483    0.5689    0.7647
              short term Reg with maintenance                    33
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                   The CORR Procedure

              Pearson Correlation Coefficients, N = 49
                   Prob > |r| under H0: Rho=0

            pi    bcdust     bcac      bcav     bcvma     bcvfa     bcfaa

ta      -0.13097  -0.38791   0.42535   0.02008   0.57737   0.10205  -0.22724
         0.3697    0.0059    0.0023    0.8911    <.0001    0.4853    0.1164

wdy      0.28050   0.24758  -0.26136   0.37652  -0.44690  -0.43640  -0.00388
         0.0509    0.0863    0.0697    0.0077    0.0013    0.0017    0.9789

ftc      0.08345  -0.26342   0.21831  -0.46899   0.22034   0.46967  -0.16943
         0.5686    0.0674    0.1318    0.0007    0.1282    0.0007    0.2445

esals    0.20490   0.00319   0.18002   0.27688   0.09425  -0.23076  -0.16497
         0.1579    0.9826    0.2158    0.0541    0.5195    0.1107    0.2573

asc     -0.57941   0.64563  -0.16695  -0.61530  -0.20241   0.53406   0.16318
         <.0001    <.0001    0.2516    <.0001    0.1631    <.0001    0.2626

age      0.06722  -0.01621   0.08171   0.08284   0.05471  -0.06367  -0.06170
         0.6463    0.9120    0.5768    0.5715    0.7089    0.6638    0.6736

              short term Reg with maintenance                    34
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                   The CORR Procedure

              Pearson Correlation Coefficients, N = 49
                   Prob > |r| under H0: Rho=0

           bcse   scdust     scac      scav     scvma     scvfa     scfaa

ta      -0.10183  -0.15460   0.30848   0.79691   0.60816  -0.69609   0.17825
         0.4863    0.2888    0.0310    <.0001    <.0001    <.0001    0.2204

wdy      0.04752  -0.05632  -0.12440  -0.57708  -0.47434   0.40870  -0.44485
         0.7458    0.7007    0.3944    <.0001    0.0006    0.0036    0.0014

ftc     -0.13040  -0.11210   0.10309   0.53851   0.46495  -0.35300   0.39175
         0.3718    0.4432    0.4809    <.0001    0.0008    0.0129    0.0054
```

```
esals   -0.15566  -0.12602   0.12820   0.10515   0.00047  -0.19288  -0.20154
          0.2855    0.3882    0.3800    0.4721    0.9975    0.1842    0.1649

asc     -0.02356   0.74116  -0.80599  -0.62885  -0.74340   0.51157   0.15295
          0.8723    <.0001    <.0001    <.0001    <.0001    0.0002    0.2941

age     -0.06186  -0.05098   0.06276   0.07589   0.03184  -0.09799  -0.04881
          0.6728    0.7279    0.6684    0.6043    0.8281    0.5030    0.7391

                    short term Reg with maintenance                    35
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                        The CORR Procedure

                   Pearson Correlation Coefficients, N = 49
                         Prob > |r| under H0: Rho=0

            scse       ppt        tb        ta       wdy       ftc     esals

ta      -0.17235  -0.85919   0.69520   1.00000  -0.85974   0.65741  -0.06273
          0.2363    <.0001    <.0001              <.0001    <.0001    0.6685

wdy      0.24334   0.99386  -0.90508  -0.85974   1.00000  -0.87938   0.28898
          0.0920    <.0001    <.0001    <.0001              <.0001    0.0440

ftc     -0.16923  -0.84790   0.98532   0.65741  -0.87938   1.00000  -0.29737
          0.2451    <.0001    <.0001    <.0001    <.0001              0.0380

esals   -0.01260   0.27529  -0.31201  -0.06273   0.28898  -0.29737   1.00000
          0.9315    0.0556    0.0291    0.6685    0.0440    0.0380

asc     -0.26317  -0.10054   0.11394  -0.30740  -0.08682   0.09287  -0.32464
          0.0677    0.4918    0.4357    0.0317    0.5531    0.5256    0.0229

age     -0.01582   0.04980  -0.06548   0.02308   0.05373  -0.06010   0.85626
          0.9141    0.7340    0.6549    0.8749    0.7139    0.6816    <.0001

                    short term Reg with maintenance                    36
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                        The CORR Procedure

                   Pearson Correlation Coefficients, N = 49
                         Prob > |r| under H0: Rho=0

                        asc           age           iri

                ta     -0.30740       0.02308      -0.10687
                         0.0317        0.8749        0.4649

                wdy    -0.08682       0.05373      -0.01105
                         0.5531        0.7139        0.9399

                ftc     0.09287      -0.06010      -0.05580
                         0.5256        0.6816        0.7033
```

```
        esals   -0.32464      0.85626      0.08556
                  0.0229       <.0001       0.5589

        asc      1.00000     -0.12177      0.43124
                               0.4046       0.0020

        age     -0.12177      1.00000      0.25277
                  0.4046                    0.0797

                 short term Reg with maintenance                   37
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                      The CORR Procedure

              Pearson Correlation Coefficients, N = 49
                     Prob > |r| under H0: Rho=0

          sgth      bth      bcth      scth     sg200       dd       omc

iri     0.01389  -0.11743  -0.24898   0.01389  -0.10700   0.15048  -0.34615
         0.9245    0.4216    0.0845    0.9245    0.4643    0.3020    0.0148

              Pearson Correlation Coefficients, N = 49
                     Prob > |r| under H0: Rho=0

            pi    bcdust     bcac      bcav     bcvma     bcvfa     bcfaa

iri    -0.40858   0.40010   0.04139  -0.26808  -0.07892   0.23483   0.11260
         0.0036    0.0044    0.7776    0.0626    0.5899    0.1043    0.4411

                 short term Reg with maintenance                   38
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                      The CORR Procedure

              Pearson Correlation Coefficients, N = 49
                     Prob > |r| under H0: Rho=0

          bcse    scdust     scac      scav     scvma     scvfa     scfaa

iri    -0.10833   0.41192  -0.29717  -0.21195  -0.38887   0.09812   0.10827
         0.4587    0.0033    0.0381    0.1437    0.0058    0.5024    0.4590

              Pearson Correlation Coefficients, N = 49
                     Prob > |r| under H0: Rho=0

          scse       ppt       tb        ta       wdy       ftc     esals

iri    -0.21628  -0.02052  -0.06020  -0.10687  -0.01105  -0.05580   0.08556
         0.1355    0.8887    0.6812    0.4649    0.9399    0.7033    0.5589

                 short term Reg with maintenance                   39
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                      The CORR Procedure
```

```
                 Pearson Correlation Coefficients, N = 49
                        Prob > |r| under H0: Rho=0

                           asc          age          iri

                 iri     0.43124      0.25277      1.00000
                          0.0020       0.0797
                     short term Reg with maintenance                    40
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                           The REG Procedure
                             Model: MODEL1
                         Dependent Variable: iri

                          Analysis of Variance

                                Sum of           Mean
 Source                 DF        Squares          Square    F Value    Pr > F

 Model                  10     4996.35429      499.63543       2.23    0.0372
 Error                  38     8530.72571      224.49278
 Corrected Total        48          13527


            Root MSE            14.98308    R-Square     0.3694
            Dependent Mean      63.41429    Adj R-Sq     0.2034
            Coeff Var           23.62730

NOTE: Model is not full rank. Least-squares solutions for the parameters are
      not unique. Some statistics will be misleading. A reported DF of 0 or B
      means that the estimate is biased.
NOTE: The following parameters have been set to 0, since the variables are a
      linear combination of other variables as shown.
                     short term Reg with maintenance                    41
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                           The REG Procedure
                             Model: MODEL1
                         Dependent Variable: iri

  scth =  0.75 * Intercept + 0.04167 * sgth
  bcac =  -12.2414 * Intercept + 0.03328 * sgth + 0.14618 * sg200 + 0.05261
         * dd - 0.17288 * omc + 0.04055 * pi + 0.15469 * bcdust
  bcav =  8.32153 * Intercept - 0.03388 * sgth + 0.01225 * sg200 - 0.01033
         * dd - 0.10965 * omc + 0.00685 * pi - 0.4456 * bcdust
 bcvma =  6.15499 * Intercept - 0.08082 * sgth + 0.03907 * sg200 + 0.0854
         * dd - 0.2074 * omc + 0.06087 * pi - 0.19327 * bcdust
 bcvfa =  24.8575 * Intercept + 0.05688 * sgth - 208E-13 * bcth - 0.01154 *
         sg200 + 0.25761 * dd + 0.29312 * omc
         + 0.09391 * pi + 2.8311 * bcdust
 bcfaa =  30.8739 * Intercept - 0.2298 * sgth - 0.07778 * sg200 + 0.14437
         * dd + 0.75634 * omc - 0.21327 * pi - 0.68116 * bcdust
  bcse =  280.273 * Intercept - 0.64929 * sgth - 1.39952 * sg200 - 0.35452
         * dd + 0.52107 * omc - 0.39356 * pi - 7.14141 * bcdust
scdust =  0.46144 * Intercept - 0.07024 * sgth - 0.02302 * sg200 + 0.05779
         * dd - 0.12452 * omc + 0.02507 * pi + 0.59746 * bcdust
```

```
  scac =  -3.09081 * Intercept + 0.05834 * sgth + 0.0959 * sg200 - 0.01318
        * dd + 0.27263 * omc - 0.09162 * pi - 0.70738 * bcdust
  scav =  -7.02349 * Intercept + 0.09982 * sgth + 0.13538 * sg200 + 0.00338
        * dd - 0.00227 * omc - 0.02187 * pi - 0.44246 * bcdust
 scvma =  8.33599 * Intercept + 0.04742 * sgth + 0.08107 * sg200 + 0.0218
        * dd + 0.10404 * omc - 0.0319 * pi - 1.13242 * bcdust
                  short term Reg with maintenance                   42
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                      The REG Procedure
                        Model: MODEL1
                    Dependent Variable: iri

 scvfa =  124.94 * Intercept - 0.5387 * sgth + 2E-11 * bcth - 0.73418 * sg200
        + 0.06115 * dd + 0.30614 * omc + 0.0894 * pi + 1.15168 * bcdust
 scfaa =  13.2068 * Intercept + 0.04903 * sgth + 0.08133 * sg200 + 0.1203
        * dd + 0.66165 * omc - 0.14325 * pi + 0.14349 * bcdust
  scse =  273.987 * Intercept + 0.18628 * sgth - 0.96974 * sg200 - 0.92804
        * dd + 1.03699 * omc - 0.38265 * pi - 5.40686 * bcdust
   ppt =  107.506 * Intercept - 0.91361 * sgth - 0.55414 * sg200 - 0.61669
        * dd + 1.87961 * omc - 0.22502 * pi + 3.40866 * bcdust
    tb =  86.2081 * Intercept + 4.31372 * sgth - 0.15952 * sg200 - 0.15226
        * dd - 0.83888 * omc + 0.89762 * pi + 2.66138 * bcdust
    ta =  -55.0158 * Intercept + 1.14909 * sgth + 0.11111 * bth
        + 0.66667 * bcth + 1.88211 * sg200 + 0.6656 * dd
        - 4.88891 * omc + 0.30771 * pi - 11.9796 * bcdust
   wdy =  99.4274 * Intercept - 1.5429 * sgth - 0.60009 * sg200 - 0.3562
        * dd + 1.41515 * omc - 0.01538 * pi + 3.79482 * bcdust
   ftc =  2.73367 * Intercept + 4.44312 * sgth + 0.28298 * sg200 - 0.38898
        * dd + 1.59085 * omc + 0.32465 * pi + 4.93441 * bcdust
   asc =  222.848 * Intercept + 0.6572 * sgth - 2.18765 * sg200 - 0.6993
        * dd + 0.67413 * omc - 0.10126 * pi + 17.7038 * bcdust
                  short term Reg with maintenance                   43
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                      The REG Procedure
                        Model: MODEL1
                    Dependent Variable: iri

                     Parameter Estimates

               Parameter     Standard                    Variance
Variable   DF    Estimate        Error   t Value  Pr > |t|    Inflation

Intercept   B    132.99184    177.98100     0.75    0.4595            0
sgth        B      1.32970      2.18439     0.61    0.5463     24.36063
bth         B   1.7448E-12      2.14923     0.00    1.0000     13.70790
bcth        B  6.76244E-12      8.15576     0.00    1.0000     33.41497
scth        0            0            .        .         .            .
sg200       B     -0.26265      2.88451    -0.09    0.9279     35.72890
dd          B     -1.22208      0.94551    -1.29    0.2040     11.44247
omc         B      1.53165      2.95053     0.52    0.6067      6.13659
pi          B     -1.27515      1.01956    -1.25    0.2187     11.23721
bcdust      B     10.58122      9.38205     1.13    0.2665      7.67997
bcac        0            0            .        .         .            .
bcav        0            0            .        .         .            .
```

```
bcvma       0           0           .      .      .              .
bcvfa      0           0           .      .      .              .
bcfaa      0           0           .      .      .              .
bcse       0           0           .      .      .              .
scdust     0           0           .      .      .              .
                 short term Reg with maintenance                   44
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                      The REG Procedure
                        Model: MODEL1
                    Dependent Variable: iri

                     Parameter Estimates

              Parameter     Standard                    Variance
Variable    DF      Estimate        Error   t Value   Pr > |t|     Inflation

scac       0           0           .      .      .              .
scav       0           0           .      .      .              .
scvma       0           0           .      .      .              .
scvfa      0           0           .      .      .              .
scfaa      0           0           .      .      .              .
scse       0           0           .      .      .              .
ppt        0           0           .      .      .              .
tb         0           0           .      .      .              .
ta         0           0           .      .      .              .
wdy        0           0           .      .      .              .
ftc        0           0           .      .      .              .
esals      1    -0.00113      0.00114    -0.99    0.3285       7.50305
asc        0           0           .      .      .              .
age        1     6.08452      3.26863     1.86   0.0704       5.85666
                 short term Reg with maintenance                   45
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                      The REG Procedure
                        Model: MODEL1
                    Dependent Variable: iri

                      Output Statistics

     Dep Var  Predicted   Std Error           Std Error   Student
 Obs       iri      Value  Mean Predict  Residual   Residual  Residual

   1   65.2000    57.3057       7.5150     7.8943     12.962     0.609
   2   90.4000    76.7589       7.6488    13.6411     12.884     1.059
   3   49.0000    58.2326       8.5769    -9.2326     12.285    -0.752
   4   56.5000    49.9228       7.6876     6.5772     12.861     0.511
   5   47.5000    48.0698       8.4403    -0.5698     12.380   -0.0460
   6   43.0000    55.3397       7.0262   -12.3397     13.233    -0.932
   7   43.0000    55.3397       7.0262   -12.3397     13.233    -0.932
   8   36.0000    48.2064       7.0262   -12.2064     13.233    -0.922
   9   36.0000    48.2064       7.0262   -12.2064     13.233    -0.922
  10   39.6000    52.6283       6.6977   -13.0283     13.403    -0.972
  11   39.6000    52.6283       6.6977   -13.0283     13.403    -0.972
  12   71.9000    62.2278       6.8426     9.6722     13.329     0.726
  13   92.0000    81.8150       6.8605    10.1850     13.320     0.765
```

```
 14   56.3000   63.9206      7.1349   -7.6206    13.175   -0.578
 15   93.4000   55.0138      6.8675   38.3862    13.317    2.883
 16   50.2000   53.6806      7.0852   -3.4806    13.202   -0.264
 17   45.6000   59.7617      6.6977  -14.1617    13.403   -1.057
          short term Reg with maintenance                   46
                                 18:15 Monday, May 8, 2006

                    The REG Procedure
                      Model: MODEL1
                 Dependent Variable: iri

                    Output Statistics

                                    Cook's
                Obs    -2-1 0 1 2           D

                  1  |      |*     |      0.011
                  2  |      |**    |      0.036
                  3  |     *|      |      0.025
                  4  |      |*     |      0.008
                  5  |      |      |      0.000
                  6  |     *|      |      0.022
                  7  |     *|      |      0.022
                  8  |     *|      |      0.022
                  9  |     *|      |      0.022
                 10  |     *|      |      0.021
                 11  |     *|      |      0.021
                 12  |      |*     |      0.013
                 13  |      |*     |      0.014
                 14  |     *|      |      0.009
                 15  |      |***** |      0.201
                 16  |      |      |      0.002
                 17  |    **|      |      0.025
          short term Reg with maintenance                   47
                                 18:15 Monday, May 8, 2006

                    The REG Procedure
                      Model: MODEL1
                 Dependent Variable: iri

                    Output Statistics

     Dep Var  Predicted    Std Error            Std Error   Student
Obs      iri     Value  Mean Predict  Residual   Residual  Residual

 18   45.6000   59.7617      6.6977  -14.1617    13.403   -1.057
 19   83.7000   55.9419      6.4619   27.7581    13.518    2.053
 20   83.7000   55.9419      6.4619   27.7581    13.518    2.053
 21   64.8000   66.3749      6.7462   -1.5749    13.378   -0.118
 22   81.2000   86.1856      6.7363   -4.9856    13.383   -0.373
 23   73.4000   69.3443      6.7060    4.0557    13.399    0.303
 24   45.8000   59.4424      6.7340  -13.6424    13.385   -1.019
 25   55.9000   58.9758      6.7082   -3.0758    13.397   -0.230
 26   93.5000   63.0752      6.4619   30.4248    13.518    2.251
 27   93.5000   63.0752      6.4619   30.4248    13.518    2.251
 28   49.2000   58.1471      6.2385   -8.9471    13.623   -0.657
```

```
 29   49.2000   58.1471       6.2385    -8.9471     13.623   -0.657
 30   63.0000   69.7472       6.9132    -6.7472     13.293   -0.508
 31   79.2000   89.8706       6.9498   -10.6706     13.274   -0.804
 32   86.7000   74.5037       7.2156    12.1963     13.131    0.929
 33   47.8000   63.2086       6.9605   -15.4086     13.268   -1.161
 34   64.8000   63.9551       7.1752     0.8449     13.153   0.0642
              short term Reg with maintenance                  48
                                   18:15 Monday, May 8, 2006

                    The REG Procedure
                      Model: MODEL1
                  Dependent Variable: iri

                    Output Statistics

                                    Cook's
                 Obs    -2-1 0 1 2            D

                  18  |    **|      |       0.025
                  19  |      |****  |        0.088
                  20  |      |****  |        0.088
                  21  |      |      |      0.000
                  22  |      |      |      0.003
                  23  |      |      |      0.002
                  24  |    **|      |       0.024
                  25  |      |      |      0.001
                  26  |      |****  |        0.105
                  27  |      |****  |        0.105
                  28  |     *|      |      0.008
                  29  |     *|      |      0.008
                  30  |     *|      |      0.006
                  31  |     *|      |      0.016
                  32  |      |*     |      0.024
                  33  |    **|      |       0.034
                  34  |      |      |      0.000
              short term Reg with maintenance                  49
                                   18:15 Monday, May 8, 2006

                    The REG Procedure
                      Model: MODEL1
                  Dependent Variable: iri

                     Output Statistics

      Dep Var  Predicted    Std Error           Std Error   Student
Obs       iri      Value  Mean Predict  Residual  Residual  Residual

 35   57.4000   65.2804       6.2385    -7.8804     13.623   -0.578
 36   57.4000   65.2804       6.2385    -7.8804     13.623   -0.578
 37   65.6000   59.2439       6.5370     6.3561     13.482    0.471
 38   65.6000   59.2439       6.5370     6.3561     13.482    0.471
 39   63.1000   72.3445       7.2520    -9.2445     13.111   -0.705
 40   84.7000   92.8700       7.3190    -8.1700     13.074   -0.625
 41   80.0000   79.3988       8.3025     0.6012     12.472   0.0482
 42   50.4000   66.3125       7.3453   -15.9125     13.059   -1.218
 43   74.9000   68.6187       8.1305     6.2813     12.585    0.499
```

```
44   72.4000   66.3772      6.5369    6.0228    13.482    0.447
45   72.4000   66.3772      6.5369    6.0228    13.482    0.447
46   59.3000   59.2323      8.1915    0.0677    12.546  0.00539
47   59.3000   59.2323      8.1915    0.0677    12.546  0.00539
48   64.3000   66.3657      8.1915   -2.0657    12.546   -0.165
49   64.3000   66.3657      8.1915   -2.0657    12.546   -0.165

          short term Reg with maintenance                   50
                              18:15 Monday, May 8, 2006

               The REG Procedure
                 Model: MODEL1
             Dependent Variable: iri

               Output Statistics

                              Cook's
           Obs    -2-1 0 1 2            D

            35  |     *|      |      0.006
            36  |     *|      |      0.006
            37  |      |      |      0.005
            38  |      |      |      0.005
            39  |     *|      |      0.014
            40  |     *|      |      0.011
            41  |      |      |      0.000
            42  |    **|      |      0.043
            43  |      |      |      0.009
            44  |      |      |      0.004
            45  |      |      |      0.004
            46  |      |      |      0.000
            47  |      |      |      0.000
            48  |      |      |      0.001
            49  |      |      |      0.001
          short term Reg with maintenance                   51
                              18:15 Monday, May 8, 2006

               The REG Procedure
                 Model: MODEL1
             Dependent Variable: iri

      Sum of Residuals                      0
      Sum of Squared Residuals     8530.72571
      Predicted Residual SS (PRESS)     13502
```

2.0 Roughness Model

```
                    The CORR Procedure

            3  Variables:    iri      asc      scdust


                    Simple Statistics

Variable        N       Mean     Std Dev        Sum     Minimum     Maximum

iri           48    63.39583    16.96447       3043    36.00000    93.50000
asc           48    44.00000    10.93351       2112    32.60000    64.00000
scdust        48     4.07917     0.56755  195.80000     3.40000     4.80000


            Pearson Correlation Coefficients, N = 48
                    Prob > |r| under H0: Rho=0

                        iri          asc       scdust

          iri         1.00000       0.43447       0.41215
                                     0.0020        0.0036

          asc          0.43447       1.00000       0.74967
                        0.0020                     <.0001
               short term Reg with maintenance                         16
                                    08:21 Tuesday, May 9, 2006

                    The CORR Procedure

            Pearson Correlation Coefficients, N = 48
                    Prob > |r| under H0: Rho=0

                        iri          asc       scdust

          scdust       0.41215       0.74967       1.00000
                        0.0036       <.0001
               short term Reg with maintenance                         17
                                    08:21 Tuesday, May 9, 2006

                    The REG Procedure
                      Model: MODEL1
                  Dependent Variable: iri

                   Analysis of Variance

                          Sum of          Mean
Source                 DF       Squares        Square    F Value    Pr > F
```

```
Model                  2     2784.02101     1392.01050       5.83    0.0056
Error                 45          10742      238.71685
Corrected Total       47          13526


             Root MSE             15.45046    R-Square     0.2058
             Dependent Mean       63.39583    Adj R-Sq     0.1705
             Coeff Var            24.37142


                     short term Reg with maintenance                        18
                                            08:21 Tuesday, May 9, 2006

                           The REG Procedure
                             Model: MODEL1
                         Dependent Variable: iri

                           Parameter Estimates

                   Parameter      Standard                      Variance
Variable    DF      Estimate         Error    t Value   Pr > |t|     Inflation

Intercept    1      19.77203      16.99760       1.16     0.2509             0
asc          1       0.44457       0.31146       1.43     0.1604       2.28313
scdust       1       5.89890       6.00006       0.98     0.3308       2.28313
                     short term Reg with maintenance                        19
                                            08:21 Tuesday, May 9, 2006

                           The REG Procedure
                             Model: MODEL1
                         Dependent Variable: iri

                            Output Statistics

             Dep Var  Predicted     Std Error            Std Error   Student
      Obs        iri      Value  Mean Predict   Residual  Residual  Residual

        1    65.2000    74.3935        4.0690    -9.1935    14.905    -0.617
        2    90.4000    76.5394        4.6997    13.8606    14.718     0.942
        3    49.0000    70.5821        3.8177   -21.5821    14.971    -1.442
        4    56.5000    58.5687        3.0268    -2.0687    15.151    -0.137
        5    47.5000    60.0564        4.9651   -12.5564    14.631    -0.858
        6    43.0000    62.1644        3.6616   -19.1644    15.010    -1.277
        7    43.0000    62.1644        3.6616   -19.1644    15.010    -1.277
        8    36.0000    54.9113        3.3401   -18.9113    15.085    -1.254
        9    36.0000    54.9113        3.3401   -18.9113    15.085    -1.254
       10    39.6000    54.9113        3.3401   -15.3113    15.085    -1.015
       11    39.6000    54.9113        3.3401   -15.3113    15.085    -1.015
       12    71.9000    74.3935        4.0690    -2.4935    14.905    -0.167
       13    92.0000    76.5394        4.6997    15.4606    14.718     1.050
       14    56.3000    70.5821        3.8177   -14.2821    14.971    -0.954
       15    93.4000    58.5687        3.0268    34.8313    15.151     2.299
       16    50.2000    60.0564        4.9651    -9.8564    14.631    -0.674
       17    45.6000    62.1644        3.6616   -16.5644    15.010    -1.104
                     short term Reg with maintenance                        20
                                            08:21 Tuesday, May 9, 2006
```

```
                 The REG Procedure
                   Model: MODEL1
              Dependent Variable: iri

                 Output Statistics

                             Cook's
         Obs    -2-1 0 1 2            D

           1  |     *|      |      0.009
           2  |      |*     |      0.030
           3  |    **|      |      0.045
           4  |      |      |      0.000
           5  |     *|      |      0.028
           6  |    **|      |      0.032
           7  |    **|      |      0.032
           8  |    **|      |      0.026
           9  |    **|      |      0.026
          10  |    **|      |      0.017
          11  |    **|      |      0.017
          12  |      |      |      0.001
          13  |      |**    |      0.038
          14  |     *|      |      0.020
          15  |      |****  |      0.070
          16  |     *|      |      0.017
          17  |    **|      |      0.024
       short term Reg with maintenance                      21
                               08:21 Tuesday, May 9, 2006

                 The REG Procedure
                   Model: MODEL1
              Dependent Variable: iri

                  Output Statistics

      Dep Var  Predicted    Std Error            Std Error   Student
Obs       iri      Value  Mean Predict  Residual  Residual  Residual

 18   45.6000    62.1644      3.6616  -16.5644     15.010    -1.104
 19   83.7000    54.9113      3.3401   28.7887     15.085     1.908
 20   83.7000    54.9113      3.3401   28.7887     15.085     1.908
 21   64.8000    74.3935      4.0690   -9.5935     14.905    -0.644
 22   81.2000    76.5394      4.6997    4.6606     14.718     0.317
 23   73.4000    70.5821      3.8177    2.8179     14.971     0.188
 24   45.8000    58.5687      3.0268  -12.7687     15.151    -0.843
 25   55.9000    60.0564      4.9651   -4.1564     14.631    -0.284
 26   93.5000    62.1644      3.6616   31.3356     15.010     2.088
 27   93.5000    62.1644      3.6616   31.3356     15.010     2.088
 28   49.2000    54.9113      3.3401   -5.7113     15.085    -0.379
 29   49.2000    54.9113      3.3401   -5.7113     15.085    -0.379
 30   63.0000    74.3935      4.0690  -11.3935     14.905    -0.764
 31   79.2000    76.5394      4.6997    2.6606     14.718     0.181
 32   86.7000    70.5821      3.8177   16.1179     14.971     1.077
 33   47.8000    58.1241      2.9647  -10.3241     15.163    -0.681
 34   64.8000    60.0564      4.9651    4.7436     14.631     0.324
```

```
             short term Reg with maintenance                    22
                                   08:21 Tuesday, May 9, 2006

                    The REG Procedure
                      Model: MODEL1
                 Dependent Variable: iri

                    Output Statistics

                                   Cook's
          Obs    -2-1 0 1 2             D

           18  |    **|     |      0.024
           19  |      |***   |      0.060
           20  |      |***   |      0.060
           21  |     *|     |      0.010
           22  |      |     |      0.003
           23  |      |     |      0.001
           24  |     *|     |      0.009
           25  |      |     |      0.003
           26  |      |****  |      0.086
           27  |      |****  |      0.086
           28  |      |     |      0.002
           29  |      |     |      0.002
           30  |     *|     |      0.015
           31  |      |     |      0.001
           32  |      |**    |      0.025
           33  |     *|     |      0.006
           34  |      |     |      0.004
             short term Reg with maintenance                    23
                                   08:21 Tuesday, May 9, 2006

                    The REG Procedure
                      Model: MODEL1
                 Dependent Variable: iri

                     Output Statistics

        Dep Var  Predicted    Std Error            Std Error   Student
 Obs        iri      Value  Mean Predict  Residual  Residual  Residual

  35    57.4000    62.1644       3.6616   -4.7644    15.010    -0.317
  36    57.4000    62.1644       3.6616   -4.7644    15.010    -0.317
  37    65.6000    54.9113       3.3401   10.6887    15.085     0.709
  38    65.6000    54.9113       3.3401   10.6887    15.085     0.709
  39    63.1000    74.3935       4.0690  -11.2935    14.905    -0.758
  40    84.7000    76.5394       4.6997    8.1606    14.718     0.554
  41    80.0000    70.5821       3.8177    9.4179    14.971     0.629
  42    50.4000    58.5687       3.0268   -8.1687    15.151    -0.539
  43    74.9000    60.0564       4.9651   14.8436    14.631     1.015
  44    72.4000    62.1644       3.6616   10.2356    15.010     0.682
  45    72.4000    62.1644       3.6616   10.2356    15.010     0.682
  46    59.3000    54.9113       3.3401    4.3887    15.085     0.291
  47    59.3000    54.9113       3.3401    4.3887    15.085     0.291
  48    64.3000    62.1644       3.6616    2.1356    15.010     0.142
```

```
  short term Reg with maintenance                    24
                         08:21 Tuesday, May 9, 2006

         The REG Procedure
           Model: MODEL1
      Dependent Variable: iri

         Output Statistics

                            Cook's
   Obs    -2-1 0 1 2            D

    35  |      |      |      0.002
    36  |      |      |      0.002
    37  |      |*     |      0.008
    38  |      |*     |      0.008
    39  |     *|      |      0.014
    40  |      |*     |      0.010
    41  |      |*     |      0.009
    42  |     *|      |      0.004
    43  |      |**    |      0.040
    44  |      |*     |      0.009
    45  |      |*     |      0.009
    46  |      |      |      0.001
    47  |      |      |      0.001
    48  |      |      |      0.000
  short term Reg with maintenance                    25
                         08:21 Tuesday, May 9, 2006

         The REG Procedure
           Model: MODEL1
      Dependent Variable: iri

Sum of Residuals                        0
Sum of Squared Residuals            10742
Predicted Residual SS (PRESS)       12061
```

K - TRAN

KANSAS TRANSPORTATION RESEARCH
AND
NEW - DEVELOPMENTS PROGRAM

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:

KANSAS DEPARTMENT OF TRANSPORTATION

THE UNIVERSITY OF KANSAS

KANSAS STATE UNIVERSITY