MINNESOTA DEPARTMENT OF TRANSPORTATION

RESEARCH

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Evaluation of Concrete Pavement Texturing Practice in Minnesota Using the Wet Weather Accident Evaluation Criterion

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16. Abstract (Limit: 200 words)

Concrete Pavements built in Minnesota are currently textured by dragging an inverted Turf or broom in the longitudinal direction. This process imparts a macro texture required to be greater than a mean texture depth of 1mm measured by the ASTM Sand Volumetric test (ASTM E 965-95). At present, this texture guideline is communicated through a special provision in pavement construction. Newly textured pavements are usually evaluated for adequacy in providing a safe riding surface through texture measurements for acceptance and friction measurements as required. The current FHWA Technical Advisory on Texture requires that performance of non-conventional textures be monitored and reported.

This report identifies pavement sites in the network where the original texture, mainly the transverse tining plus Burlap, was either overlaid or rebuilt and the new surface finished with longitudinal inverted turf drag, or broom drag. It extracts wet weather accident data from the Mn/DOT Office of Traffic, Safety and Operations (OTSO) database and analyzes the annual wet weather accident and crash rates, pre-construction, during construction and after construction. It performs a descriptive statistics of the period before and the period of the new texturing to determine if, wet weather accident counts, percentage of wet weather accidents in total count and crash rates and /or ratio of annual wet to dry accident counts, and crashes clearly increased with current texturing practices. Data was analyzed with statistical tools for data comparison including the descriptive statistics, U-test & and "before and after" comparison (Z-test).

The analyses of the data for the sections show that current texturing practices did not cause an increase in the annual wet weather accidents, crash rates, or ratio of wet to dry weather accidents.

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Evaluation of Concrete Pavement Texturing Practices in Minnesota Using the Wet Weather Accident Evaluation Criterion

Final Report

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Executive Summary

This project studied the effect of texturing practices on wet weather accident data in some concrete paving projects in the network of Minnesota Roads. The study responded to the requirement of Federal Highway Administration's (FHWA) Texture advisory TP 1060 of June 2005. It catalogued the various accident counts, percentage of wet weather accident and crash rates and percentage of crashes occurring in wet weather.

Currently, Minnesota textures concrete pavements by dragging an Astro-turf or a stiff -bristled broom longitudinally on the surface of freshly placed concrete pavements, right behind the paver. Prior to 1998 texturing in Minnesota was accomplished by the application of tining on a surface that had already been textured by burlap-dragging when the pavement concrete was still in a plastic state. Complaints from communities proximate to freeways in which the concrete was transversely tined resulted on a moratorium on transverse textures in 1998. In consequence, the Minnesota Department of Transportation (Mn/DOT) Office of Materials developed effective ways of texturing concrete pavements quietly to facilitate low tire-pavement noise. The methods derived included the Astro-turf drag and the longitudinal-broom-drag techniques.

The previous Mn/DOT special provision required a texture of 0.8mm behind the paver. In 2001 this requirement was increased to 1mm measured by the sand volumetric technique ASTM E-965. Although the current special provision requires 1mm behind the paver, when texture measurements in isolated locations fall below 1mm, the contractor is required to guarantee that subsequent paving will be void of such failing textures. There is no penalty for poor texture except that a large frequency of low texture measurements may require correction by texture planning at the expense of the contractor. Izevbekhai (2004) developed an algorithm and a visual basic program of suggested penalization and reward for bad and good texture respectively as well as ride quality.

Subsequently, due to texture decay observed after construction, the standard was revised to 1mm behind the paver and specified as the average measured by the Sand Volumetric Technique (ASTM 865-96). Although this was not adopted as the Standard Specification for construction it has been used in most of the concrete paving in the

State since 1999 as a special provision. As part of the monitoring process, this report catalogues the performance of some concrete surfaces finished with current texturing techniques, which include the Astro-turf drag and longitudinal broom drag. This report addresses the following:

- o Describes current texturing practices and the Minnesota procedure for achieving specified texture standards.
- o Elucidates Minnesota's current texturing practices and the corresponding texture measurements in construction projects
- o Describes the annual wet weather accident trends observed with the textured sections and determines if wet weather accident trends indicate adequate texture.
- o Addresses the requirements stated in the current FHWA technical advisory on texture, which calls for a documentation of performance of some texturing techniques.
- o Determines whether the use of Astro-turf drag or longitudinal broom drag is adequate for safety, if these techniques are not combined with other texturing techniques, to achieve sufficient friction.

To accomplish these objectives, traffic accident count, and crash rate data from selected test sections was obtained from the Mn/DOT Office of Traffic, Safety and Operations (OTSO). Some of the test sections chosen were part of previous surface characteristics studies from which historical data could be utilized. The sections were required to be in areas of the network where a previous surface texture had been replaced with a current surface texture (Astro-turf drag or longitudinal broom drag) any time between 1994 and 2004, thus providing pre texturing and post texturing accident data. Additionally the test section was required to be minimally influenced by other potential accident-causing phenomena such as curves, poor sight distance, largely undulating terrain, and badly distressed surfaces. Thus the test sections were deliberately matched with some of the sections from the Marquette University study of (1999) and the NCAT Mn/DOT texture and Noise Study of 2003, Hanson et al 2004, as well as Mn/DOT's friction Study test sections maintained since 1998.

Traffic accident data from OTSO is a voluminous data base comprising multiple combinations of accident events, surface conditions, climatic conditions, collision type and other variables resulting in many possible descriptors of one accident event. From this data, total annual counts, wet weather accident events and percentage of accidents occurring in wet weather conditions were extracted. Total crash rates for wet weather accidents, and percentage of wet weather crashes to the total number of crashes where also extracted and analyzed for each year from 1994 to 2004.

Chapter one catalogues previous cognate research work and discusses the history of texturing practices. Chapter two discusses the data sourcing and extraction. Chapter three discusses the Federal Highway advisory on texture (2005) and Minnesota's resource. Chapter four describes the statistical methods used in evaluating the wet weather accident data.

To interpret the data, 3 statistical tests were used, the X^2 (Chi squared) test, the Z (Mann Whitney) test and the descriptive statistics test. The descriptive statistics compared the mean and standard deviation before texturing to the same statistics after texturing; this data showed that there was no significant, or determinable, shift in the statistics after the new texturing was applied. The means before and after were similar though there was a disparity in standard deviation. The Mann Whitney test is a definite test for data similarity between 2 sets of samples.

This test was applied to the accident count, wet weather accident and the percentage of accidents in wet weather. The comparative statistic based on a 95 percent confidence limit showed that 15 out of 16 sites had similar before-and-after accident counts, wet weather accident counts, and wet weather accident percentages. The same tests were also applied to crash rates.

Deviations between accident counts and other data before versus after were computed and the statistics showed that there was a change in accident data on account of the current texturing practices. In the hypothesis testing, a 95% confidence limit has a statistic of 3.84 for 2 degrees of freedom. The null hypothesis holds when equation E.1 is true. The accident counts and crash rates were statistically lower with the current texturing. However, the scope of this study is insufficient to attribute accident reduction to current texturing practices.

$$\frac{(X - X_0)^2}{X_0} < 3.84 \qquad \text{E.1}$$

This study, through analysis of existing annual accident data, concludes that the current texturing practices do not increase the accident counts, crash rates a percentage of wet weather crashes in the test sections analyzed.

Chapter 1. Introduction

1.1 Background Information

Prior to 1976, Minnesota concrete pavements were finished with the wet burlap drag technique. Pavements that were constructed to this finish type predominantly had tining mainly because the burlap drag was not considered sufficient in itself to provide sufficient friction. In 1976 the finishing standard was revised to a combination of Astro-turf texturing plus tining with 1 inch effective spacing. In 1983 the tining spacing was increased to 1.5”. In 1995 the tining was reduced to 5/8” interval and specified for speeds ≥ 35 miles per hour. In 1995 the tining interval was changed to 1” and specified for the same traffic speeds. In 1998-1999, a moratorium on tining was established in Minnesota in order to reduce noise. This moratorium led to the use of inverted Astro-turf drag as the finishing practice in 1998 with a specification of 0.8mm texture depth specified behind the paver. Subsequently and predominantly based on the texture decay observed after construction, the standard was revised to 1mm behind the paver and specified as the average measured by the Sand Volumetric Technique (ASTM 865-96). Although this was not adopted as the standard specification for construction, it has been used in most of the concrete paving in the state since 1999. As part of the monitoring process, this report catalogues the performance of some concrete surfaces finished with the current texturing techniques of Astro-turf drag and longitudinal broom drag.

1.2 Report Objectives

- To evaluate current texturing practices by using wet weather accident data. Describe current texturing practices and the Minnesota procedure for achieving specified texture standards.
- Elucidate Minnesota’s current texturing practices and the corresponding texture measurements in construction projects
- Analyze the annual wet weather accident trends observed with the textured sections and determine if wet weather accident trends are an indication of adequate texture.

o Address the requirements stated in the Current FHWA Technical advisory on texture, which calls for a documentation of performance of some texturing techniques.

1.3 Previous Studies

In studies conducted by the Marquette University Multi state report [Corvetti et al (1999)] included some Minnesota test Sections that evaluated the inverted astro turf drag (ATD), also known as the "Minnesota Drag" in comparison to other surface finish. The study showed that the inverted Astro drag favorably compared with many other finishing types including the bituminous surface in terms of noise. The Marquette University multi state pooled fund report did not identify the specification to which the turf drag was built and did not clearly distinguish between the new inverted Astro turf drag and the obsolescent Burlap drag as the report was released at the early stages of the use of inverted Astro turf drag. The specification has since improved and contractors are now more familiar with the texturing practice. Minnesota also uses the longitudinal broom drag for surface finishing. When corrective action is taken on a bump or on a poorly textured surface diamond grinding or grooving is used for corrective action. Another report by Hanson et al (2003) on their noise and friction testing in Minnesota in 2003/2004 showed that Astro-drag surface was quieter than tinned and diamond ground surfaces within the auditory spectrum. The Mn/DOT Office of Environmental Services evaluated the Astro turf drag (ATD) by comparing it to tined surfaces and Nova chip surfaces in Albertville, Mn. The report is available online at <http//:www.mrr.dot.state.mn.us/research/mnroad_project/onlinereports>. In this report the base line for the test was a burlap drag, with a noise reference of 70 dB proved to be quieter than both the tined and nova chip surfaces.

As part of the study on the influence of texturing on Ride Quality in 2002, Minnesota created a test section on US TH 212 in Bird Island Minnesota and measured ride on textured and untextured strips in juxtaposition. This test section was ultimately diamond ground and was recently tested for noise and texture by Transtec, Inc. under the ISU/SHRP ACPA Surface Characteristics Part 2 that preceded Part 3 Transportation Pooled Fund Project TPF 5 (134), Pavement Surface Characteristics Studies. This section forms part of the type 2PSC study report on the optimization of surface characteristics under the ISU SHRP ACPA study.

Izevbekhai (2004) [4] discussed the testing report on TH 212 at Bird Island and concluded that texture had an influence on the measured ride quality. The report proposed an algorithm and a software program for compensating good texture and good ride. The software also provides guidance for penalizing poor texture irrespective of the ride quality. However, the algorithm that was proposed was based on Profile Index (PI) that has been superseded by IRI for Pavement construction in Minnesota. Hanson et al (2003) [3] through National Center for Asphalt Technology performed an evaluation of texture and noise on some Minnesota test Sections. Their analysis proposed a correlation between noise and texture for all surface finish and texture types. The problem with such a correlation is that by proposing a global correlation for all textures to sound intensity, it agglomerates a group of differing frequencies and corresponding noise characteristics. That algorithm underrates the effect of tine spacing and how uniform texture patterns result in a spike in the noise spectrum. A change in the distribution of finishing types will change that correlation.

According to Wu and Nagi [5] Surface irregularities may be characterized accordingly

Micro-texture : Amplitude of deviation from a plane with wavelength .02-inch (0.5-mm)

Macro-texture: Amplitude of deviation from a plane with wavelength 0.02-inch (0.5-mm) < T < 2-inch (50-mm).

Mega-texture: Amplitude of deviation from a plane with wavelength 2-inch (50-mm) < T <20-inch (500-mm). This is a transition region between Macro-texture and surface irregularity.

Surface irregularity or Roughness: Amplitude of deviation from a plane with wavelength 20-inch (500-mm) < T <166.7-ft (50-m). This is the range we are concerned with. Sandberg and Ejsmont (6) identified the surface characteristics influenced primarily by distinct texture ranges. In the reference manual (6) Sandberg et al attributed wet weather skid resistance to surface textures ranging from .07mm to 10mm.

Previous reports and studies did not evaluate wet weather accidents and associated parameters in assuring smooth, safe, and durable pavements. There have been no previous attempts in Minnesota to evaluate the effectiveness of current texturing practices. This study bridges that gap. It also fulfills the requirements that the Federal Highway Administration (FHWA) stated for the texture Advisory T1PT 5040 of

June 2005; that among other things, unconventional texturing practice should be monitored for performance and reported periodically.

Chapter 2. Governing Statutes Underlying Principles

2.1 Federal Highway Administration (FHWA) Texture Advisory

According to the FHWA Technical advisory on texture released in June 2005 [7], the following evaluation factors should be considered when evaluating new or innovative texturing methods for concrete pavement.

1) The primary purpose of adequate surface texture is to reduce wet-weather and total vehicle crashes. Where a State Highway Agency (SHA) has time-history data to show a specific surface treatment or texturing method results in similar or improved safety performance compared to transverse tining texture, the proposed method should be allowed.

2) Performance. Safety performance shall be based upon long-term performance monitoring of either wet-weather crash performance or friction test results. In the absence of long-term safety performance data for alternate texturing methods or treatments, alternative methods may be used on an experimental basis provided safety performance is monitored and reported.

The advisory also recommends the following:

This approach may also be utilized to evaluate the impact of changes to asphalt pavement surfaces on pavement safety performance.

1) Wet weather crash performance. Reduced wet-weather and/or total vehicle crash rates at the same or similar locations.

2) Friction test results. Similar or improved friction test results and speed gradient when tested in conformance with American Society for Testing and Materials (ASTM) E-274 (skid trailer) using the smooth tire (ASTM E-524), or International Friction Index (IFI) ASTM E-1960.

2.2 Justification For Wet Weather Analysis

It is not statistically expedient to attribute all accident effects to a change in texture except that the critical texture range in question, affects certain types of surface characteristics. Figure 2.1 shows that a macrotexture frequency range of approximately 0.1mm to 50 mm affects wet weather accidents. Expectedly, a pavement surfacing will exhibit poor wet weather accident trends if such a surface provides inadequate texture and vice versa. Analyzing the wet weather accident data is therefore an acceptable way of determining the sufficiency of the pavement against skid resistance. Moreover the Federal Highway Administration [7] requires that in pavements where unconventional texturing was used, there should be a monitoring of the performance of these pavements. The requirement included wet weather friction and texture among the parameters used for evaluation.

Most measured Astro-turf drag textures based on the 1999 specification of 0.8mm behind the paver ranged from 0.8mm to 1mm that increased from 1mm to 1.3mm based on the 2001 specification of 1mm behind the paver. Consequently, the adequacy of current texturing practices can be judged by the trend of wet weather accident pre and post application. Figure 2.1 shows classification of textures and their influence on surface parameters. According to Sandberg and Ejsmont (1989) the range of macrotexture that affect wet weather friction is 0.1mm to 10 mm. The characteristic dimensions of texturing practices are within this range. Diamond grinding typically comes in dimensions of 1.8 inch by 1/8 inch. Most Astro-turf textures have mean texture depths ranging from 0.5mm to 2mm. Most longitudinal tines are at intervals ranging from 5/8 inch to over1 inch. This range has been largely reduced by the knowledge of the influence of texturing intervals on noise. This has also resulted in the specification of tining intervals at 5/8 inches for optimum noise and safety characteristics.

Since Mn/DOT texturing dimensions are within the range that governs wet weather friction effects, it is adequate to evaluate a texturing practice on the basis of the following parameters:

- Wet weather accident counts
- Friction (ASTM E-274)
- Hydroplaning Potential
- Mean Texture Depth. This study evaluates on the basis of wet weather accidents but mentions the associated texture standards and recorded measurements.
- This report covers wet weather evaluation with the accident criterion.

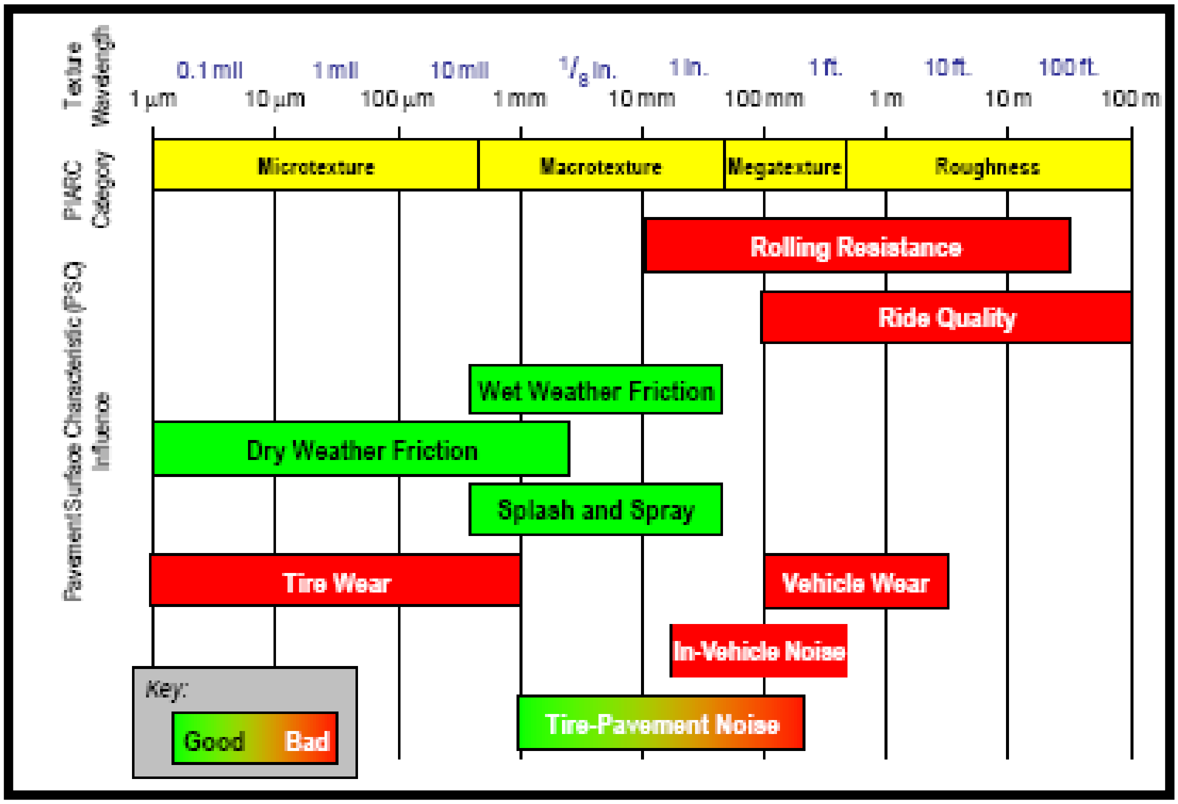

Figure 2.1. Texture Categories and Influence on Surface Characteristics Sandberg et al [8]

2.3 Existing Statistics on Wet Weather Accidents

Proceedings of 8th International Conference on Concrete pavements Larson R. and Scofield L. 2005 stated that Highway crashes in the U.S. currently result in almost 43,000 fatalities and 3 million injuries annually; poor pavement conditions (including poor surface texture and friction characteristics) contribute to about 13,000 deaths annually. According To Snyder (2005), If wet weather crashes account for about 19 percent of all fatal crashes, improved pavement texture/friction could reduce overall highway crash, fatality and injury rates by 13 percent (i.e., 5600 fewer deaths, 390,000 fewer injuries and 3.25 million fewer accidents each year). More then 80% of accidents occur in dry weather and in non-texture related scenarios, but these accidents will not be considered in this study.

2.4 Miscellaneous WWA Evaluations

Percentage of WWA / Total is a conservative measure when reduction is considered, because a reduction in wet weather accidents yields a reduction in total accidents.

A/B versus (A-n)/(B-n)

When there is a reduction n in the total accident count,

2.5 Texture Evaluation

Surface Characteristics (SC) are a function of the mean texture depth (MTD), the characteristic wavelength of the texture (λ), the porosity (AV), a reflectivity function (R) as shown in equation 2.1.

$$SC = f\,(MTD, \lambda, AV, R). \qquad \text{(Equation 2.1)}$$

The chosen method of evaluation is the sand Volumetric Technique ASTM 850 and the Circular Texture Track ASTM. Figure 2.2 shows the Texture techniques that were historically, and are currently performed in Minnesota. The Diamond grinding specified in Minnesota is a 1/8inch by 1/6 inch by 1/8 inch groove kerf width and depth. The Astro-turf and the longitudinal broom drag typically achieve a texture of 1mm. Bituminous pavements do not typically have a texture specification; friction is usually measured if and only if there is an observable and remarkable accident trend related to hydro-planning.

Figure 2.3 shows the schematics of a sand volumetric method of texture evaluation. It is assumed that the glass beads used are small compared to the characteristic dimensions of the textured surface. Consequently when texture is lost on a pavement, the sand volumetric technique may not be a very efficient way to measure texture. Figure 2.4 is an actual petrographic slice on an Astroturf textured pavement showing the glass beads as well as a waveform pattern. This waveform characterizes the performance of that surface when in contact with vehicular tires. The sand volumetric technique may not be performed in windy conditions.

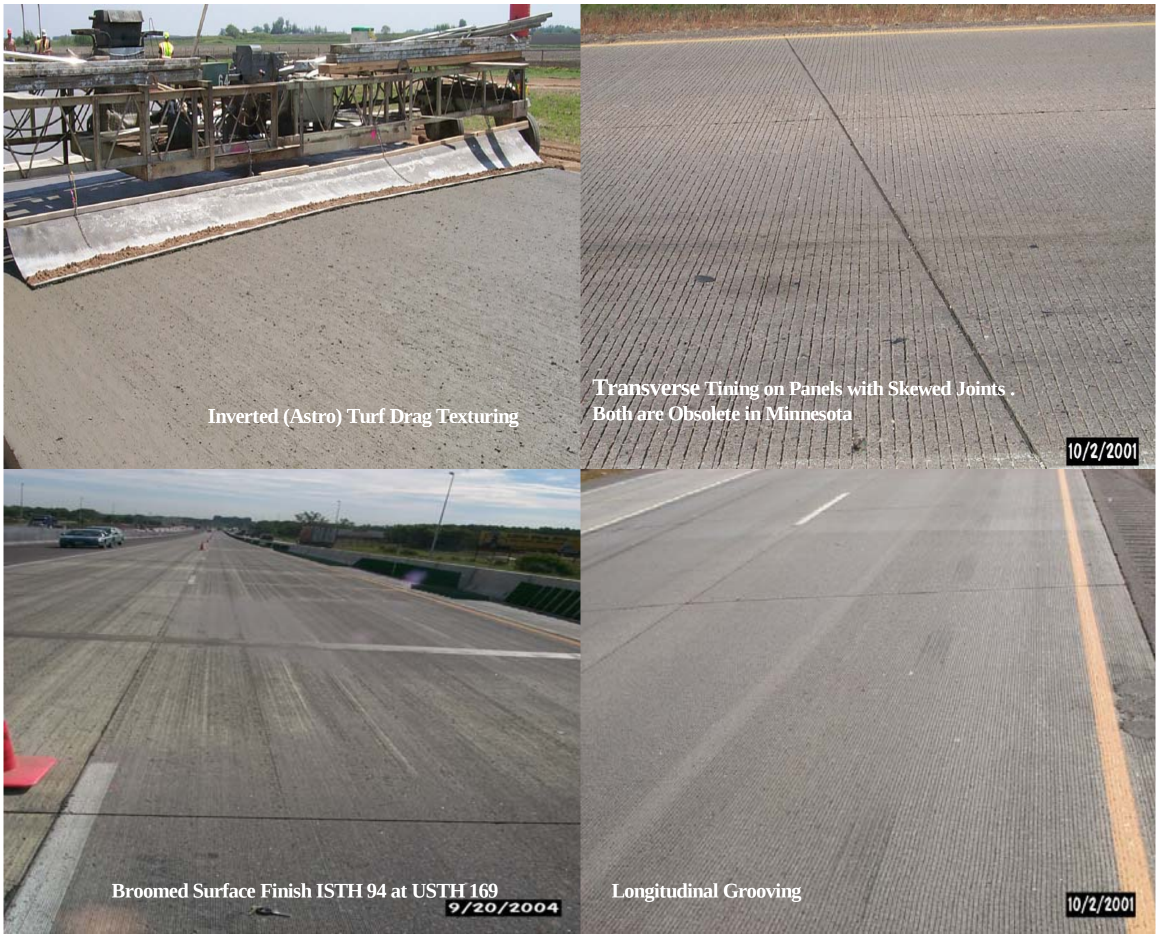

Figure 2.2. A Collage of MN Texturing Practices

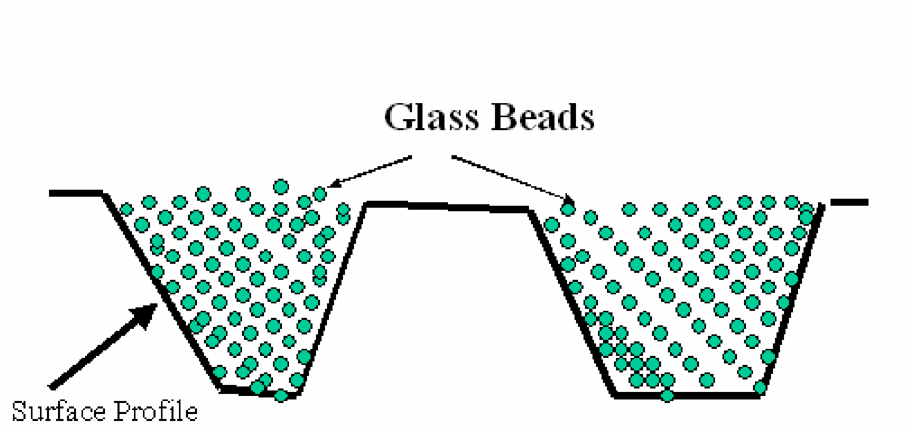

Figure 2.3. ASTM E-965 Sand Volumetric Measurement of a Textured Surface

Figure 2.4. Petrographic slice of Astro-turf textured pavement

Figure 2.4 shows wavelengths in the Astroturf drag surface magnified in a petrographic analysis. From the above waveform the texturing appears to be negative, as most of the longitudinal geometry lies beneath the hypothetical line of average texture. The radiant feature above the concrete is the glass beads for the sand Volumetric test (ASTM E-965-95 (1995) Inconsistencies in the cement paste are visible as dark features in the matrix but these appear to be significant at the surface with respect to the texture dimensions. Change in texture configuration after the first winter season has been associated with scallop removal by snowplow operations and exposure of the upper bound portions of fine aggregate. While texture generally changed within the first year, friction numbers exhibit a non-descript trend within the period.

The hysteresis mechanism is initiated by the instantaneous or transient deformations of the tire around the point of pavement contact. This results in adhesion and hysteresis forces at the tire pavement interface. The adhesion is a function of the surface tires and growetry but hysteresis is a fraction of the tire stiffness, texture configuration and speed. The suction plus hysteresis force gem to give skid resistance.

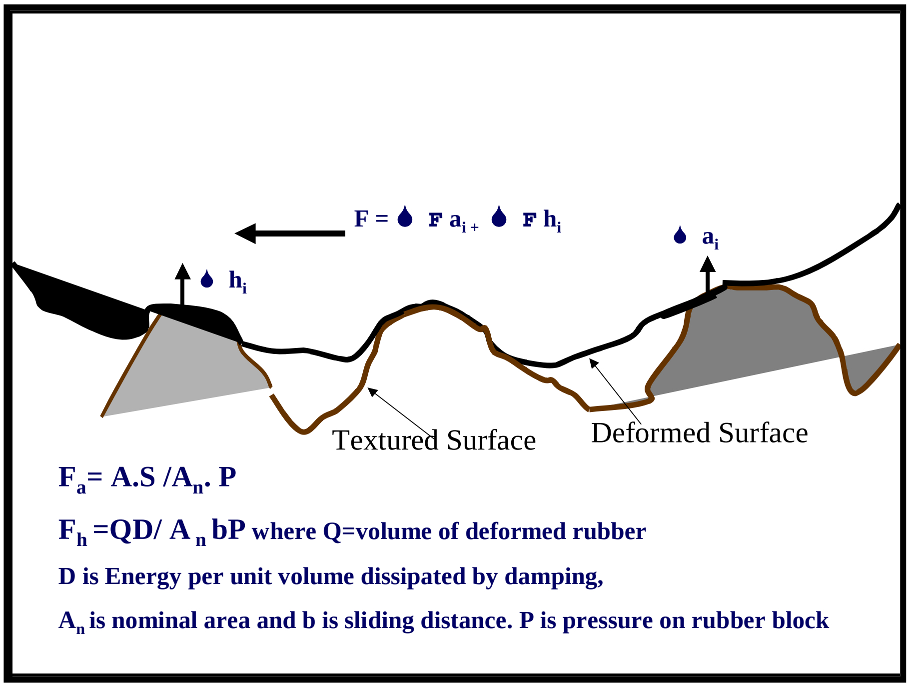

Figure 2.5. Schematic Representation of the Hystersis Theory (Wu Nagi 2000)

Chapter 3. Data Generation Extraction and Reduction

3.1 OTSO & Materials Data

The MnDOT Office of Traffic, Safety and Operations (OTSO)) maintains a large database of traffic accidents. This record categorizes the accident events in terms of: weather, human, and pavement conditions with a large number of possible combinations. It enables the extraction by a simple excel query of required accident type and combinations.

Mn/DOT Office of Materials keeps data of post-construction textures of State projects. Table 3.1 shows the test sections (more complete data can be found in Appendix A), and Figure 3.1 shows the relative locations of the test sections in which current texturing practices were used. This table shows the time of construction as well as the test sections that are not likely to be influenced by such accident features that becloud the effect of texture. Data pruning was performed in an effort to minimize the influence of other variables including geometrical and material factors that could introduce unwanted variables to the evaluation of texture using the wet weather accident criterion. The data from Table 3.1 was reduced to exclude bituminous overlaid sections, sections that contained parts of horizontal curves subject to skidding, as well as those that contained steep vertical slopes. After the pruning, the number of test sections examined in the study was fourteen.

Independently, the MnDOT Research section had maintained a set of test sections for monitoring texture; these sections included many different surface types for annual monitoring, primarily for the purpose of establishing friction time decay curves of the innovative texturing techniques. After deciding on the relevant test sections, these were queried for annual wet weather accident counts pre and post construction. The sections chosen had their construction period within the 1994 to 2005 period. By choosing from this period, most of the construction periods were between 1999 and 2002, which allowed a staggered pre and post application analysis. The wet weather accident counts and total accident counts were analyzed for percentage of annual wet weather accidents in the section.

Table 3.1 Record of Post Construction Textures Measured with ASTM E-965

SP	Highway	Method	Year Paved	Average	Standard
			Overall Average	1.30	
4302-46	TH 7	Astroturf	1999	1.03	0.8
5580-72	I-90	Astroturf	1999	1.30	0.8
0280-49	TH 35W	Astroturf	2000	0.97	0.8
2480-91	I-35	Astroturf	2000	1.68	0.8
5304-30	TH 59	Astroturf	2000	1.26	0.8
62-696-06	TH 96	Astroturf	2000	0.95	0.8
6680-94	TH 35	Astroturf	2000	1.27	0.8
7380-200	TH 94	Astroturf	2000	1.13	0.8
8480-28	TH 94	Astroturf	2000	1.22	0.8
1002-61	TH 5	Broom	2001	1.09	1.0
2001-23	TH 14	Astroturf	2001	1.25	1.0
2106-30	TH 27	Astroturf	2001	1.30	1.0
2481-41	I-90	Astroturf	2001	1.44	1.0
25-601-19	CSAH 1	Astroturf	2001	1.99	1.0
25-601-19	Bench Street	Astroturf	2001	1.99	1.0
2735-134	TH 100	Astroturf	2001	1.29	1.0
2762-13	TH 212	Broom	2001	0.98	1.0
3204-63	TH 60	Astroturf	2001	1.34	1.0
3411-63	TH 71	Astroturf	2001	1.26	1.0
4001-45	TH 60	Astroturf	2001	1.02	1.0
5411-14	TH 200	Astroturf	2001	1.26	1.0
7007-23	TH 169	Astroturf	2001	1.39	1.0
8285-86	TH 494	Astroturf	2001	0.84	1.0
0280-50	95th Ave	Broom	2002	1.02	1.0
0702-107	TH 14	Astroturf	2002	1.65	1.0
1414-02	TH 336	Astroturf	2002	1.06	1.0
2480-81	I-35	Astroturf	2002	2.87	1.0
6680-95	TH 35	Astroturf	2002	1.28	1.0
7408-29	TH 14 DB	Astroturf	2002	1.28	1.0
7408-29	TH 14	Astroturf	2002	1.28	1.0
2610-10	TH 59	Astroturf	2003	1.23	1.0
2786-113	TH 694	Astroturf	2003	1.61	1.0
55-625-19	16th Street	Astroturf	2003	1.21	1.0
1982-129	35E	Broom	2004	0.96	1.0
2510-10	TH 58	Astroturf	2004	1.22	1.0
2725-59	TH 55	Broom	2004	1.12	1.0
2785-301	TH 494	Broom	2004	1.21	1.0
2785-327	TH 494	Broom	2004	1.15	1.0
2786-115	TH 94	Broom	2004	1.10	1.0
26-116	TH 694	Astroturf	2004	1.19	1.0
2786-11787	TH 94	Broom	2004	1.41	1.0
4310-45	TH 212	Broom	2004	1.35	1.0
5401-29	TH 200	Astroturf	2004	1.10	1.0
5509-69	48th St	Astroturf	2004	1.70	1.0
55-601-14	CSAH 1	Astroturf	2004	1.57	1.0

(Source: Mn/DOT Concrete Engineering Unit)

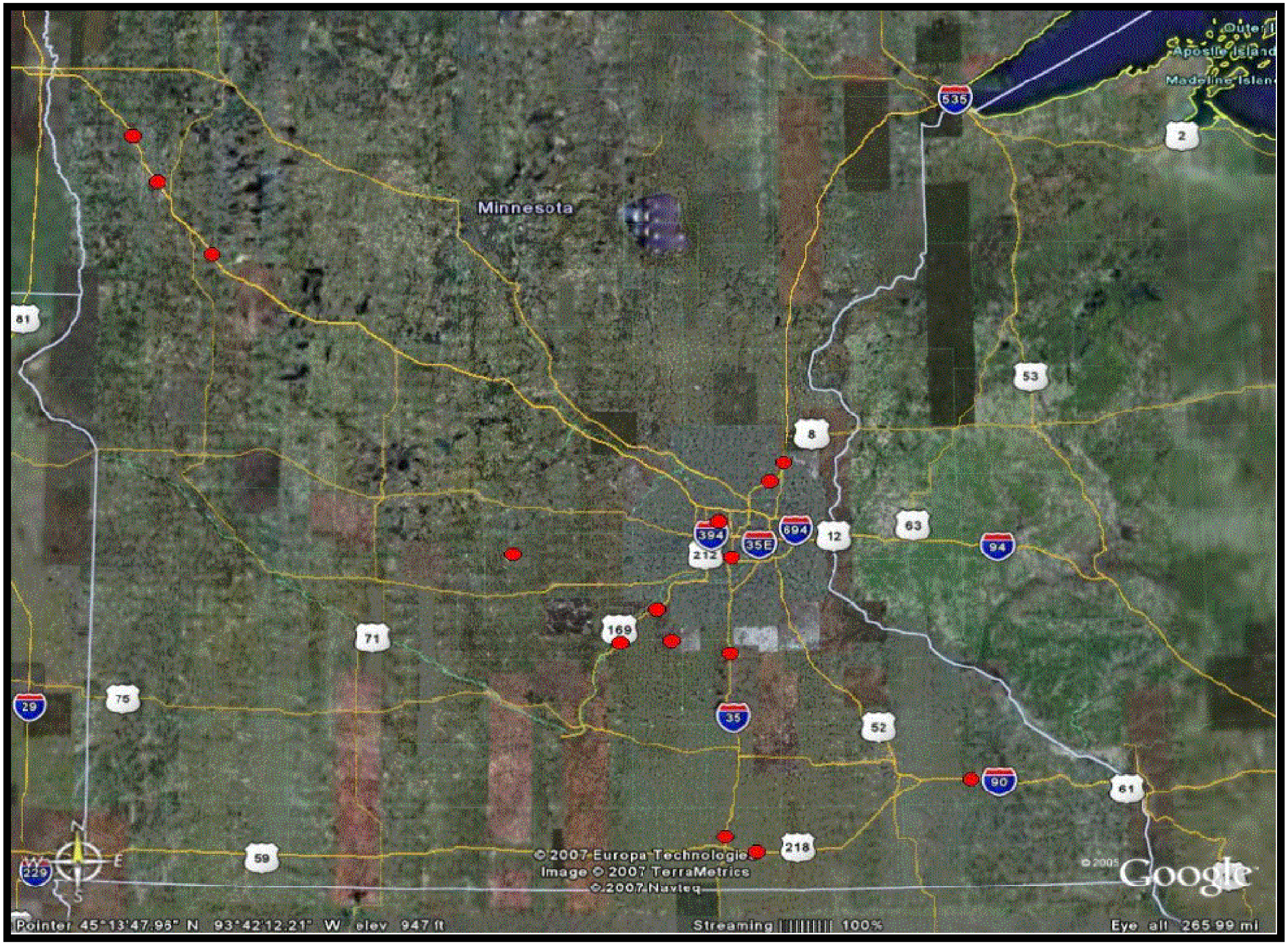

Figure 3.1. Test Section Locations (Map Courtesy of Google Earth)

3.2 Crash Rate Calculation

Using data obtained from OTSO, Equation 3.1 was used to accurately determine the crash rates in these sections from 1994 to 2005 by accounting for the traffic exposure. Note that the critical crash rates were not considered. The data also included crash rates that were in wet weather conditions thus facilitating an analysis of the annual percentage of wet weather accident in each section. The wet weather data analyzed are the following:

- Annual wet weather accident counts from 1994 to 2004 (WWC).
- Annual total accident counts from 1994 to 2004 (TAC).
- Annual Percentage of wet weather accidents in total from 1994 to 2004 (PWW).
- Annual crash rates in wet weather from 1994 to 2005 (WCR)
- Total Annual Crash rates from 1994 to 2005 (TCR)
- Annual Percentage of crashes in wet weather to total crash rates (APC)

$$R = N\,(1\text{million})/Y\,(ADT)\,(S)\,(365) \qquad \text{(Equation 3.1)}$$

Where:

R is the rate per million of entering vehicles, N is number of crashes, Y is the number of Years, and S is segment length (miles)

Each of these datasets were plotted against the year in order to determine the effect of current texturing practices. The table of test sites provided by the Concrete Engineering unit identified the year of construction as a pivot year for comparison of previous to present texturing.

For each of these data sets the following statistical analyses were performed:

- **Descriptive Statistics**: The mean and standard deviation of the annual accidents before and after construction.
- **X^2 (C hi^2) Analysis**: A simplified before and after study, using the construction period as pivot year to evaluate decrease or increase in corresponding year.
- **Mann-Whitney Analysis**: A comparative statistic of data set before and after to determine similarity of the data set to a chosen confidence limit

3.3 Pavement Management Data

Within the Mn/DOT Pavement Management System, there are two types of dynamically segmented records Design (D) Records, and Milepost (M) Records. In a D-record, the section is identified by a design type or a unique construction activity from a chronological perspective. M records show the network in mile posts irrespective of intervening D-records. The test sections of interest are mainly D records.

Due to the programming nature of D-records, the test sections chosen were not of the same length. Sections were of various texturing specification depending on the year of texturing and the applicable specification at that time. The sections were characterized by varying traffic in each direction and differing traffic levels in each section. With these variations, a global comparison of all the previous and current data in all the test sections was not considered adequate. Comparison was done only for annual trends in each test section. However, the cumulative effect of the trend in each test section was considered for hypothesis validation in the statistical tools used. Due to variations, data from each section was treated as independent to data from other sections.

Chapter 4. Data Analysis

4.1 Visual Analysis

The accident and crash rate data from a continuous ten, or eleven year interval was visually inspected to determine if there was a difference between the pre and post texturing data. Table 4.1 and Table 4.2 show the annual wet weather accident counts and the total accident counts respectively, from 1994 to 2004 for all fourteen test sections. Table 4.3 shows the fraction of wet weather accidents of total accidents for all observed test sections. The yellow shading indicates the pre-texturing data, no shading indicates data at the time of construction, and green shading indicates post-texturing data. Note that numbers in parentheses represent the reference posts of the segment under study. All subsequent tables and plots will retain the same ordering of the test sections, but will not include the reference posts in parentheses for convenience.

It can be observed that there are stark differences in the number of accidents between the sections themselves; some high volume sections show wet weather counts in the mid thirties to the low forties for a single year, while other sections show no counts, a similar trend is observed for total accidents and crash rates. It is difficult to make any conclusions by visual inspection alone, as there is significant variation within a single section from year to year, and among different sections.

Table 4.1. Wet Weather Accident Counts

	94	95	96	97	98	99	00	01	02	03	04
TH21	3	3	4	4	2	1	4	4	2	1	3
TH35	5	2	6	3	4	2	3	6	6	5	6
TH35	5	6	7	10	10	7	6	5	14	5	26
TH35W	16	10	10	10	8	5	13	5	4	8	12
TH35W	1	3	7	3	5	5	9	1	1	2	2
TH90	2	2	3	4	5	2	4	0	2	1	2
TH 90)	1	0	2	0	0	0	3	0	0	3	2
TH 94	3	1	0	3	3	4	0	1	1	3	0
TH 94	1	2	1	2	0	1	0	1	5	0	2
TH 94	1	2	1	4	0	0	1	3	0	1	1
TH 169	5	3	2	3	8	7	10	6	8	2	5
TH 7	4	6	2	2	2	1	2	4	0	1	2
TH 100	36	41	28	31	30	34	39	43	32	15	18
TH 169	3	2	1	4	2	2	3	1	1	1	2

Table 4.2. Total Accidents of Test Sections

	94	95	96	97	98	99	00	01	02	03	04
TH 21	20	28	27	28	21	33	32	39	35	30	19
TH 35	48	17	59	75	41	58	57	107	48	50	55
TH 35	33	55	96	82	61	66	71	68	104	93	141
TH 35W	53	52	41	44	42	52	57	36	32	42	64
TH 35W	34	27	40	32	31	47	56	39	50	55	48
TH90	17	11	36	27	27	25	28	41	19	33	37
TH 90	15	8	21	16	11	14	22	14	9	13	19
TH 94	25	34	42	45	37	37	28	48	41	31	33
TH 94	14	9	12	29	10	10	10	18	13	12	15
TH 94	13	29	17	48	10	14	19	21	18	28	27
TH 169	32	31	24	22	36	37	57	35	35	28	35
TH 7	22	31	27	29	26	14	17	28	17	26	14
TH 100	169	187	196	174	161	161	208	205	187	136	110
TH 169	11	6	2	6	10	8	13	7	7	6	18

Table 4.3. Wet Weather Accidents as a Fraction of Total Accidents of Test Sections

	94	95	96	97	98	99	00	01	02	03	04
TH 21	0.15	0.11	0.15	0.14	0.10	0.03	0.13	0.10	0.06	0.03	0.16
TH 35	0.10	0.12	0.10	0.04	0.10	0.03	0.05	0.06	0.13	0.10	0.11
TH 35	0.15	0.11	0.07	0.12	0.16	0.11	0.08	0.07	0.13	0.05	0.18
TH 35W	0.30	0.19	0.24	0.23	0.19	0.10	0.23	0.14	0.13	0.19	0.19
TH 35W	0.03	0.11	0.18	0.09	0.16	0.11	0.16	0.03	0.02	0.04	0.04
TH90	0.12	0.18	0.08	0.15	0.19	0.08	0.14	0.00	0.11	0.03	0.05
TH 90	0.07	0.00	0.10	0.00	0.00	0.00	0.14	0.00	0.00	0.23	0.11
TH 94	0.12	0.03	0.00	0.07	0.08	0.11	0.00	0.02	0.02	0.10	0.00
TH 94	0.07	0.22	0.08	0.07	0.00	0.10	0.00	0.06	0.38	0.00	0.13
TH 94	0.08	0.07	0.06	0.08	0.00	0.00	0.05	0.14	0.00	0.04	0.04
TH 169	0.16	0.10	0.08	0.14	0.22	0.19	0.18	0.17	0.23	0.07	0.14
TH 7	0.18	0.19	0.07	0.07	0.08	0.07	0.12	0.14	0.00	0.04	0.14
TH 100	0.21	0.22	0.14	0.18	0.19	0.21	0.19	0.21	0.17	0.11	0.16
TH 169	0.27	0.33	0.50	0.67	0.20	0.25	0.23	0.14	0.14	0.17	0.11

Crash rates were computed using equation 3.1 and analyzed in order to introduce traffic volume, test section length and study period into the analysis of wet weather accident data. The crash rates allow for an easier comparison among the section and across years.

Table 4.4 and Table 4.5 show crash rates and wet weather crash rates as a percentage of total sections respectively. Figure 4.1 and Figure 4.2 show crash rates and wet weather crash rates as a percentage of total sections respectively. Note that most wet weather crash rates are below 1%, with the exception of three test sections.

Table 4.4. Crash Rates of Test Sections

	94	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**
TH 21	4.9	3.3	1.8	2.3	1.6	1.8	3.1	2.7	2.1	0.8	1.0	1.3
TH 35	0.8	0.3	0.8	1.1	0.6	0.8	0.7	1.2	0.6	0.6	0.6	0.7
TH 35	0.3	0.5	0.9	0.8	0.6	0.6	0.6	0.5	0.7	0.7	0.9	0.5
TH35W	2.0	2.3	1.7	1.6	1.2	1.5	1.4	0.9	1.0	1.2	1.5	1.2
TH35W	0.5	0.4	0.6	0.5	0.4	0.6	0.7	0.5	0.6	0.7	0.5	0.5
TH 90	0.4	0.3	0.6	0.5	0.5	0.4	0.5	0.6	0.3	0.5	0.6	0.5
TH 90	0.6	0.2	0.7	0.7	0.5	0.6	0.8	0.6	0.3	0.5	0.7	0.4
TH 94	0.5	0.6	0.6	0.7	0.6	0.5	0.4	0.7	0.5	0.4	0.4	0.6
TH 94	0.6	0.3	0.5	1.2	0.4	0.3	0.3	0.6	0.5	0.4	0.5	1.2
TH 94	0.3	0.7	0.4	1.2	0.2	0.3	0.4	0.4	0.4	0.6	0.5	0.6
TH 169	0.9	0.9	0.7	0.6	0.9	0.9	1.2	0.7	0.8	0.6	0.6	0.5
TH 169	1.4	0.7	0.2	0.7	1.1	0.8	1.3	0.7	0.8	0.7	1.8	0.7
TH 7	2.0	2.4	1.7	1.5	1.6	0.7	1.3	1.5	1.1	1.3	1.3	1.2
TH 100	1.6	1.6	1.8	1.2	1.3	1.3	1.7	1.6	1.5	1.1	0.7	0.6

Table 4.5. WW Crash Rates as a Percentage of all Total Crashes of Test Sections

	94	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**
TH 21	0.19	0.36	0.00	0.25	0.00	0.13	0.08	0.00	0.20	0.00	0.20	0.29
TH 35	0.09	0.13	0.11	0.06	0.19	0.08	0.06	0.07	0.15	0.10	0.12	0.11
TH 35	0.15	0.11	0.07	0.13	0.16	0.10	0.09	0.07	0.13	0.05	0.18	0.13
TH35W	0.30	0.29	0.25	0.23	0.23	0.13	0.21	0.17	0.17	0.16	0.19	0.17
TH35W	0.03	0.11	0.16	0.07	0.14	0.11	0.13	0.03	0.04	0.04	0.04	0.17
TH 90	0.11	0.15	0.08	0.13	0.19	0.08	0.14	0.00	0.10	0.03	0.05	0.12
TH 90	0.11	0.00	0.10	0.05	0.07	0.00	0.08	0.00	0.00	0.17	0.09	0.00
TH 94	0.11	0.03	0.00	0.07	0.13	0.10	0.00	0.02	0.02	0.10	0.00	0.08
TH 94	0.08	0.25	0.08	0.07	0.00	0.10	0.00	0.06	0.39	0.00	0.13	0.08
TH 94	0.08	0.07	0.05	0.07	0.00	0.00	0.04	0.12	0.00	0.03	0.06	0.08
TH 169	0.15	0.12	0.08	0.14	0.21	0.17	0.17	0.17	0.20	0.13	0.12	0.07
TH 169	0.25	0.33	0.50	0.67	0.18	0.25	0.23	0.14	0.13	0.14	0.16	0.00
TH 7	0.16	0.24	0.16	0.12	0.19	0.12	0.07	0.11	0.04	0.06	0.13	0.17
TH 100	0.20	0.20	0.16	0.19	0.21	0.17	0.18	0.22	0.16	0.10	0.15	0.21

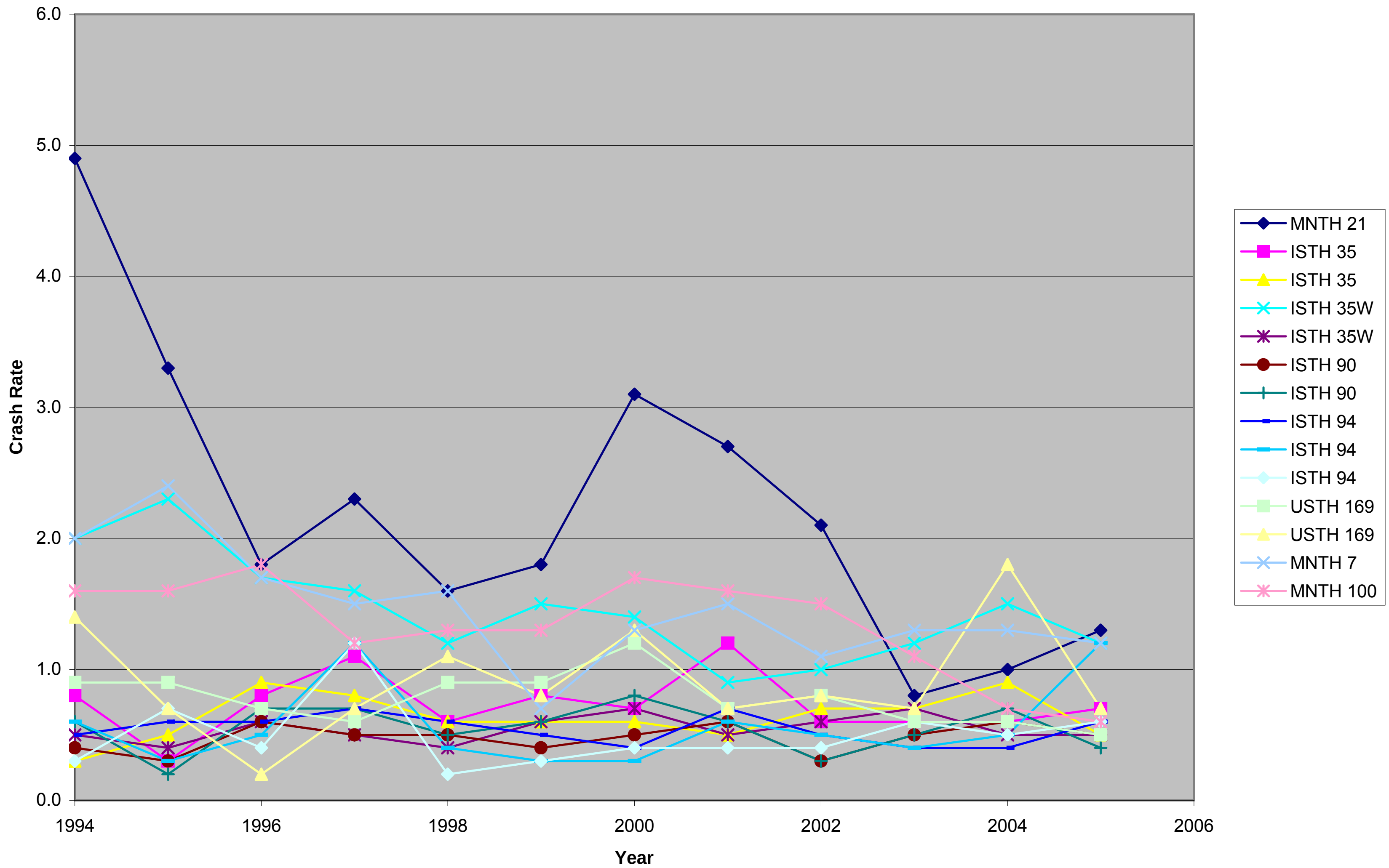

Figure 4.1. Crash Rates in Test Sections

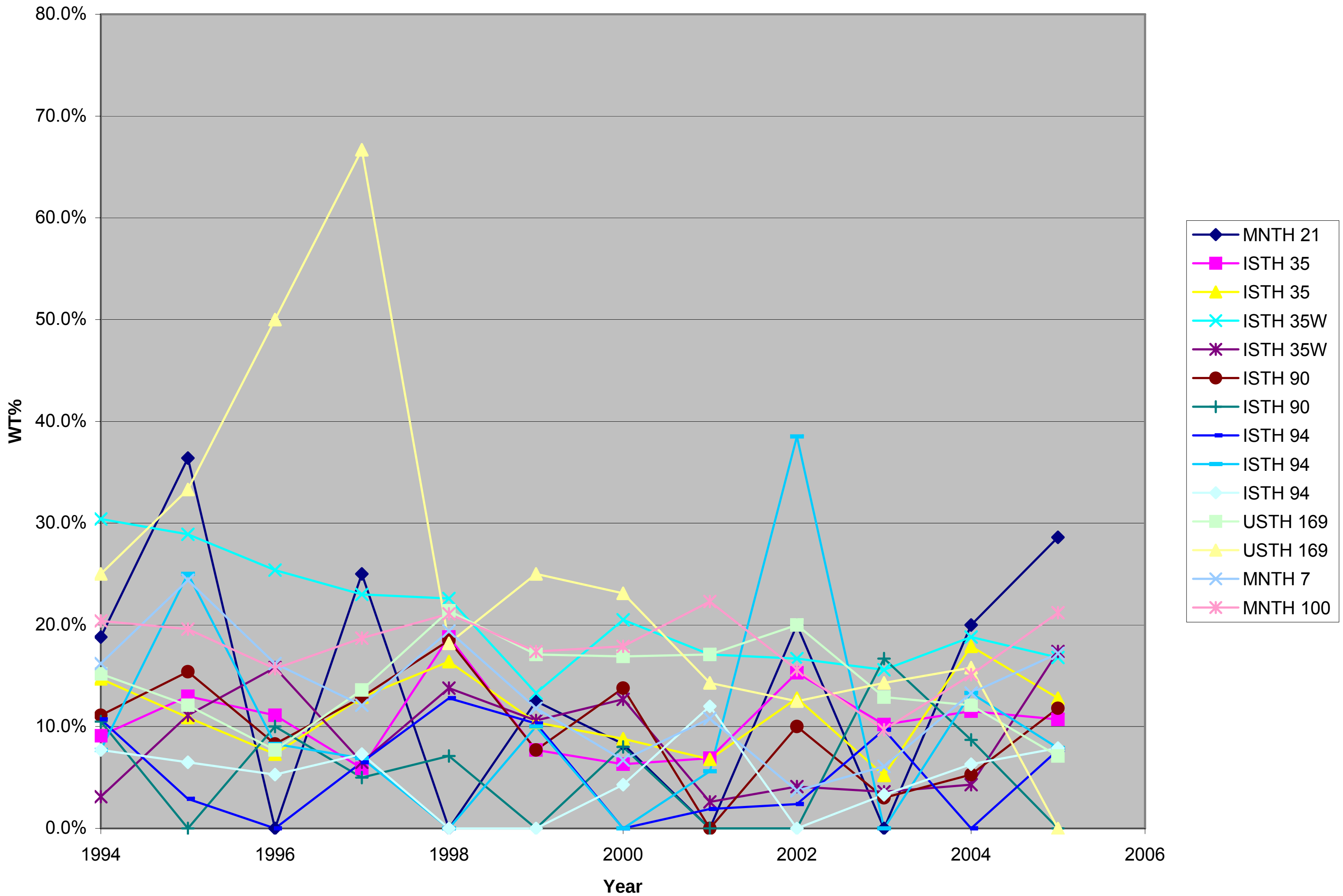

Figure 4.2. Percentage of WWA in Total Accidents

4.2 Summary of Visual Analysis

The visual analysis examined accident data over a ten to eleven year period and found that there was large variation, both within a particular test section, and between test sections. When crash rates were calculated, in order to account for different traffic levels, sections lengths, and the length of the study period, it was observed that the variation of the crash rates appeared to decrease. More importantly, based on the presented accident and crash data, it was not clear which year a particular section received the new texture. In other words dramatic increases, or increasing trends were not observed in the data suggesting that the change in friction did not cause an increase in the wet weather crash rates.

4.3 Statistical Analysis

4.3.1 Descriptive Statistics

Table 4.6 presents the descriptive statistics of annual wet weather accident (WWA) counts and crash rates for TH 21, the remaining sections can be found in Appendix B. All descriptive statistics were calculated assuming that the data set was a sample from a normal distribution. The mean, median, mode, standard deviation, variance, and standard error were calculated using standard statistical definitions. The Kurtosis characterizes the relative peakedness, or flatness of a distribution. A peaked distribution will have a positive kurtosis value and a relatively flat distribution will have a negative kurtosis value. The skewness characterizes the degree of asymmetry of a distribution; a positive value indicates a positive asymmetric tail, and a negative value indicates a negative asymmetric tail. The minimum and maximum depict the minimum and maximum WWA counts respectively. The sum depicts the total WWA counts for the analysis period, and count depicts the sample size. The 95% confidence indicates, with a 95% level of confidence, the amount by which the mean value will vary.

The General statistics do not indicate a situation where there was a reduction in Total accident while at the same time there was an increase in wet weather accidents. In occurrences of increase in wet weather accidents there were observed increases in the total accidents also but it is inconclusive as to which influences the other if we consider Table 4.5 that shows that the percentage of wet weather accident is generally less than 20.

Table 4.6. TH 21 Descriptive Statistics

	WWA Count		Total Acc. Count		WWA% of Total Acc.	
TH 21	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	3.20	2.80	24.80	31.00	0.13	0.10
Standard Error	0.37	0.58	1.77	3.36	0.01	0.02
Median	3.00	3.00	27.00	32.00	0.14	0.10
Mode	3.00	4.00	28.00	#N/A	#N/A	#N/A
Standard Deviation	0.84	1.30	3.96	7.52	0.03	0.05
Sample Variance	0.70	1.70	15.70	56.50	0.00	0.00
Kurtosis	-0.61	-1.49	-3.07	1.82	-2.58	-1.59
Skewness	-0.51	-0.54	-0.60	-1.13	-0.68	-0.06
Range	2.00	3.00	8.00	20.00	0.05	0.12
Minimum	2.00	1.00	20.00	19.00	0.10	0.03
Maximum	4.00	4.00	28.00	39.00	0.15	0.16
Sum	16.00	14.00	124.00	155.00	0.64	0.48
Count	5.00	5.00	5.00	5.00	5.00	5.00
Confidence Level(95.0%)	1.04	1.62	4.92	9.33	0.03	0.06

Table 4.7 shows the mean wet weather accident counts (WWA), total accidents (TA), and the fraction of WWA of TA (WWA/TA) both before, and after the new texture for all fourteen test csections. The shaded cells indicate that there was an increase in counts, and no shading indicates a decrease. Note that in general the proportion of WWA of TA does not increase. There are several instances where the mean WWA and the mean TA increase, but these increases cannot necessarily be attributed to the change in friction, as traffic, or geometric changes could also be contributing factors. In fact most of the roadways were widened and therefore may have received less traffic per lane after construction. In consequence, the level of exposure would not have remained constant.

Though the data and the descriptive statistical analysis are not sufficient to ascribe a reduction in wet weather accident to current texturing practices, it appears that there is no statistically significant increase in mean WWA/TA due to current texturing practices.

Table 4.7. Comparison of mean Accident Counts

	Mean WWA		**Mean TA**		**Mean WWA/TA**	
	Before	**After**	**Before**	**After**	**Before**	**After**
21	3.20	2.80	24.80	31.00	0.13	0.10
35	4.00	4.67	49.75	62.50	0.09	0.08
35	7.29	15.00	66.29	112.67	0.12	0.12
35W	10.29	8.00	48.71	46.00	0.21	0.17
35W	3.80	3.00	32.80	49.60	0.11	0.06
90	3.20	1.80	23.60	31.60	0.14	0.07
90	0.75	1.33	15.00	15.17	0.04	0.08
94	2.00	1.00	36.60	36.20	0.06	0.03
94	1.17	2.00	14.00	14.50	0.09	0.14
94	1.33	1.25	21.83	23.50	0.05	0.05
169	4.67	5.25	30.33	33.25	0.15	0.15
7	2.83	1.75	24.83	21.25	0.11	0.08
100	33.33	27.00	174.67	159.50	0.19	0.16
169	2.43	1.33	8.00	10.33	0.35	0.14

4.3.2 The X^2 Analysis

The X^2 (Chi-squared) is a simple "before" and "after" test. In this statistical test data of x-number of years (n) before reconstruction was compared to data of the (5-n) years after construction. For instance if construction year was 2000, the 1998 data was compared to the 2002 data. The X^2 was used to test for the independence of the crash rates and the wet weather accidents (as a percentage of total accidents) from before the texture change to those same rates and counts after the texture change. The crash rates (or wet weather accidents as a percentage of total accidents) prior to the texture change is denoted P_a and the same rates and counts after the change is denoted P_b. The null hypothesis was tested against the alternate hypothesis; which were defined as follows:

- H_o: $P_a = P_b$. Crash and accident data pre-texturing and post-texturing are similar.
- H_a: $P_a \neq P_b$ Crash and accident data pre-texturing and post-texturing are not similar.

Table 4.8 and Table 4.9 depict the crash rates before and after the texture change, and the X^2 test of the crash rates respectively. Note that the tables show that in every case the null hypothesis can be accepted, this indicates that the crash rates are independent of the texture change, providing evidence that there is no difference in crash rates between the new texture and the old texture. This implies that the crash rates did not increase, thus fulfilling the federal requirements.

Table 4.10 and Table 4.11 depict the crash rates, as a percentage of total accidents before and after the texture change, and the X^2 test of the same value, respectively. Note that the tables show that in every case the null hypothesis can be accepted, this indicates that the crash rates, as a percentage of total accidents, are independent of the texture change, providing evidence that there is no difference in the crash rates, as a percentage of total accidents between the new texture and the old texture. This implies that the crash rates, as a percentage of total accidents did not increase, thus fulfilling the federal requirements.

Table 4.8. X^2 Test: Crash Rates Before and After

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	X-X0	X-X02	X-X03	X-X04	X-X05
1.8	2.3	1.6	1.8	3.1	2.7	2.1	0.8	1.0	1.3	2.2	1.2	1.0	1.3	0.3
0.8	1.1	0.6	0.8	0.7	1.2	0.6	0.6	0.6	0.7	-0.4	-0.3	0.2	0.5	-0.1
0.9	0.8	0.6	0.6	0.6	0.5	0.7	0.7	0.9	0.5	-0.2	-0.2	0.2	-0.1	0.1
1.7	1.6	1.2	1.5	1.4	0.9	1.0	1.2	1.5	1.2	1.1	1.3	0.5	0.1	0.0
0.6	0.5	0.4	0.6	0.7	0.5	0.6	0.7	0.5	0.5	0.0	-0.2	-0.1	0.0	-0.1
0.6	0.5	0.5	0.4	0.5	0.6	0.3	0.5	0.6	0.5	-0.2	0.0	0.1	-0.1	0.0
0.7	0.7	0.5	0.6	0.8	0.6	0.3	0.5	0.7	0.4	0.0	-0.1	0.2	0.0	0.1
0.6	0.7	0.6	0.5	0.4	0.7	0.5	0.4	0.4	0.6	-0.2	0.1	0.2	0.3	0.0
0.5	1.2	0.4	0.3	0.3	0.6	0.5	0.4	0.5	1.2	0.0	-0.2	0.1	0.7	-0.8
0.4	1.2	0.2	0.3	0.4	0.4	0.4	0.6	0.5	0.6	-0.1	0.3	-0.2	0.7	-0.4
0.7	0.6	0.9	0.9	1.2	0.7	0.8	0.6	0.6	0.5	0.2	0.1	0.1	0.0	0.4
0.2	0.7	1.1	0.8	1.3	0.7	0.8	0.7	1.8	0.7	0.7	-0.1	-0.5	-1.1	0.4
1.7	1.5	1.6	0.7	1.3	1.5	1.1	1.3	1.3	1.2	0.5	1.3	0.4	0.2	0.4
1.8	1.2	1.3	1.3	1.7	1.6	1.5	1.1	0.7	0.6	0.0	0.1	0.7	0.5	0.7

Table 4.9. X^2Test of Crash Rates

(X-X0)^2/X0	(X-X0)^2/X0	(X-X0)^2/X0	(X-X0)^2/X0	(X-X0)^2/X0	Summation	S-3.84	Result
0.99	0.44	0.56	0.73	0.06	2.77	-1.07	Accept H_0
0.20	0.30	0.05	0.23	0.02	0.79	-3.05	Accept H_0
0.13	0.08	0.04	0.01	0.02	0.29	-3.55	Accept H_0
0.61	0.73	0.15	0.01	0.00	1.49	-2.35	Accept H_0
0.00	0.10	0.02	0.00	0.03	0.14	-3.70	Accept H_0
0.10	0.00	0.02	0.02	0.00	0.14	-3.70	Accept H_0
0.00	0.05	0.06	0.00	0.02	0.13	-3.71	Accept H_0
0.08	0.02	0.07	0.13	0.00	0.29	-3.55	Accept H_0
0.00	0.13	0.02	0.41	1.60	2.16	-1.68	Accept H_0
0.03	0.13	0.10	0.41	0.80	1.47	-2.37	Accept H_0
0.04	0.01	0.01	0.00	0.18	0.25	-3.59	Accept H_0
0.35	0.01	1.25	1.73	0.15	3.49	-0.35	Accept H_0
0.13	0.70	0.09	0.03	0.10	1.05	-2.79	Accept H_0
0.00	0.01	0.27	0.21	0.38	0.86	-2.98	Accept H_0

Table 4.10. X^2 Test: Crash Rates, as a Percent of Wet Weather Crashes

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	$X-X_0$	$X-X_02$	$X-X_03$	$X-X_04$	$X-X_05$
0.0	25.0	0.0	12.5	8.3	0.0	20.0	0.0	20.0	28.6	0.2	0.2	0.0	0.1	-0.3
11.1	5.9	18.8	7.7	6.3	6.9	15.3	10.2	11.5	10.7	0.0	0.0	0.0	-0.1	0.1
7.3	12.9	16.4	10.4	8.8	6.8	12.8	5.2	17.9	12.8	0.1	0.0	0.0	-0.1	0.0
25.4	23.0	22.6	13.3	20.5	17.1	16.7	15.6	18.8	16.8	0.1	0.1	0.1	0.0	0.1
15.8	6.5	13.8	10.6	12.7	2.6	4.1	3.6	4.3	17.4	0.0	0.1	0.1	0.0	0.0
8.3	12.9	18.5	7.7	13.8	0.0	10.0	3.0	5.3	11.8	0.1	0.1	0.1	0.1	0.1
10.0	5.0	7.1	0.0	8.0	0.0	0.0	16.7	8.7	0.0	0.1	0.0	-0.1	0.0	0.1
0.0	6.5	12.8	10.3	0.0	1.9	2.4	9.7	0.0	7.7	0.1	0.0	-0.1	0.1	0.1
8.3	6.9	0.0	10.0	0.0	5.6	38.5	0.0	13.3	7.9	0.0	-0.1	0.1	-0.1	-0.1
5.3	7.3	0.0	0.0	4.3	12.0	0.0	3.3	6.3	7.9	0.0	0.1	0.0	0.0	-0.1
7.7	13.6	21.4	17.1	16.9	17.1	20.0	12.9	12.1	7.1	0.0	-0.1	-0.1	0.0	0.1
50.0	66.7	18.2	25.0	23.1	14.3	12.5	14.3	15.8	0.0	0.1	0.2	0.4	0.5	0.2
16.2	12.1	19.4	11.8	6.7	10.8	3.7	6.1	13.3	17.2	0.1	0.2	0.1	0.0	0.0
15.7	18.7	21.1	17.4	17.9	22.3	15.6	9.7	15.1	21.2	0.0	0.0	0.1	0.0	0.0

Table 4.11. X^2 Test of Crash Rates as a Percent of Wet Weather Crashes

$(X-X_0)^2/X_0$	$(X-X_0)^2/X_0$	$(X-X_0)^2/X_0$	$(X-X_0)^2/X_0$	$(X-X_0)^2/X_0$	Σ	S-3.84	Result
0.19	0.07		0.01		0.27	-3.57	Accept H_0
0.01	0.00	0.00	0.05	0.03	0.10	-3.74	Accept H_0
0.04	0.00	0.01	0.02	0.01	0.08	-3.76	Accept H_0
0.06	0.05	0.04	0.01	0.01	0.17	-3.67	Accept H_0
0.00	0.04	0.09	0.01	0.01	0.16	-3.68	Accept H_0
0.11	0.02	0.03	0.04	0.02	0.23	-3.61	Accept H_0
0.11		0.04	0.03	0.07	0.25	-3.59	Accept H_0
0.07	0.00		0.07	0.02	0.16	-3.68	Accept H_0
0.01	0.07	0.08	0.06		0.22	-3.62	Accept H_0
0.02	0.07	0.01	0.00		0.10	-3.74	Accept H_0
0.00	0.05	0.04	0.00	0.10	0.19	-3.65	Accept H_0
0.05	0.13	0.25	0.39	0.18	1.00	-2.84	Accept H_0
0.02	0.18	0.06	0.00	0.00	0.26	-3.58	Accept H_0
0.00	0.01	0.02	0.01	0.00	0.04	-3.80	Accept H_0

4.3.3 Mann Whitney U Test

The Mann Whitney U test compares the means from two independent samples. The two samples being tested are the accident counts before texturing against the accident counts after the texturing. The null hypothesis (H_0) and the alternate hypothesis (H_a) were defined as follows:

- H_o: Accident counts pre and post current texturing are the same, within a 95 percent level of confidence.
- H_a: Accident counts pre and post current texturing are different, within a 95 percent level of confidence

The Mann Whitney U test rank orders the data from both of the independent samples n_1, n_2. The sum of the ranks corresponding to each sample (n_1, n_2) can be denoted as (w_1,w_2) and the U statistics, u_1 or u_2 can be found as follows:

$$u_1 = w_1 - \frac{n_1(n_1+1)}{2} \quad \text{or} \quad u_2 = w_2 - \frac{n_2(n_2+1)}{2}$$

However when both n_1 and n_2 exceed 8, the sampling distribution of U_1 (or U_2) approaches the Normal distribution and can be approximated as follows:

$$\mu_{U_1} = \frac{n_1 n_2}{2} \quad \text{and} \quad \sigma_{U_1} = \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}} \quad \text{with} \quad Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

Table 4.12 shows the results of the Mann Whitney Analysis on the WWA count, Total accident count, and the WWA as a fraction of Total Accidents respectively. The table shows that the value of Z_0 to obtain a 95% confidence level is 1.64, and if $Z_0 < z$ the null hypothesis cannot be accepted.

The null hypothesis is validated in every test section, for total accident counts and total crash rates. In the WWA counts, 2 sections do not fulfill the null hypothesis. Similarly one out of 14 sections does not fulfill the null hypothesis in the crash rate, percentage of wet weather crash rates and percentage of wet weather accident counts. In a total of 5 tables of 14 datasets per table, 65 out of 70 validate the null hypothesis. It is evident that to a 95 % confidence limit it can be concluded that the texturing practices did not result in increase in accidents in the analyzed sections.

4.4 Summary of Statistical Analyses

Three different statistical tests were called upon to confirm the earlier findings of the visual analysis which indicated that the change in texture did not cause a noticeable increase in the crash rates. The descriptive statistics showed that in many cases the mean WWA/TA actually decreased after the new texturing was applied, although there was insufficient evidence, and it was outside the scope of the study, to attribute the reduction to the texture change. It was also demonstrated that there were many factors that affected the accident counts, which was the motivation for investigating crash rates.

The X^2 test indicated that the accident counts and the crash rates were not dependant upon the texture change. This provided evidence that the accident counts and the crash rates did not increase as a result of said change. The failure of the X^2 method to identify causative factors was compensated by a summation of nay and ayes. General decreases totaled 45 and increases totaled 18 for total wet weather accident counts and 47 and 15 for percentage of wet weather accident statistics. In all cases the X^2 test showed that there was a change in statistics.

The Mann Whitney test confirmed these results by indicating that there were no increases in both the mean accident counts and the mean crash rates from before to after the application of the new texture.

Table 4.12. Mann Whitney Analysis

Wet Weather Accident Count										
	Total Before R	Total After R	n	m	U	Uv	σ	z	Z0	Test Z<Z0
TH 21 Jordan	20.0	25	5	5	20	12.5	7.42	1.01	1.64	0.63
TH 35, RP 13to27	21	32	4	6	13	12	8.12	0.12	1.64	1.52
TH 35, RP 68to79	41.0	20	7	3	8	10.5	5.74	-0.44	1.64	2.08
TH 35W, RP 9 to11	30.0	27	7	3	19	10.5	5.74	1.48	1.64	0.16
TH 35W, RP 35to41	30.0	29	5	5	10	12.5	7.42	-0.34	1.64	1.98
TH90, RP 222to235	21.0	33	5	5	19	12.5	7.42	0.88	1.64	0.76
TH 90, RP 166to174	19	26	4	6	15	12	8.12	0.37	1.64	1.27
TH 94, RP 115 to 128	21.0	24	5	5	19	12.5	7.42	0.88	1.64	0.76
TH 94, RP 2 1 to 27	28.0	24	6	4	17	12	6.63	0.75	1.64	0.89
TH 94, 38 to 51	25.0	19	6	4	20	12	6.63	1.21	1.64	0.43
TH 169, RP 96 to 102	40.0	18	6	4	5	12	6.63	-1.06	1.64	2.70
TH 7, RP 142 to 151	17.0	26	6	4	28	12	6.63	2.41	1.64	-0.77
TH 100, RP 8 to 13	34.0	21	6	4	11	12	6.63	-0.15	1.64	1.79
TH 169, RP 88 to 90	25.0	24	7	3	24	10.5	5.74	2.35	1.64	-0.71
Total Accidents										
	Total Before R	Total After R	n	m	U	Uv	σ	z	Z0	Test Z<Z0
TH 21 Jordan	39.0	23	5	5	1	12.5	7.42	-1.55	1.64	3.19
TH 35, RP 13to27	30	35	4	6	4	12	8.12	-0.98	1.64	2.62
TH 35, RP 68to79	57.0	13	7	3	-8	10.5	5.74	-3.22	1.64	4.86
TH 35W, RP 9 to11	36.0	28	7	3	13	10.5	5.74	0.44	1.64	1.20
TH 35W, RP 35to41	42.0	18	5	5	-2	12.5	7.42	-1.96	1.64	3.60
TH90, RP 222 to235	40.0	27	5	5	0	12.5	7.42	-1.69	1.64	3.33
TH 90, RP 166to174	23	40	4	6	11	12	8.12	-0.12	1.64	1.76
TH 94, RP 115 to 128	34.0	29	5	5	6	12.5	7.42	-0.88	1.64	2.52
TH 94, RP 2 1 to 27	34.0	21	6	4	11	12	6.63	-0.15	1.64	1.79
TH 94, 38 to 51	42.0	21	6	4	3	12	6.63	-1.36	1.64	3.00
TH 169, RP 96 to 102	46.0	18	6	4	-1	12	6.63	-1.96	1.64	3.60
TH 7, RP 142 to 151	26.0	24	6	4	19	12	6.63	1.06	1.64	0.58
TH 100, RP 8 to 13	35.0	17	6	4	10	12	6.63	-0.30	1.64	1.94
TH 169, RP 88 to 90	42.0	20	7	3	7	10.5	5.74	-0.61	1.64	2.25
Wet Weather Accidents, Fraction of Total										
	Total Before R	Total After R	n	m	U	Uv	σ	z	Z0	Test Z<Z0
TH 21 Jordan	23.0	32	5	5	17	12.5	7.42	0.61	1.64	1.03
TH 35, RP 13to27	15	42	4	6	19	12	8.12	0.86	1.64	0.78
TH 35, RP 68to79	36.0	24	7	3	13	10.5	5.74	0.44	1.64	1.20
TH 35W, RP 9 to11	30.0	25	7	3	19	10.5	5.74	1.48	1.64	0.16
TH 35W, RP 35to41	29.0	37	5	5	11	12.5	7.42	-0.20	1.64	1.84
TH90, RP 222to235	22.0	39	5	5	18	12.5	7.42	0.74	1.64	0.90
TH 90, RP 166to174	20	27	4	6	14	12	8.12	0.25	1.64	1.39
TH 94, RP 115 to 128	22.0	29	5	5	18	12.5	7.42	0.74	1.64	0.90
TH 94, RP 2 1 to 27	35.0	27	6	4	10	12	6.63	-0.30	1.64	1.94
TH 94, 38 to 51	26.0	24	6	4	19	12	6.63	1.06	1.64	0.58
TH 169, RP 96 to 102	41.0	21	6	4	4	12	6.63	-1.21	1.64	2.85
TH 7, RP 142 to 151	27.0	29	6	4	18	12	6.63	0.90	1.64	0.74
TH 100, RP 8 to 13	28.0	28	6	4	17	12	6.63	0.75	1.64	0.89
TH 169, RP 88 to 90	26.0	26	7	3	23	10.5	5.74	2.18	1.64	-0.54

Chapter 5. Conclusion

To a 95 % Confidence limit the wet weather Accident distribution in the analyzed test sections have the same distribution when the pre texturing data is compared to data post texturing. Crash rates in the test sections studied retained the same distribution to a 95 % confidence limit after current texturing

In the X^2 analysis there was a decrease in WWA counts after new construction and texturing. In the sections tested and analyzed, neither the WWA counts, nor the crash rates increased. WWA results are considered along with the actual measured friction numbers in an overall evaluation of the texturing practices. A typical Friction Versus Time plot was also shown)

The General percentage of wet weather accident (After current texturing) from 1994 to 2005 was lower than the National average of 20%. This effort fulfils the requirements of FHWA's current technical advisory as it evaluates the current texturing with the stipulated metrics.

This report catalogues the accident data in some test sections where the adequacy of Minnesota texturing practices is examined. It compared wet weather accident counts prior to, and after the application of current texturing. It also compares the crash rates prior to and after placement of, new surfacing finished with current texturing. It performed three statistical analyses to compare the data and to validation or other wise the hypothesis and statistic for data comparison.

Three statistical tests used were the descriptive statistics; the Mann Whitney U-Test and the X^2 (Chi – squared) test. Each test validates the null hypotheses that data prior to application of new textures did not change after the application of new textures to a 95% confidence limit.

This report concludes that current texturing practices, which are Astroturf drag or longitudinal broom drag did not result in an increase in wet weather accident counts, crash rates and percentage of wet weather accidental in the sections examined. In addition, as far as wet weather accident criterion is concerned, this study addresses the requirement of FHWA to perform wet weather accident analysis in sections where unconventional textures were applied for the purposes of monitoring the performance of the unconventional textures.

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Appendix A – Detailed Information on Friction Sections

Table A.1. Friction Sections

Yr	SP	TH	Beg RP	End RP	New Beg RP	New End RP	Prior To	After	Let	Start	Comp	Spec.	Rate
99	7002-33	21	2	35	2	35		12/99	4/99			0.80	99
02	2480-81	35 NB	0	13.431	0	13.431	5/02	12/02	3/02	5/02	A+B	1.00	02
98	2480-88	35 NB	13.431	27.141	13.473	27.133	7/98	12/98	4/98	7/98	77 WD	Tining	98
00	6680-94	35 NB	59.251	62.769	59.251	62.769	5/00	12/00	3/00	5/00	40 WD	0.80	00
02	6680-95	35 NB	68.469	78.894	68.469	78.894	7/01	12/01	6/01	7/01		1.00	02
04	6680-96	35 SB	68.461	76.891	68.461	76.891	5/04	12/04	3/04	5/04		1.00	04
00	2480-91	35 SB	20.113	25.05	20.113	25.05	7/00	12/00	1/00	7/00	65 WD	0.80	00
01	2782-268	35W	9	10.425	9	10.425		12/01	5/99			0.80	01
00	0280-49	35W	34.859	40.978	34.859	40.978			6/99			0.80	00
01	8285-86	494	58	59	58	59		12/02					02
99	2785-307	494	CSAH-5					12/99	3/98			Tining	99
01	8580-148	90	271.227	278.66	271.227	278.655	7/00	12/01	5/00	7/00	60 WD	0.80	01
01	8580-147	I-90	272.135	276.66	272.135	276.655	5/01	12/01	2/01	5/01	75 WD	1.00	01

Table A.2. Friction Sections

Yr	SP	TH	Beg RP	End RP	New Beg RP	New End RP	Prior To	After	Let	Start	Comp	Spec	Rate
01	2481-41	90 EB	154.625	166.17	154.625	166.172	4/01	12/01	2/01	4/01		1.00	01
99	5580-72	90 EB	222.472	235	222.472	235		12/99	4/99			0.80	99
98	2482-63	90 WB	166.229	174.105	166.229	174.105		12/98	1/98			Tining	98
99	7380-199	94 EB	115.283	127.67	115.28	127.669		12/99	7/98			Tining	99
00	1480-127	94 EB	20.750	26.997	24.039	31.834	6/00	12/00	4/00	6/00	65 WD	0.80	00
98	2180-80	94 EB	102.793	110.02	102.793	110.024		12/98	3/98			Tining	98
00	7380-200	94 WB	114	127	114	127		12/00	4/99			0.80	00
98	5680-111	94 WB	38.231	50.604	38.231	50.604		12/98				Tining	98
98	1480-131	94 WB			24.04	31			3/98			Tining	99
03	7702-41	10	108.06	114.28	108.06	114.278	4/03	12/03	6/02	4/03	10/03	1.00	03
04	2755-75	100	12.688	14.049	12.688	14.049	6/03	12/04	3/03	6/03	8/05	1.00	04
03	2735-134	100	8.318	09.887	8.318	9.887	5/00	12/03	4/00	5/00	10/02	0.80	03
04	2735-159	100	8.430	13.733	8.43	13.733	7/01	12/04	6/01	7/01	8/03	1.00	04

Table A.3. Friction Sections

Yr	SP	TH	Beg RP	End RP	New Beg RP	New End RP	Prior To	After	Let	Start	Comp	Spec	Rate
00	0702-110	14	130.118	133.798	130.118	133.798	6/00	12/01	4/00	6/00	51 WD	0.80	01
03	0702-108	14	140.692	145.458	140.692	145.458	7/02		3/02	7/02	11/03	1.00	
02	7408-29	14						12/02					02
00	7007-23	169	88.96	90.08	088.096	090.008	7/00	12/01	5/00	7/00	11/01	0.80	01
00	7009-64	169 SB	96.674	102.08	096.674	102.083	4/00	12/00	2/00	4/00	8/00	0.80	00
98	6404-32	19											
	6933-77	194	17.160	15.162	17.160	015.162		12/02				Tining	02
00	6019-22	2	40	55	40.000	55.000	5/00	12/00	3/00	5/00	60 WD	0.80	00
04	5401-29	200	17.952	19.497	17.952	19.497	5/04	12/04	2/04	5/04	140 WD	1.00	04
01	5411-14	200					5/01	12/01	2/01	5/01	55 WD	1.00	01
03	7002-38	21	26.407	26.928	26.407	26.928		12/03					03
02	6511-30	212	76.706	78.096	76.706	78.096	5/02	12/03	4/02	5/02		1.00	03
02	6511-31/32	212	82.182	89.732	82.182	89.732	5/02	12/02	11/01	5/02	90 WD	1.00	02

Table A.4. Friction Sections

Yr	SP	TH	Beg RP	End RP	New Beg RP	New End RP	Prior To	After	Let	Start	Comp	Spec	Rate
04	4310-45	212	116.627	121.192	116.627	121.192	6/04	12/04	4/04	6/04	50 WD	1.00	04
99	2762-11	212						12/00	2/98			Tining	00
01	2762-12	212						12/01	5/99			tining 0.8	01
01	2762-13	212						12/01	9/98			Tining	01
98	6511-26	212						12/98					98
98	0714-32	22											
02	1202-47	23	90.356	90.903	90.356	90.903	5/02	12/02	12/01	5/02	40 WD	1.00	02
01	2106-30	27	81	90	81.000	90.000	6/01	12/03	4/01	6/01	105 WD	1.00	03
03	1414-02	336	0	2.18	0.000	2.018	4/02	12/03	12/01	4/02	10/03	1.00	03
02	1008-51	41	2.26	3.539	2.260	3.539			9/01			1.00	02
02	8285-86	494	59.878	58.214	59.878	58.214		12/02	let 2001			0.80	02
02	1002-61	5	42.422	44.883	42.422	44.883	8/00	12/02	6/00	8/00	6/02	1.00	02

Table A.5. Friction Sections

Yr	SP	TH	Beg RP	End RP	New Beg RP	New End RP	Prior To	After	Let	Start	Comp	Spec	Rate
04	5502-85	52						12/05				1.00	05
04	6915-123	53	2.040	3.252	2.040	3.252	4/03	12/04	11/02	4/03	8/05	Tining	04
00	2724-102	55							6/03			tining 0.8	
99	2724-105	55						12/00	6/98			Tining	00
04	2510-30	58	18.522	23.298	018.522	023.298	4/03	12/04	2/03	4/03	110 WD	1.00	04
03	2610-10	59	178.645	188.808	178.645	188.808	7/02	12/03	4/02	7/02	6/03	1.00	03
98	4208-39	59						12/98	2/98			Tining	98
04	5104-36	59					5/04		3/04	5/04	62 WD	1.00	
01	3204-62	60	19.63	27.62	019.063	027.062	8/00	12/01	2/00	8/00	50 WD	0.80	01
03	3204-59	60	27.680	35.607	027.680	035.607	9/01	12/03	7/01	9/01	10/02	1.00	03
98	3805-67	61	17	21	017.000	021.000		12/98	7/96			Tining	98
04	8205-99	61	128.868	129.947	128.868	129.947	5/02	12/04	3/02	5/02		1.00	04
98	6926-42	61						12/99	5/98			Tining	99

Table A.6. Friction Sections

Yr	SP	TH	Beg RP	End RP	New Beg RP	New End RP	Prior To	After	Let	Start	Comp	Spec	Rate
02	0217-16	610	0.764	1.823	0.764	1.823	4/01	12/02	12/00	4/01	7/02	1.00	02
02	0217-19	610	9.616	11.609	9.616	11.609	6/00	12/02	4/00	6/00	11/00	0.80	02
99	2771-11	610						12/00	4/98			Tining	00
00	2771-14	610						12/00	5/99			0.80	00
00	2771-15	610						12/00	6/98			Tining	00
02	1202-47	7	124.937	125.32	124.937	125.323							
01	3411-63	71	123-143, 123-126		123-143, 123-126		4/01	12/01	3/01	4/01	85 WD	1.00	01
01	2758-62	77						12/01	6/00			1.00	01
04	2786-117	94	216.886	218.612	216.886	218.612	5/03	12/04	3/03	5/03	10/04	1.00	04
03	2786-114	94	217.363	217.988	217.363	217.988		12/03	6/01			0.80	03
04	2786-115	94	218.612	221.363	218.612	221.363	6/02	12/04	4/02	6/02	7/04	1.00	04
03	2786-113	94	220.145	220.541	220.145	220.541	6/01	12/03	4/01	6/01	6/03	1.00	03
04	2786-116	94	221.363	224.935	221.363	224.935	4/03	12/04	1/03	4/03	11/04	1.00	04

Table A.7. Friction Sections

Yr	SP	TH	Beg RP	End RP	New Beg RP	New End RP	Prior To	After	Let	Start	Comp	Spec	Rate
01	2733-77	100											
01	2735-160	100					5/00	12/03	3/00	5/00	10/20 01	0.80	03
01	4001-45	13/60					7/01	12/02	6/01	7/01	55 WD	1.00	02
01	0702-107	14	129.1	131.38	129.001	131.038							01
01	2001-23	14	188	196	188	196	5/01	12/01	6/00	5/01	77 WD	1.00	01
99	0714-30	22 INC	N OF TH-14		N OF 14				5/98			Tining	99
00	4302-46	7	142.452	151.13	142.452	151.13		12/00	4/99			0.80	00
00	4302-39	7											
99	3412-60	71 DEC	126.264	129.32	126.264	129.319		12/99					99
00	8816-41						6/00	12/00	1/00	6/00	9 WD	0.80	00

Appendix B – Descriptive Statistics

Table B.1. TH 169 Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA % of TOTAL	WWA % of TOTAL
169, RP 88 to 90	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	2.43	1.33	8.00	10.33	0.35	0.14
Standard Error	0.37	0.33	1.40	3.84	0.06	0.02
Median	2.00	1.00	8.00	7.00	0.27	0.14
Mode	2.00	1.00	6.00	#N/A	#N/A	#N/A
Standard Deviation	0.98	0.58	3.70	6.66	0.17	0.03
Sample Variance	0.95	0.33	13.67	44.33	0.03	0.00
Kurtosis	0.04	#DIV/0!	-0.28	#DIV/0!	0.77	#DIV/0!
Skewness	0.28	1.73	-0.33	1.69	1.32	-0.42
Range	3.00	1.00	11.00	12.00	0.47	0.06
Minimum	1.00	1.00	2.00	6.00	0.20	0.11
Maximum	4.00	2.00	13.00	18.00	0.67	0.17
Sum	17.00	4.00	56.00	31.00	2.45	0.42
Count	7.00	3.00	7.00	3.00	7.00	3.00
Confidence Level(95.0%)	0.90	1.43	3.42	16.54	0.16	0.07

Table B.2. IS TH 35 W Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
TH 35, RP 13 to 27	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	4.00	4.67	49.75	62.50	0.09	0.08
Standard Error	0.91	0.71	12.24	9.04	0.02	0.01
Median	4.00	5.50	53.50	56.00	0.10	0.08
Mode	#N/A	6.00	#N/A	#N/A	#N/A	#N/A
Standard Deviation	1.83	1.75	24.49	22.15	0.03	0.04
Sample Variance	3.33	3.07	599.58	490.70	0.00	0.00
Kurtosis	-3.30	-1.21	1.00	5.36	3.31	-2.25
Skewness	0.00	-0.92	-0.83	2.28	-1.75	0.03
Range	4.00	4.00	58.00	59.00	0.08	0.09
Minimum	2.00	2.00	17.00	48.00	0.04	0.03
Maximum	6.00	6.00	75.00	107.00	0.12	0.13
Sum	16.00	28.00	199.00	375.00	0.36	0.48
Count	4.00	6.00	4.00	6.00	4.00	6.00
Confidence Level(95.0%)	2.91	1.84	38.96	23.25	0.06	0.04

Table B.3. IS TH 35 Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
35, RP 68 to 79	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	7.29	15.00	66.29	112.67	0.12	0.12
Standard Error	0.75	6.08	7.58	14.52	0.01	0.04
Median	7.00	14.00	66.00	104.00	0.11	0.13
Mode	6.00	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	1.98	10.54	20.06	25.15	0.03	0.07
Sample Variance	3.90	111.00	402.57	632.33	0.00	0.00
Kurtosis	-1.07	#DIV/0!	0.61	#DIV/0!	-1.00	#DIV/0!
Skewness	0.72	0.42	-0.24	1.37	0.31	-0.69
Range	5.00	21.00	63.00	48.00	0.09	0.13
Minimum	5.00	5.00	33.00	93.00	0.07	0.05
Maximum	10.00	26.00	96.00	141.00	0.16	0.18
Sum	51.00	45.00	464.00	338.00	0.81	0.37
Count	7.00	3.00	7.00	3.00	7.00	3.00
Confidence Level(95.0%)	1.83	26.17	18.56	62.47	0.03	0.16

Table B.4. IS TH 35W Descriptive Statistics

35W, RP 9 to 11	Before	After	Before	After	Before	After
Mean	10.29	8.00	48.71	46.00	0.21	0.17
Standard Error	1.32	2.31	2.37	9.45	0.02	0.02
Median	10.00	8.00	52.00	42.00	0.23	0.19
Mode	10.00	#N/A	52.00	#N/A	#N/A	#N/A
Standard Deviation	3.50	4.00	6.26	16.37	0.06	0.04
Sample Variance	12.24	16.00	39.24	268.00	0.00	0.00
Kurtosis	0.61	#DIV/0!	-1.96	#DIV/0!	1.84	#DIV/0!
Skewness	0.26	0.00	-0.14	1.03	-0.71	-1.72
Range	11.00	8.00	16.00	32.00	0.21	0.07
Minimum	5.00	4.00	41.00	32.00	0.10	0.13
Maximum	16.00	12.00	57.00	64.00	0.30	0.19
Sum	72.00	24.00	341.00	138.00	1.48	0.50
Count	7.00	3.00	7.00	3.00	7.00	3.00
Confidence Level(95.0%)	3.24	9.94	5.79	40.67	0.06	0.09

Table B.5. IS TH 35 W Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
35W, RP 35 to 41	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	3.80	3.00	32.80	49.60	0.11	0.06
Standard Error	1.02	1.52	2.13	3.04	0.03	0.03
Median	3.00	2.00	32.00	50.00	0.11	0.04
Mode	3.00	1.00	#N/A	#N/A	#N/A	#N/A
Standard Deviation	2.28	3.39	4.76	6.80	0.06	0.06
Sample Variance	5.20	11.50	22.70	46.30	0.00	0.00
Kurtosis	-0.18	4.57	1.30	0.84	-0.32	4.58
Skewness	0.40	2.12	0.67	-1.03	-0.60	2.12
Range	6.00	8.00	13.00	17.00	0.15	0.14
Minimum	1.00	1.00	27.00	39.00	0.03	0.02
Maximum	7.00	9.00	40.00	56.00	0.18	0.16
Sum	19.00	15.00	164.00	248.00	0.57	0.28
Count	5.00	5.00	5.00	5.00	5.00	5.00
Confidence Level(95.0%)	2.83	4.21	5.92	8.45	0.07	0.07

Table B.6. TH 90 Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
90, RP 166 to 174	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	0.75	1.33	15.00	15.17	0.04	0.08
Standard Error	0.48	0.61	2.68	1.89	0.02	0.04
Median	0.50	1.00	15.50	14.00	0.03	0.05
Mode	0.00	0.00	#N/A	14.00	0.00	0.00
Standard Deviation	0.96	1.51	5.35	4.62	0.05	0.10
Sample Variance	0.92	2.27	28.67	21.37	0.00	0.01
Kurtosis	-1.29	-2.83	1.50	-0.32	-4.32	-0.72
Skewness	0.85	0.21	-0.55	0.39	0.30	0.78
Range	2.00	3.00	13.00	13.00	0.10	0.23
Minimum	0.00	0.00	8.00	9.00	0.00	0.00
Maximum	2.00	3.00	21.00	22.00	0.10	0.23
Sum	3.00	8.00	60.00	91.00	0.16	0.47
Count	4.00	6.00	4.00	6.00	4.00	6.00
Confidence Level(95.0%)	1.52	1.58	8.52	4.85	0.08	0.10

Table B.7. TH 94 Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
94, RP 115 to 128	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	2.00	1.00	36.60	36.20	0.06	0.03
Standard Error	0.63	0.55	3.47	3.65	0.02	0.02
Median	3.00	1.00	37.00	33.00	0.07	0.02
Mode	3.00	0.00	#N/A	#N/A	#N/A	0.00
Standard Deviation	1.41	1.22	7.77	8.17	0.05	0.04
Sample Variance	2.00	1.50	60.30	66.70	0.00	0.00
Kurtosis	-1.75	2.00	0.24	-0.90	-0.75	3.45
Skewness	-0.88	1.36	-0.74	0.79	-0.02	1.80
Range	3.00	3.00	20.00	20.00	0.12	0.10
Minimum	0.00	0.00	25.00	28.00	0.00	0.00
Maximum	3.00	3.00	45.00	48.00	0.12	0.10
Sum	10.00	5.00	183.00	181.00	0.30	0.14
Count	5.00	5.00	5.00	5.00	5.00	5.00
Confidence Level(95.0%)	1.76	1.52	9.64	10.14	0.06	0.05

Table B.8. TH 94 Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
94, RP21 to 27	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	1.17	2.00	14.00	14.50	0.09	0.14
Standard Error	0.31	1.08	3.09	1.32	0.03	0.08
Median	1.00	1.50	11.00	14.00	0.08	0.09
Mode	1.00	#N/A	10.00	#N/A	#N/A	#N/A
Standard Deviation	0.75	2.16	7.56	2.65	0.07	0.17
Sample Variance	0.57	4.67	57.20	7.00	0.01	0.03
Kurtosis	-0.10	1.50	4.83	-0.29	2.85	1.99
Skewness	-0.31	1.19	2.16	0.86	1.16	1.42
Range	2.00	5.00	20.00	6.00	0.22	0.38
Minimum	0.00	0.00	9.00	12.00	0.00	0.00
Maximum	2.00	5.00	29.00	18.00	0.22	0.38
Sum	7.00	8.00	84.00	58.00	0.55	0.57
Count	6.00	4.00	6.00	4.00	6.00	4.00
Confidence Level(95.0%)	0.79	3.44	7.94	4.21	0.08	0.27

Table B.9. TH 94 Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
94, RP 38 to 51	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	1.33	1.25	21.83	23.50	0.05	0.05
Standard Error	0.61	0.63	5.88	2.40	0.02	0.03
Median	1.00	1.00	15.50	24.00	0.06	0.04
Mode	1.00	1.00	#N/A	#N/A	0.00	#N/A
Standard Deviation	1.51	1.26	14.41	4.80	0.04	0.06
Sample Variance	2.27	1.58	207.77	23.00	0.00	0.00
Kurtosis	1.53	2.23	1.88	-3.96	-1.89	2.85
Skewness	1.27	1.13	1.54	-0.29	-0.77	1.52
Range	4.00	3.00	38.00	10.00	0.08	0.14
Minimum	0.00	0.00	10.00	18.00	0.00	0.00
Maximum	4.00	3.00	48.00	28.00	0.08	0.14
Sum	8.00	5.00	131.00	94.00	0.29	0.22
Count	6.00	4.00	6.00	4.00	6.00	4.00
Confidence Level(95.0%)	1.58	2.00	15.13	7.63	0.04	0.10

Table B.10. TH 169 Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
169, RP 96 to 102	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	4.67	5.25	30.33	33.25	0.15	0.15
Standard Error	0.99	1.25	2.51	1.75	0.02	0.03
Median	4.00	5.50	31.50	35.00	0.15	0.16
Mode	3.00	#N/A	#N/A	35.00	#N/A	#N/A
Standard Deviation	2.42	2.50	6.15	3.50	0.05	0.07
Sample Variance	5.87	6.25	37.87	12.25	0.00	0.00
Kurtosis	-1.79	0.93	-1.64	4.00	-1.24	0.64
Skewness	0.46	-0.56	-0.45	-2.00	0.20	-0.31
Range	6.00	6.00	15.00	7.00	0.14	0.16
Minimum	2.00	2.00	22.00	28.00	0.08	0.07
Maximum	8.00	8.00	37.00	35.00	0.22	0.23
Sum	28.00	21.00	182.00	133.00	0.88	0.61
Count	6.00	4.00	6.00	4.00	6.00	4.00
Confidence Level(95.0%)	2.54	3.98	6.46	5.57	0.06	0.10

Table B.11. TH 7 Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
7, RP 142 to 151	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	2.83	1.75	24.83	21.25	0.11	0.08
Standard Error	0.75	0.85	2.50	3.40	0.02	0.04
Median	2.00	1.50	26.50	21.50	0.08	0.09
Mode	2.00	#N/A	#N/A	#N/A	#N/A	0.14
Standard Deviation	1.83	1.71	6.11	6.80	0.06	0.07
Sample Variance	3.37	2.92	37.37	46.25	0.00	0.01
Kurtosis	0.86	0.34	1.58	-4.66	-1.77	-4.66
Skewness	1.24	0.75	-1.28	-0.09	0.98	-0.23
Range	5.00	4.00	17.00	14.00	0.12	0.14
Minimum	1.00	0.00	14.00	14.00	0.07	0.00
Maximum	6.00	4.00	31.00	28.00	0.19	0.14
Sum	17.00	7.00	149.00	85.00	0.67	0.32
Count	6.00	4.00	6.00	4.00	6.00	4.00
Confidence Level(95.0%)	1.93	2.72	6.42	10.82	0.06	0.12

Table B.12. TH 100 Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
TH 100, RP 8 to 13	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	33.33	27.00	174.67	159.50	0.19	0.16
Standard Error	1.93	6.49	5.81	22.04	0.01	0.02
Median	32.50	25.00	171.50	161.50	0.20	0.17
Mode	#N/A	#N/A	161.00	#N/A	#N/A	#N/A
Standard Deviation	4.72	12.99	14.24	44.08	0.03	0.04
Sample Variance	22.27	168.67	202.67	1943.00	0.00	0.00
Kurtosis	0.06	-2.55	-1.12	-3.64	0.41	1.49
Skewness	0.77	0.54	0.65	-0.15	-1.02	-0.53
Range	13.00	28.00	35.00	95.00	0.08	0.10
Minimum	28.00	15.00	161.00	110.00	0.14	0.11
Maximum	41.00	43.00	196.00	205.00	0.22	0.21
Sum	200.00	108.00	1048.00	638.00	1.15	0.65
Count	6.00	4.00	6.00	4.00	6.00	4.00
Confidence Level(95.0%)	4.95	20.67	14.94	70.14	0.03	0.07

Table B.13. TH 169 Descriptive Statistics

	WWA COUNT	WWA COUNT	TOTAL ACCIDENT	TOTAL ACCIDENT	WWA Fraction of TOTAL	WWA Fraction of TOTAL
169, RP 88 to 90	**Before**	**After**	**Before**	**After**	**Before**	**After**
Mean	2.43	1.33	8.00	10.33	0.35	0.14
Standard Error	0.37	0.33	1.40	3.84	0.06	0.02
Median	2.00	1.00	8.00	7.00	0.27	0.14
Mode	2.00	1.00	6.00	#N/A	#N/A	#N/A
Standard Deviation	0.98	0.58	3.70	6.66	0.17	0.03
Sample Variance	0.95	0.33	13.67	44.33	0.03	0.00
Kurtosis	0.04	#DIV/0!	-0.28	#DIV/0!	0.77	#DIV/0!
Skewness	0.28	1.73	-0.33	1.69	1.32	-0.42
Range	3.00	1.00	11.00	12.00	0.47	0.06
Minimum	1.00	1.00	2.00	6.00	0.20	0.11
Maximum	4.00	2.00	13.00	18.00	0.67	0.17
Sum	17.00	4.00	56.00	31.00	2.45	0.42
Count	7.00	3.00	7.00	3.00	7.00	3.00
Confidence Level(95.0%)	0.90	1.43	3.42	16.54	0.16	0.07