WET PAVEMENT CRASH STUDY
OF LONGITUDINALLY TINED PCC PAVEMENTS
TRANSVERSELY TINED PCC PAVEMENTS
AND
ASPHALT PAVEMENTS

A research effort expanding on a comparison of
Longitudinally and Transversely tined PCC Pavements

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July 8, 2004

This report represents the findings and opinions of the authors. It does not reflect official views of any private or public organization. The assumptions, data and analysis methodology used herein are presented in detail in the appendices of this document, so the reader can form an educated opinion about the validity of this effort.

ABSTRACT

This report provides crash statistics for Longitudinally Tined (LT) Portland Cement Concrete (PCC), Transversely Tined (TT) PCC and asphalt pavement surfaces. The statistics were compiled for urban and rural freeways, classified in two Average Daily Traffic (ADT) categories: pavements carrying less than 60,000 vehicles per day (VPD) and those carrying an ADT in excess of 60,000 VPD.

In California LT had a consistently lower crash rate than asphalt (although the difference was trivial on urban freeways with less than 60,000 ADT). This finding was based on very extensive data and is reliable. A direct comparison between TT (present only on bridge decks) and LT surfaces for urban freeways carrying more than 60,000 VPD indicated that TT had a lower crash rate than LT which, in turn, had a lower crash rate than asphalt pavements (95 crashes per 100 million vehicle miles of travel vs. 100, vs.108, respectively).

For Wisconsin rural freeways with an ADT less than 60,000 VPD the critical safety issue was not wet pavement performance, but pavement performance when snow or ice were present on the pavement. Although TT had a lower ratio of crashes on wet pavement divided by crashes on dry pavement (wet-to-dry ratio) than asphalt (0.16 and 0.23, respectively), the (wet + snow/ice)-to-dry ratio was in favor of asphalt pavements (1.50 for TT vs. 1.26 for asphalt). When the percent of time that frozen precipitation was present on pavements was taken into account, asphalt was still outperforming TT: the risk of being involved in a crash on snow- or ice- covered pavement compared to the risk of a crash on dry pavement was 20.30 times higher for TT vs. 15.09 times higher for asphalt.

Although urban and rural Wisconsin freeways demonstrated relatively small differences in terms of wet-to-dry ratios, the ice/snow-to-dry ratio for urban freeways was dramatically smaller than that for rural freeways, and smaller than the wet-to-dry ratio both for TT and asphalt surfaces. Based on this finding, it was hypothesized that the identified safety problem when frozen precipitation was present on rural pavements was not so much a function of pavement texture, as it was a function of winter maintenance operations (or any number of factors that differentiate rural from urban freeways when snow is present on the pavement).

This report represents the findings and opinions of the authors. It does not reflect official views of any private or public agency. The assumptions, data and analysis methodology used herein are presented in detail in the appendices of this document, so the reader can form an educated opinion about the validity of this effort.

ACRONYMS AND ABBREVIATIONS USED IN THE REPORT

100MVMT	=	Hundred Million Vehicle Miles of Travel
ADT	=	Average Daily Traffic
CalTrans	=	California Department of Transportation
DOT	=	Department of Transportation
FC	=	Friction Coefficient
FHWA	=	Federal Highway Administration
FN	=	Friction Number
HMVMT	=	Hundred Million Vehicle Miles of Travel
Long PCC	=	Longitudinally tined PCC surface
LT	=	Longitudinally Tined
MOE	=	Measures of Effectiveness
MVMT	=	Million Vehicle Miles of Travel
PCC	=	Portland Cement Concrete
Trns PCC	=	Transversely tined PCC surface
TT	=	Transversely Tined
TWG	=	Technical Working Group
WisDOT	=	Wisconsin Department of Transportation
VPD	=	Vehicles Per Day
VMT	=	Vehicle Miles of Travel
FSR	=	Frozen precipitation (snow or ice) Safety Ratio
LSR	=	Liquid precipitation (rain) Safety Ratio
HSIS	=	Highway Safety Information System

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INTRODUCTION

During the last few decades transverse tining (TT) was the surface texture predominantly used on high-speed Portland Cement Concrete (PCC) pavements. A number of studies pointed to definitive advantages of longitudinally tined (LT) PCC surface textures over TT ones in terms of traffic-generated noise. These studies provided a motivation for Departments of Transportation to adopt LT pavement surfaces; however, the fundamental issue of safety performance differences between the two types of surface textures needed to be addressed with a definitive study before LT surfaces were officially adopted in pavement design guidelines.

Lack of sufficient mileage of different types of pavement surface textures within the confines of any given State, necessitated an inter-State effort in order to create a substantial crash experience database. A number of states have sporadically applied LT texture on a small number of highway segments; only the state of California has adopted LT surface texture as the standard for all high-speed PCC pavements (with the exception of bridge decks where TT surfaces are used).

The present effort addresses the question whether LT pavement surfaces would be expected to perform at least equally well with the currently used TT pavement surfaces in Wisconsin. A definitive answer to this question was elicited through a safety performance comparison between TT and asphalt Wisconsin pavements and LT and asphalt California pavements.

At the outset of this investigation, differences between the two pavement surface textures were expected to emerge mainly when pavements were wet. Extensive hourly weather data were used in order to account for the dramatically different weather conditions between Wisconsin and California and year-to-year rainfall variations. Weather information was used to estimate the number of hours that pavements were wet in the two states, and thus estimate wet and dry pavement conditions exposure for crashes in each state.

The analysis was limited to freeways, the predominant high-volume, high-speed facilities in order to minimize, as much as practical, the influence of many extraneous factors that would be present in non-limited access facilities, such as intersections and driveways, traffic control, pedestrians, on-street parking etc. In addition, freeway design standards are generally uniform across states and the influence of highway geometry on safety performance would be minimized, given the requirements for gentle horizontal and vertical curvature on such facilities.

A total of eight years of statewide crash statistics were analyzed for each state, providing adequate temporal and spatial coverage. Database size allowed inclusion of thousands of crashes in each analyzed category.

Crash characteristics are quite different between urban and rural freeways: most crashes in urban freeways occur during peak traffic periods, involve multiple vehicles and, because they occur at the lower speeds present during these periods, have lower severity outcomes. Crash rates on rural freeways (which typically operate at a much higher Level of Service) are lower; single-vehicle crashes are proportionately higher, due to higher operating speeds, and more severe crash outcomes are more prevalent. For these reasons, urban and rural freeways were analyzed separately. In addition, freeways were classified by Average Daily Traffic (ADT) level. Because Wisconsin terrain is mainly level or rolling, only level and rolling terrain California data were used for comparisons with Wisconsin pavements. Mountainous terrain California data are available for the interested reader in **Appendix C**.

REPORT ORGANIZATION

Information presented in the body of the report is supported by self-contained Appendices that address specific issues. Appendix tables and figures are addressed by alphanumeric reference, for example, Figure D6 will be found in Appendix D; page C15 is in Appendix C.

The body of the report contains a **Literature Review**, followed by a description of the **Fundamental Issue Addressed in the Report**. **Database Considerations** are addressed next, pertaining to the types of data that were critical for this effort. ***The reader is encouraged to review the*** **Methodology** ***section that provides detailed definitions and explanations about the fundamental statistics used in the analysis.*** The **Findings** section presents the core findings about rural freeways in detailed and summarized format, followed by the **Conclusions** section where findings are discussed and some hypotheses are set forth. Four **Recommendations** conclude the body of the report.

Appendix A presents the textures that were in use in some of the contacted states, as well as PCC pavement texture specifications from CA, IL, MI, UT and WA.

Appendix B is a self-contained discussion on Wisconsin Friction Number data. The Appendix provides support for the Database Considerations part of the report.

Appendix C provides a self-contained description of the crash, pavement and analysis databases. A crash rate summary for Wisconsin and California is provided in **table C1. Table C2** provides a very detailed listing of annual crash rates and other crash statistics for urban and rural freeways for each state. Mountainous terrain California data are presented separately from rolling/level terrain data.

Appendix D provides **background data for the Findings** section of the report. The information is provided in tables and figures. **Important cautions for data presented in Appendix D are listed on page D2.**

Appendix E addresses the need for weather and precipitation data, the reasoning for choosing particular first order weather stations, and the reasoning for the chosen weather analysis methodology. Percentages of time that pavements were dry or covered with liquid or frozen precipitation are presented in **tables E3 and E4**. The issue of crashes on snow- or ice-covered freeways in Wisconsin is given extensive coverage and provides **support for the Conclusions** part of the report.

Appendix F provides a yearly summary of analyzed rural and urban Wisconsin mileage.

Appendix G presents detailed information about the analyzed Highway Safety Information System California database.

Appendix H provides a summary of information acquired during the data collection effort.

Appendix I is a listing of persons contacted during the data collection effort at various Agencies.

LITERATURE REVIEW

The following paragraphs contain a literature review focusing on issues related to PCC pavement surface textures: federal and state policy evolution, safety performance, Friction Number, and crash experience.

Federal and State PCC texture policy evolution

Portland Cement Concrete (PCC) pavements have been used extensively for many decades in the U.S., especially on high-volume high-speed highways. The Federal Highway Administration (FHWA) policy on surface finishing of PCC pavements, established in the late 1960s, stated that pavement surfaces provided on federally-aided highway projects should have a skid-resistant surface. FHWA favored an almost exclusive use of TT (with equally-spaced tines) on highways with speed limits of 65 km/hr or greater.

The California Department of Transportation, concerned with wet pavement crash experience, increased the minimum requirement for friction coefficient (FC) of new PCC pavements from 0.25 to 0.30 [1]. At the time, the most common texturing method was burlap drag, which typically satisfied the 0.25 FC requirement on new pavements. However the FC fell below the minimum even after very little traffic had used a new pavement. With the new requirement for a 0.30 FC, California was in urgent need to come up with a surface texturing technique that would produce long-lasting high FC. The concern with PCC textures that needed surface texture rehabilitation in order to obtain a satisfactory FC extended to other States as well.

Thus, a number of States (GA, TX, CA) embarked, in cooperation with FHWA, in various pilot projects to construct and test short highway segments using different pavement surface finishing techniques to produce a variety of textures, and choose those textures that seemed promising in terms of maintaining a high FC, while still being economically feasible. Most States decided to use TT texture, with the most notable exception of the State of California which started using LT texture exclusively (except on bridge decks where it used TT).

After the intense research activity on PCC surface textures in the seventies, most State DOT and FHWA pavement research activity concentrated on pavement structures, until the 1990s when the issue of pavement noise came to the forefront.

A Technical Working Group (TWG) representing State Highway Agencies, Industry, Academia and the FHWA convened on September 27, 1993 to address the issue of tire/pavement noise generated by TT pavements that generated complaints from motorists and property owners. The TWG published a comprehensive report [2] addressing the issues of: i) the basis for surface texture selection; ii) safety considerations; iii) the need for quality mix designs on heavily traveled high-speed-speed highways; iv) general PCC surface texture considerations; v) profile considerations; vi) alternative surface treatments to improve friction properties of existing PCC surfaces; and vii) research needs. The final meeting of the TWG was held on January 31, 1996.

The original FHWA policy favoring TT was modified in a Policy Memorandum authored by William A. Weseman, Director, Office of Engineering, dated November 1, 1995, to allow State highway agencies to select TT or LT or other surface texture techniques which meet the policy, if such decisions are supported by quantifiable data. The Policy Memorandum acknowledges the work of the TWG and refers readers to the preliminary summary of its findings.

A subsequent FHWA Policy Memorandum, issued on November the 12th, 1996, signed by Joseph S.Toole, Director, Office of Engineering , and Gerald L.Eller, Director, Office of Technology Applications, acknowledges the TWG final report and suggests that State highway agencies immediately update TT specifications for highways with design speeds of 80 km/h or higher to those suggested in Section 4 of the TWG final report Executive Summary. The recommended PCC surface textures were: i) transverse tining (with random tine spacing), preceded by a longitudinal artificial carpet or burlap drag; ii) longitudinal tining; iii) longitudinal plastic brushing; iv) exposed aggregate surface and other premium surface treatments (open-graded, two-layer construction, chip sprinkling).

Most common PCC pavement textures in use today

Since Federal guidelines have favored TT pavements for almost three decades, States have had an incentive to gravitate toward this surface treatment.

Indeed, most States, with the notable exception of California, have long adopted policies that parallel FHWA recommendations. For example, WisDOT Standard Specifications [3] require that all PCC pavements with design speeds of 60 km/h or higher receive an artificial turf (longitudinal) drag finish, followed by a transverse tined finish (WisDOT Standard Specifications Subsection 415.5.9.6.3).[1] However, CalTrans Standard Specifications require longitudinal texturing performed with a burlap drag or a broom, followed by the application of spring steel tine which will produce grooves parallel with the centerline (CalTrans Highway Design Manual [4] subsection 607.7).[1]

[1] See Appendix A.

Safety performance of PCC pavement textures

Although LT surface texture offers measurable traffic noise reduction, which is an important input in choosing PCC surface treatments for state-wide application, both FHWA and AASHTO currently recommend that safety not be compromised to obtain a slight, or short-term, initial reduction in noise levels [5, 6]. Safety performance remains the paramount consideration in Federal and State design guidelines. Quoting the TWG final report, **"The purpose of surface texture is to reduce the number and severity of wet weather accidents."**

Skid surveys and crash data in the late 1960s provided the motivation for California Department of Transportation engineers to seek PCC pavement surface treatments that would produce a higher FC. The most common treatment for PCC pavements with low FC used in California, was longitudinal grooving by diamond saws. In the late 1970s, a number of studies identified that wet pavement crash experience on such longitudinal surfaces was much lower. Crash reductions of 85% at 14 different Los Angeles locations and 75% at 77 locations across 13 states were noted [7]. Thus, California DOT was not concerned with the safety performance of longitudinal texture created with the use of diamond saws. Diamond sawing was only applied as a FC restoration measure on pavements that were typically six or more years old and was very costly (nearly $8 million spent between 1967 and 1973). A method to create a longitudinal texture during construction using a "steel runner sled groover" proved to be easy to use during construction, but was discarded when the California Highway Patrol concluded that the texture was very hazardous to motorcyclists, and probably to compact cars as well [8]. This was due to texture configuration and the fact that grooves did not run perfectly straight.

A LT texture created during another research effort (1972-1976) [9] using steel tines was judged to create only minor discomfort to light motorcycles with certain tire treads and occasionally slight lateral drift for light passenger cars and was adopted for all new concrete pavement construction. The texture was tested using three different motorcycle sizes at slow and highway speeds by representatives of the Transportation Laboratory and the California Highway Patrol.

LT texturing was thought to impart a "tracking" effect by providing resistance to lateral movement. Longitudinal diamond grooving was thought to reduce crashes, especially on curving highways [1].

Very few crash experience comparisons between different types of concrete pavement textures have been performed in the U.S. as of this writing [10]. A recent analysis was performed in Australia [11]. The TWG report cites a Minnesota study comparing crash experience on four types of concrete pavements in urban areas, based on crash experience between 1991 and 1993. The study provides Wet / (Wet+ Dry) crash ratios which are shown to be lower for TT pavements compared to diamond ground, burlap drag and "worn" PCC pavements. The TWG recommended that all States conduct similar types of analyses to verify that the surface textures being constructed result in low wet weather crash rates. The lack of crash experience comparisons was recognized at an international level at the PIARC 20th World Congress in September of 1995.

A crash rate comparison based on six years of crash experience (1988-1993) was conducted by the Marquette University Center for Highway and Traffic Engineering for WisDOT as part of a project to evaluate the effects of spot diamond grinding on the performance of PCC pavements [12] and the results were published in 1998 [13]. Longitudinally ground pavements were found to have lower crash rates than TT ones; six-year crash rate trends (similar to those recommended in the TWG report) did not reveal any detectable changes in crash rates for either texture type. FN information was not available for the analyzed highway segments.

Friction Number as a safety performance proxy

The lack of substantial mileage of different types of pavement textures within close proximity to each-other, and the need to introduce surface textures that promise noise and/or safety benefits in parts of the country where their presence is currently very limited or non-existent, has turned investigators' attention to the study of pavement skid resistance properties. Most commonly, Friction Number (FN), measured using either a ribbed or smooth tire (using ASTM Method E 274, tire E 501 or E 524) as the metric of a pavement's skid resistance. Benefits of using FN to assess pavement skid resistance properties include: i) ability to evaluate a texture based on very short pavement segments (crash rate-based safety evaluations require significant vehicle-miles of travel for reliable results); ii) transferability of findings across the country (however, FHWA recognizes that similar textures may yield different FN due to wide variations in climate, materials quality and variability); and, iii) ability to monitor FN variations with time.

Substantial FN differences between different pavement textures, and a general deterioration of FN with pavement age (with the exception of exposed aggregate surface treatment that shows an initial increase in FN after construction), and cumulative vehicle passes since construction have been documented in the literature [14, 15, 16]. Despite the general usefulness of FN in assessing pavement friction properties, and the transferability of results between different parts of the country, the final TWG report recognizes that: "Available information supports only a general correlation between friction numbers and wet weather crash rates." The report recommends that additional multi-year studies are necessary to establish FN relations with crash occurrence.

FUNDAMENTAL ISSUE ADDRESSED

The present effort is a comparison of transversely tined Wisconsin PCC pavements with longitudinally tined PCC pavements in other states. The focus of this comparison is wet pavement crashes. Motivation is provided by findings of lower highway noise levels generated by longitudinally tined surfaces vis-à-vis concerns for the safety performance of these pavements when compared to the widely used transversely tined surfaces.

Departments of Transportation would use a quieter pavement surface texture, especially in urban areas, if it is shown not to be detrimental to safety; inferior safety performance will immediately disqualify a surface texture from further consideration.

DATABASE CONSIDERATIONS

As indicated in the literature review, the most prevalent PCC pavement surface texture in use today on high-speed (speeds over 40 mph) high-volume pavements is TT tining, which is also the prevalent PCC pavement texture in use by the Wisconsin Department of Transportation. Various studies that indicated that longitudinal textures have traffic noise reduction benefits motivated a comprehensive review of various pavement surface textures. States currently applying TT texture are hesitant to experiment with longitudinal textures without proof that they are at least equally safe.

Issues needed to be addressed

The critical issue that needed to be addressed was whether differences existed in the safety performance of TT and LT pavement surface textures on high-speed, high-volume facilities. If any such differences existed, they were expected to be evident under wet pavement conditions, rather than on dry pavements.

The fundamental shortcomings of safety analyses conducted thus far had been their limited spatial and/or temporal scope, limitations that the present analysis attempts to overcome. Ideally, a direct comparison of crash performance of different types of surface treatments should be conducted within a limited geographic area (a State or a part of a State), in order to control for factors not related to pavement texture such as: environment (e.g., weather, daylight hours), driver characteristics (e.g., aggressive driving habits, driver education), speed limits (maximums differ by State), access control policies, design and construction parameters (e.g., allowable maximum superelevation values, minimum radii, construction materials). However, at the outset of the present study, it was very improbable that adequate mileage of different PCC surface texture treatments could be found within a limited geographic area, since it was more economical for State governments to limit PCC pavement texture choices in order to simplify the design, bidding and construction processes.

Database: variables and spatial extent

Crash data

Given the above observations, an inter-state safety performance comparison would be necessary. With an emphasis on a safety performance comparison with Wisconsin TT pavements, the first preference for the present study would be a comparison with Mid-Western states. The closest states known to have used LT texture were Minnesota, Iowa, Colorado, and Virginia. Although these states had used LT texture, its application was either recent and very limited or had been discontinued (Virginia), creating a research challenge because: 1) where limited mileage was available it would have not been adequate to accumulate a substantial number of crashes for a valid statistical analysis; 2) pavement construction and reconstruction dates would be difficult to determine; 3) exact project limits would be difficult to determine. Where LT texture was employed sporadically, crash experience would be very difficult to analyze given the difficulty of matching temporally and spatially with pavement surface texture data and the non-uniform analysis periods.

The literature review indicated that California had used LT texture on high-speed PCC pavements exclusively for the last few decades. Application of LT texture statewide for an extensive period of time guaranteed that LT texture would be present in all analyzed PCC pavements.

Weather data

Climate differences between California, the best identified LT pavement crash experience source, and Wisconsin, necessitated the use of detailed and accurate weather information, in order to account for the effect of weather differences between the two states on crash experience. This information could be used to calculate an approximation of the hours during which pavements were wet in each analyzed state during each analysis year, and calculate specific wet pavement crash rates.

Friction data

The explanatory variable most commonly used to establish a relationship between safety performance and pavement surface texture has been Friction Number (FN). Use of FN as a surrogate for wet pavement safety performance would allow transferability of results between different parts of the country, under the assumption that similar textures would produce similar FNs. However, FN measurements have a great variability; their correlation with crash experience was found to be weak.[2]

The final TWG report states that: "Available information supports only a general correlation between friction numbers and wet weather crash rates." Appendix D of the same report states: "While friction properties are a convenient way to estimate the safety characteristics of various pavement types and surface textures, the real test is whether the pavement texture reduces the number and severity of wet weather accidents." The report recommended that analyses over consecutive 3- to 5-year periods were needed to determine (1) the wet weather accident rates of different textures and pavement types and (2) the change in friction numbers and accident rates over time for the different textures and pavement types."

Availability of extensive FN databases was investigated during the data collection effort (see **Appendix H** for a list of collected data).

Database emphasis

The main focus of the data collection effort was on identifying multi-year state-wide crash databases that could readily be linked to travel and roadway information (pavement surface material and texture, highway classification, Average Daily Traffic, pavement condition at the time of the crash). Weather information was also necessary in order to estimate the number of hours pavements had been wet during each year and thus calculate estimates of the relative risk of a crash occurring on a wet versus a dry pavement surface. The FN data collection effort was given secondary importance for reasons explained in **Appendix B**.

[2] A discussion based on a brief analysis of Wisconsin FN information is presented in Appendix B.

METHODOLOGY

If safety differences existed between LT and TT pavement surfaces, these differences were expected to be the greatest under wet conditions, and especially where high operating speeds prevailed. Rural freeways were chosen as the ideal facilities for the desired comparison for a number of reasons:

1. They are typically not congested, thus free-flow speeds are likely to prevail.
2. No intersections are present—intersections introduce a large number of variables affecting safety performance (number of approach lanes, traffic control parameters, cross-street volumes etc.)
3. There is no friction with on-street parking, pedestrians and bicyclists.
4. Good quality crash data and other highway information is available.
5. High geometric design standards eliminate the influence of sharp horizontal and vertical curves on crashes.
6. Uniform geometric design standards eliminate the influence of differences in state-specific geometric design practices.
7. A large number of crashes is typically available for analysis.

The facilities chosen for analysis also met the following criteria:

- Design speed of 50 mph or higher;
- Level or Rolling terrain.

Deer crashes were eliminated from analysis.[3]

Extensive data were available in California for LT and asphalt pavement surfaces; Wisconsin had information on TT and asphalt pavement surfaces. Information on TT in California was derived exclusively from bridge decks, the only TT pavements in California. It was used with caution, given the special nature of bridge decks.

The following safety performance Measures of Effectiveness (MOE) were calculated for each pavement surface texture for each year for each of the two states (definitions and interpretations of these MOE are presented in the following section):

- Crash rate
- Wet-to-Dry ratio
- Snow/Ice-to-Dry ratio
- Liquid precipitation Safety Ratio
- Frozen precipitation Safety Ratio

The most valid comparisons among pavement surface textures were those performed within each state, since they reflected similar climate, driving habits etc. Thus, asphalt pavements were compared within each individual state to the other pavement texture for which reliable

[3] Detailed information on crashes included in the analysis is presented in Appendix C.

information was available within the state (LT in California, TT in Wisconsin). The relative performance of the textures of interest (LT and TT) was derived through a comparison with asphalt pavements.

MOE Definitions and Interpretations

This section presents the meaning and interpretation of statistics discussed below. Information presented in the Findings section[4] was calculated using eight significant digits; tabulated information was rounded in the interest of presentation economy thus some small discrepancies may be noted between the presented rounded figures.

Crash rates were calculated as total crashes per one hundred million vehicle miles of travel (HMVMT OR 100 MVMT) and rounded to integer values. A higher crash rate indicates that a higher number of crashes occurred per vehicle-mile of travel, and is an indication of poorer safety performance.

$$Crash\,Rate = (Total\,crashes) \div (100\ MVMT)$$

The wet-to-dry ratio (Wet to Dry crashes) is the number of crashes that occurred on wet pavement, divided by the number of crashes that occurred on dry pavement. This ratio is affected by the amount of wet precipitation in a given area. For example, a wet-to-dry ratio of 0.50 indicates that half as many crashes occurred on wet pavements as they did on dry pavements. If the region where this ratio was observed had half as many rain days as it had dry days, then the risk of being involved in a crash on a wet pavement would be equal to the risk of being involved in a crash on a dry pavement. However, the same wet-to-dry ratio (0.50) would indicate a much higher risk of a wet pavement crash, if pavements were wet only 25% of the time. Thus, the wet-to-dry ratio is mainly useful in comparisons between facilities that experience similar rainfall patterns. Under similar rainfall patterns, a high wet-to-dry ratio would indicate facilities that are more prone to wet pavement crashes.

The snow/ice-to-dry ratio (Frozen to Dry crashes) is the number of crashes that occurred on pavement covered with frozen precipitation (snow or ice) divided by the number of crashes on dry pavement. Its interpretation is similar to that of the wet-to-dry ratio.

Because the denominators of the wet-to-dry ratio and the snow/ice-to-dry ratio are the same (number of crashes on dry pavement), the two ratios can be added to provide a ratio of crashes when any precipitation is present on a pavement, to crashes on dry pavement.

[4] A complete listing can be found in Appendix D.

The Liquid precipitation Safety Ratio (LSR) was defined based on the following formula:

$$LSR = \left(Tot\_Liquid \div \%\ time\ Liquid\ \ precip\ on\ pavement\right) \div \left(Tot\_Dry \div \%\ \ dry\ time\right)$$

Where:

Tot_Liquid is the number of crashes on wet pavement
Tot_Dry is the number of crashes on dry pavement
% time Liquid precip on pavement is the percent of time a pavement is wet
% dry time is the percent of time a pavement is dry

The LSR can be thought of as the ratio of the *wet pavement crash rate* (number of crashes on wet pavement divided by 100 MVMT on wet pavement) divided by the *dry pavement crash rate* (number of crashes on dry pavement divided by 100 MVMT on dry pavement). Since travel on wet (dry) pavement is calculated by multiplying the total vehicular travel in a year by the percent time that a pavement is wet (dry), total travel is eliminated, and the result is the above formula.

The LSR can also be expressed as:

$$\begin{aligned} LSR &= (Tot\_Liquid \div Tot\_Dry) \times (\%\ dry\ time \div \%\ Liquid\ time) \\ &= (wet-to-dry\ ratio) \times (\%\ dry\ time \div \%\ Liquid\ time) \end{aligned}$$

That is, LSR is the wet-to-dry ratio multiplied by an adjustment factor that indicates how much more frequently pavements are dry than wet. This factor allows comparisons of wet pavement performance across areas with different rainfall patterns.

LSR provides a measure of how many times more likely one is to be involved in a wet pavement crash, relative to being involved in a dry pavement crash if equal mileage is driven under each of these two pavement conditions. Calculation of LSR requires weather and precipitation information, as well as information of how long pavements remain wet after precipitation accumulation on the pavement. Details of how weather and precipitation data were used are provided in **Appendix E**.

Frozen precipitation Safety Ratios (FSR) were defined based on the following formula:

$$FSR = \left(Tot\_Fzn \div \%\ time\ \ Frozen\ precip\ on\ pavement\ \right) \div \left(Tot\_Dry \div \%\ time\ dry\ pavement\right)$$

Where:

Tot_Fzn is the number of crashes when snow or ice were present on the pavement
Tot_Dry is the number of crashes on dry pavement

Thus, FSR interpretation is identical to the LSR interpretation, with the difference being that this ratio refers to the risk of a crash occurring when snow or ice are present on the pavement surface, relative to the risk of a crash occurring on dry pavement if equal mileage is driven under each of these two pavement conditions.

Analyzed freeway length is presented in *directional miles* for Wisconsin freeways, and *centerline miles* for California freeways; traffic volumes were appropriately adjusted to provide vehicular travel. Average Daily Traffic (ADT) volume thresholds used in presented summaries are bi-directional.

FINDINGS

Essential background

The following presentation of findings is based on safety performance statistics listed in the Appendices: **Appendix C** contains comprehensive tables of findings; **Appendix D** presents information (tables and figures) focused on:

- Wisconsin rural freeways with less than 60,000 ADT.
- California rural freeways with less than 60,000 ADT.
- California urban freeways with less than 60,000 ADT.
- California urban freeways with more than 60,000 ADT.

The focus of the present evaluation was a safety comparison of wet TT and LT high-speed pavements. Rural freeways were chosen as the ideal representatives of such pavements. The majority of available mileage is rural freeways with less than 60,000 VPD; very limited mileage is available for other rural freeways, especially in Wisconsin. Statistics for Wisconsin rural freeways are presented first, followed by California statistics.

The section concludes with a presentation of urban California freeway statistics which are of secondary importance to the present analysis (since lower speeds prevail on such pavements), but still quite useful: LT texture is desired in the urban environment because it generates a lower noise level. Very limited information was available for Wisconsin urban freeways; it is not presented here--all available information can be found in **Appendices C and D**.

Wisconsin Rural Freeways

Table 1 below (identical to **table D1**) presents statistics extracted from **Appendix C** for Wisconsin rural freeways with ADT less than 60,000 VPD. **Figures D1-D5** provide a visualization of this information. With minor exceptions in 1991 and 1997, asphalt surfaces provided a lower overall crash rate than TT surfaces (38 crashes compared to 42 crashes per 100 MVMT), higher wet-to-dry ratios (0.23 vs. 0.16) and lower snow/ice to dry ratios (1.00 vs. 1.34). Thus, overall, asphalt surfaces provided a lower crash ratio when any form of precipitation was present on the pavement, compared to dry pavements (1.23 vs. 1.50).

Overall, LSR were lower for TT pavements with the exception of 1992 and 1996 (**figure D4**). Given the meteorological conditions present in Wisconsin during the analyzed years, the risk of getting involved in a crash on wet TT surface was 2.25 (LSR = 2.25) times higher than that of being involved in a dry TT surface crash. The relative risk was 3.11 times higher on asphalt surfaces.

Overall, FSR were lower for asphalt surfaces (15.09 vs. 20.30 for TT). The exception was 1993 when asphalt and TT surfaces had nearly equal performance (**figure D5**). FSR values were much higher than LSR values, indicating that the risk of being involved in a crash when snow or ice were present on the pavement was much higher compared to the risk of being involved in a crash when pavements were wet. This finding, although tangential to the main focus of the present effort on wet pavement crashes, was one of the most significant findings of the present effort.

The high values of FSR make sense, given that an almost equal number of crashes occurred when snow or ice were present on the pavement (conditions present for only 5.8 % of the VMT) with the number of crashes on dry pavement (condition present for 88% of the VMT). **Table E3** presents a summary of Wisconsin weather conditions.

Table 1. Wisconsin Rural Freeway Statistics 1991-1998. Less than 60K VPD.

Year	Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
1991	Trns PCC	47	.19	1.54	267	2.21	22.25	119.7	5.6
	Asphalt	49	.26	1.47	244	3.05	21.22	122.8	5.0
1992	Trns PCC	40	.28	1.08	233	3.18	14.12	121.4	5.8
	Asphalt	31	.23	.75	249	2.56	9.75	176.2	8.1
1993	Trns PCC	46	.20	1.15	391	2.16	13.27	166.8	8.5
	Asphalt	40	.25	1.18	358	2.71	13.55	195.1	8.9
1994	Trns PCC	40	.08	1.56	345	1.21	22.48	166.8	8.6
	Asphalt	35	.23	1.14	316	3.70	16.39	195.1	9.0
1995	Trns PCC	40	.12	1.00	382	1.51	14.28	185.6	9.6
	Asphalt	37	.21	.70	337	2.72	10.06	195.1	9.2
1996	Trns PCC	50	.23	2.03	522	4.07	34.35	196.8	10.4
	Asphalt	47	.20	1.41	496	3.52	23.86	218.9	10.6
1997	Trns PCC	35	.13	1.62	411	2.39	28.84	219.7	11.6
	Asphalt	36	.20	.95	477	3.61	16.87	268.7	13.2
1998	Trns PCC	40	.14	1.00	497	2.16	22.76	233.7	12.5
	Asphalt	35	.25	.72	511	3.88	16.50	296.7	14.5
Overall Statistics									
	Trns PCC	42	.16	1.34	3048	2.25	20.30	233.7	72.6
	Asphalt	38	.23	1.00	2988	3.11	15.09	296.7	78.4

A brief discussion on crashes when frozen precipitation is present on pavements can be found in **Appendix E**.

Thus, the most important finding is that of very high numbers of crashes and a high risk of being involved in a crash, when pavements were covered with snow or ice. The number of crashes under such conditions was almost equal, or exceeded the number of crashes on dry pavement in five of the eight analyzed years (**Table C1**).

California Rural Freeways

Table 2 below (also **table D5**) presents statistics extracted from **Appendix C** for rural freeways with ADT less than 60,000 VPD. Only rolling and flat terrain freeways were included.

Statistics for LT and asphalt pavements were very consistent from year-to-year, with minor fluctuations (**figures D6-D10**). Asphalt pavements had a higher crash rate in each of the analyzed eight years with an overall 50 crashes per HMVMT, compared to 42 crashes per HMVMT for LT pavements.

Asphalt surfaces had lower wet-to-dry ratios during five years and almost equal ratios during the remaining three years (**figure D7**). There were too few crashes on rural freeways covered with snow (typically less than 100 per year-**table C1**) for reliable annual statistics, however, the snow-to-dry pavement ratios were remarkably stable through the analyzed years (**figure D8**). The overall snow-to-dry pavement ratio for LT pavements at 0.03 was three times as high as that for asphalt pavements.

Liquid precipitation Safety Ratios (LSR) for asphalt pavements were lower five out of the eight analyzed years (**figure D9**). Asphalt pavements had an overall LSR of 2.13 compared to an LSR value of 2.39 for LT pavements.

Although Frozen precipitation Safety Ratios are presented in **table 2**, available California frozen precipitation data were not reliable. ***Appendix E*** *provides more detailed information on this caution*.

As mentioned above, the only information for TT pavements was based solely on the performance of bridge decks. Due to their limited length (23.4 miles) and thus limited crash experience, possibility of special geometry (narrower shoulders) and factors affecting pavement condition (ice formation before ice formation on adjacent highway segments), annual statistics are provided only as general information. The overall performance of this pavement texture was inferior to that of asphalt and LT pavements, in terms of crash rate (65 crashes per HMVMT), wet-to-dry ratio (0.17), and LSR (3.57).

Limited mileage is available for rural freeways carrying ADT greater than 60,000 VPD, especially for asphalt and TT pavements. Statistics for these freeways can be found in **Appendix C**. *This information should be used with caution due to the limited extent of the supporting database.*

Table 2. California Rural Freeway Statistics 1991-1998. Rolling & Flat terrain. Less than 60K VPD.

Year	Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Wet Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
1991	Trns PCC	66	.12	.03	143	2.54	12.68	23.5	2.2
	Long PCC	42	.08	.02	2668	1.62	8.34	733.5	63.4
	Asphalt	50	.08	.01	2514	1.66	2.24	655.8	50.5
1992	Trns PCC	66	.16	.01	143	3.68	3.23	23.5	2.2
	Long PCC	41	.11	.02	2608	2.42	7.44	733.5	63.4
	Asphalt	45	.09	.01	2295	2.08	3.09	655.8	50.5
1993	Trns PCC	70	.22	.06	151	4.19	23.21	23.5	2.2
	Long PCC	42	.09	.02	2663	1.71	9.54	733.5	63.4
	Asphalt	49	.09	.01	2471	1.79	2.67	655.8	50.5
1994	Trns PCC	62	.15	.02	134	4.09	6.91	23.5	2.2
	Long PCC	42	.09	.02	2646	2.60	8.84	731.6	63.6
	Asphalt	51	.07	.01	2580	2.05	2.16	656.1	50.8
1995	Trns PCC	58	.17	.04	126	2.79	17.38	23.4	2.2
	Long PCC	44	.14	.02	2720	2.27	9.89	730.1	62.5
	Asphalt	50	.13	.01	2667	2.13	2.70	656.1	53.5
1996	Trns PCC	65	.19	.10	146	3.99	66.84	23.4	2.2
	Long PCC	45	.14	.03	2922	2.93	20.23	730.8	64.5
	Asphalt	51	.11	.01	2775	2.24	5.25	654.1	54.0
1997	Trns PCC	70	.14	.06	159	4.41	17.45	23.2	2.3
	Long PCC	42	.09	.02	2726	2.66	6.11	719.8	64.6
	Asphalt	51	.09	.00	2834	2.75	1.22	658.7	55.8
1998	Trns PCC	59	.22	.08	134	3.62	24.47	23.1	2.3
	Long PCC	42	.19	.05	2692	3.06	15.80	715.4	64.4
	Asphalt	53	.14	.02	3004	2.34	4.99	657.3	56.2
Overall Statistics									
	Trns PCC	65	.17	.05	1136	3.57	18.89	23.1	17.6
	Long PCC	42	.12	.03	21645	2.39	10.13	715.4	509.7
	Asphalt	50	.10	.01	21140	2.13	2.93	657.3	421.8

California Urban Freeways

Aggregate eight-year statistics for all California Urban freeways with an **ADT of less than 60,000 VPD** are presented in **table 3** below (also **table D6**). Annual summaries are presented in **tables C1** and **D6** and **figures D11-D15**. Crash rates for LT and asphalt surfaces are virtually identical (76 vs. 77 crashes per HMVMT) with minor year-to-year fluctuations throughout the analyzed period (**figure D11**). Wet-to-dry ratios are lower for LT than asphalt surfaces, with an overall difference of 0.03. LT pavements have a lower LSR (3.45) than asphalt pavements (4.15).

TT bridge decks have a slightly higher crash rate (78 crashes per HMVMT) than the other two analyzed pavement surfaces. They also have a higher wet-to-dry ratio and a substantially higher LSR. *Because these findings are based on a limited mileage, they should be viewed as preliminary.*

Table 3. California Urban Freeway Statistics 1991-1998. Less than 60K VPD.

Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Trns PCC	78	.25	.01	2900	5.27	4.78	31.6	37.1
Long PCC	76	.17	.00	23132	3.45	1.83	260.3	304.2
Asphalt	77	.20	.00	22011	4.15	1.80	282.3	285.8

Eight-year statistics for urban freeways with an **ADT of more than 60,000 VPD** are presented in **table 4**. Annual statistics are presented in **tables C1** and **D7** and **figures D16-D20**. Very substantial databases are available for each surface texture in this category, with approximately 700 thousand crashes contributing to the summary statistics. TT surfaces had the lowest crash rates with 95 crashes per HMVMT, followed by LT and asphalt surfaces with 100 and 108 crashes per HMVMT, respectively. Crash rate statistics were exceptionally stable through the analyzed time period (**figure D16**). LT surfaces had the lowest wet-to-dry and LSR (0.16 and 3.22, respectively). TT and asphalt surfaces were virtually tied at a wet-to-dry ratio of 0.20 and LSR of 4.09 and 4.10, respectively. Substantial mileage and crashes were available for TT (109 miles, more than 46,000 crashes); *it should be kept in mind that these statistics represent bridge deck performance exclusively.*

Table 4. California Urban Freeway Statistics 1991-1998. More than 60K VPD.

Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Trns PCC	95	.20	.00	46380	4.09	.29	114.9	490.3
Long PCC	100	.16	.00	486892	3.22	.17	1114.6	4863.0
Asphalt	108	.20	.00	159060	4.10	.17	404.1	1467.0

Summary of findings

Rural freeways less than 60,000 VPD
The focus of the present effort was on the safety performance of rural freeways under wet pavement conditions. Safety performance statistics were analyzed for Wisconsin and California freeways with ADT less than 60,000 VPD.

Wisconsin data indicated that TT surfaces had higher crash rates than asphalt surfaces (42 vs. 38 crashes per HMVMT). The wet-to-dry ratio for TT surfaces was lower than that of asphalt surfaces (0.16 vs. 0.23, respectively). The number of crashes when the pavement surface was covered with frozen precipitation (ice or snow) was very substantial, equal to or surpassing the number of crashes on dry pavement five out of the eight analyzed years. TT pavements had a substantially higher frozen-to-dry ratio than asphalt pavements (1.34 vs. 1.00). Thus, asphalt pavements provided a lower crash ratio when any form of precipitation was present on the pavement, relative to dry pavements (0.23 + 1.00 = 1.23) compared to TT surfaces (0.16 + 1.34 = 1.50).

Similar findings were reflected in the LSR and FSR for the two pavement textures: TT surfaces had lower LSR (2.25 vs. 3.11 for asphalt), but higher FSR (20.30 vs. 15.09).

California data demonstrated that LT pavement surfaces had lower crash rates than asphalt surfaces (42 vs. 50 crashes per HMVMT). The wet-to-dry ratio was higher for LT surfaces (0.12 vs. 0.10 for asphalt); the same applied for LSR (2.39 vs. 2.13, respectively).

TT surfaces had the highest crash rates, wet-to-dry ratios and LSR among analyzed surfaces. However, statistics were based on a very limited mileage (23.4 miles) of bridge decks. Given the limited spatial extent and special conditions that may be present on bridges, *this information can only be viewed as preliminary.*

Urban California freeways less than 60,000 VPD
Crash rates for LT and asphalt surfaces were virtually identical (76 vs. 77 crashes per HMVMT). LT surfaces had lower wet-to-dry ratio and LSR (0.17 and 3.45 , respectively), compared to 0.20 and 4.15 for asphalt surfaces.

TT surfaces had the poorest performance, but closely followed asphalt surfaces, with a crash rate of 78 crashes per HMVMT, a wet-to-dry ratio 0.25 and LSR = 4.78). *These results should be viewed as preliminary, because they are based on a limited mileage* (33 miles) comprising exclusively of bridge decks.

Urban California freeways more than 60,000 VPD
LT surfaces outperformed asphalt surfaces, with a lower crash rate (100 vs. 108 crashes per HMVMT, respectively), lower wet-to-dry ratio (0.16 vs 0.20) and lower LSR (3.22 vs. 4.10). The data are extremely stable, based on 650 thousand crash records.

A substantial database exists for TT bridge decks (109 miles, 46,000 crashes), which outperform LT surfaces in terms of crash rate (95 vs. 100 crashes per HMVMT) but are outperformed in terms of wet-to-dry ratio (0.20 vs. 0.16) and LSR (4.09 vs. 3.22).

Overall

Wisconsin: Asphalt surfaces had lower crash rates, slightly higher wet to-dry ratios and LSR and substantially lower snow-to-dry ratios and FSR than TT surfaces on rural freeways carrying less than 60,000 VPD.

California: LT surfaces had lower crash rates and slightly higher wet-to-dry ratios and LSR than asphalt surfaces on rural freeways. On urban freeways with less than 60,000 VPD, LT surfaces had virtually identical crash rates with asphalt; they had lower crash rates than asphalt on urban freeways with more than 60,000 VPD. Wet-to-dry ratios and LSR were lower for LT surfaces in general in the urban environment.

CONCLUSIONS

Direct crash rate comparisons between California and Wisconsin are not meaningful, because of the major climate differences between the two states. Wisconsin crash rates are influenced by the significant presence of frozen precipitation, which is almost absent in California. However, crash rate comparisons between pavement textures within each of the analyzed states are meaningful, since crashes within each state occurred under similar weather conditions.

Asphalt pavements that are present in both analyzed states can serve to measure the relative performance of Transversely Tined (TT) and Longitudinally Tined (LT) pavements, provided that similar asphalt surfaces are used in both states, and comparisons are performed on similar facilities carrying similar traffic volumes. Thus, conclusions summarized below are organized by facility type and ADT level; comparisons are confined to one state at a time.

Rural freeways with less than 60,000 ADT

LT surfaces had a lower overall crash rate than asphalt surfaces (42 vs. 50 crashes per HMVMT) and slightly higher wet-to-dry ratio (0.12 vs. 0.10) and Liquid precipitation Safety Ratio[5] (LSR = 2.39 vs. 2.13). These findings are firmly established, based on the extensive California crash database.

TT surfaces had a higher crash rate than asphalt surfaces (42 vs. 38 crashes per HMVMT), a lower wet-to-dry ratio (0.16 vs. 0.23) but higher frozen-to-dry ratio (1.34 vs. 1.00) on rural Wisconsin freeways. When wet-to-dry and frozen-to-dry precipitation ratios were added, TT surfaces had a ratio of 1.50 compared to 1.23 for asphalt surfaces. TT surfaces had lower Liquid precipitation Safety Ratio (LSR = 2.25 vs. 3.11 for asphalt), but higher Frozen precipitation Safety Ratio[5] (FSR = 20.30 vs. 15.09).

[5] Wet-to-Dry ratio, Liquid precipitation Safety Ratio (LSR), snow/ice-to-dry ratio and Frozen precipitation Safety Ratio (FSR) are defined in the Methodology part of the report.

As was pointed out in the Findings section, the most important safety issue revealed during the present analysis was pavement performance when snow or ice were present on the pavement. Overall pavement safety performance in Wisconsin greatly depended on the magnitude of the snow-to-dry ratio, and by extension on the FSR. As was demonstrated for Wisconsin rural freeways, although TT surfaces had a lower wet-to-dry ratio than asphalt surfaces, the scales tip in the opposite direction for the (wet + ice/snow)-to-dry ratio, which is higher for TT than asphalt surfaces, to the point that the TT crash rate is higher.

(California frozen precipitation data were not reliable, as explained in page E5).

Urban freeways
All comparisons were based on California data; TT information was derived exclusively from bridge decks.

LT had lower crash rates, wet-to-dry ratios and LSR than asphalt surfaces (76 vs. 77 crashes per HMVMT, 0.17 vs. 0.20 ratio and 3.45 vs. 4.15 LSR) on lower volume freeways (ADT < 60,000 VPD). The limited TT mileage did not provide adequately supported statistics.

Adequate information was available to compare all three textures on higher volume urban freeways. TT (present exclusively on bridge decks) had the lowest crash rate (crash rates were 95 crashes per HMVMT for TT, 100 for LT and 108 for asphalt). LT had the lowest LSR (3.22) with TT and asphalt virtually tied (4.09 and 4.10, respectively). It is interesting to observe that TT had the lowest crash rate, despite a higher LSR than LT.

In the above comparison, one texture had the lowest crash rate (TT), and the other (LT) had the lowest LSR. Which of these two statistics should be driving decision-making? It seems logical to choose the texture associated with the lower crash rate: the lower crash rate indicates a lower overall number of crashes for the same amount of vehicular travel. As long as the higher LSR does not result in a larger overall number of crashes, higher chances of being involved in a crash on wet pavement (i.e., a higher LSR) do not indicate higher overall chances of being involved in a crash (crash rate).

Overall
The picture that emerges from California is that LT had a consistently lower crash rate than asphalt (although the difference was trivial on urban freeways with less than 60,000 ADT). This finding was based on very extensive data and is reliable. The only reliable direct comparison between TT and LT surfaces was for urban freeways carrying more than 60,000 VPD: TT bridge decks had a lower crash rate than LT freeway segments. They both had lower crash rates than asphalt pavements.

It was shown for Wisconsin rural freeways that the critical safety issue was not wet pavement performance, but pavement performance when snow or ice were present on the pavement. Although TT had a lower wet-to-dry ratio than asphalt, the (wet + snow/ice)-to-dry ratios were overwhelmingly in favor of asphalt pavements (1.50 for TT vs. 1.26 for asphalt). FSR were also overwhelmingly in favor of asphalt with a value of 20.30 for TT vs. 15.09 for asphalt.

Unfortunately, due to data scarcity, FSR could not be calculated accurately for the analyzed California database and the safety performance of LT relative to TT under frozen precipitation conditions could not be estimated.

The discussion on differences between urban and rural Wisconsin crash experience in **Appendix E** indicates that, although urban and rural freeways demonstrate relatively small differences in terms of wet-to-dry ratios, a large discrepancy exists between ice/snow-to-dry ratios. *Preliminary findings* for asphalt pavements carrying more than 60,000 VPD, indicate a similar discrepancy: urban and rural wet-to-dry ratios were very similar (0.24 and 0.19, respectively- **tables D2 and D4**), however snow/ice-to dry ratios varied widely (0.20 urban vs. 0.62 rural).

For urban Wisconsin freeways the **frozen-to-dry ratio** is **lower** than the **wet-to-dry ratio** due, perhaps, to more aggressive urban winter maintenance programs (plowing and spreading salt and abrasives), lower operating speeds, and higher traffic volumes that help maintain brine on the pavement and/or help the pavement dry faster. Thus, frozen precipitation may be melted (or removed) before it has the extremely detrimental effects it apparently has on rural Wisconsin freeways.

This observation leads to the following suggestions:

1. The identified safety problem when frozen precipitation is present on rural pavements is not so much a function of pavement texture, as it is a function of winter maintenance operations. The effect of winter maintenance operations may be significant enough to dwarf the magnitude of any identified differences between TT and asphalt surfaces, in terms of safety performance when frozen precipitation is present on the pavement; and,
2. If LT textures were to be constructed in the urban environment (where their lower noise generation makes them desirable) they would be performing mostly under liquid (melted), not frozen precipitation. A safety performance similar to that quantified for urban California freeways would then be expected:
    - For ADT < 60,000 VPD crash rates identical to asphalt.
    - For ADT > 60,000 VPD crash rates lower than asphalt (but higher than TT).

It was not possible to assess LT performance on bridge decks, since bridge decks were TT in all contacted states.

RECOMMENDATIONS

1. The importance of frozen precipitation for Wisconsin rural freeway pavement safety performance emerged during the present analysis. It was not possible to accurately assess LT texture performance when frozen precipitation was present on the pavement. It was observed, however, that urban pavement safety performance in the presence of frozen

precipitation was similar to that under wet pavement conditions. Crash rates for wet LT pavements were shown to be within an acceptable range (below those of asphalt pavements and above those of TT pavements). Thus, it is recommended that, if LT pavements are constructed in Wisconsin, they be constructed in an urban area, with high winter maintenance standards where any frozen precipitation would either be removed or melted promptly.

2. It was indicated in the literature search that initial attempts at constructing LT textures were abandoned due to concerns about the quality of ride for motorcycles and light vehicles. It is recommended that extensive communications are exchanged with Departments of Transportation that are currently constructing LT textures in order to avoid similar pavement surface construction pitfalls when/if they are first introduced in Wisconsin.
3. LT texture is used extensively in CalTrans District 3, which is in charge of an extensive network of snow routes. Contacts with the District 3 Office of Maintenance Equipment and Emergency Operations are recommended in order to address any winter maintenance concerns related to LT surfaces. Such contacts will identify the types of winter maintenance equipment, materials and policies in force by CalTrans.
4. Aggressive winter maintenance on rural Wisconsin freeways will, in all likelihood provide dramatic crash reductions, if frozen precipitation is promptly removed and/or melted.

ACKNOWLEDGMENTS

This report was compiled by Alex Drakopoulos and Dave Kuemmel of Marquette University, Milwaukee, Wisconsin. The authors gratefully acknowledge the help of a great number of individuals, without whose help this volume would have not been possible: From the Wisconsin Department of Transportation-Steve Krebbs, Dave Larson, Dick Lange, Brad Javenkoski, Mike Schumacher, Peter Amakobe, Laura Fenley; from the Turner-Fairbank Highway Research Center, Yusuf Mohamedshah; from the Midwest Research Institute Doug Harwood; from NOAA William Brown; from the Wisconsin State Climatologist Office Lyle Anderson; and all individuals mentioned in **Appendix I.**

This report represents the findings and opinions of the authors. It does not reflect official views of any private or public organization. The assumptions, data and analysis methodology used herein are presented in detail in the appendices of this document, so the reader can form an educated opinion about the validity of this effort.

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APPENDIX A

PCC PAVEMENT SURFACE TEXTURES IN USE
AND
PCC PAVEMENT SURFACE TEXTURE SPECIFICATIONS

INTRODUCTION

The present Appendix contains information gathered from contacted states. Pavement surface treatment specifications are either direct quotes from specification manuals or information provided via e-mail contact (MI transversely tined, UT).

PCC PAVEMENT SURFACE TEXTURES IN USE

CALIFORNIA

Longitudinally tined texture was used since the 1970s on all high-speed PCC pavements, except bridge decks where transversely tined texture was used.

COLORADO

Longitudinal texture: uniformly spaced longitudinal tining at 3/4 of an inch intervals with the depth and width of 1/8 of an inch is currently specified. Transversely tined texture: tines every 1” .

ILLINOIS

Two types of surface textures in use on PCC pavements: Type A (transversely grooved) and Type B (single artificial turf drag). Type A used on pavements with a posted speed greater than 40 mph; Type B texture used on pavements with lower posted speeds.

MAINE

Asphaltic concrete used exclusively since 1975-1976; about 72 lane miles of PCC were slated to be overlaid with asphalt; bridge decks transversely tined PCC.

MICHIGAN

Prior to 1969 no tining was used. Transverse tining used since 1975. Michigan has used very little longitudinal tining on a trial basis.

UTAH

Transverse tining for high-speed PCC pavements. No tining for urban highways with speeds less than 65 km/hr.

VIRGINIA

Two tining processes in the Road and Bridge Specifications - longitudinal tining and transverse tining. Up until the early 1980s most of VDOT's PCC pavements were tined in the longitudinal direction. As concerns for hydroplaning increased, VDOT moved to uniform transverse tining.

WASHINGTON STATE

PCC is primarily used on interstates, but densely graded asphalt is also used. Only transversely tined pavement surface texture is used for PCC. The state has approximately 700 miles of interstate highways, 250 miles of which have been rehabbed. In the majority of the rehabbed pavements, the right lane has been continuously ground.

WISCONSIN

Transverse tining used on PCC pavements since 1978. Asphalt pavements used as well.

PCC PAVEMENT SURFACE TEXTURE SPECIFICATIONS

CALIFORNIA

STANDARD SPECIFICATIONS
STATE OF CALIFORNIA
BUSINESS, TRANSPORTATION AND HOUSING AGENCY
DEPARTMENT OF TRANSPORTATION
JULY, 1999
ISSUED BY

DEPARTMENT OF TRANSPORTATION
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
PUBLICATION DISTRIBUTION UNIT
1900 Royal Oaks Drive
Sacramento, California 95815
Telephone (916) 445-3520

40-1.09 PRELIMINARY FINISHING

- In each day's work the Contractor shall mark the pavement with an approved stamp. This stamp shall be approximately 0.3-m by 0.6-m in size and shall be furnished by the Contractor at the Contractor's expense. The stamp mark shall be located 6 m ± 1.5 m from the transverse contact joint formed at the start of each day's work and 0.3-m± 0.1-m from the outside edge of pavement. The stamp mark shall show month, day and year of placement, and Engineer's station for the transverse contact joint and shall be oriented so that the stamp mark can be read from a position at the outside edge of pavement.
- Prior to completion of float finishing and texturing, water shall not be applied to the pavement surface in excess of the amount lost by evaporation.
- Placement of concrete shall cease at such time that finishing operations can be completed during daylight hours, unless lighting facilities provided by the Contractor are determined by the Engineer to be adequate for allowing later placement and finishing.

40-1.09A Stationary Side Form Finishing

- After spreading and compacting, concrete shall be given a preliminary finish by one of the following methods:

40-1.09A(1) Machine Float Method

- Self-propelled machine floats shall be used to finish pavement smooth and true to grade.
- The number and capacity of machine floats furnished shall be adequate to perform all work required at a rate equal to that at which concrete is delivered. Any delay exceeding 30 minutes in performing preliminary finishing shall constitute cause for stopping delivery of concrete until machines performing the work are again in proper position to continue without delay.

- Machine floats shall be capable of running either on side forms or on adjacent lanes of pavement. When machine floats run on adjacent pavement, its surface shall be protected as specified in Section 40-1.07, "Spreading, Compacting and Shaping."
- Floats shall be constructed of hardwood, steel or steel-shod wood. They shall be equipped with devices to permit adjusting the under side to a true flat surface.

40-1.09A(2) Hand Method

- Pavement shall be finished smooth and true to grade with suitable manually operated floats or powered finishing machines.
- Finishing shall take place as far back of concrete spreading operations as concrete remains workable, and the number of passes shall be sufficient to remove all perceptible inequalities.

40-1.09B Slip-Form Finishing

- Pavement shall be given a preliminary float finish by means of devices incorporated in the slip-form paver. These may be supplemented, at the Contractor's option, with suitable machine floats.
- Any edge slump of pavement, exclusive of edge rounding, in excess of 6 mm shall be corrected before concrete has hardened.

40-1.10 FINAL FINISHING

- After preliminary finishing has been completed, edges of initial paving widths shall be rounded to 12 mm radius. Transverse contact joints and the edge of longitudinal contact joints adjacent to hardened concrete pavement shall be rounded to 6 mm radius.
- In advance of curing operations, pavement shall be given an initial and a final texturing. Initial texturing shall be performed with a burlap drag or broom device which will produce striations parallel with centerline. Final texturing shall be performed with a spring steel tine device which will produce grooves parallel with centerline. The spring steel tine device shall be operated within 130 mm, but not closer than 75 mm, of pavement edges.
- Except when texturing areas of pavement finished in conformance with the provisions in Section 40-1.09A(2), "Hand Method," burlap drags, brooms and tine devices shall be installed on self-propelled equipment having external alignment control. The installation shall be such that when texturing, the area of burlap in contact with the pavement surface shall be maintained constant at all times. Broom and tine devices shall be provided with positive elevation control. Down pressure on pavement surface shall be maintained at all times during texturing so as to achieve uniform texturing without measurable variations in pavement profile. Self-propelled texturing machines shall be operated so that travel speed when texturing is maintained constant. Failure of equipment to conform to all provisions in this paragraph shall constitute cause for stopping placement of concrete until the equipment deficiency or malfunction is corrected.
- Spring steel tines of the final texturing device shall be rectangular in cross-section, 2.4 to 3.2 mm wide, on 19-mm centers, and of sufficient length, thickness and resilience to form grooves approximately 5 mm deep in the fresh concrete surface. Final texture shall be uniform in appearance with substantially all of the grooves having a depth between 1.5 and 8 mm.
- Initial and final texturing shall produce a surface having a coefficient of friction not less than 0.30 as determined by California Test 342.

- Tests to determine coefficient of friction will be made before pavement is opened to public traffic, but not sooner than 7 days after concrete placement. Pavement containing areas that have a coefficient of friction less than 0.30 shall be grooved as directed by the Engineer before opening it to public traffic.
- Finished pavement shall conform to the following provisions in not more than 10 days following placement of concrete:

The surface will be straightedged, at locations to be determined by the Engineer, with a straightedge 3.6 m ± 0.06-m long. When the straightedge is laid on finished pavement in a direction parallel with centerline or normal to centerline, the surface shall not vary more than 6 mm from the lower edge.

Any high points that cause the surface to exceed these tolerances shall be removed by grinding as provided in this Section 40-1.10.

The surface shall be profiled, by the Contractor in the presence of the Engineer, using a California Profilograph or equivalent in conformance with the requirements in California Test 526 and these provisions. Prior to beginning profiles, the profilograph shall be calibrated in the presence of the Engineer. Profiles shall be made 1.0 m from and parallel with each edge of pavement and at the approximate location of each longitudinal joint for all pavement areas except those specified herein.

Pavement so profiled shall conform to the following Profile Index requirements:

1. Pavement on tangent alignment and pavement on horizontal curves having a centerline radius of curve 600 m or more shall have a Profile Index of 11 mm or less for each 0.1-km.
2. Pavement on horizontal curves having a centerline radius of curve 300 m or more but less than 600 m and pavement within the superelevation transition of those curves shall have a Profile Index of 19 mm or less for each 0.1-km.

Pavement within 15 m of a transverse joint that separates the pavement from a structure deck or an approach slab shall meet the profile requirements of Section 51-1.17, "Finishing Bridge Decks."

Checking the following areas of pavement surface with the California Profilograph or equivalent will not be required:

1. Pavement on horizontal curves having a centerline radius of curve less than 300 m and pavement within the superelevation transition of those curves.
2. Pavement within 15 m of a transverse joint that separates the pavement from an existing pavement not constructed under the contract.
3. Pavement for exit ramp termini, truck weigh stations, ramps and connectors with steep grades and high rates of superelevation and short sections of city or county streets and roads.

Individual high points in excess of 7.5 mm, as determined by measurements of the profilogram in conformance with the requirements in California Test 526, shall be reduced by grinding as provided in this Section 40-1.10, until the high points as indicated by reruns of the profilograph do not exceed 7.5 mm.

After grinding has been completed to reduce individual high points in excess of 7.5 mm, additional grinding shall be performed as necessary to reduce the Profile Index to values specified above in any 0.1-km section along any line parallel with the pavement edge.

Additional grinding shall be performed as necessary to extend the area ground in each lateral direction so that the lateral limits of grinding are at a constant offset from, and parallel with, the nearest lane line or pavement edge, and in each longitudinal direction so that the grinding begins and ends at lines normal to the pavement centerline, within any one ground area. All ground areas shall be neat rectangular areas of uniform surface appearance.

When pavement is ground or grooved as specified herein, the work shall be performed in conformance with the provisions in Section 42, "Groove and Grind Pavement," except that residue from grinding or grooving operations shall be disposed of outside the highway right of way in conformance with the provisions in Section 7-1.13.

The original of final profilograms that indicate the pavement surface is within the Profile Index specified shall become the property of the State and shall be delivered to the Engineer prior to acceptance of the contract.

ILLINOIS

Standard Specifications for Road and Bridge Construction
Adopted January 1, 2002.

SECTION 420. PORTLAND CEMENT CONCRETE PAVEMENT
420.11 Final Strike Off, Consolidation, and Finishing.

(e) Final Finish. Type A final finish shall be used unless Type B is specified.
(1) Type A. Type A final finish shall be obtained by the use of a carpet drag composed of an artificial turf approved by the Engineer followed immediately by a mechanically operated metal comb transverse grooving device. The artificial turf shall be made of molded polyethylene with synthetic turf blades approximately 20 mm (0.85 in.) long and contain approximately 7,200 individual blades per 0.1 sq m (sq ft).

The artificial turf shall be suitably attached to an approved device that will permit control of the time and rate of texturing. The artificial turf carpet shall be full pavement width and of sufficient size that during the finishing operation, approximately 600 mm (2 ft) of carpet parallel to the pavement centerline will be in contact with the pavement surface. The drag shall be operated in a longitudinal direction so as to produce a uniform appearing finish meeting the approval of the Engineer. If necessary for maintaining intimate contact with the pavement surface, the carpet may be weighted.

The metal comb shall consist of a single line of tempered spring steel tines spaced at 20 mm (3/4 in.) centers and securely mounted in a suitable head. The tines shall be flat and of a size and stiffness sufficient to produce a groove of the specified dimensions in the plastic concrete without tearing of the pavement edge or surface. The Contractor shall modify the equipment or operations if an acceptable pavement edge or surface is not produced. The mechanically operated metal comb shall be attached to an exclusive piece of equipment which is mechanically self-propelled and capable of traversing the entire pavement width being placed in a single pass. The artificial turf carpet drag may be attached to this piece of equipment provided a surface texture is produced satisfactory to the Engineer. The tining device shall be operated so as to produce a relatively uniform pattern of grooves perpendicular to the pavement centerline spaced at approximately 20 mm (3/4 in.) centers, 3 to 5 mm (1/8 to 3/16 in.) deep and 2.5 to 3.2 mm (0.100 to 0.125 in.) wide. No other operation will be permitted with this equipment. Separate passes will be required for the turf dragging operation and the tining operation.

Hand tining or tining with a mechanically operated comb combined with the curing equipment specified in Article 1101.09 will be permitted where the Specifications permit hand finishing or vibratory screeds, one lane construction up to 5 m (16 ft) wide, gaps, projects with a net length of 800 m (1/2 mile) or less, and where the production rate on any paving day will be less than 1200 cu m (1,500 cu yd) per day. A foot bridge shall be provided for the hand tining operation for all pavement over 3.6 m (12 ft) wide, unless it can be demonstrated to the satisfaction of the Engineer that an alternate texturing operation produces satisfactory results.

Pavement texture not meeting the above spacing and depth requirements shall be corrected by the Contractor at his/her own expense. Regrooving in either plastic or hardened concrete shall be done transversely meeting the spacing and depth requirements as stated above.

(2) Type B. Type B final finish shall be obtained by the use of a single artificial turf drag. The artificial turf shall conform and be operated according to the requirements for Type A finish, except this device shall not be attached to other pieces of equipment in the paving train but shall be a separate piece of equipment used expressly for the texturing operation. Pavement texture damaged by rain may be restored by retexturing the concrete while in the plastic state.

MICHIGAN

Current specification:

Transverse tining: 3/4" nominal spacing between grooves with some desired random spacing for noise mitigation. The grooves are approximately 1/8" wide by 1/8" deep. A burlap drag precedes the tinning. The timing of the grooving is specified to prevent excessive tearing of the concrete.

Few short applications of longitudinal tining on a trial basis are based on the following specification:

MICHIGAN
DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION
FOR
LONGITUDINAL TINNING SURFACE TEXTURE

a. Description- This work shall consist of texturing concrete pavement with longitudinal tinning. Replace the second paragraph in section 6.02.03K, 1996 Standard Specifications for Construction, with the following :

Immediately after dragging, all surfaces other than concrete base courses, shoulders and gore areas shall be tinned longitudinally with a track machine. The tinning process shall produce grooves of 2.5 mm (± 0.5 mm) width, by 3mm (± 0.5 mm) depth, spaced on 19 mm (± 2 mm) centers. The grooves shall be parallel to the longitudinal joint(s) without noticeable wander, overlap, or a wave pattern. The grooves shall be formed in the plastic concrete without either slumping of the edges or severe tearing of the surface. Prior to paving, the Contractor shall provide a written description of the intended tinning process for the Engineer's approval to ensure that the grooves will be parallel and uniformly spaced.

If surface corrections are made to the hardened concrete, the amount of macro-texture shall be verified in accordance with ASTM E965, “Test Method for Measuring Surface Macrotexture Depth Using a Sand Volumetric Technique,” to ensure the texture is adequate for skid resistance and does not cause excessive tire noise. A minimum mean texture depth (MTD) of 1.0 mm is required, but it shall not exceed 2.50 mm to assure noise mitigation. If the specified MTD is not being achieved, the Contractor shall suspend operations until a revised procedure is approved by the Engineer. In lieu of re-correcting the surface, a MTD between 0.80 mm and 1.0 mm is acceptable with a contract pay adjustment equal to ten percent of the unit cost of the concrete pavement. A MTD of less than 0.80 mm is unacceptable and shall be corrected to achieve the desired macro-texture.

Any areas represented by a single test with a texture depth of less than 0.50 mm or greater than 2.50 mm will require additional correction. The limits for correction shall be determined by performing additional test measurements at a maximum 30 meter interval along the wheel path from the original failing test location. Additional testing shall continue until a minimum 0.80 mm texture depth is achieved. The Engineer will then use the results to determine the limits for texture correction.

b. Measurement and Payment - All costs associated with this special provision will not be paid for separately, but shall be included in the pay item for concrete pavement.

UTAH

Current Standard Specification for Portland Cement Concrete Pavement states:

Texture the pavement by burlap drag and transverse tining.

1. Use at least three piles of wet burlap and drag parallel to the centerline without tearing.
2. Complete the drag finish with one pass.
3. Form depressions in the plastic concrete surface with the tining comb:
    a. Randomly spaced (15mm to 25mm)
    b. 2 mm to 4 mm deep normal to centerline.
    c. Do not tear or remove excess mortar in the tining process.
4. Do not tine Category 5 highways (i.e., Urban highways with design speed < 65 km/hr).

WASHINGTON STATE

From the 2000 Standard Specifications-English units, pp. 5-44 and 5-45 (these specifications remain unchanged in the 2004 edition)
http://www.wsdot.wa.gov/fasc/EngineeringPublications/Manuals/SS2000English.pdf

5-05.3(11) Finishing
After the concrete has been given a preliminary finish by means of finishing devices incorporated in the slip-form paving equipment, the surface of the fresh concrete shall be checked by the Contractor with a straightedge device not less than 10 feet in length. High areas indicated by the straightedge device shall be removed by the hand-float method.

Each successive check with the straightedge device shall lap the previous check path by at least one half of the length of the straightedge. The requirements of this paragraph may be waived if it is successfully demonstrated that other means will consistently produce a surface with a satisfactory profile index and meeting the 10-foot straightedge requirement specified in Section 5-05.3(12).

Any edge slump of the pavement, exclusive of specified edging, in excess of 1/4 inch shall be corrected before the concrete has hardened. If edge slump on any 1foot or greater length of hardened concrete exceeds 1 inch, the concrete shall be repaired as provided in section 5-05.3(22).

The pavement shall be given a final finish surface by texturing with a comb perpendicular to the center line of the pavement. The comb shall produce striations approximately 1/8 inch to 3/16 inch in depth. Randomly space the striations from 1/2 inch to 11/4 inch. The comb shall be operated mechanically either singly or in gangs with several placed end to end. Finishing shall take place with the elements of the comb as nearly perpendicular to the concrete surface as is practical, to eliminate dragging the mortar. If the striation equipment has not been previously approved, a test section shall be constructed prior to approval of the equipment. If the pavement has a raised curb without a formed concrete gutter, the texturing shall end 2 feet from the curb line.
At the beginning and end of paving each day, the Contractor shall, with an approved stamp, indent the concrete surface near the right hand edge of the panel to indicate the date, month, and year of placement.

At approximate 500-foot intervals where designated by the Engineer the Contractor shall, with an approved stamp, indent the concrete surface near the right hand edge of the pavement with the stationing of the roadway.

APPENDIX B

WISCONSIN PCC PAVEMENT FRICTION NUMBER DISCUSSION

INTRODUCTION

The explanatory variable most commonly used to establish a relationship between safety performance and pavement surface texture has been Friction Number (FN). The method used to obtain the FN for a given pavement simulates pavement performance under wet pavement conditions. Thus, a typical operating assumption for a number of previous research efforts was that low FNs would be associated with a higher number of wet pavement crashes; conversely, higher FNs would be associated with fewer wet pavement crashes.

Benefits and disadvantages of FN as pavement safety performance explanatory variable

FN allowed transferability of results between different parts of the country, under the assumption that similar textures would produce similar FNs. As indicated in the literature search part of the report, both assumptions were not universally true:

1. Although a general correlation has been identified between low FN and inferior safety performance, this correlation was not found to be very strong; and,
2. Quite different FNs can be obtained for the same pavement surface texture due to materials quality and variability, among other factors.

In other words, FN was not found to be a good explanatory variable for safety performance, and FN-based findings were not guaranteed exact transferability across the country.

FN varies depending on when measurements were taken (for example, after a long dry period, or after a strong rain), and the locations at which they were taken. It should also be noted that data are typically collected at 40-50 mph speeds, which are much lower than typical freeway free-flow operating speeds, thus FNs at freeway operating speeds are typically extrapolated; any correlations with safety performance are subject to errors related to the accuracy of such extrapolations.

FN data are collected on one lane and in one wheel path at a time. Under typical highway traffic conditions, FN is lower for the shoulder lane than for the median lane, due to a heavier lane usage; FN values vary among wheel paths. Thus, a single FN cannot meaningfully characterize a freeway segment friction performance. Although a lower FN can be expected on the shoulder lane (as a result of higher pavement wear due to heavier traffic), the lower speeds present in this lane may more than compensate for this deficiency—wet pavement crashes may be due to higher vehicle speeds in the median lane, despite its higher FN, but information on the lane in which a crash occurred is not typically available, thus this issue cannot be resolved satisfactorily.

Ideal FN database attributes

The final TWG report states that: “Available information supports only a general correlation between friction numbers and wet weather crash rates.” Appendix D of the same report states: “While friction properties are a convenient way to estimate the safety characteristics of various pavement types and surface textures, the real test is whether the pavement texture reduces the number and severity of wet weather accidents.” The report recommended that “additional analyses over consecutive 3- to 5-year periods were needed to determine (1) the wet weather accident rates of different textures and pavement types and (2) the change in friction numbers and accident rates over time for the different textures and pavement types.”

A large, multi-year FN database would be necessary to address the issue of FN deterioration with pavement age/cumulative vehicle passes. An ideal FN database would contain information collected at the same location for a large number of pavement sections, over a number of years.

DISCUSSION BASED ON WISCONSIN FN DATA

This Appendix presents a discussion of FN data collected during the period 1975-1994 in Wisconsin for a variety of pavement surface textures. The discussion focuses on some of the FN fluctuations addressed above. A complete listing of the database is accompanied by figures demonstrating FN fluctuation along a single direction of travel and between directions of travel for a specific highway, and year-to-year FN fluctuations at a specific location. The Appendix also presents FN correlations with the number of years a pavement had been in service and with cumulative heavy vehicle passes since construction.

The database comprises of 534 Friction Number (FN) observations. **Table B1** presents a comprehensive listing of the recorded FN organized by pavement surface texture treatment, highway, location (from reference point, to reference point), lane in which the data were collected and the data collection year and month. Data from **Table B1** were used to create **figures B1–B4**.

Figure B1 presents data collected in both directions of Interstate 90 (I-90) in September of 1981. The figure demonstrates that substantial FN variations exist within and between travel directions. The tested pavement was constructed between 1959 and 1973. It is thus to be expected that substantial differences exist in cumulative vehicle passes between freeway segments. However, FN varies substantially within pavement sections in a given travel direction constructed during the same year and experiencing similar traffic volume levels. Furthermore, if an even daily directional split is assumed for I-90, FN differences between directions of travel for the same freeway segment cannot easily be explained, given that all FN tests were conducted on the same month.

Figure B2 presents FN variations between lanes on a three-lane Eastbound segment of Interstate 90 for the period 1985-1994. As expected, the shoulder lane (lane 1), carrying the heaviest traffic volumes consistently displays the lowest FN. FN change from year-to-year for each of the three lanes does not show a consistent FN deterioration; furthermore, the direction of change from year-to-year is not consistent among the three lanes.

The most comprehensive FN database was for transversely tined PCC pavements, with a total of 291 observations. FN relations with pavement age are summarized in **figure B3**, where information is presented separately for the shoulder lane and other lanes. No clear FN pattern emerges in that figure, perhaps due to the substantially different traffic volumes carried on the pavements in the database. In order to account for the effect of traffic on FN, **figure B4** presents FN information as a function of cumulative Million Heavy Vehicle Passes (MHVP) for tined PCC pavement surfaces. Heavy vehicle volume information was only available for the shoulder lane, thus the sample size used in **figure B4** is 170 observations. There is a very broad range of FN values at each level of MHVP, thus the correlation between the two analyzed variables was not strong. Among the best fitting simple regression models used to explain FN as a function of MHVP,[1] the power model:

$$FN = 49.33 * MHVP^{-0.37569}$$

provided the best fit with an $R^2 = 0.123$ (the regression line for the model is shown on **Figure B4**). Similar results ($R^2 = 0.152$) were obtained from a simple regression model using Accumulated Vehicle Passes in the shoulder lane.

DISCUSSION

Given the variability of FN values present in the analyzed database, using FN as a proxy for the likelihood of wet pavement crashes was given a much lower priority than a comprehensive crash experience analysis. Still, FN data availability was investigated with each of the contacted state Departments of Transportation, in order to assess the following issues:

1. Whether FN measurements could readily be "mapped" to crash locations.
2. Whether a large number of observations was available in order to correlate FN with crashes as close as possible to the location where FN measurements were obtained. Ideally, a representative FN would be available fro each of a large number of short freeway segments.
3. Whether a large number of observations was available in order to correlate FN with crashes that occurred during the same year FN information was obtained.
4. Whether FN variability similar to that presented in the preceding discussion, based on Wisconsin data, existed in other states.

[1] The following regression models were calibrated: Linear, logarithmic, inverse, compound, power, growth, exponential, logistic.

Table B1. FN data 1975-1994 Part 1

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
ASTRO-TURF DRAG	43N	95D	99K	N/B Shoulder lane	75	Dec.	45
			99M	N/B Shoulder lane	76	Oct.	51
					77	May	54
					78	May	50
					79	Jun.	43
					80	Jun.	49
						Sep.	44
					81	Jun.	40
						Oct.	47
					82	Jul.	44
					83	Jul.	36
					84	Aug.	36
		99M	101D	N/B Shoulder lane	75	Dec.	49
					76	Oct.	60
					77	May	63
					78	May	57
					79	Jun.	51
					80	Jun.	55
						Sep.	53
					81	Jun.	46
						Oct.	49
					82	Jul.	49

Table B1. FN data 1975-1994 Part 2

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
ASTRO-TURF DRAG	43N	99M	101D	N/B Shoulder lane	83	Jul.	41
					84	Aug.	42
	Mean						48
	43S	95D	99M	S/B Shoulder lane	75	Dec.	46
					76	Oct.	53
					77	May	57
					78	May	53
					79	Jun.	47
		99M	101D	S/B Shoulder lane	75	Dec.	47
					76	Oct.	62
					77	May	64
					78	May	55
					79	Jun.	50
	Mean						53
Mean							50

Table B1. FN data 1975-1994 Part 3

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
BURLAP DRAG	15E	70K	70K	E/B Shoulder lane	82	Sep.	35
					84	Jul.	33
	Mean						34
	15W	70K	70K	W/B Shoulder lane	82	Sep.	36
					84	Jul.	34
			73	W/B lane 2	82	Sep.	37
					84	Jul.	36
	Mean						36
	41N	14	15K	N/B lane 2	82	Sep.	30
					84	Jul.	28
	Mean						29
	41S	14	15K	S/B lane 2	82	Sep.	30
					84	Jul.	28
	Mean						29
	45N	49	50	N/B lane 2	82	Sep.	29
					84	Jul.	28
		50	53	N/B lane 2	82	Sep.	30
					84	Jul.	28
	Mean						29
	45S	49	50	S/B lane 2	82	Sep.	28
					84	Jul.	26
		50	53	S/B lane 2	82	Sep.	28
					84	Jul.	27
	Mean						27
	81E	99B	112B	-E-	80	Jun.	53

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
BURLAP DRAG	81E	99B	112B	-E-	80	Aug.	49
					81	Jun.	44
						Oct.	50
					82	Aug.	49
					83	Aug.	46
					84	Aug.	47
					90	Aug.	53
					92	Sep.	54
					94	Jul.	54
				E&W	76	Nov.	54
					77	May	60
					78	May	54
					79	May	46
	Mean						51
	90E	1C	3K	E/B Shoulder lane	81	Sep.	38
		3K	5T	E/B Shoulder lane	81	Sep.	40
		10D	13G	E/B Shoulder lane	81	Sep.	38
		13G	20K	E/B Shoulder lane	81	Sep.	37
		20K	28K	E/B Shoulder lane	81	Sep.	41
		28K	34D	E/B Shoulder lane	81	Sep.	39
		34D	39T	E/B Shoulder lane	81	Sep.	36
		39T	43M	E/B Shoulder lane	81	Sep.	37

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
BURLAP DRAG	90E	45T	52K	E/B Shoulder lane	81	Sep.	40
		52K	55G	E/B Shoulder lane	81	Sep.	39
		55G	60G	E/B Shoulder lane	81	Sep.	40
		61K	68D	E/B Shoulder lane	81	Sep.	41
		69K	74G	E/B Shoulder lane	81	Sep.	37
		79K	85T	E/B Shoulder lane	81	Sep.	38
		86K	89M	E/B Shoulder lane	81	Sep.	36
		89M	92M	E/B Shoulder lane	81	Sep.	39
		106M	111M	E/B Shoulder lane	81	Sep.	32
		111M	118K	E/B Shoulder lane	81	Sep.	34
		118K	123D	E/B Shoulder lane	81	Sep.	34
		123D	126G	E/B Shoulder lane	81	Sep.	34
		129K	133M	E/B Shoulder lane	81	Sep.	33
		134M	137D	E/B Shoulder lane	81	Sep.	33
		138D	142G	E/B Shoulder lane	81	Sep.	37
						Nov.	36
					82	Sep.	34
					83	Sep.	30
					84	Aug.	31
					85	Aug.	32
					86	Aug.	32

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
BURLAP DRAG	90E	138D	142G	E/B Passing lane	81	Nov.	43
					82	Sep.	47
					83	Sep.	42
					84	Aug.	39
					85	Aug.	44
					86	Aug.	43
		142G	145K	E/B Shoulder lane	81	Sep.	35
		145K	150D	E/B Shoulder lane	81	Sep.	37
		150D	154G	E/B Shoulder lane	81	Sep.	36
		155M	159K	E/B Shoulder lane	81	Sep.	37
		159K	163G	E/B Shoulder lane	81	Sep.	37
		163G	167T	E/B Shoulder lane	81	Sep.	38
		168T	172G	E/B Shoulder lane	81	Sep.	38
		172G	174K	E/B Shoulder lane	81	Sep.	36
		174K	177K	E/B Shoulder lane	81	Sep.	36
		177K	182K	E/B Shoulder lane	81	Sep.	38
		182K	187T	E/B Shoulder lane	81	Sep.	36
	Mean						37
	90W	1C	3K	W/B Shoulder lane	81	Sep.	38
		3K	5T	W/B Shoulder lane	81	Sep.	42
		10D	13G	W/B Shoulder lane	81	Sep.	38
		13G	20K	W/B Shoulder lane	81	Sep.	38

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
BURLAP DRAG	90W	20K	28K	W/B Shoulder lane	81	Sep.	42
		28K	34D	W/B Shoulder lane	81	Sep.	39
		34D	39T	W/B Shoulder lane	81	Sep.	36
		39T	43M	W/B Shoulder lane	81	Sep.	35
		45T	52K	W/B Shoulder lane	81	Sep.	39
		52K	55G	W/B Shoulder lane	81	Sep.	38
		55G	60G	W/B Shoulder lane	81	Sep.	37
		61K	68D	W/B Shoulder lane	81	Sep.	38
		69K	74G	W/B Shoulder lane	81	Sep.	36
		79K	85T	W/B Shoulder lane	81	Sep.	42
		86K	89M	W/B Shoulder lane	81	Sep.	37
		89M	92M	W/B Shoulder lane	81	Sep.	39
		94M	97K	W/B Shoulder lane	81	Sep.	40
		98M	101T	W/B Shoulder lane	81	Sep.	41
		101T	106M	W/B Shoulder lane	81	Sep.	43
		106M	111M	W/B Shoulder lane	81	Sep.	34
		111M	118K	W/B Shoulder lane	81	Sep.	36
		118K	123D	W/B Shoulder lane	81	Sep.	34
		123D	126G	W/B Shoulder lane	81	Sep.	33
		129K	133M	W/B Shoulder lane	81	Sep.	32
		134M	137D	W/B Shoulder lane	81	Sep.	32

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
BURLAP DRAG	90W	138D	142G	W/B Shoulder lane	81	Sep.	46
		142G	145K	W/B Shoulder lane	81	Sep.	35
		145K	150D	W/B Shoulder lane	81	Sep.	36
		150D	154G	W/B Shoulder lane	81	Sep.	39
		155M	159K	W/B Shoulder lane	81	Sep.	38
		159K	163G	W/B Shoulder lane	81	Sep.	39
		163G	167T	W/B Shoulder lane	81	Sep.	39
		168T	172G	W/B Shoulder lane	81	Sep.	38
		172G	174K	W/B Shoulder lane	81	Sep.	37
		174K	177K	W/B Shoulder lane	81	Sep.	39
		177K	182K	W/B Shoulder lane	81	Sep.	39
		182K	187T	W/B Shoulder lane	81	Sep.	38
	Mean						38
	94E	311D	312D	E/B lane 2	82	Sep.	28
					84	Jul.	26
		312M	314K	E/B lane 2	82	Sep.	31
					84	Jul.	28
		314K	315D	E/B lane 2	82	Sep.	28
					84	Jul.	26
		315D	315G	E/B lane 2	82	Sep.	31
					84	Jul.	28
		318G	323T	E/B lane 2	82	Sep.	35

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
BURLAP DRAG	94E	318G	323T	E/B lane 2	84	Jul.	32
		323T	325D	E/B lane 2	82	Sep.	37
	Mean						30
	94W	311D	312D	W/B lane 2	82	Sep.	29
					84	Jul.	28
		312M	314K	W/B lane 2	82	Sep.	30
					84	Jul.	29
		314K	315D	W/B lane 2	82	Sep.	28
					84	Jul.	26
		315D	315G	W/B lane 2	82	Sep.	30
					84	Jul.	27
		318G	323T	W/B lane 2	82	Sep.	33
					84	Jul.	30
		323T	325D	W/B lane 2	82	Sep.	35
	Mean						30
	119E	3	5	E/B Shoulder lane	82	Jul.	53
					84	Jul.	50
	Mean						51
	119W	3	5	W/B Shoulder lane	82	Jul.	47
					84	Jul.	45
	Mean						46
	145N	3	6	N/B lane 2	82	Sep.	40
					84	Jul.	38
	Mean						39

Table B1. FN data 1975-1994 Part 10

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
BURLAP DRAG	145S	3	6	S/B lane 2	82	Sep.	41
					84	Jul.	38
	Mean						40
	894E	4T	4T	E/B lane 2	82	Sep.	30
			7D	E/B lane 2	82	Sep.	32
		7D	8D	E/B lane 2	82	Sep.	28
		8D	9D	E/B lane 2	82	Sep.	30
				W/B lane 2	82	Sep.	30
	Mean						30
	894W	4T	4T	W/B lane 2	82	Sep.	31
			7D	W/B lane 2	82	Sep.	33
		7D	8D	W/B lane 2	82	Sep.	28
	Mean						31
Mean							37

Table B1. FN data 1975-1994 Part 11

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
CONTINUOUS GRINDING	41N	61	66	N/B Shoulder lane	80	Jun.	42
						Sep.	42
					81	Jun.	38
						Oct.	38
					82	Jul.	41
					83	Jul.	30
					84	Jul.	36
					85	Jul.	35
					86	Jul.	32
					87	Jul.	34
					88	Jul.	35
				N/B Passing lane	80	Jun.	49
						Sep.	48
					81	Jun.	43
						Oct.	46
					82	Jul.	48
					83	Jul.	39
					84	Jul.	45
					85	Jul.	44
					86	Jul.	43
					87	Jul.	42

Table B1. FN data 1975-1994 Part 12

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
CONTINUOUS GRINDING	41N	61	66	N/B Passing lane	88	Jul.	45
	Mean						41
	90W	138D	142G	W/B Shoulder lane	81	Nov.	43
					82	Sep.	37
					83	Sep.	31
					84	Aug.	33
					85	Aug.	33
					86	Aug.	32
				W/B Passing lane	81	Nov.	46
					82	Sep.	44
					83	Sep.	40
					84	Aug.	39
					85	Aug.	42
					86	Aug.	40
	Mean						38
Mean							40

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
GROOVED SURFACE	43S	75K	76T	S/B lane 2	76	Jun.	25
					77	May	27
					78	May	29
					79	Jun.	26
						Oct.	26
					80	May	25
						Aug.	24
					81	Jul.	24
						Oct.	24
					82	Jul.	26
	Mean						26
Mean							26

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
SKIP-GRINDING	90E	138D	142G	E/B Shoulder lane	81	Nov.	37
					82	Sep.	35
					83	Sep.	30
					84	Aug.	30
					85	Aug.	34
					86	Aug.	32
				E/B Passing lane	81	Nov.	45
					82	Sep.	48
					83	Sep.	42
					84	Aug.	42
					85	Aug.	45
					86	Aug.	43
	Mean						39
Mean							39

Table B1. FN data 1975-1994 Part 15

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	10E	304	309	E&W	81	Jun.	50
						Nov.	52
					82	Aug.	51
					83	Aug.	46
					84	Sep.	46
					86	Aug.	43
					88	Sep.	43
					90	Aug.	47
					92	Aug.	47
					94	Aug.	47
	Mean						47
	11E	83B	86B	E/B Shoulder lane	79	May	48
					80	Jun.	50
						Aug.	50
					81	Jun.	43
						Oct.	47
					82	Aug.	48
					83	Aug.	45
					84	Aug.	47
					86	Jul.	46
					88	Aug.	49
					90	Sep.	53

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	11E	83B	86B	E/B Shoulder lane	92	Sep.	54
					94	Jul.	55
	Mean						49
	12E	361B	362B	E&W	79	May	47
					80	Jun.	48
						Oct.	47
					81	Jun.	44
						Oct.	44
					82	Sep.	43
					83	Sep.	41
					84	Sep.	41
					86	Sep.	41
					88	Sep.	42
					92	Sep.	49
	Mean						44
	14E	211B	216B	E/B Shoulder lane	79	May	51
					80	Jun.	53
						Aug.	51
					81	Jun.	50
						Sep.	51
					82	Sep.	52
					83	Sep.	48

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	14E	211B	216B	E/B Shoulder lane	84	Sep.	49
					86	Sep.	51
					88	Sep.	53
					90	Sep.	59
					92	Sep.	60
					94	Jul.	56
	Mean						52
	14W	211B	216B	W/B Shoulder lane	79	May	49
					81	Jun.	50
						Sep.	49
					82	Sep.	51
					83	Sep.	45
					84	Sep.	48
					86	Sep.	48
					88	Sep.	53
					90	Sep.	57
					92	Sep.	57
					94	Sep.	55
	Mean						51
	18W	99D	101K	W/B Shoulder lane	81	Jun.	52
						Sep.	55
					82	Sep.	54

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	18W	99D	101K	W/B Shoulder lane	83	Sep.	50
					84	Sep.	47
					86	Sep.	50
					88	Sep.	47
					89	Oct.	43
					90	Sep.	56
					92	Oct.	54
					94	Aug.	52
	Mean						51
	19E	24E	27M	E&W	81	Jun.	45
						Oct.	48
					82	Aug.	49
					83	Sep.	44
					84	Aug.	44
					86	Aug.	46
					88	Aug.	42
					90	Aug.	45
					92	Aug.	45
					94	Aug.	41
	Mean						45
	43N	4K	9M	N/B Shoulder lane	76	Nov.	54
					77	May	56

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	43N	4K	9M	N/B Shoulder lane	78	May	51
					79	May	46
					80	Jun.	52
						Aug.	49
					81	Jun.	45
						Oct.	50
					82	Aug.	49
					83	Aug.	47
					84	Aug.	47
					86	Aug.	46
					88	Aug.	50
					90	Aug.	57
					92	Sep.	56
		11D	15B	N/B Shoulder lane	76	Nov.	60
					77	May	61
					78	May	56
					79	May	51
					80	Jun.	55
						Aug.	52
					81	Jun.	48
						Oct.	52

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	43N	11D	15B	N/B Shoulder lane	82	Aug.	50
					83	Aug.	48
					84	Aug.	49
					86	Aug.	49
					88	Aug.	53
					90	Aug.	59
					92	Sep.	59
		25D	30K	N/B Shoulder lane	76	Nov.	60
					77	May	60
					78	May	56
					79	May	49
					80	Jun.	57
						Aug.	50
					81	Jun.	46
						Oct.	52
					82	Aug.	51
					83	Aug.	48
					84	Aug.	48
					86	Aug.	47
					88	Aug.	40
					90	Aug.	45

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	43N	102D	107K	N/B Shoulder lane	75	Dec.	46
					76	Oct.	62
					77	May	62
					78	May	54
					79	Jun.	47
					80	Jun.	52
						Sep.	47
					81	Jun.	43
						Oct.	44
					82	Jul.	43
					83	Jul.	37
					84	Aug.	37
					86	Aug.	37
					88	Jul.	38
					90	Jul.	47
		108D	113T	N/B Shoulder lane	75	Dec.	47
					76	Oct.	63
					77	May	64
					78	May	57
					79	Jun.	50
					80	Jun.	53

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	43N	108D	113T	N/B Shoulder lane	80	Sep.	47
					81	Jun.	43
						Oct.	46
					82	Jul.	46
					83	Jul.	38
					84	Aug.	39
					86	Aug.	38
					88	Jul.	40
					90	Jul.	44
	Mean						50
	43S	4K	9M	S/B Shoulder lane	76	Nov.	61
					77	May	58
					78	May	57
					79	May	49
		11D	15B	S/B Shoulder lane	76	Nov.	60
					77	May	64
					78	May	60
					79	May	52
		25D	30K	S/B Shoulder lane	76	Nov.	64
					77	May	61
					78	May	59
					79	May	51

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	43S	102D	107K	S/B Shoulder lane	75	Dec.	51
					76	Oct.	59
					77	May	61
					78	May	55
					79	Jun.	48
					86	Aug.	38
		108D	113T	S/B Shoulder lane	75	Dec.	47
					76	Oct.	58
					77	May	61
					78	May	52
					79	Jun.	46
					86	Aug.	39
	Mean						55
	51S	176	185	S/B Shoulder lane	81	Jun.	48
						Oct.	52
					82	Aug.	54
					83	Aug.	49
					84	Aug.	50
					86	Aug.	50
					88	Aug.	54
					90	Aug.	59
					92	Sep.	56

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	51S	176	185	S/B Shoulder lane	94	Jul.	52
	Mean						52
	81E	112B	121	-E-	76	Nov.	53
					77	May	61
					78	May	59
					79	May	49
					80	Jun.	57
						Aug.	53
					81	Jun.	49
						Oct.	54
					82	Aug.	52
					83	Aug.	48
					84	Aug.	41
					86	Aug.	47
					88	Aug.	52
					90	Aug.	59
					92	Sep.	57
					94	Jul.	57
	Mean						53
	90E	92M	106G	E/B Shoulder lane	75	Sep.	47
					76	Jun.	50
						Oct.	51

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	90E	92M	106G	E/B Shoulder lane	77	Apr.	51
					78	May	44
					79	May	45
					80	Jun.	48
						Sep.	50
					81	Jun.	46
						Sep.	48
					82	Sep.	49
					83	Aug.	46
					84	Sep.	47
					86	Sep.	48
					88	Sep.	49
					90	Sep.	55
					93	Aug.	55
					94	Aug.	50
		119M	123D	E/B lane 1	85	Aug.	47
					86	Aug.	43
					87	Aug.	48
					88	Aug.	46
					89	Aug.	53
					90	Aug.	47

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	90E	119M	123D	E/B lane 1	91	Aug.	50
					92	Aug.	48
					93	Aug.	51
					94	Aug.	46
				E/B lane 2	85	Aug.	49
					86	Aug.	46
					87	Aug.	50
					88	Aug.	48
					89	Aug.	55
					90	Aug.	50
					91	Aug.	52
					92	Aug.	51
					93	Aug.	54
					94	Aug.	48
				E/B lane 3	85	Aug.	53
					86	Aug.	51
					87	Aug.	53
					88	Aug.	55
					89	Aug.	61
					90	Aug.	57
					91	Aug.	56

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	90E	119M	123D	E/B lane 3	92	Aug.	58
					93	Aug.	57
					94	Aug.	53
		123D	126T	E/B lane 1	85	Aug.	47
					86	Aug.	46
					87	Aug.	47
					88	Aug.	46
					89	Aug.	53
					90	Aug.	51
					91	Aug.	50
					92	Aug.	48
					93	Sep.	39
					94	Aug.	49
				E/B lane 2	85	Aug.	49
					86	Aug.	45
					87	Aug.	49
					88	Aug.	50
					89	Aug.	57
					90	Aug.	54
					91	Aug.	53
					92	Aug.	52

PCC Surface Texture	Highway	From Ref Point	To Ref Point	Lane	Test Year	Test Month	FN value
TINED SURFACE	90E	123D	126T	E/B lane 2	93	Sep.	51
					94	Aug.	49
				E/B lane 3	85	Aug.	53
					86	Aug.	52
					87	Aug.	53
					88	Aug.	55
					89	Aug.	64
					90	Aug.	59
					91	Aug.	58
					92	Aug.	59
					93	Sep.	49
					94	Aug.	57
	Mean						51
	138E	11T	19B	E&W	81	Sep.	47
					82	Sep.	48
					83	Sep.	45
					84	Sep.	45
							46
					88	Sep.	48
					90	Sep.	55
					92	Sep.	52
					94	Jul.	52
	Mean						49
Mean							50

Construction year and Design Lane Average Daily Traffic information for figure B1.

I-90 Segment Construction Year

Year	From Ref Point	To Ref Point
1959	172G	187T
1961	86K	92M
	106M	142G
1962	142G	172G
1964	39T	85T
1967	1C	5T
1969	10D	34D
1973	94M	106M

I-90 Segment Design Lane Volume

Lane ADT (VPD)	From Ref Point	To Ref Point
0.8K - 2.3K	28K	39T
2.3K - 3.7K	3K	5T
	10D	28K
	39T	52K
3.7K - 7.0K	1C	3K
	52K	74G
7.0K - 21.0K	79K	187T

Notes:

- Reference points are highway features located within the milepoint indicated by the numeric part of the Reference Point code.
- This information was extracted from the WisDOT Metamanager database.
- Segment extent is approximate.
- Short Transversely tined pavement segments were also present on I-90 in 1981.
- Data in figure B1 are for Burlap Drag segments only.
- Design Lane = Shoulder lane.

Figure B1. Friction Number Variation Along Interstate 90. (Burlap Drag Surface Texture).

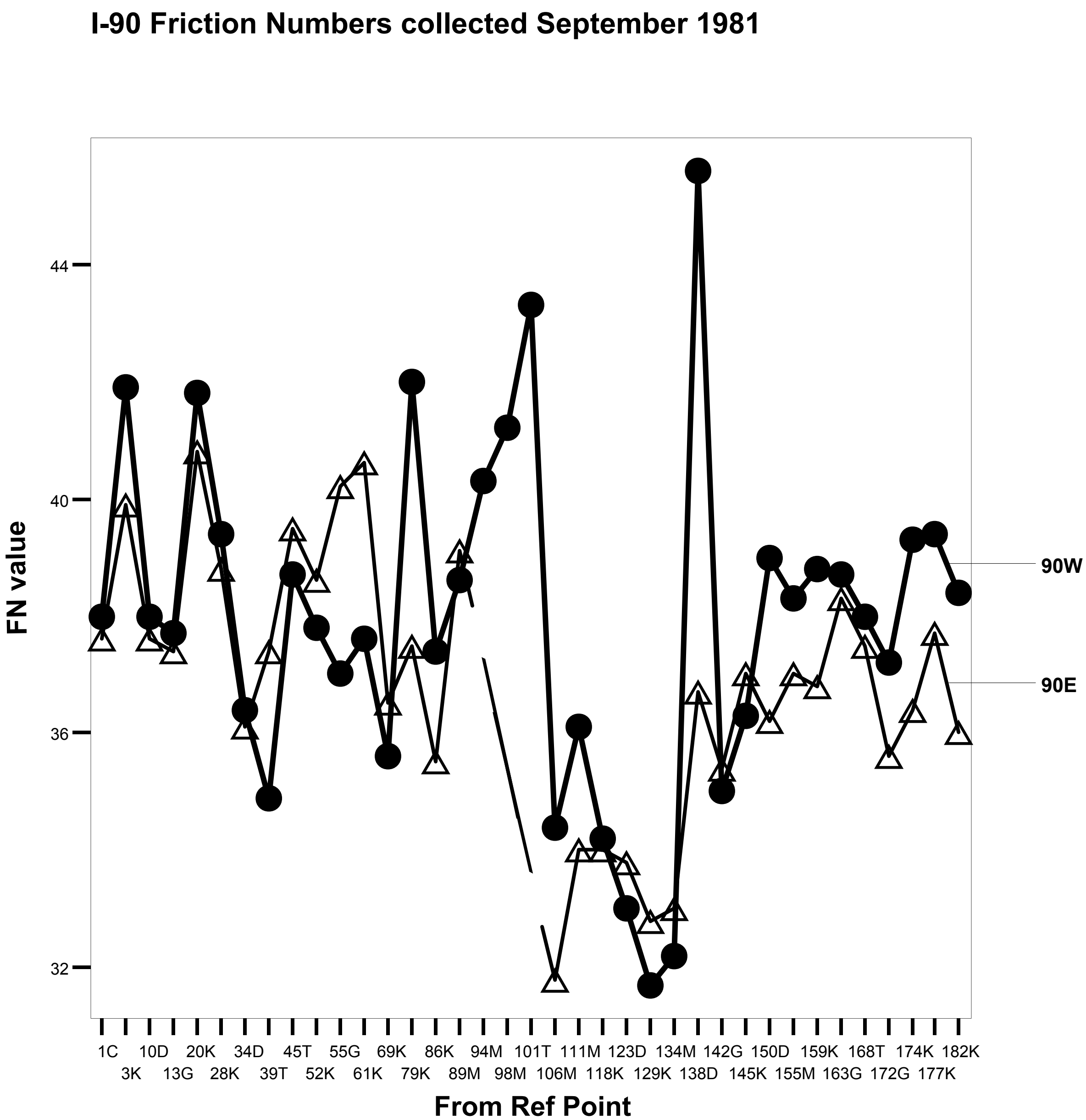


Figure B2. Friction Number Variation Between Lanes Interstate 90. (Tined Surface Texture).

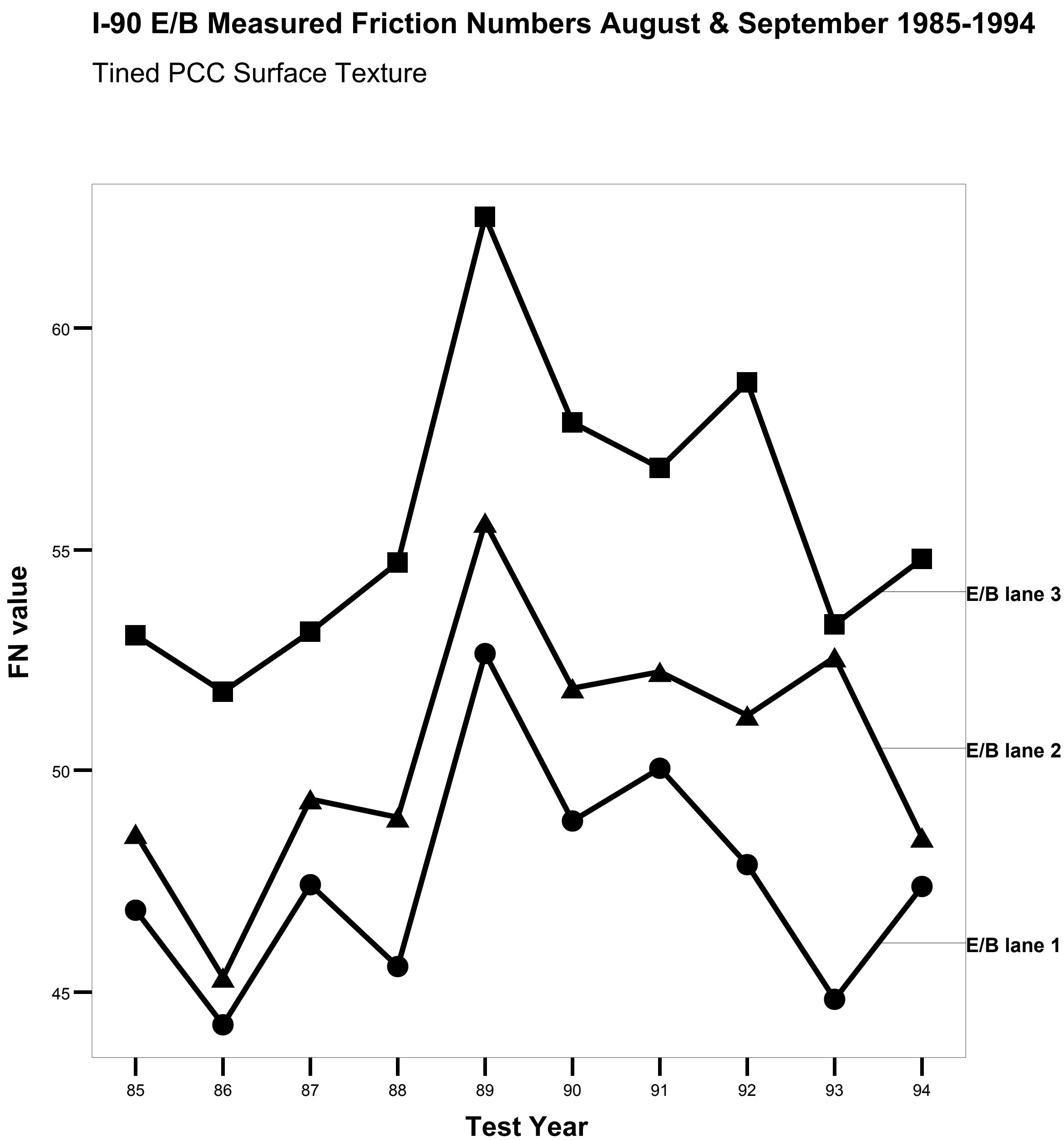
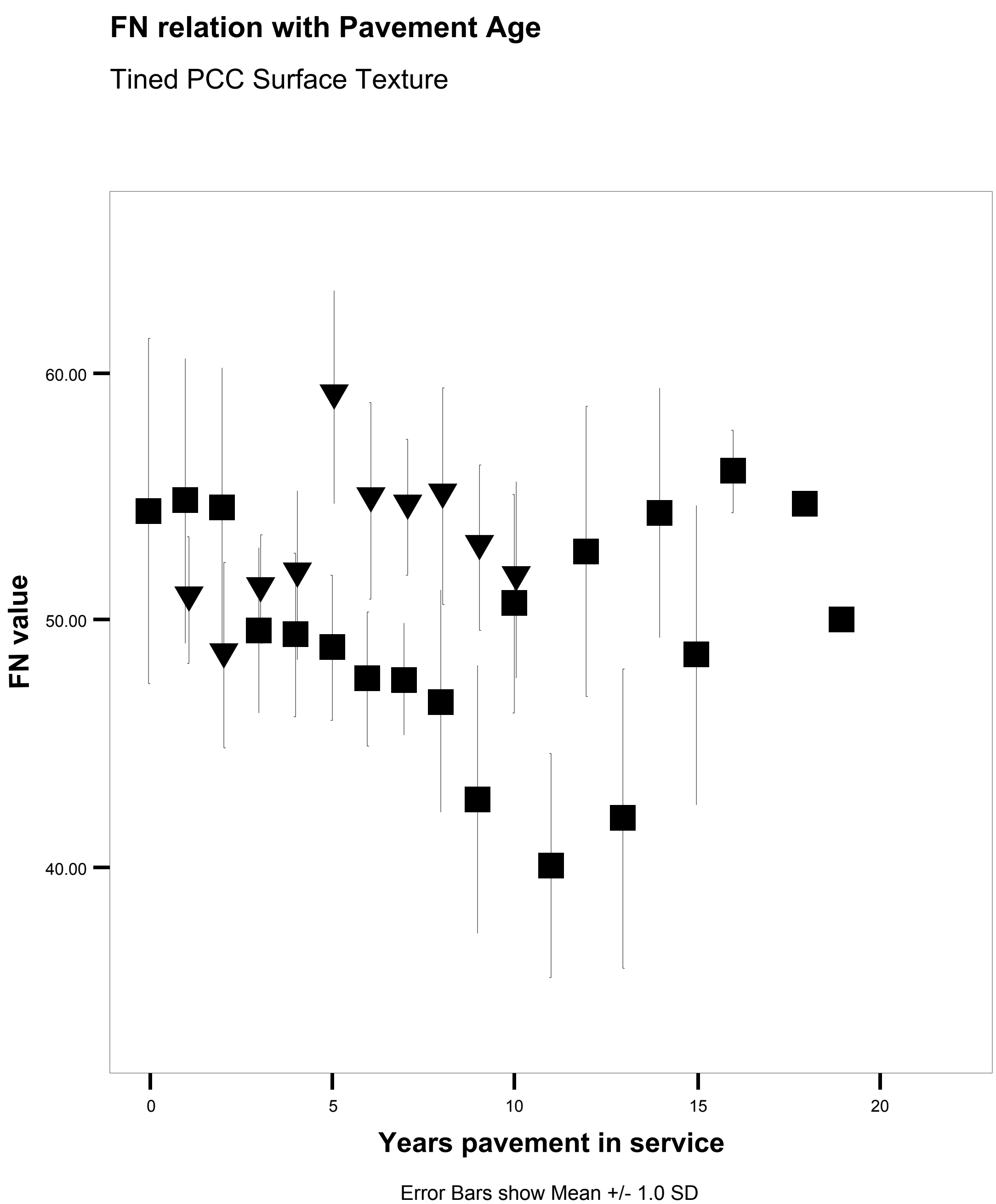
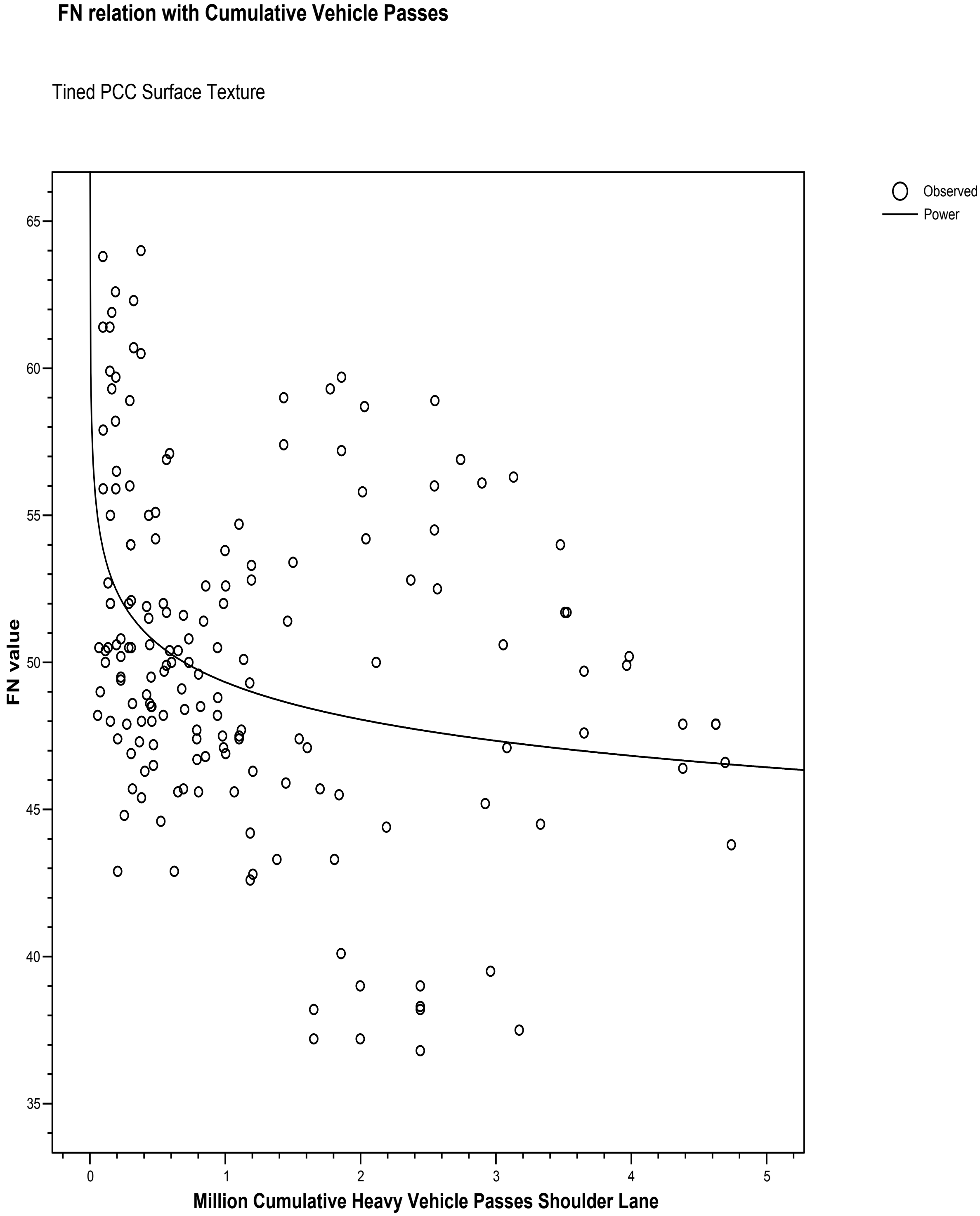


Figure B3. Friction Number Variation with Pavement Age. (Tined Surface Texture).
(Square markers-Shoulder lane, Triangular markers-Passing lane)



Friction Number differences between lanes

Figure B4. Friction Number Variation with Vehicle Passes. Shoulder Lane.



APPENDIX C

CRASH STATISTICS

INTRODUCTION

A description of the crash and pavement selection process is provided for Wisconsin and California data. The description is followed by **table C1** summarizing annual crash rates for Wisconsin and California. **Table C2** provides more detailed annual and cumulative findings for Wisconsin and California freeways (refer to the Methodology section of the report for detailed descriptions of statistics presented herein).

Wisconsin data listings are followed by California data for level and rolling terrain; listings for mountainous California terrain data conclude the Appendix. ***Important cautions about information provided in Table C2 are presented on page C4.*** Tables and figures specific to the crash statistics discussion in the Findings section of the report are presented in **Appendix D**.

Use of weather and precipitation information in producing the Liquid precipitation Safety Ratio (LSR) and the Frozen precipitation Safety Ratio (FSR) is described in **Appendix E**.

CRASH AND PAVEMENT SELECTION PROCESS

The analyzed database consists of crashes that occurred between 1991 and 1998 (inclusive). A detailed description of the analyzed databases for each state is provided below:

WISCONSIN

Crash database
All freeway crashes on all sections of I-90, I-94, I-894 and I-794 with a speed limit greater or equal to 50 mph, that occurred on pavements constructed between 1978 and the year before a crash occurred. Deer crashes were excluded from consideration. Out of a state-wide total of approximately 69,000 crashes, 34,635 freeway crashes fit the above criteria.

Pavement database
Pavement data were extracted from the "Metamanager" WisDOT database. The database provided pavement materials information (PCC or asphalt), the date a pavement surface was constructed, travel information (freeway segment length and ADT) and freeway type (urban or rural). The 1999 database was used in order to include the pavement surface construction dates relevant to all analyzed segments; travel information was based on extrapolations of annual traffic growth to each analyzed year.

Analysis database
The pavement database was queried for pavements constructed between 1978 (the first year that all new PCC pavements were required to have transversely tined surfaces) and 1990. Crashes that occurred during 1991 were then matched with 1991 travel information on the pavement on which they occurred. The pavement selection method guaranteed that any selected PCC freeway pavement would be transversely tined. Any new PCC

pavement mileage constructed during 1991 was added to the database, and 1992 crashes were matched to the corresponding travel information. This process was repeated for each analyzed year, up to and including the 1998 crash data. Thus the analyzed mileage increased from 1991 to 1998. Details on the pavements analyzed each year are provided in **Appendix F**. The total number of crashes matched to analyzed freeway segments was 11,887. Most, (7,838) occurred on rural freeways and the remainder (4,049) on urban freeways. Thus, the analyzed database included approximately 34% (11,887 / 34,635) of the crashes that occurred on I-90, I-94, I-794, and I-894, which approximately correspond to 17% (11,887 / 69,000) of all Wisconsin freeway crashes, in all analysis years.

It should be noted that the emphasis of the present analysis was on rural freeways. Most urban pavements constructed on the analyzed freeways were asphalt; very few PCC pavement miles were constructed in urban areas, thus reliable statistics are not available for these pavements.

CALIFORNIA

Crash database
The Highway Safety Information System (HSIS) California database (see **Appendix G** for details) was utilized to provide freeway crashes. All 832,129 reported freeway crashes that occurred between 1991 and 1998 were analyzed.

Pavement databases
The HSIS Roadway Inventory and the Traffic Volume databases were used to provide urban/rural freeway designation, travel information (based on ADT and freeway segment length), and terrain information (Level, Rolling or Mountainous). Information was available for every year from 1993 to 1998. Travel information for years 1991 and 1992 was extracted from the 1993 data.

Analysis database
The crash and pavement databases were merged for each analysis year. Each crash was matched to a freeway section. There were 74,548 crashes on rural freeways and 757,581 crashes on urban freeways during all analysis years. Very small freeway mileage changes occurred during the analyzed years.

California PCC pavements were LT, except for bridge decks, that were TT. It is important to keep this in mind when comparing TT statistics, given that bridge deck safety performance may be affected by factors other than pavement surface texture, such as narrower shoulders and/or special pavement conditions (early freezing, stronger crosswinds etc.)

California freeways were analyzed in two terrain groups: level or rolling terrain, and mountainous terrain. This grouping allowed comparisons with Wisconsin, where no mountainous terrain is present. Mountainous terrain statistics are listed in the present Appendix, but are not discussed in the body of the report.

INTRODUCTION TO CRASH STATISTICS TABLE C2

Statistics were calculated for freeways with less than 60,000 VPD and those with 60,000+ VPD. The focus of this effort is on rural freeways, where free-flow speeds prevail, crash rates are lower, but crash outcomes are more severe. The majority of rural freeways are in the lower ADT range. These freeways are addressed extensively in the Findings section of the report; abbreviated tables and figures relating to the Findings section are presented in **Appendix D**.

Separate statistics are provided for level/rolling terrain and for mountainous terrain California freeways. Level/rolling terrain summaries are more appropriate for comparisons with Wisconsin, which has a similar terrain.

Urban freeway statistics are provided in the interest of a comprehensive presentation of findings, and are briefly discussed in the **Findings** section of the report. Summary statistics (tables and figures) relating to that discussion are presented in **Appendix D**. The majority of wet pavement crashes on urban freeways occur during peak traffic periods when speeds are substantially below free-flow speed levels. Congestion (traffic shock waves), tailgating, driver impatience, and inattention may play a more significant role than pavement surface frictional properties in such crashes.

The following cautions should be kept in mind when interpreting table C2 information:

- California TT data represent bridge decks exclusively.
- Wisconsin mileage represents directional miles.
- California mileage represents centerline miles (both directions).
- 100% of California freeway crashes were analyzed.
- 34% of Wisconsin freeway crashes were analyzed.
- Frozen Safety Ratio information is not reliable for California (details explained in **Appendix E**).
- Statistics based on very few freeway miles are not reliable and are presented as preliminary information. It is recommended to consult statistics based on more than 100 miles of freeway.

Table C1. Crash Rate (Crashes per 100MVMT) Summary Wisconsin and California 1991 - 1998.

Year	Wisconsin				California Statewide Rolling & Level Terrain						
	Statewide		Analyzed Rural <60K ADT		Rural <60K ADT		Urban <60K ADT		Urban 60K+ ADT		
	Urban	Rural	Asphalt	TT PCC	Asphalt	LT PCC	Asphalt	LT PCC	Asphalt	LT PCC	TT PCC
1991	118	72	49	47	50	42	78	72	101	97	93
1992	115	59	31	40	45	41	72	70	104	95	91
1993	108	67	40	46	49	42	77	74	103	94	89
1994	126	66	35	40	51	42	78	76	108	99	92
1995	104	66	37	40	50	44	75	76	111	98	94
1996	100	64	47	50	51	45	80	80	111	105	99
1997	104	57	36	35	51	42	78	78	114	104	98
1998	98	51	35	40	53	42	78	84	113	108	98
	n ≈ 60,000 crashes		n = 6,036 crashes		n = 42,785 crashes		n = 45,143 crashes		n = 692,332 crashes		

Notes:
Statewide WI data provided by WisDOT Office of Traffic.
Statewide CA data from the HSIS database.

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type.

Wisconsin Pavements built between 1978 and 1990 Year 1991

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow+Ice crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	47	.19	1.54	267	95	18	146	2.21	22.25	120	5.6
	All		47	.19	1.54	267	95	18	146	2.21	22.25	120	5.6
	Asphalt	<60K	49	.26	1.47	244	88	23	129	3.05	21.22	123	5.0
		60K+	44	.25	.62	188	100	25	62	2.92	8.97	36	4.3
	All		47	.26	1.02	432	188	48	191	2.98	14.71	159	9.3
Overall			47	.23	1.19	699	283	66	337	2.72	17.24	279	14.9
Urban	Trns PCC	<60K	103	.31	.23	20	13	4	3	3.59	3.34	2	.2
	All		103	.31	.23	20	13	4	3	3.59	3.34	2	.2
	Asphalt	<60K	23	1.00	1.50	14	4	4	6	11.68	21.71	8	.6
		60K+	60	.26	.26	236	155	40	41	3.01	3.83	23	3.9
	All		55	.28	.30	250	159	44	47	3.23	4.28	31	4.6
Overall			57	.28	.29	270	172	48	50	3.26	4.21	33	4.8
WI 1991			49	.25	.85	969	455	114	387	2.93	12.31	312	19.6

Statistics based on directional information. AADT vpd is bidirectional volume for analyzed segments.

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

Wisconsin Pavements built between 1978 and 1991 Year 1992

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow+Ice crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	40	.28	1.08	233	96	27	104	3.18	14.12	121	5.8
	All		40	.28	1.08	233	96	27	104	3.18	14.12	121	5.8
	Asphalt	<60K	31	.23	.75	249	119	27	89	2.56	9.75	176	8.1
		60K+	43	.23	.80	185	90	21	72	2.64	10.42	36	4.3
	All		35	.23	.77	434	209	48	161	2.59	10.04	212	12.4
Overall			37	.25	.87	667	305	75	265	2.78	11.32	334	18.2
Urban	Trns PCC	<60K	40	.00	1.67	8	3	0	5	.00	21.72	2	.2
	All		40	.00	1.67	8	3	0	5	.00	21.72	2	.2
	Asphalt	<60K	26	.00	1.10	21	10	0	11	.00	14.33	11	.8
		60K+	68	.22	.28	274	182	40	51	2.48	3.65	23	4.0
	All		61	.21	.32	295	192	40	62	2.35	4.21	34	4.8
Overall			61	.21	.34	303	195	40	67	2.32	4.48	36	5.0
WI 1992			42	.23	.66	970	500	115	332	2.60	8.65	370	23.3

Statistics based on directional information. AADT vpd is bidirectional volume for analyzed segments.

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

Wisconsin Pavements built between 1978 and 1992 Year 1993

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow+Ice crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	46	.20	1.15	391	162	32	187	2.16	13.27	167	8.5
	All		46	.20	1.15	391	162	32	187	2.16	13.27	167	8.5
	Asphalt	<60K	40	.25	1.18	358	145	36	171	2.71	13.55	195	8.9
		60K+	50	.18	.87	219	105	19	91	1.97	9.96	36	4.4
	All		43	.22	1.05	577	250	55	262	2.40	12.04	231	13.3
Overall			45	.21	1.09	968	412	87	449	2.30	12.52	398	21.7
Urban	Trns PCC	<60K	54	.20	1.00	11	5	1	5	2.18	11.49	2	.2
	All		54	.20	1.00	11	5	1	5	2.18	11.49	2	.2
	Asphalt	<60K	32	.07	.67	27	15	1	10	.73	7.66	12	.9
		60K+	73	.26	.20	297	201	52	40	2.82	2.29	23	4.1
	All		66	.25	.23	324	216	53	50	2.68	2.66	35	4.9
Overall			65	.24	.25	335	221	54	55	2.67	2.86	37	5.1
WI 1993			49	.22	.80	1303	633	141	504	2.43	9.15	435	26.9

Statistics based on directional information. AADT vpd is bidirectional volume for analyzed segments.

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

Wisconsin Pavements built between 1978 and 1993 Year 1994

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow+Ice crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	40	.08	1.56	345	131	10	204	1.21	22.48	167	8.6
	All		40	.08	1.56	345	131	10	204	1.21	22.48	167	8.6
	Asphalt	<60K	35	.23	1.14	316	133	31	151	3.70	16.39	195	9.0
		60K+	50	.17	1.02	224	102	17	104	2.64	14.72	36	4.4
	All		40	.20	1.09	540	235	48	255	3.24	15.66	231	13.5
Overall			40	.16	1.25	885	366	58	459	2.51	18.10	398	22.1
Urban	Trns PCC	<60K	29	1.00	4.00	6	1	1	4	15.87	57.74	2	.2
	All		29	1.00	4.00	6	1	1	4	15.87	57.74	2	.2
	Asphalt	<60K	30	.00	1.36	26	11	0	15	.00	19.68	12	.9
		60K+	81	.20	.42	335	207	42	86	3.22	6.00	23	4.1
	All		72	.19	.46	361	218	42	101	3.06	6.69	35	5.0
Overall			71	.20	.48	367	219	43	105	3.12	6.92	37	5.2
WI 1994			46	.17	.96	1252	585	101	564	2.74	13.92	435	27.3

Statistics based on directional information. AADT vpd is bidirectional volume for analyzed segments.

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

Wisconsin — Pavements built between 1978 and 1994 — Year 1995

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow+Ice crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	40	.12	1.00	382	180	21	180	1.51	14.28	186	9.6
	All		40	.12	1.00	382	180	21	180	1.51	14.28	186	9.6
	Asphalt	<60K	37	.21	.70	337	176	37	124	2.72	10.06	195	9.2
		60K+	52	.18	.66	236	127	23	84	2.34	9.45	36	4.5
	All		42	.20	.69	573	303	60	208	2.56	9.80	231	13.7
Overall			41	.17	.80	955	483	81	388	2.17	11.47	417	23.2
Urban	Trns PCC	<60K	57	.00	.50	12	8	0	4	.00	7.14	2	.2
	All		57	.00	.50	12	8	0	4	.00	7.14	2	.2
	Asphalt	<60K	45	.30	.65	40	20	6	13	3.88	9.28	12	.9
		60K+	74	.18	.30	358	242	44	72	2.35	4.25	26	4.9
	All		69	.19	.32	398	262	50	85	2.47	4.63	37	5.7
Overall			69	.19	.33	410	270	50	89	2.40	4.71	40	6.0
WI 1995			47	.17	.63	1365	753	131	477	2.25	9.05	456	29.2

Statistics based on directional information. AADT vpd is bidirectional volume for analyzed segments.

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

Wisconsin Pavements built between 1978 and 1995 Year 1996

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow+Ice crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	50	.23	2.03	522	160	37	325	4.07	34.35	197	10.4
	All		50	.23	2.03	522	160	37	325	4.07	34.35	197	10.4
	Asphalt	<60K	47	.20	1.41	496	190	38	268	3.52	23.86	219	10.6
		60K+	52	.20	.88	235	113	23	99	3.58	14.82	36	4.6
	All		48	.20	1.21	731	303	61	367	3.54	20.48	255	15.1
Overall			49	.21	1.49	1253	463	98	692	3.72	25.28	452	25.5
Urban	Trns PCC	<60K	17	.	.	1	0	0	1	.	.	1	.1
		60K+	33	.38	.88	18	8	3	7	6.59	14.80	5	.6
	All		31	.38	1.00	19	8	3	8	6.59	16.91	5	.6
	Asphalt	<60K	50	.38	.86	47	21	8	18	6.70	14.50	12	.9
		60K+	79	.26	.22	435	294	75	66	4.49	3.80	28	5.5
	All		75	.26	.27	482	315	83	84	4.63	4.51	40	6.4
Overall			71	.27	.28	501	323	86	92	4.68	4.82	45	7.0
WI 1996			54	.23	1.00	1754	786	184	784	4.12	16.87	497	32.5

Statistics based on directional information. AADT vpd is bidirectional volume for analyzed segments.

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

Wisconsin Pavements built between 1978 and 1996 Year 1997

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow+Ice crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	35	.13	1.62	411	149	20	241	2.39	28.84	220	11.6
	All		35	.13	1.62	411	149	20	241	2.39	28.84	220	11.6
	Asphalt	<60K	36	.20	.95	477	222	45	210	3.61	16.87	269	13.2
		60K+	44	.21	.73	202	104	22	76	3.77	13.03	36	4.6
	All		38	.21	.88	679	326	67	286	3.66	15.64	305	17.8
Overall			37	.18	1.11	1090	475	87	527	3.27	19.78	525	29.4
Urban	Trns PCC	<60K	18	.33	.00	4	3	1	0	5.94	.00	5	.2
		60K+	32	.17	.33	18	12	2	4	2.97	5.94	5	.6
	All		28	.20	.27	22	15	3	4	3.57	4.75	10	.8
	Asphalt	<60K	39	.25	1.14	67	28	7	32	4.46	20.38	29	1.7
		60K+	77	.19	.18	596	433	82	80	3.38	3.29	37	7.8
	All		70	.19	.24	663	461	89	112	3.44	4.33	66	9.5
Overall			67	.19	.24	685	476	92	116	3.45	4.35	75	10.3
WI 1997			45	.19	.68	1775	951	179	643	3.36	12.06	600	39.6

Statistics based on directional information. AADT vpd is bidirectional volume for analyzed segments.

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

Wisconsin Pavements built between 1978 and 1997 Year 1998

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow+Ice crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	40	.14	1.00	497	233	32	232	2.16	22.76	234	12.5
	All		40	.14	1.00	497	233	32	232	2.16	22.76	234	12.5
	Asphalt	<60K	35	.25	.72	511	259	64	187	3.88	16.50	297	14.5
		60K+	53	.14	.11	313	248	35	28	2.22	2.58	46	5.9
	All		40	.20	.42	824	507	99	215	3.07	9.69	342	20.4
Overall			40	.18	.60	1321	740	131	447	2.78	13.81	576	32.9
Urban	Trns PCC	<60K	44	.50	3.50	10	2	1	7	7.85	80.00	5	.2
		60K+	40	.45	.64	23	11	5	7	7.14	14.55	5	.6
	All		41	.46	1.08	33	13	6	14	7.25	24.61	10	.8
	Asphalt	<60K	47	.29	.81	88	42	12	34	4.49	18.50	32	1.9
		60K+	88	.29	.07	1057	779	223	52	4.49	1.53	55	12.0
	All		83	.29	.10	1145	821	235	86	4.49	2.39	88	13.8
Overall			81	.29	.12	1178	834	241	100	4.54	2.74	97	14.6
WI 1998			53	.24	.35	2499	1574	372	547	3.71	7.94	673	47.5

Statistics based on directional information. AADT vpd is bidirectional volume for analyzed segments.

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California — Rolling and Level Terrain — Year 1991

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Wet Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	66	.12	.03	143	124	15	4	2.54	12.68	23.5	2.2
		60K+	35	.31	.00	64	49	15	0	6.43	.00	5.4	1.8
	All		52	.17	.02	207	173	30	4	3.64	9.09	28.9	4.0
	Long PCC	<60K	42	.08	.02	2668	2429	188	52	1.62	8.34	733.5	63.4
		60K+	42	.15	.01	1202	1040	152	10	3.07	3.82	91.9	28.7
	All		42	.10	.02	3870	3469	340	62	2.06	6.99	825.4	92.1
	Asphalt	<60K	50	.08	.01	2514	2317	183	13	1.66	2.24	655.8	50.5
		60K+	40	.14	.02	368	318	45	5	2.97	6.18	30.9	9.3
	All		48	.09	.01	2882	2635	228	18	1.82	2.72	686.7	59.8
Overall			45	.10	.01	6959	6277	598	84	2.00	5.25	1541.0	155.9
Urban	Trns PCC	<60K	70	.19	.01	323	270	51	2	3.97	2.91	34.5	4.6
		60K+	93	.15	.00	5498	4797	699	2	3.06	.16	106.0	59.4
	All		91	.15	.00	5821	5067	750	4	3.11	.31	140.5	64.0
	Long PCC	<60K	72	.12	.00	2888	2571	309	8	2.52	1.24	299.1	40.2
		60K+	97	.12	.00	56825	50761	6036	28	2.50	.22	1054.2	586.9
	All		95	.12	.00	59713	53332	6345	36	2.50	.26	1353.3	627.1
	Asphalt	<60K	78	.15	.00	2729	2374	351	4	3.11	.66	274.1	35.2
		60K+	101	.13	.00	17200	15154	2042	4	2.83	.10	348.8	170.5
	All		97	.14	.00	19929	17528	2393	8	2.87	.18	622.9	205.6
Overall			95	.12	.00	85463	75927	9488	48	2.63	.25	2116.7	896.8
CA 1991			88	.12	.00	92422	82204	10086	132	2.58	.63	3657.7	1052.7

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California — Rolling and Level Terrain — Year 1992

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	66	.16	.01	143	122	20	1	3.68	3.23	23.5	2.2
		60K+	37	.68	.00	69	41	28	0	15.34	.00	5.4	1.8
	All		53	.29	.01	212	163	48	1	6.61	2.42	28.9	4.0
	Long PCC	<60K	41	.11	.02	2608	2315	249	44	2.42	7.44	733.5	63.4
		60K+	45	.22	.00	1298	1058	237	3	5.04	1.12	91.9	28.7
	All		42	.14	.01	3906	3373	487	47	3.24	5.46	825.4	92.1
	Asphalt	<60K	45	.09	.01	2295	2086	193	16	2.08	3.09	655.8	50.5
		60K+	43	.22	.01	396	321	72	3	5.04	3.69	30.9	9.3
	All		45	.11	.01	2691	2407	265	19	2.47	3.17	686.7	59.8
Overall			44	.13	.01	6809	5943	799	67	3.02	4.45	1541.0	155.9
Urban	Trns PCC	<60K	74	.23	.01	343	275	64	4	5.26	5.82	34.5	4.6
		60K+	91	.19	.00	5421	4547	872	2	4.31	.18	106.0	59.4
	All		90	.19	.00	5764	4822	936	6	4.36	.50	140.5	64.0
	Long PCC	<60K	70	.18	.00	2807	2380	418	9	3.95	1.52	299.1	40.2
		60K+	95	.16	.00	55581	47715	7852	14	3.70	.12	1054.2	586.9
	All		93	.17	.00	58388	50095	8270	23	3.71	.18	1353.3	627.1
	Asphalt	<60K	72	.21	.00	2548	2099	441	8	4.72	1.50	274.1	35.2
		60K+	104	.18	.00	17774	15034	2734	6	4.09	.16	348.8	170.5
	All		99	.19	.00	20322	17133	3175	14	4.16	.32	622.9	205.6
Overall			94	.17	.00	84474	72050	12381	43	3.86	.24	2116.7	896.8
CA 1992			87	.17	.00	91283	77992	13181	110	3.80	.56	3657.7	1052.7

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California | Rolling and Level Terrain | Year 1993

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	70	.22	.06	151	118	26	7	4.19	23.21	23.5	2.2
		60K+	41	.38	.06	76	53	20	3	7.26	22.23	5.4	1.8
	All		57	.27	.06	227	171	46	10	5.14	22.91	28.9	4.0
	Long PCC	<60K	42	.09	.02	2663	2390	215	58	1.71	9.54	733.5	63.4
		60K+	47	.20	.00	1359	1131	224	4	3.76	1.38	91.9	28.7
	All		44	.12	.02	4022	3521	439	62	2.37	6.92	825.4	92.1
	Asphalt	<60K	49	.09	.01	2471	2245	211	15	1.79	2.67	655.8	50.5
		60K+	44	.17	.00	411	353	58	0	3.14	.00	30.9	9.3
	All		48	.10	.01	2882	2597	269	15	1.97	2.31	686.7	59.8
Overall			46	.12	.01	7131	6289	754	88	2.28	5.45	1541.0	155.9
Urban	Trns PCC	<60K	79	.25	.02	366	289	71	6	4.67	8.12	34.5	4.6
		60K+	89	.19	.00	5293	4449	835	9	3.57	.79	106.0	59.4
	All		88	.19	.00	5659	4738	906	15	3.63	1.24	140.5	64.0
	Long PCC	<60K	74	.17	.00	2990	2556	425	9	3.15	1.38	299.1	40.2
		60K+	94	.16	.00	54986	47464	7505	17	3.00	.14	1054.2	586.9
	All		92	.16	.00	57976	50020	7930	26	3.01	.20	1353.3	627.1
	Asphalt	<60K	77	.21	.01	2694	2218	456	20	3.90	3.58	274.1	35.2
		60K+	103	.21	.00	17563	14509	3044	10	3.99	.27	348.8	170.5
	All		99	.21	.00	20257	16727	3499	30	3.97	.71	622.9	205.6
Overall			94	.17	.00	83892	71485	12335	71	3.28	.39	2116.7	896.8
CA 1993			86	.17	.00	91023	77774	13090	159	3.20	.80	3657.7	1052.7

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California — Rolling and Level Terrain — Year 1994

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	62	.15	.02	134	115	17	2	4.09	6.91	23.5	2.2
		60K+	39	.18	.00	73	62	11	0	4.97	.00	5.4	1.9
	All		51	.16	.01	207	177	28	2	4.40	4.50	28.9	4.1
	Long PCC	<60K	42	.09	.02	2646	2370	223	53	2.60	8.84	731.6	63.6
		60K+	42	.15	.00	1212	1052	155	5	4.06	1.89	90.5	28.7
	All		42	.11	.02	3858	3422	378	58	3.05	6.70	822.0	92.3
	Asphalt	<60K	51	.07	.01	2580	2390	177	13	2.05	2.16	656.1	50.8
		60K+	49	.11	.00	523	473	50	0	2.93	.00	34.4	10.6
	All		51	.08	.00	3103	2862	228	13	2.20	1.81	690.5	61.4
Overall			45	.10	.01	7168	6462	634	73	2.71	4.47	1541.4	157.8
Urban	Trns PCC	<60K	77	.27	.00	370	291	79	0	7.48	.00	33.3	4.8
		60K+	92	.17	.00	5497	4680	815	2	4.82	.17	107.5	59.6
	All		91	.18	.00	5867	4971	894	2	4.97	.16	140.7	64.4
	Long PCC	<60K	76	.14	.00	2923	2568	353	2	3.80	.31	282.3	38.7
		60K+	99	.13	.00	58699	52144	6534	21	3.46	.16	1071.8	591.5
	All		98	.13	.00	61622	54712	6887	23	3.48	.17	1354.2	630.1
	Asphalt	<60K	78	.17	.01	2861	2436	412	13	4.68	2.12	280.9	36.5
		60K+	108	.17	.00	19181	16398	2774	9	4.68	.22	364.9	177.5
	All		103	.17	.00	22042	18833	3186	22	4.68	.47	645.9	214.0
Overall			99	.14	.00	89531	78516	10967	47	3.86	.24	2140.7	908.6
CA 1994			91	.14	.00	96699	84978	11601	120	3.77	.56	3682.2	1066.3

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California — Rolling and Level Terrain — Year 1995

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	58	.17	.04	126	104	18	4	2.79	17.38	23.4	2.2
		60K+	46	.43	.00	90	63	27	0	6.91	.00	5.4	1.9
	All		52	.27	.02	216	167	45	4	4.34	10.82	28.8	4.1
	Long PCC	<60K	44	.14	.02	2720	2339	330	51	2.27	9.89	730.1	62.5
		60K+	49	.27	.00	1516	1191	320	5	4.34	1.90	92.6	30.7
	All		45	.18	.02	4236	3530	650	56	2.97	7.19	822.7	93.2
	Asphalt	<60K	50	.13	.01	2667	2344	309	14	2.13	2.70	656.1	53.5
		60K+	51	.21	.00	548	453	94	1	3.33	1.00	34.7	10.8
	All		50	.14	.01	3215	2797	403	15	2.32	2.42	690.8	64.3
Overall			47	.17	.01	7667	6494	1098	75	2.73	5.23	1542.3	161.7
Urban	Trns PCC	<60K	87	.32	.00	409	310	98	1	5.10	1.46	32.7	4.7
		60K+	94	.22	.00	5766	4711	1052	3	3.60	.29	109.2	61.0
	All		94	.23	.00	6175	5021	1150	4	3.69	.36	141.9	65.8
	Long PCC	<60K	76	.18	.00	2824	2392	424	8	2.86	1.54	269.8	37.0
		60K+	98	.19	.00	59490	50062	9405	23	3.03	.21	1092.6	606.1
	All		97	.19	.00	62314	52454	9828	31	3.02	.27	1362.4	643.1
	Asphalt	<60K	75	.22	.00	2675	2191	477	7	3.51	1.44	270.3	35.6
		60K+	111	.24	.00	20350	16349	3996	5	3.94	.14	376.9	182.7
	All		105	.24	.00	23025	18540	4473	12	3.89	.29	647.2	218.4
Overall			99	.20	.00	91514	76015	15451	47	3.28	.28	2151.4	927.2
CA 1995			91	.20	.00	99181	82509	16550	122	3.23	.67	3693.8	1088.9

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California — Rolling and Level Terrain — Year 1996

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	65	.19	.10	146	113	22	11	3.99	66.84	23.4	2.2
		60K+	39	.52	.00	76	50	26	0	10.65	.00	5.4	2.0
	All		53	.29	.07	222	163	48	11	6.03	46.34	28.8	4.2
	Long PCC	<60K	45	.14	.03	2922	2492	356	73	2.93	20.23	730.8	64.5
		60K+	53	.26	.00	1644	1303	339	2	5.32	1.05	92.0	30.7
	All		48	.18	.02	4566	3795	695	75	3.75	13.65	822.7	95.2
	Asphalt	<60K	51	.11	.01	2775	2484	272	19	2.24	5.25	654.1	54.0
		60K+	54	.28	.00	597	466	131	0	5.76	.00	35.5	11.0
	All		52	.14	.01	3372	2950	403	19	2.80	4.42	689.6	64.9
Overall			50	.17	.02	8160	6909	1146	105	3.40	10.48	1541.1	164.3
Urban	Trns PCC	<60K	74	.30	.00	337	259	78	1	6.14	2.66	31.7	4.5
		60K+	99	.22	.00	6218	5106	1109	3	4.45	.40	111.7	62.5
	All		98	.22	.00	6555	5364	1187	4	4.53	.51	143.3	67.1
	Long PCC	<60K	80	.18	.00	2970	2517	443	10	3.61	2.73	265.2	37.0
		60K+	105	.16	.00	65031	55957	9044	30	3.31	.37	1096.2	618.7
	All		104	.16	.00	68001	58474	9487	40	3.32	.47	1361.5	655.7
	Asphalt	<60K	80	.23	.00	2779	2259	512	8	4.64	2.43	263.3	34.9
		60K+	111	.22	.00	21432	17501	3922	9	4.59	.35	398.2	193.8
	All		106	.22	.00	24211	19761	4433	17	4.59	.59	661.5	228.7
Overall			104	.18	.00	98767	83599	15107	61	3.70	.50	2166.3	951.5
CA 1996			96	.18	.00	106927	90508	16253	166	3.68	1.26	3707.4	1115.8

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California — Rolling and Level Terrain — Year 1997

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	70	.14	.06	159	132	19	8	4.41	17.45	23.2	2.3
		60K+	59	.20	.00	122	102	20	0	6.00	.00	5.5	2.1
	All		65	.17	.03	281	234	39	8	5.10	9.85	28.7	4.3
	Long PCC	<60K	42	.09	.02	2726	2460	214	52	2.66	6.11	719.8	64.6
		60K+	52	.16	.00	1683	1455	227	1	4.79	.20	96.4	32.5
	All		45	.11	.01	4409	3915	441	53	3.45	3.91	816.3	97.1
	Asphalt	<60K	51	.09	.00	2834	2591	232	11	2.75	1.22	658.7	55.8
		60K+	58	.13	.00	681	601	80	0	4.08	.00	37.3	11.7
	All		52	.10	.00	3515	3192	312	11	3.00	.99	696.1	67.4
Overall			49	.11	.01	8205	7340	792	72	3.30	2.83	1541.1	168.9
Urban	Trns PCC	<60K	79	.17	.00	364	310	54	0	5.28	.00	31.5	4.6
		60K+	98	.17	.00	6252	5363	887	2	5.07	.12	111.8	63.5
	All		97	.17	.00	6616	5673	941	2	5.08	.11	143.3	68.1
	Long PCC	<60K	78	.13	.00	2701	2385	311	5	3.99	.60	252.2	34.8
		60K+	104	.12	.00	66491	59488	6990	13	3.60	.06	1112.2	637.0
	All		103	.12	.00	69192	61873	7301	18	3.61	.08	1364.4	671.8
	Asphalt	<60K	78	.15	.00	2805	2430	371	4	4.67	.47	265.8	36.0
		60K+	114	.14	.00	22384	19629	2742	12	4.28	.18	398.9	196.8
	All		108	.14	.00	25189	22059	3113	16	4.32	.21	664.7	232.8
Overall			104	.13	.00	100997	89606	11355	36	3.88	.12	2172.4	972.7
CA 1997			96	.13	.00	109202	96946	12147	109	3.84	.32	3713.4	1141.6

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California | Rolling and Level Terrain | Year 1998

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	59	.22	.08	134	103	23	8	3.62	24.47	23.1	2.3
		60K+	59	.43	.02	125	86	37	2	6.97	7.33	5.6	2.1
	All		59	.32	.05	259	189	60	10	5.14	16.67	28.8	4.4
	Long PCC	<60K	42	.19	.05	2692	2172	411	109	3.06	15.80	715.4	64.4
		60K+	50	.32	.01	1734	1305	413	16	5.13	3.89	102.6	34.4
	All		45	.24	.04	4426	3477	824	125	3.84	11.33	818.0	98.9
	Asphalt	<60K	53	.14	.02	3004	2589	374	41	2.34	4.99	657.3	56.2
		60K+	58	.22	.00	717	585	130	2	3.61	1.08	38.9	12.4
	All		54	.16	.01	3721	3174	504	43	2.57	4.27	696.2	68.6
Overall			49	.20	.03	8406	6840	1388	178	3.29	8.20	1542.9	171.9
Urban	Trns PCC	<60K	85	.30	.05	388	287	87	14	4.91	15.37	31.6	4.5
		60K+	98	.27	.00	6435	5069	1361	5	4.35	.31	114.9	65.5
	All		97	.27	.00	6823	5356	1448	19	4.38	1.12	146.5	70.0
	Long PCC	<60K	84	.25	.02	3029	2387	601	41	4.08	5.41	260.3	36.0
		60K+	108	.21	.00	69789	57739	12014	36	3.37	.20	1114.6	649.0
	All		106	.21	.00	72818	60126	12615	77	3.40	.40	1374.9	685.0
	Asphalt	<60K	78	.28	.01	2920	2268	632	20	4.51	2.78	282.3	37.2
		60K+	113	.27	.00	23176	18196	4976	4	4.43	.07	404.1	204.9
	All		108	.27	.00	26096	20464	5608	24	4.44	.37	686.4	242.1
Overall			106	.23	.00	105737	85946	19671	120	3.71	.44	2207.7	997.1
CA 1998			98	.23	.00	114143	92786	21059	298	3.68	1.01	3750.6	1168.9

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California Mountainous Terrain Year 1991

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Wet Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	59	.33	.13	22	15	5	2	7.00	52.43	6.5	.4
		60K+	17	.00	.00	5	5	0	0	.00	.00	1.0	.3
	All		40	.25	.10	27	20	5	2	5.25	39.32	7.5	.7
	Long PCC	<60K	48	.14	.16	625	481	67	77	2.90	63.05	125.3	13.1
		60K+	39	.10	.01	378	340	34	4	2.08	4.69	35.3	9.6
	All		44	.12	.10	1003	822	100	81	2.56	38.88	160.6	22.7
	Asphalt	<60K	50	.12	.11	408	331	41	36	2.57	43.03	136.9	8.1
		60K+	35	.00	.00	3	3	0	0	.00	.00	.3	.1
	All		50	.12	.11	411	334	41	36	2.55	42.64	137.2	8.2
Overall			46	.12	.10	1441	1176	146	119	2.60	39.96	305.3	31.6
Urban	Trns PCC	<60K	186	1.83	.00	17	6	11	0	38.52	.00	.7	.1
		60K+	78	.10	.00	87	79	8	0	2.13	.00	2.5	1.1
	All		86	.22	.00	104	85	19	0	4.70	.00	3.1	1.2
	Long PCC	<60K	230	.98	.00	70	35	35	0	20.65	.00	2.0	.3
		60K+	86	.12	.00	1026	915	111	0	2.56	.00	25.9	11.9
	All		90	.15	.00	1096	950	146	0	3.23	.00	28.0	12.2
	Asphalt	<60K	64	.22	.00	145	119	26	0	4.63	.00	16.5	2.3
		60K+	81	.14	.00	636	560	76	0	2.86	.00	10.8	7.9
	All		77	.15	.00	781	679	102	0	3.17	.00	27.3	10.2
Overall			84	.16	.00	1981	1714	267	0	3.28	.00	58.4	23.6
CA 1991			62	.14	.04	3422	2889	413	119	3.00	16.26	363.7	55.2

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California Mountainous Terrain Year 1992

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	56	.20	.20	21	15	3	3	4.49	78.87	6.5	.4
		60K+	61	.33	.17	18	12	4	2	7.49	65.73	1.0	.3
	All		58	.26	.19	39	27	7	5	5.82	73.03	7.5	.7
	Long PCC	<60K	46	.24	.13	604	443	106	56	5.35	49.41	125.3	13.1
		60K+	47	.17	.01	452	384	65	2	3.82	2.11	35.3	9.6
	All		47	.21	.07	1056	827	171	58	4.64	27.43	160.6	22.7
	Asphalt	<60K	46	.16	.13	377	291	48	38	3.67	51.42	136.9	8.1
		60K+	12	.00	.00	1	1	0	0	.00	.00	.3	.1
	All		46	.16	.13	378	292	48	38	3.65	51.25	137.2	8.2
Overall			47	.20	.09	1473	1147	226	101	4.42	34.58	305.3	31.6
Urban	Trns PCC	<60K	218	1.18	.55	20	7	9	4	26.54	215.11	.7	.1
		60K+	71	.08	.03	80	72	6	2	1.87	10.95	2.5	1.1
	All		82	.18	.08	100	79	15	6	4.15	29.83	3.1	1.2
	Long PCC	<60K	167	.70	.00	51	30	21	0	15.72	.00	2.0	.3
		60K+	89	.18	.00	1063	901	162	0	4.05	.00	25.9	11.9
	All		91	.20	.00	1114	931	183	0	4.43	.00	28.0	12.2
	Asphalt	<60K	71	.43	.04	162	110	48	4	9.70	14.29	16.5	2.3
		60K+	79	.18	.00	622	525	96	1	4.13	.75	10.8	7.9
	All		77	.23	.01	784	635	144	5	5.09	3.11	27.3	10.2
Overall			85	.21	.01	1998	1645	342	11	4.67	2.64	58.4	23.6
CA 1992			63	.20	.04	3471	2792	568	112	4.57	15.76	363.7	55.2

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California — Mountainous Terrain — Year 1993

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	64	.47	.13	24	15	7	2	8.87	52.18	6.5	.4
		60K+	51	.20	.30	15	10	2	3	3.80	117.40	1.0	.3
	All		58	.36	.20	39	25	9	5	6.84	78.27	7.5	.7
	Long PCC	<60K	49	.23	.16	642	459	107	76	4.45	64.36	125.3	13.1
		60K+	52	.13	.01	503	444	56	3	2.41	2.65	35.3	9.6
	All		50	.18	.09	1145	903	164	79	3.44	34.02	160.6	22.7
	Asphalt	<60K	50	.18	.10	405	315	57	33	3.45	41.01	136.9	8.1
		60K+	35	.00	.00	3	3	0	0	.00	.00	.3	.1
	All		50	.18	.10	408	318	57	33	3.41	40.63	137.2	8.2
Overall			50	.18	.09	1592	1246	230	117	3.50	36.60	305.3	31.6
Urban	Trns PCC	<60K	197	8.00	.00	18	2	16	0	151.97	.00	.7	.1
		60K+	63	.13	.03	71	61	8	2	2.50	13.57	2.5	1.1
	All		73	.38	.03	89	63	24	2	7.25	13.14	3.1	1.2
	Long PCC	<60K	177	.97	.00	54	27	27	0	18.46	.00	2.0	.3
		60K+	81	.18	.00	965	819	145	1	3.36	.48	25.9	11.9
	All		83	.20	.00	1019	847	171	1	3.85	.46	28.0	12.2
	Asphalt	<60K	71	.51	.02	161	105	54	2	9.68	7.43	16.5	2.3
		60K+	79	.14	.00	624	549	75	0	2.60	.00	10.8	7.9
	All		77	.20	.00	785	654	129	2	3.74	1.20	27.3	10.2
Overall			80	.21	.00	1893	1564	324	5	3.94	1.28	58.4	23.6
CA 1993			63	.20	.04	3485	2809	554	122	3.75	16.94	363.7	55.2

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California — Mountainous Terrain — Year 1994

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	55	.13	.20	20	15	2	3	3.69	79.51	6.5	.4
		60K+	40	.33	.00	12	9	3	0	9.21	.00	1.0	.3
	All		48	.21	.13	32	24	5	3	5.76	49.69	7.5	.7
	Long PCC	<60K	54	.19	.19	665	484	90	91	5.16	74.65	121.2	12.3
		60K+	54	.10	.01	568	511	53	4	2.87	3.11	39.4	10.5
	All		54	.14	.10	1233	995	143	95	3.98	37.90	160.6	22.8
	Asphalt	<60K	53	.11	.07	427	362	40	25	3.03	27.49	136.9	8.1
		60K+	48	.00	.00	4	4	0	0	.00	.00	.3	.1
	All		53	.11	.07	431	366	40	25	3.00	27.19	137.2	8.1
Overall			54	.14	.09	1696	1385	188	123	3.75	35.28	305.3	31.6
Urban	Trns PCC	<60K	200	1.71	.00	19	7	12	0	47.39	.00	.7	.1
		60K+	93	.16	.00	103	89	14	0	4.35	.00	2.5	1.1
	All		101	.27	.00	122	96	26	0	7.49	.00	3.1	1.2
	Long PCC	<60K	215	1.92	.00	64	22	42	0	53.02	.00	1.9	.3
		60K+	103	.11	.00	1198	1080	118	0	3.01	.00	26.1	11.7
	All		105	.14	.00	1262	1102	160	0	4.00	.00	28.0	12.0
	Asphalt	<60K	73	.31	.12	166	116	36	14	8.60	48.25	16.5	2.3
		60K+	90	.11	.00	686	617	69	0	3.10	.00	10.8	7.6
	All		86	.14	.02	852	733	105	14	3.97	7.63	27.3	9.9
Overall			97	.15	.01	2236	1931	291	14	4.17	2.90	58.4	23.0
CA 1994			72	.14	.04	3932	3316	479	137	3.99	16.42	363.7	54.7

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California | Mountainous Terrain | Year 1995

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	63	.31	.06	22	16	5	1	5.04	28.24	6.5	.4
		60K+	48	.25	.00	15	12	3	0	4.03	.00	1.0	.3
	All		56	.29	.04	37	28	8	1	4.61	16.13	7.5	.7
	Long PCC	<60K	54	.24	.17	644	456	109	79	3.84	78.59	113.3	11.9
		60K+	59	.25	.01	618	489	122	7	4.02	6.47	37.7	10.5
	All		57	.24	.09	1262	945	231	86	3.93	41.27	150.9	22.3
	Asphalt	<60K	55	.21	.08	469	364	75	30	3.32	37.67	146.5	8.6
		60K+	23	.00	.00	2	2	0	0	.00	.00	.3	.1
	All		54	.20	.08	471	366	75	30	3.30	37.47	146.8	8.7
Overall			56	.23	.09	1770	1339	314	118	3.78	39.71	305.3	31.6
Urban	Trns PCC	<60K	207	2.17	.00	19	6	13	0	34.93	.00	.7	.1
		60K+	89	.48	.00	100	68	32	0	7.71	.00	2.5	1.1
	All		98	.62	.00	119	74	45	0	9.93	.00	3.1	1.2
	Long PCC	<60K	270	1.64	.00	84	32	52	0	26.39	.00	2.0	.3
		60K+	99	.21	.00	1196	985	210	1	3.43	.46	25.9	12.1
	All		103	.26	.00	1280	1017	262	1	4.15	.44	28.0	12.4
	Asphalt	<60K	69	.27	.03	154	118	32	4	4.37	15.31	16.5	2.2
		60K+	80	.18	.00	614	521	93	0	2.86	.00	10.8	7.7
	All		77	.19	.01	768	639	125	4	3.14	2.83	27.3	9.9
Overall			92	.25	.00	2167	1730	432	5	4.03	1.31	58.4	23.5
CA 1995			71	.24	.04	3937	3069	745	123	3.92	18.06	363.7	55.2

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California | Mountainous Terrain | Year 1996

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	109	.32	.41	38	22	7	9	6.51	280.90	6.4	.3
		60K+	47	.23	.00	16	13	3	0	4.73	.00	1.1	.3
	All		79	.29	.26	54	35	10	9	5.85	176.57	7.5	.7
	Long PCC	<60K	61	.22	.25	683	466	102	115	4.46	169.29	109.2	11.2
		60K+	53	.18	.02	635	532	94	9	3.63	11.68	41.8	11.9
	All		57	.20	.12	1318	998	196	124	4.02	85.33	150.9	23.1
	Asphalt	<60K	56	.30	.10	491	351	104	36	6.04	70.36	146.5	8.8
		60K+	11	.00	.00	1	1	0	0	.00	.00	.3	.1
	All		55	.29	.10	492	352	104	36	6.03	70.16	146.8	8.9
Overall			57	.22	.12	1864	1385	310	169	4.57	83.78	305.3	32.7
Urban	Trns PCC	<60K	182	.89	.00	17	9	8	0	18.20	.00	.7	.1
		60K+	90	.26	.00	107	85	22	0	5.30	.00	2.5	1.2
	All		97	.32	.00	124	94	30	0	6.53	.00	3.1	1.3
	Long PCC	<60K	239	.91	.00	74	39	35	0	18.63	.00	2.0	.3
		60K+	96	.22	.00	1245	1018	227	0	4.56	.00	25.9	12.9
	All		100	.25	.00	1319	1057	262	0	5.08	.00	28.0	13.3
	Asphalt	<60K	79	.52	.03	180	116	61	3	10.70	17.72	16.5	2.3
		60K+	95	.15	.00	738	644	94	0	3.00	.00	10.8	7.8
	All		92	.20	.00	918	760	155	3	4.18	2.71	27.3	10.0
Overall			96	.23	.00	2361	1911	447	3	4.79	1.08	58.4	24.6
CA 1996			74	.23	.05	4225	3296	757	172	4.70	35.84	363.7	57.2

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California — Mountainous Terrain — Year 1997

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	75	.26	.16	27	19	5	3	8.06	45.47	6.4	.4
		60K+	38	.08	.00	13	12	1	0	2.55	.00	1.1	.3
	All		57	.19	.10	40	31	6	3	5.92	27.87	7.5	.7
	Long PCC	<60K	56	.20	.13	647	484	99	65	6.24	38.71	109.2	11.6
		60K+	63	.15	.00	762	663	96	3	4.46	1.30	41.8	12.1
	All		59	.17	.06	1409	1146	195	68	5.21	17.09	150.9	23.7
	Asphalt	<60K	57	.25	.05	516	397	100	19	7.74	13.79	146.5	9.1
		60K+	33	.00	.00	3	3	0	0	.00	.00	.3	.1
	All		57	.25	.05	519	400	100	19	7.68	13.69	146.8	9.2
Overall			59	.19	.06	1968	1577	301	90	5.85	16.44	305.3	33.6
Urban	Trns PCC	<60K	124	.57	.00	11	7	4	0	17.49	.00	.7	.1
		60K+	88	.04	.00	105	101	4	0	1.23	.00	2.5	1.2
	All		90	.07	.00	116	108	8	0	2.29	.00	3.1	1.3
	Long PCC	<60K	147	1.58	.00	31	12	19	0	48.47	.00	1.6	.2
		60K+	94	.17	.00	1228	1047	180	1	5.26	.28	26.4	13.1
	All		95	.19	.00	1259	1059	199	1	5.75	.27	28.0	13.3
	Asphalt	<60K	62	.13	.00	145	128	17	0	4.07	.00	16.6	2.3
		60K+	86	.12	.00	662	593	69	0	3.57	.00	10.7	7.7
	All		80	.12	.00	807	721	86	0	3.66	.00	27.3	10.0
Overall			89	.16	.00	2182	1888	293	1	4.75	.15	58.4	24.6
CA 1997			71	.17	.03	4150	3465	594	91	5.25	7.56	363.7	58.2

Table C2. Annual Wisconsin and California Crash Statistics by Pavement Surface Type. (continued)

California — Mountainous Terrain — Year 1998

Freeway	Wear Surface	AADT vpd	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Dry pvt crashes	Wet pvt crashes	Snow crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
Rural	Trns PCC	<60K	90	.29	.59	32	17	5	10	4.76	185.35	6.4	.4
		60K+	40	.40	.00	14	10	4	0	6.48	.00	1.1	.4
	All		65	.33	.37	46	27	9	10	5.40	116.70	7.5	.7
	Long PCC	<60K	62	.54	.39	705	365	198	141	8.79	121.99	109.2	11.3
		60K+	68	.29	.01	848	653	191	4	4.72	1.94	41.8	12.5
	All		65	.38	.14	1553	1019	389	145	6.18	44.99	150.9	23.8
	Asphalt	<60K	71	.52	.32	633	345	178	109	8.36	99.63	146.5	8.9
		60K+	76	.00	.00	7	7	0	0	.00	.00	.3	.1
	All		71	.51	.31	640	352	178	109	8.19	97.65	146.8	9.0
Overall			67	.41	.19	2239	1398	576	265	6.67	59.65	305.3	33.4
Urban	Trns PCC	<60K	65	1.00	.50	5	2	2	1	16.20	157.54	.6	.1
		60K+	111	.31	.06	134	98	30	6	4.96	19.29	2.5	1.2
	All		108	.32	.07	139	100	32	7	5.18	22.06	3.1	1.3
	Long PCC	<60K	117	.62	.00	14	9	5	0	9.97	.00	1.1	.1
		60K+	105	.34	.00	1384	1032	351	1	5.52	.31	26.9	13.2
	All		105	.34	.00	1398	1040	357	1	5.55	.30	28.0	13.3
	Asphalt	<60K	72	.39	.06	161	111	43	7	6.27	19.87	15.7	2.2
		60K+	89	.21	.00	690	572	119	0	3.36	.00	11.6	7.7
	All		85	.24	.01	851	683	162	7	3.83	3.23	27.3	10.0
Overall			97	.30	.01	2388	1823	550	15	4.89	2.59	58.4	24.6
CA 1998			80	.35	.09	4627	3221	1126	280	5.66	27.36	363.7	58.0

APPENDIX D

SUMMARY CRASH FINDINGS

INTRODUCTION

This Appendix provides background data for the **Findings** section of the report. Annual statistics are extracted from the comprehensive crash statistics in **Table C2**. Wisconsin statistics in **Tables D2, D3 and D4** are provided as preliminary findings only.

The following cautions should be kept in mind when interpreting APPENDIX D information:

- California TT data represent bridge decks exclusively.
- Wisconsin mileage represents directional miles.
- California mileage represents centerline miles (both directions).
- 100% of California freeway crashes were analyzed.
- 34% of Wisconsin freeway crashes were analyzed.
- Frozen Safety Ratio information is not reliable for California (details explained in Appendix E).
- Statistics based on very few freeway miles are not reliable and are presented as preliminary information. It is recommended to consult statistics based on more than 100 miles of freeway.

Table D1. Wisconsin Rural Freeway Statistics 1991-1998. Less than 60K VPD.

Year	Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
1991	Trns PCC	47	.19	1.54	267	2.21	22.25	119.7	5.6
	Asphalt	49	.26	1.47	244	3.05	21.22	122.8	5.0
1992	Trns PCC	40	.28	1.08	233	3.18	14.12	121.4	5.8
	Asphalt	31	.23	.75	249	2.56	9.75	176.2	8.1
1993	Trns PCC	46	.20	1.15	391	2.16	13.27	166.8	8.5
	Asphalt	40	.25	1.18	358	2.71	13.55	195.1	8.9
1994	Trns PCC	40	.08	1.56	345	1.21	22.48	166.8	8.6
	Asphalt	35	.23	1.14	316	3.70	16.39	195.1	9.0
1995	Trns PCC	40	.12	1.00	382	1.51	14.28	185.6	9.6
	Asphalt	37	.21	.70	337	2.72	10.06	195.1	9.2
1996	Trns PCC	50	.23	2.03	522	4.07	34.35	196.8	10.4
	Asphalt	47	.20	1.41	496	3.52	23.86	218.9	10.6
1997	Trns PCC	35	.13	1.62	411	2.39	28.84	219.7	11.6
	Asphalt	36	.20	.95	477	3.61	16.87	268.7	13.2
1998	Trns PCC	40	.14	1.00	497	2.16	22.76	233.7	12.5
	Asphalt	35	.25	.72	511	3.88	16.50	296.7	14.5
Overall Statistics									
	Trns PCC	42	.16	1.34	3048	2.25	20.30	233.7	72.6
	Asphalt	38	.23	1.00	2988	3.11	15.09	296.7	78.4

Figure D1. Wisconsin Rural Freeway Crash Rates. <60K VPD

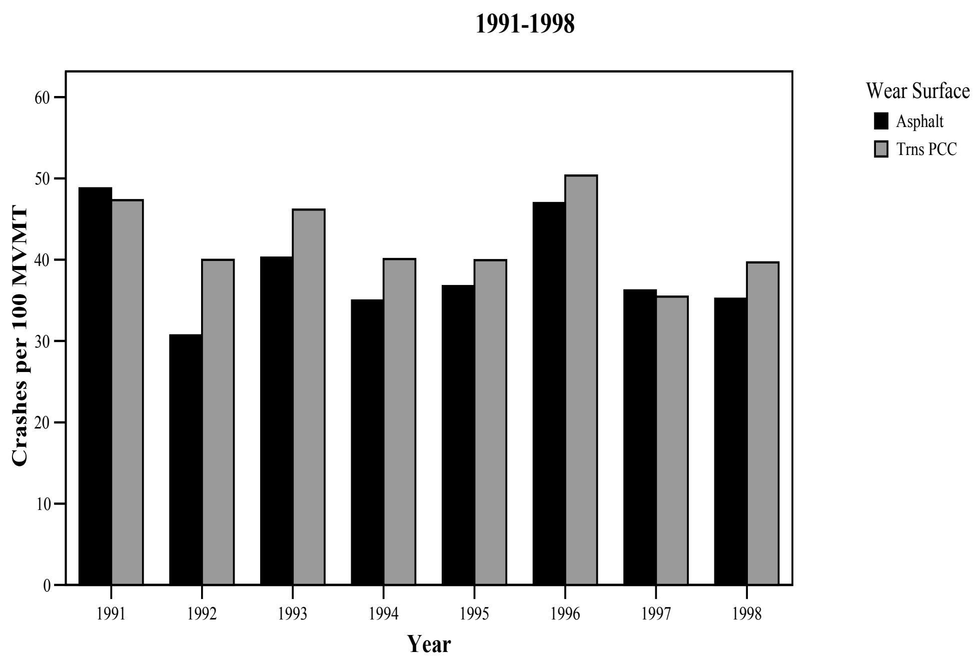


Figure D2. Wisconsin Rural Freeway Wet/Dry Ratios. <60K VPD

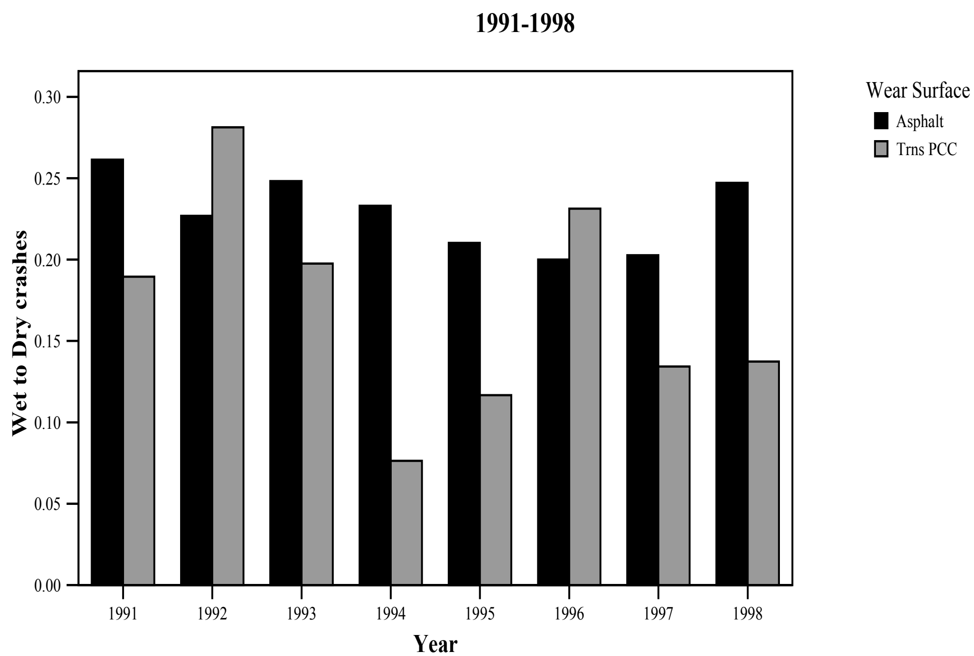


Figure D3. Wisconsin Rural Freeway Snow/Dry Ratios. <60K VPD

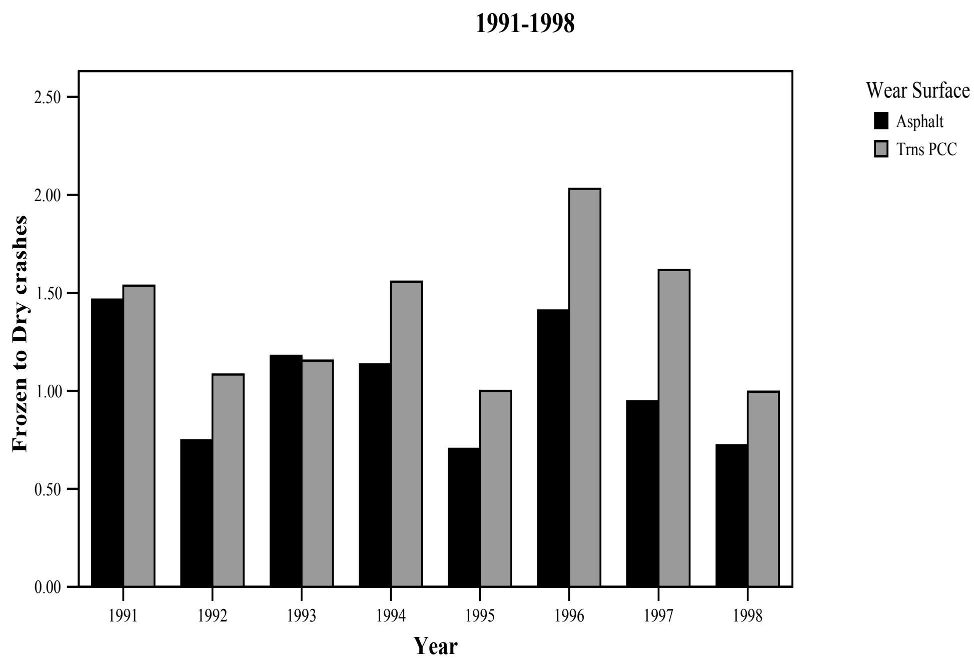


Figure D4. Wisconsin Rural Freeway Liquid Precip. Safety Ratios. <60K VPD

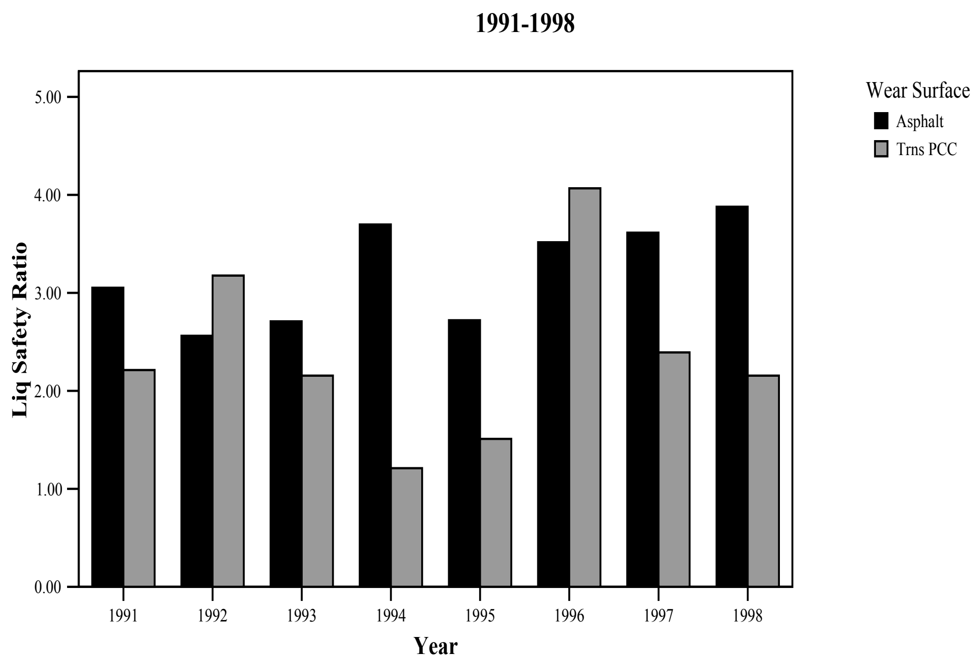


Figure D5. Wisconsin Rural Freeway Frozen Precip. Safety Ratios. <60K VPD

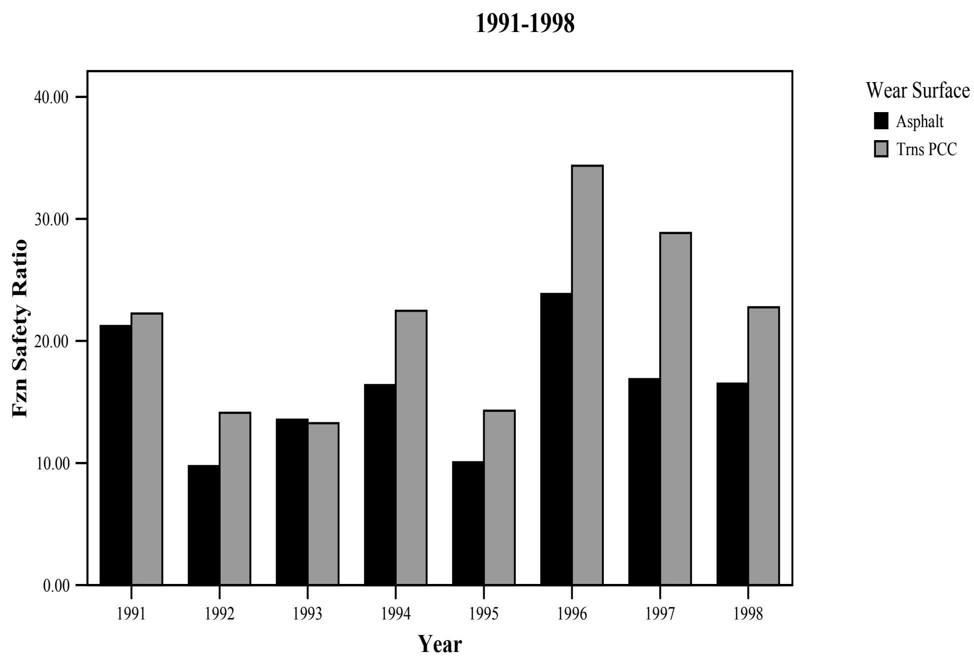


Table D2. Wisconsin Rural Freeway Statistics 1991-1998. 60K+ ADT

Year	Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
1991	Asphalt	44	.25	.62	188	2.92	8.97	36.2	4.3
1992	Asphalt	43	.23	.80	185	2.64	10.42	36.2	4.3
1993	Asphalt	50	.18	.87	219	1.97	9.96	36.2	4.4
1994	Asphalt	50	.17	1.02	224	2.64	14.72	36.2	4.4
1995	Asphalt	52	.18	.66	236	2.34	9.45	36.2	4.5
1996	Asphalt	52	.20	.88	235	3.58	14.82	36.2	4.6
1997	Asphalt	44	.21	.73	202	3.77	13.03	36.2	4.6
1998	Asphalt	53	.14	.11	313	2.22	2.58	45.7	5.9
Overall Statistics									
	Asphalt	49	.19	.62	1802	2.58	9.42	45.7	36.9

Table D3. Wisconsin Urban Freeway Statistics 1991-1998. Less than 60K VPD.

Year	Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
1991	Trns PCC	103	.31	.23	20	3.59	3.34	2.2	.2
	Asphalt	23	1.00	1.50	14	11.68	21.71	8.3	.6
1992	Trns PCC	40	.00	1.67	8	.00	21.72	2.2	.2
	Asphalt	26	.00	1.10	21	.00	14.33	10.8	.8
1993	Trns PCC	54	.20	1.00	11	2.18	11.49	2.2	.2
	Asphalt	32	.07	.67	27	.73	7.66	11.6	.9
1994	Trns PCC	29	1.00	4.00	6	15.87	57.74	2.2	.2
	Asphalt	30	.00	1.36	26	.00	19.68	11.6	.9
1995	Trns PCC	57	.00	.50	12	.00	7.14	2.2	.2
	Asphalt	45	.30	.65	40	3.88	9.28	11.6	.9
1996	Trns PCC	17	.	.	1	.	.	.8	.1
	Asphalt	50	.38	.86	47	6.70	14.50	12.1	.9
1997	Trns PCC	18	.33	.00	4	5.94	.00	4.9	.2
	Asphalt	39	.25	1.14	67	4.46	20.38	28.8	1.7
1998	Trns PCC	44	.50	3.50	10	7.85	80.00	4.9	.2
	Asphalt	47	.29	.81	88	4.49	18.50	32.3	1.9
Overall Statistics									
	Trns PCC	47	.23	.83	72	3.15	12.53	4.9	1.5
	Asphalt	39	.25	.92	330	3.47	13.92	32.3	8.5

Table D4. Wisconsin Urban Freeway Statistics 1991-1998. 60K+ VPD.

Year	Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Liq Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
1991	Asphalt	60	.26	.26	236	3.01	3.83	23.0	3.9
1992	Asphalt	68	.22	.28	274	2.48	3.65	23.0	4.0
1993	Asphalt	73	.26	.20	297	2.82	2.29	23.0	4.1
1994	Asphalt	81	.20	.42	335	3.22	6.00	23.0	4.1
1995	Asphalt	74	.18	.30	358	2.35	4.25	25.7	4.9
1996	Asphalt	79	.26	.22	435	4.49	3.80	28.0	5.5
1997	Asphalt	77	.19	.18	596	3.38	3.29	37.0	7.8
1998	Asphalt	88	.29	.07	1057	4.49	1.53	55.4	12.0
Overall Statistics									
	Asphalt	78	.24	.20	3588	3.31	2.96	55.4	46.2

Table D5. California Rural Freeway Statistics 1991-1998. Rolling and Level Terrain.
Less than 60K VPD.

Year	Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Wet Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
1991	Trns PCC	66	.12	.03	143	2.54	12.68	23.5	2.2
	Long PCC	42	.08	.02	2668	1.62	8.34	733.5	63.4
	Asphalt	50	.08	.01	2514	1.66	2.24	655.8	50.5
1992	Trns PCC	66	.16	.01	143	3.68	3.23	23.5	2.2
	Long PCC	41	.11	.02	2608	2.42	7.44	733.5	63.4
	Asphalt	45	.09	.01	2295	2.08	3.09	655.8	50.5
1993	Trns PCC	70	.22	.06	151	4.19	23.21	23.5	2.2
	Long PCC	42	.09	.02	2663	1.71	9.54	733.5	63.4
	Asphalt	49	.09	.01	2471	1.79	2.67	655.8	50.5
1994	Trns PCC	62	.15	.02	134	4.09	6.91	23.5	2.2
	Long PCC	42	.09	.02	2646	2.60	8.84	731.6	63.6
	Asphalt	51	.07	.01	2580	2.05	2.16	656.1	50.8
1995	Trns PCC	58	.17	.04	126	2.79	17.38	23.4	2.2
	Long PCC	44	.14	.02	2720	2.27	9.89	730.1	62.5
	Asphalt	50	.13	.01	2667	2.13	2.70	656.1	53.5
1996	Trns PCC	65	.19	.10	146	3.99	66.84	23.4	2.2
	Long PCC	45	.14	.03	2922	2.93	20.23	730.8	64.5
	Asphalt	51	.11	.01	2775	2.24	5.25	654.1	54.0
1997	Trns PCC	70	.14	.06	159	4.41	17.45	23.2	2.3
	Long PCC	42	.09	.02	2726	2.66	6.11	719.8	64.6
	Asphalt	51	.09	.00	2834	2.75	1.22	658.7	55.8
1998	Trns PCC	59	.22	.08	134	3.62	24.47	23.1	2.3
	Long PCC	42	.19	.05	2692	3.06	15.80	715.4	64.4
	Asphalt	53	.14	.02	3004	2.34	4.99	657.3	56.2
Overall Statistics									
	Trns PCC	65	.17	.05	1136	3.57	18.89	23.1	17.6
	Long PCC	42	.12	.03	21645	2.39	10.13	715.4	509.7
	Asphalt	50	.10	.01	21140	2.13	2.93	657.3	421.8

Figure D6. California Rural Freeway Crash Rates. <60K VPD

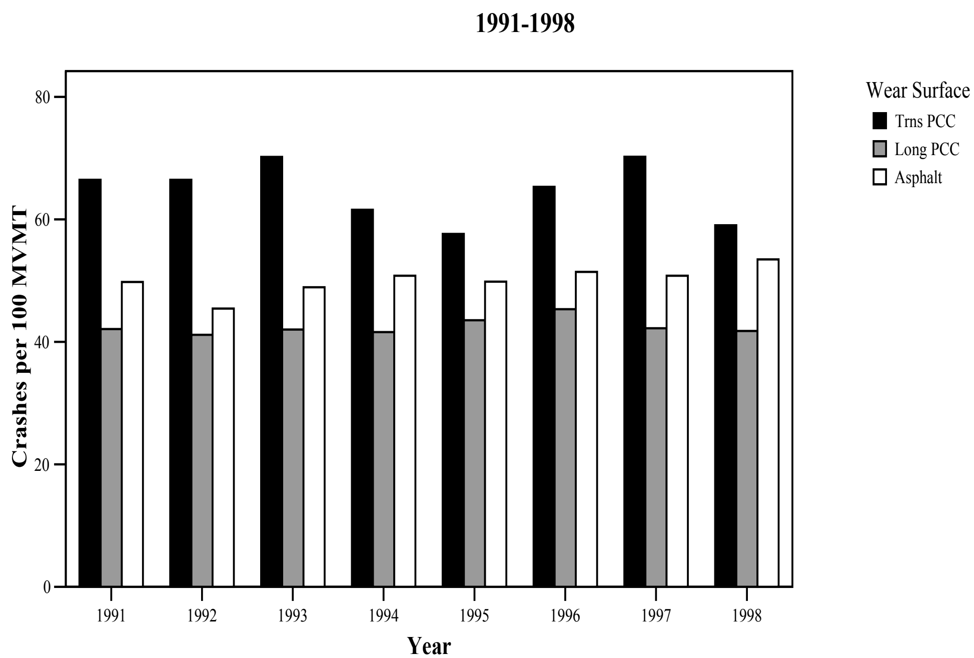
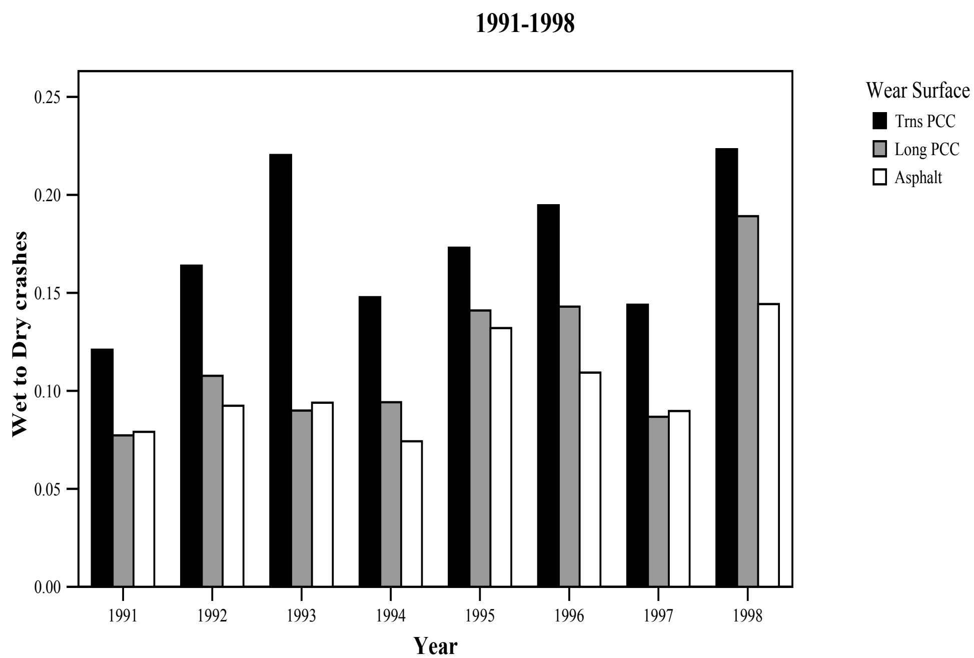


Figure D7. California Rural Freeway Wet/Dry Ratios. <60K VPD



Figue D8. California Rural Freeway Snow/Dry Ratios. <60K VPD

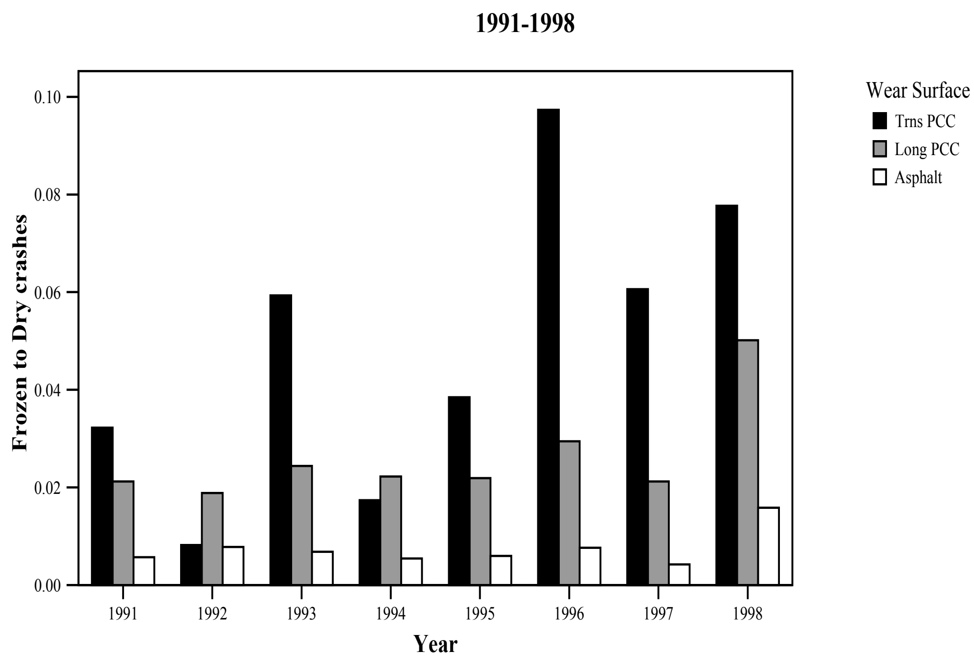


Figure D9. California Rural Freeway Liquid Precip. Safety Ratios. <60K VPD

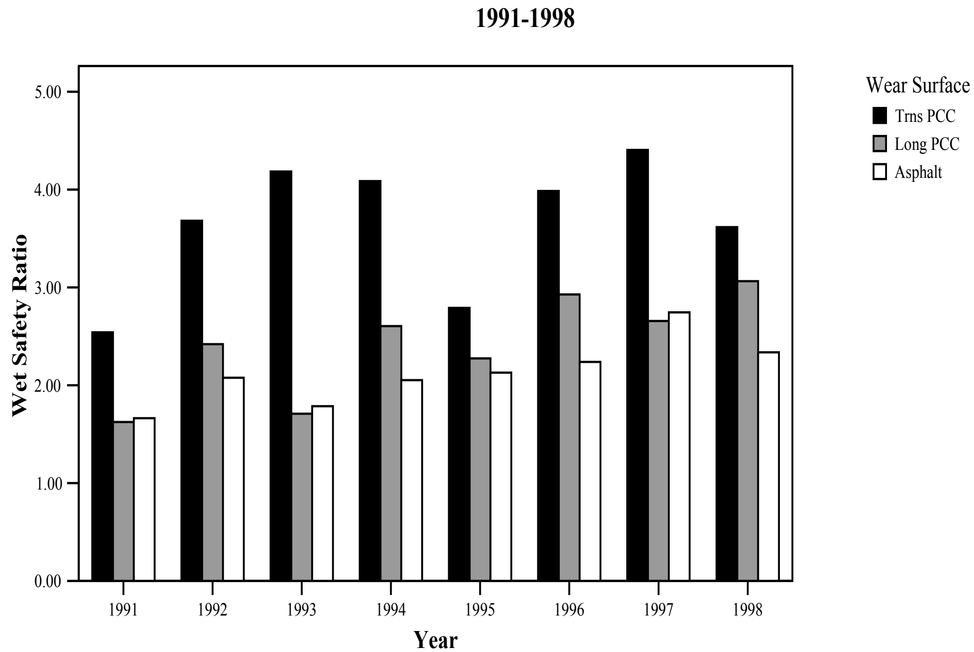


Figure D10. California Rural Freeway Frozen Precip. Safety Ratios. <60K VPD

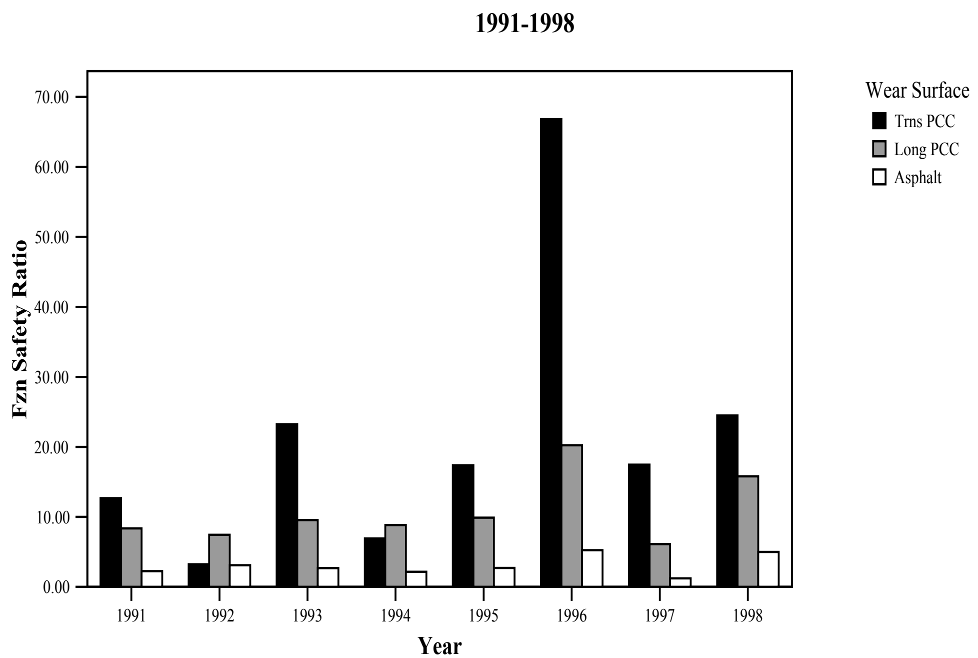


Table D6. California Urban Freeway Statistics 1991-1998. Rolling and Level Terrain. Less than 60K VPD.

Year	Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Wet Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
1991	Trns PCC	70	.19	.01	323	3.97	2.91	34.5	4.6
	Long PCC	72	.12	.00	2888	2.52	1.24	299.1	40.2
	Asphalt	78	.15	.00	2729	3.11	.66	274.1	35.2
1992	Trns PCC	74	.23	.01	343	5.26	5.82	34.5	4.6
	Long PCC	70	.18	.00	2807	3.95	1.52	299.1	40.2
	Asphalt	72	.21	.00	2548	4.72	1.50	274.1	35.2
1993	Trns PCC	79	.25	.02	366	4.67	8.12	34.5	4.6
	Long PCC	74	.17	.00	2990	3.15	1.38	299.1	40.2
	Asphalt	77	.21	.01	2694	3.90	3.58	274.1	35.2
1994	Trns PCC	77	.27	.00	370	7.48	.00	33.3	4.8
	Long PCC	76	.14	.00	2923	3.80	.31	282.3	38.7
	Asphalt	78	.17	.01	2861	4.68	2.12	280.9	36.5
1995	Trns PCC	87	.32	.00	409	5.10	1.46	32.7	4.7
	Long PCC	76	.18	.00	2824	2.86	1.54	269.8	37.0
	Asphalt	75	.22	.00	2675	3.51	1.44	270.3	35.6
1996	Trns PCC	74	.30	.00	337	6.14	2.66	31.7	4.5
	Long PCC	80	.18	.00	2970	3.61	2.73	265.2	37.0
	Asphalt	80	.23	.00	2779	4.64	2.43	263.3	34.9
1997	Trns PCC	79	.17	.00	364	5.28	.00	31.5	4.6
	Long PCC	78	.13	.00	2701	3.99	.60	252.2	34.8
	Asphalt	78	.15	.00	2805	4.67	.47	265.8	36.0
1998	Trns PCC	85	.30	.05	388	4.91	15.37	31.6	4.5
	Long PCC	84	.25	.02	3029	4.08	5.41	260.3	36.0
	Asphalt	78	.28	.01	2920	4.51	2.78	282.3	37.2
Overall Statistics									
	Trns PCC	78	.25	.01	2900	5.27	4.78	31.6	37.1
	Long PCC	76	.17	.00	23132	3.45	1.83	260.3	304.2
	Asphalt	77	.20	.00	22011	4.15	1.80	282.3	285.8

Figure D11. California Urban Freeway Crash Rates. <60K VPD

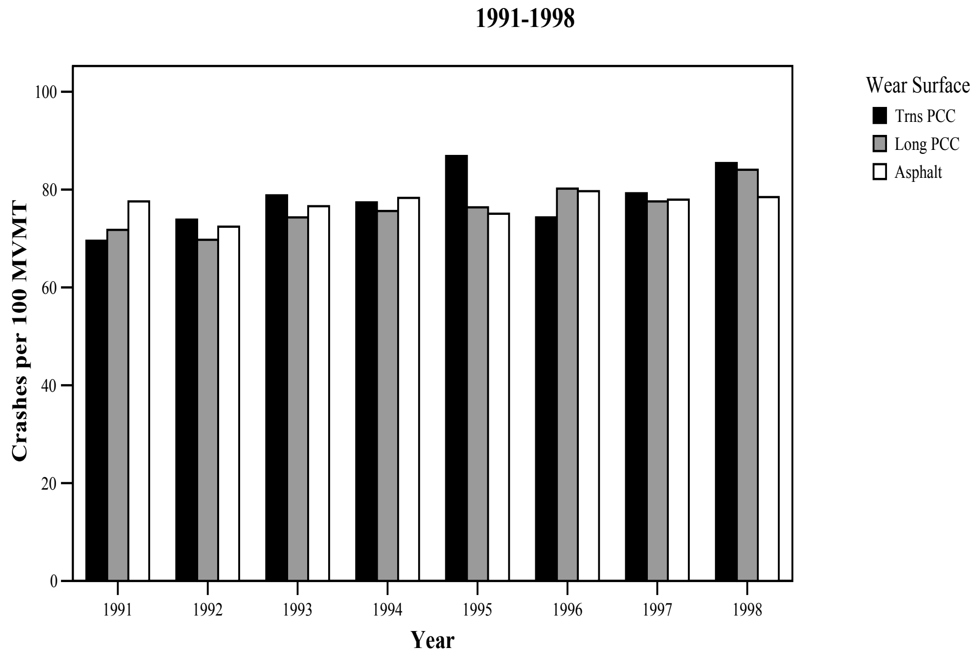


Figure D12. California Urban Freeway Wet/Dry Ratios. <60K VPD

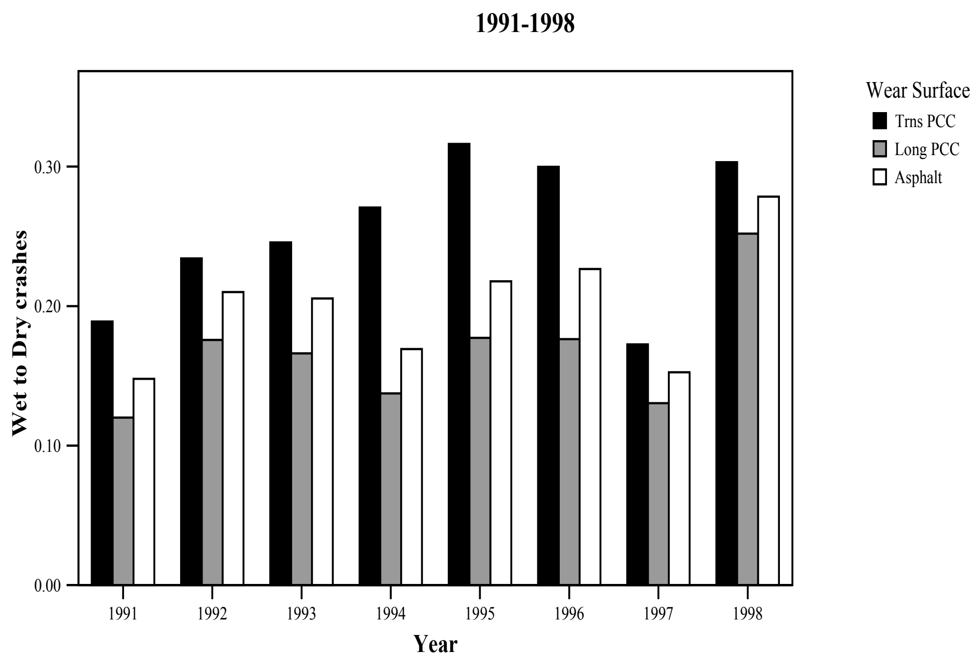


Figure D13. California Urban Freeway Snow/Dry Ratios. <60K VPD

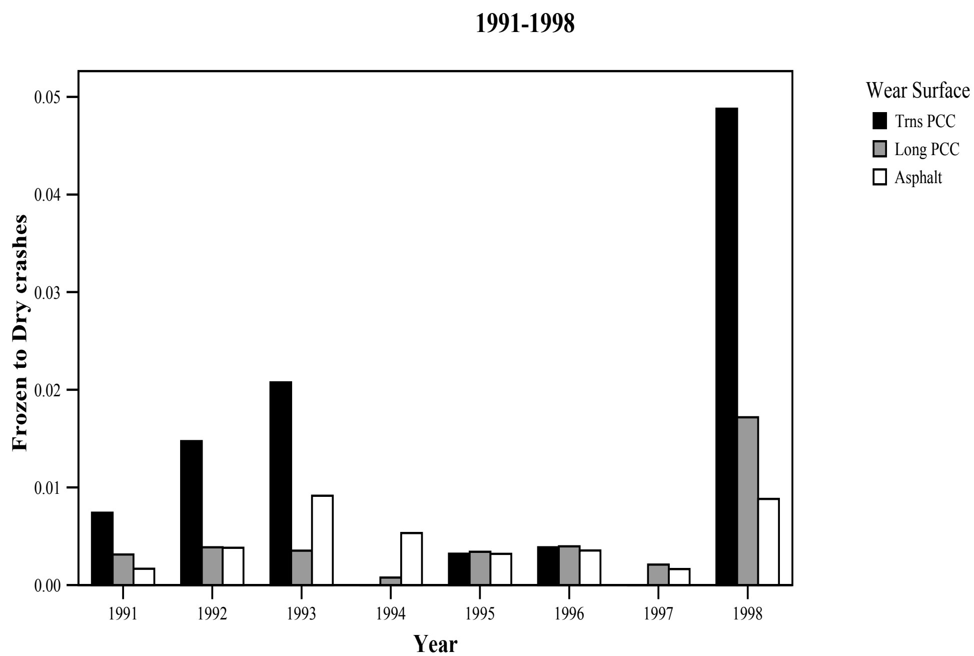


Figure D14. California Urban Freeway Liquid Precip. Safety Ratios. <60K VPD

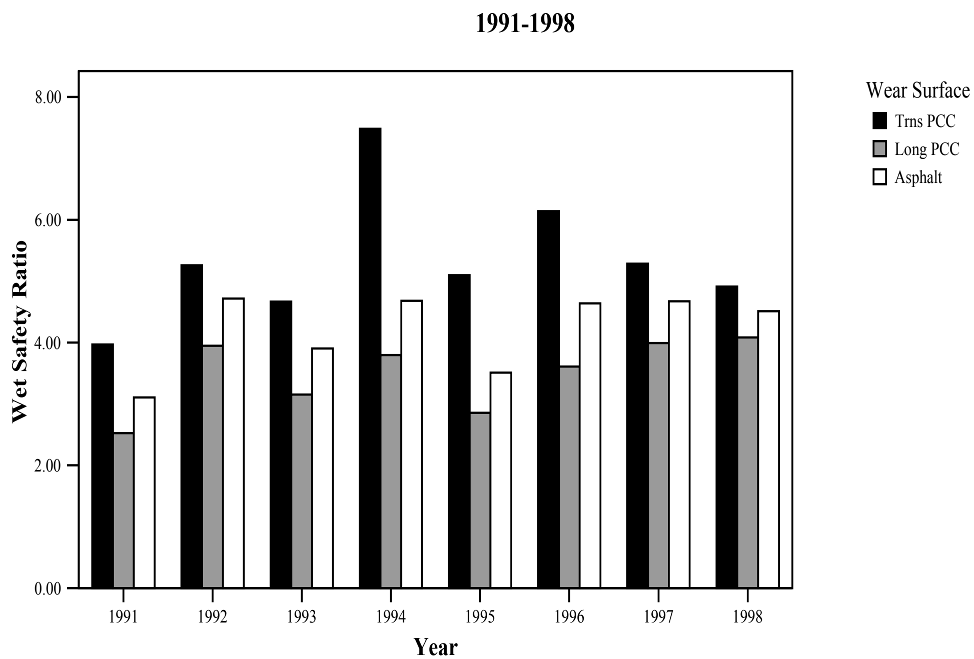


Figure D15. California Urban Freeway Frozen Precip. Safety Ratios. <60K VPD

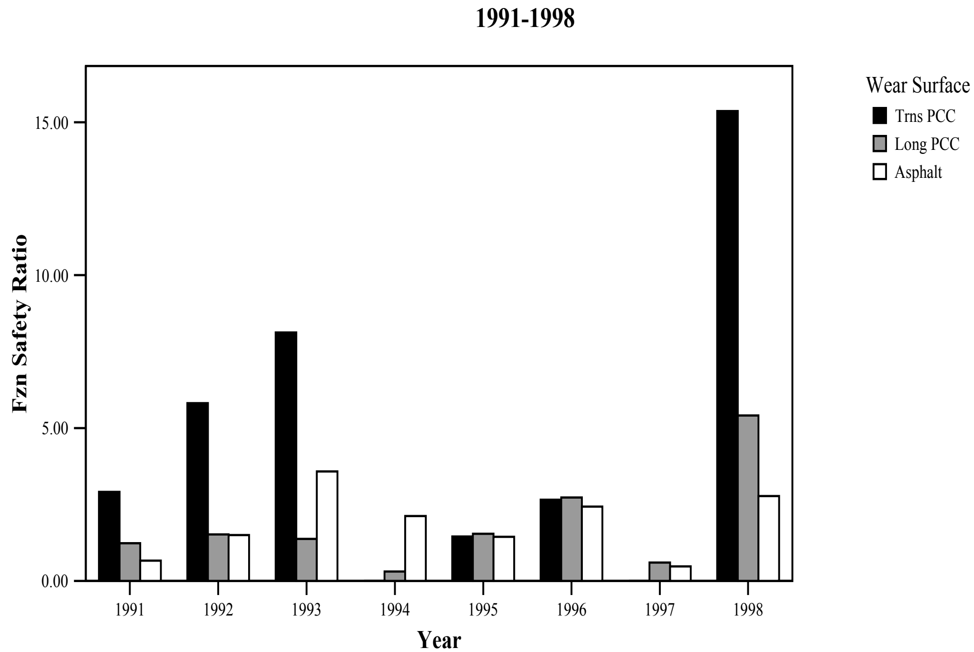


Table D7. California Urban Freeway Statistics 1991-1998. Rolling and Level Terrain. More than 60K VPD.

Year	Wear Surface	Crashes per 100 MVMT	Wet to Dry crashes	Frozen to Dry crashes	Total crashes	Wet Safety Ratio	Fzn Safety Ratio	Length miles	100 MVMT
1991	Trns PCC	93	.15	.00	5498	3.06	.16	106.0	59.4
	Long PCC	97	.12	.00	56825	2.50	.22	1054.2	586.9
	Asphalt	101	.13	.00	17200	2.83	.10	348.8	170.5
1992	Trns PCC	91	.19	.00	5421	4.31	.18	106.0	59.4
	Long PCC	95	.16	.00	55581	3.70	.12	1054.2	586.9
	Asphalt	104	.18	.00	17774	4.09	.16	348.8	170.5
1993	Trns PCC	89	.19	.00	5293	3.57	.79	106.0	59.4
	Long PCC	94	.16	.00	54986	3.00	.14	1054.2	586.9
	Asphalt	103	.21	.00	17563	3.99	.27	348.8	170.5
1994	Trns PCC	92	.17	.00	5497	4.82	.17	107.5	59.6
	Long PCC	99	.13	.00	58699	3.46	.16	1071.8	591.5
	Asphalt	108	.17	.00	19181	4.68	.22	364.9	177.5
1995	Trns PCC	94	.22	.00	5766	3.60	.29	109.2	61.0
	Long PCC	98	.19	.00	59490	3.03	.21	1092.6	606.1
	Asphalt	111	.24	.00	20350	3.94	.14	376.9	182.7
1996	Trns PCC	99	.22	.00	6218	4.45	.40	111.7	62.5
	Long PCC	105	.16	.00	65031	3.31	.37	1096.2	618.7
	Asphalt	111	.22	.00	21432	4.59	.35	398.2	193.8
1997	Trns PCC	98	.17	.00	6252	5.07	.12	111.8	63.5
	Long PCC	104	.12	.00	66491	3.60	.06	1112.2	637.0
	Asphalt	114	.14	.00	22384	4.28	.18	398.9	196.8
1998	Trns PCC	98	.27	.00	6435	4.35	.31	114.9	65.5
	Long PCC	108	.21	.00	69789	3.37	.20	1114.6	649.0
	Asphalt	113	.27	.00	23176	4.43	.07	404.1	204.9
Overall Statistics									
	Trns PCC	95	.20	.00	46380	4.09	.29	114.9	490.3
	Long PCC	100	.16	.00	486892	3.22	.17	1114.6	4863.0
	Asphalt	108	.20	.00	159060	4.10	.17	404.1	1467.0

Figure D16. California Urban Freeway Crash Rates. 60K+ VPD

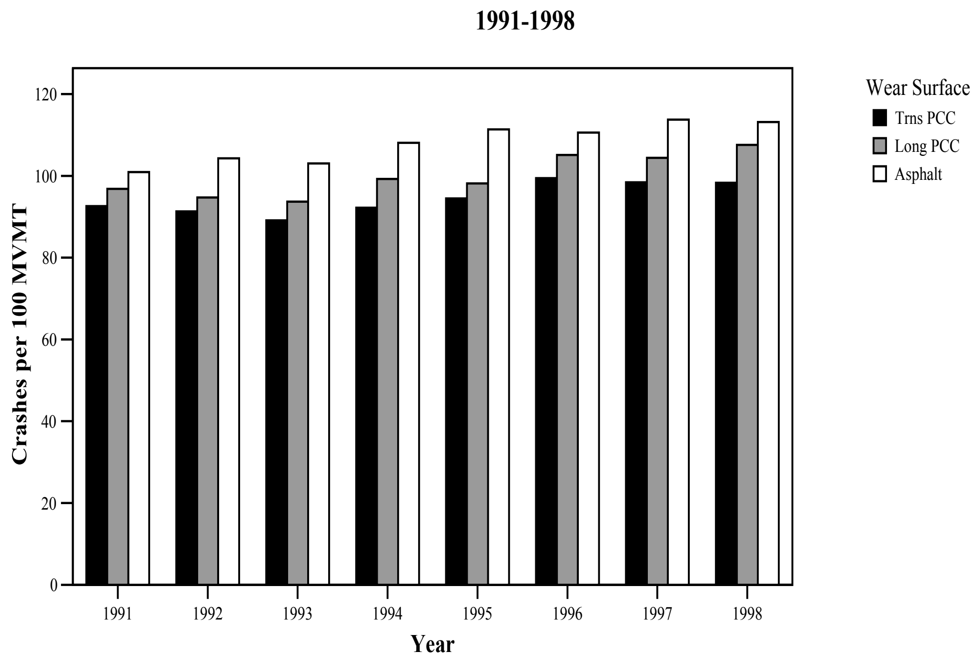


Figure D17. California Urban Freeway Wet/Dry Ratios. 60K+ VPD

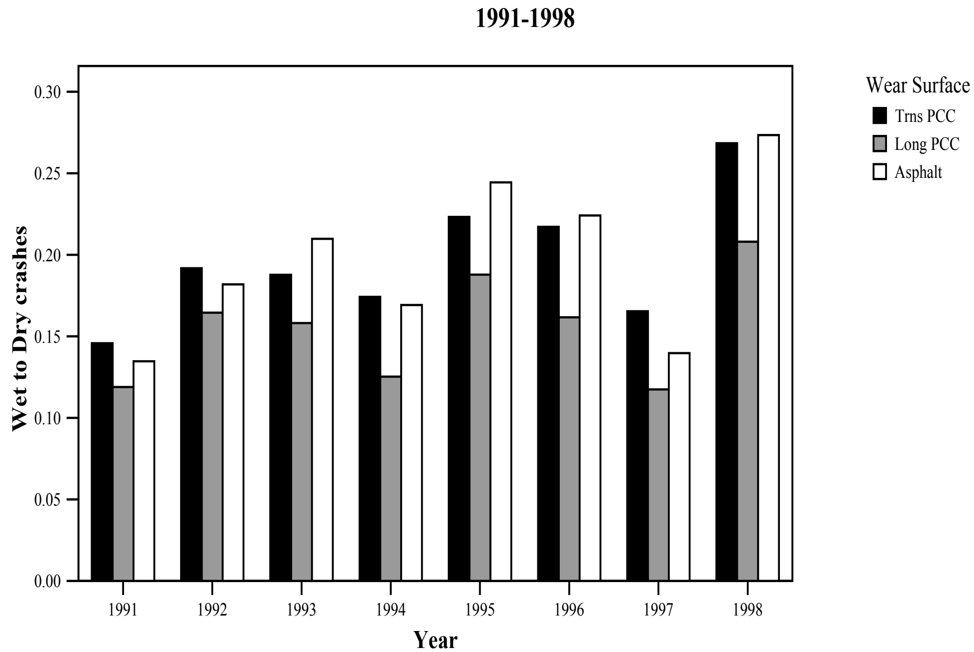


Figure D18. California Urban Freeway Snow/Dry Ratios. 60K+ VPD

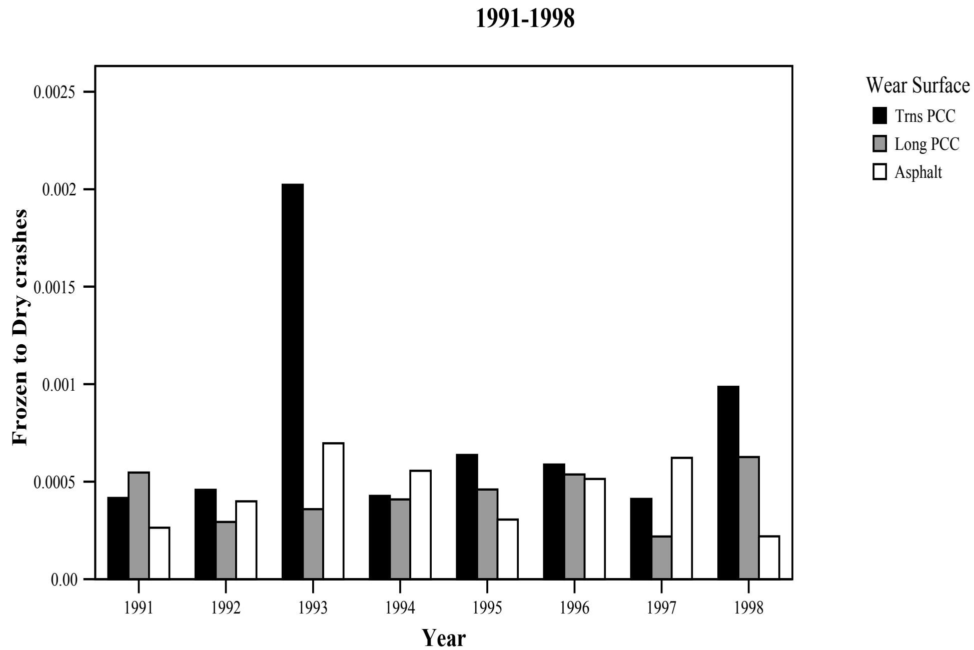


Figure D19. California Urban Freeway Liquid Precip. Safety Ratios. 60K+ VPD

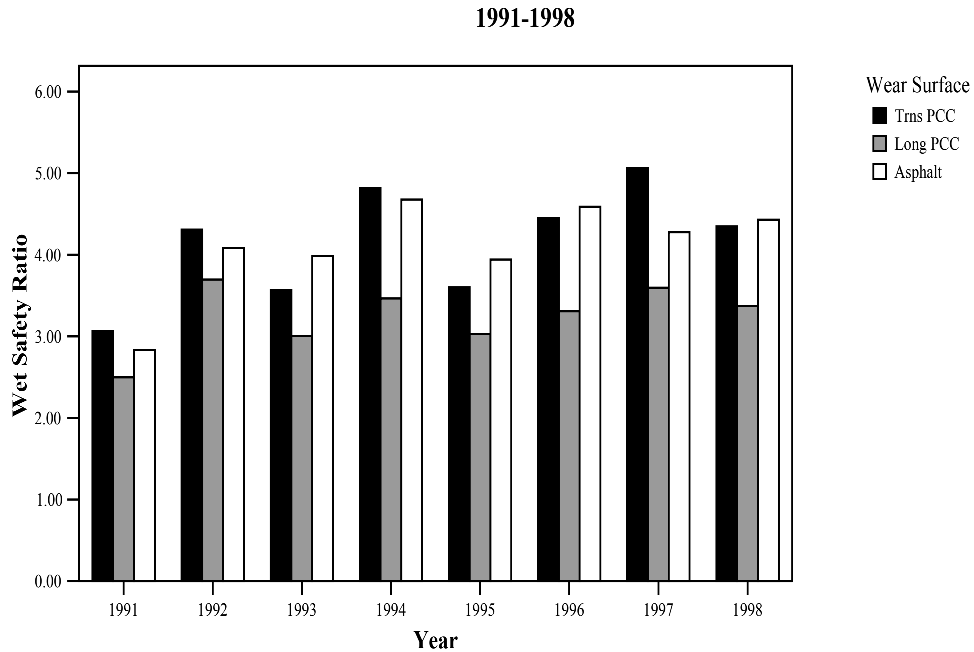
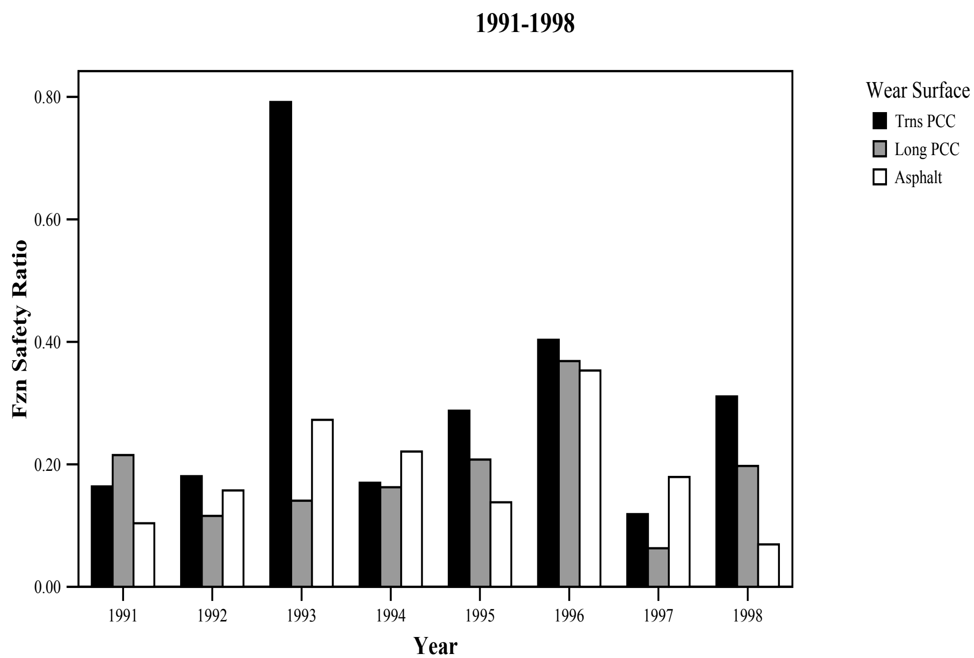


Figure D20. California Urban Freeway Frozen Precip. Safety Ratios. 60K+ VPD



APPENDIX E

WEATHER DATA

INTRODUCTION

Weather and precipitation data were needed in order to calculate the percent time pavements were dry, or covered with liquid or frozen precipitation. The present Appendix addresses a number of critical issues related to this topic. Tables and figures located at the end of the Appendix provide supporting information.

The **Weather Station Selection** section addresses the method and reasoning in choosing the first order weather stations that were used in the analysis (**table E1**). The California snow route map is presented in **figure E1**.

The **Weather and Precipitation Data Analysis** section describes the attempt to use the WETTIME software, the effect of missing information (**table E2**), and the chosen method used to calculate the hours pavements were dry or covered with liquid or frozen precipitation (**Tables E3 and E4**). ***A caution is provided on page E5 against relying on statistics using California frozen precipitation information.***

The section **Crashes on Snow or Ice-Covered Freeways in Wisconsin** discusses the clustering of crashes on snow- or ice-covered pavements (**figures E2 and E3**) compared to crash clusters on wet pavement (**figure E4**), and the large discrepancy in snow/ice-to-dry pavement crashes identified between urban and rural Wisconsin freeways. This important issue was uncovered during the investigation of wet pavement performance. Supporting evidence for this section was provided from the 1998-2000 state-wide crash databases (**tables E5-E10**) used exclusively in this Appendix.

WEATHER STATION SELECTION

After extensive communications with NOAA, the comprehensive list (n = 6,352) of world-wide stations providing International Station Meteorological Climate Summary (ISMCS) information was downloaded from the NOAA web site and searched through custom-made software in order to identify all first order weather stations in each state that was under consideration for the present analysis. An effort was made to select weather stations that would be as representative as possible of conditions for the majority of a state's freeway system, using maps and comparing a station's latitude and longitude to the orientation of a state's freeway system. Hourly weather data were purchased for each selected station for each of the eight analysis years. Hourly precipitation data were provided to Marquette University at no cost from NOAA. Data were received for the stations listed in **Table E1**.

Only the California, Wisconsin and Minnesota stations were used in the analysis (the latter two stations were used to represent conditions on the analyzed Wisconsin freeways).

The three California were selected among a total of 25 identified first order stations in California. San Francisco was chosen to represent coastal weather conditions in the north part of the state, and Los Angeles to represent the southern coastal part of the state. The

Bishop station was selected because it was the first order station with the highest elevation in the state (1257 meters = 4,124 feet), in order to capture representative frozen precipitation information. A California snow route map is presented in **figure E1** (snow routes are defined as routes at an elevation of over 2,000 ft). First order stations located further north than Bishop, CA had a maximum elevation of 163 meters (= 534 feet) [the Redding, CA station] and were thus not suitable to provide frozen precipitation data for snow routes. A preliminary crash data analysis indicated that freeway crashes occurred under snow/ice conditions across counties that cover almost the entire length of California from North to South, east of the Sierra Nevada mountain range. When the data was broken down into Mountainous and Rolling or Level terrain freeways, the number of crashes in each of these two categories was very small (110-280 crashes per year). Given the scarcity of snow crashes and their wide scatter across the state, it would not be possible to compile a reliable Frozen precipitation Safety Ratio (FSR) for California freeways.

The Milwaukee station was chosen among the four identified first order stations in Wisconsin, to represent conditions on the Southeastern part of the state, where most freeway travel is accumulated.

The Minneapolis/St. Paul station was chosen among the four identified first order Minnesota stations, to provide information for the Western part of Wisconsin. Thus, the Milwaukee and Minneapolis/St. Paul weather stations, represent conditions along the SE-to-NW main orientation of the analyzed Wisconsin freeways.

WEATHER AND PRECIPITATION DATA ANALYSIS

Weather files contained station identification, date and time information, wind speed and direction, sky cover, temperature, dew point, barometric pressure, and four weather codes describing weather conditions in the vicinity of the weather station. Although other variables were coded in the database, they typically contained no information. Precipitation files contained station identification date and time information, amount of liquid precipitation (frozen precipitation was converted to equivalent liquid precipitation) for each hour for which precipitation was recorded. The file also contained special flags indicating, among other conditions, time periods of missing information.

Thus, information from both files was necessary to calculate how many hours liquid or frozen precipitation were present on a pavement: weather files provided the nature of any precipitation (for example "Shower(s) of snow or of rain and snow"), but the amount of this precipitation was recorded in the precipitation files.

Doug Harwood of the Midwest Research Institute was contacted and graciously agreed to provide a copy of the WETTIME software he authored, as well as the accompanying "Users Guide for the 'Wettime' Exposure Estimation Model."[1]

The Wettime software estimates the percentages of time that a pavement is dry, or

[1] Publication No. FHWA-RD-87-106, February 1988.

covered with liquid or frozen precipitation, using precipitation and surface weather data, available from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA).

Considerable effort was expended searching for weather and precipitation data in the formats used in the program, both through NOAA and commercial weather data providers. However the particular formats of the TD 3280 weather data and the TD 3240 precipitation data used in the program were abolished in 1996-7 and were no longer available. The NOAA database was extensively searched for data that could be used to re-create the variables used in the program (for example, relative humidity had to be reconstituted from other available information, cloud coverage was no longer available in the same format, etc.) Despite excellent WETTIME documentation, it was not possible to follow the program logic, which relied to a great extent to various "flags" that were coded in the particular format of the datasets used by the software author, because the original flags and their meanings were no longer available from NOAA.

Given the difficulties in correctly applying the WETTIME software, but also concerns with missing information described below, it was decided to proceed with a different method to assess the number of hours a pavement was covered with liquid or frozen precipitation. Hourly weather and precipitation information were matched. It was decided than hours during which both liquid and frozen precipitation were recorded would be considered hours of frozen precipitation. Following this decision rule, hours with liquid and frozen precipitation were tallied separately for each analysis year; it was assumed that precipitation remained on the pavement for the entire hour during which precipitation was recorded. (WETTIME uses a variety of factors to adjust the length of time precipitation remained on the pavement. Depending on prevailing weather conditions and amount of precipitation, precipitation may be present on the pavement less than an hour or may remain on the pavement considerably longer. However, the drying effect of traffic is not taken into account. Concerns about missing precipitation data, described below would have also diminished WETTIME applicability to the present effort).

Missing data

Extensive testing of matched precipitation and weather information revealed that in many instances, although a weather database (TD 3280 data) code indicated presence of precipitation (either liquid or frozen), no precipitation was recorded in the precipitation database (TD 3240 data) for the same hour.

NOAA precipitation data was recorded in the following manner:

- Each record represented information for a 24-hour period and contained individual fields for each hour of the day;
- A record was produced for the first day of each month, regardless of whether or not precipitation was present during that day;
- One record was added to the database for each day during which precipitation was recorded for at least one hour;
- Special flags were used to mark the beginning and ending times of missing data.

Thus, the user had to rely on the presence of missing data flags in order to identify periods with missing precipitation information.

Given the above-described database scheme, if missing data flags were not properly recorded, it would not be possible to independently verify whether days for which no record was present indeed had no precipitation or were simply missing (due to equipment failure), because in both cases no precipitation record would be present in the database.

One record was provided for each hour in the NOAA weather data, thus identification of missing weather information was straight-forward, without reliance on specially coded flags.

The noted discrepancy between the weather and precipitation information, led to a decision to use weather data exclusively, since it was apparent that precipitation data was missing for quite a number of days, when weather information reported some form of precipitation. Missing weather information would bias findings especially against rarely occurring conditions (e.g., snow in California).

Available hours of weather information data are presented in **table E2** for each analyzed weather station. All stations, with the exception of Bishop, CA had very few missing hours of observations (there were 259 missing hours in Milwaukee in 1996; all other years had less than 38 hours of missing observations for any one station).

A total of 8020 hours (equivalent to approximately 90% of one year) were missing from the Bishop, CA station weather observations in the eight analysis years. Most of the missing data were from years 1992-1994.

It should be noted that the number of missing observations was not known until after data were purchased and analyzed.

Weather data processing
Precipitation information was averaged between the first order weather stations used to represent each state.

- For Wisconsin, Minnesota and Milwaukee data were averaged.
- For California, San Francisco and Los Angeles data were averaged for liquid precipitation. Since virtually no frozen precipitation was present in these two stations, hours of frozen precipitation were extracted from the Bishop station for years 1995-1998 that had few missing hours; the average frozen precipitation for these years was used for the rest of the years, when many observations were missing for this station. ***Thus, statistics based on frozen precipitation are not reliable for California, and are presented as preliminary information.***

Tables E3 and E4 present the calculated percentages of dry, liquid and frozen precipitation (percent of the time in a year that this type of condition is present on pavements) for Wisconsin and California, respectively. This information was used in the calculation of the Liquid precipitation Safety Ratio (LSR) and Frozen precipitation Safety Ratio (FSR)[2] statistics presented in **Appendices C and D** and the Findings section of the report.

[2] The definitions and meanings of LSR and FSR are presented in the Methodology part of the report.

CRASHES ON SNOW- OR ICE-COVERED FREEWAYS IN WISCONSIN

Figure E2 lists all crashes in the analysis database that occurred on snow/ice covered pavements in 1998. The crashes took place between January 4 and April 16, and between November 9 and December 30, 1998. There were 64 days on which crashes were reported on pavements that were covered with snow or ice. **Figure E3** indicates that concentrations of 20 or more crashes occurred on 12 of those days. Forty or more crashes in one day occurred on seven separate occasions.

Such concentrations of crashes were unusual when the pavement was wet. Crashes on wet pavements were reported on 145 days; there were eight days with 12 or more crashes; the maximum number of crashes in one day was 19-see **figure E4**.

Differences between urban and rural crash experience
It is very interesting to note the substantial difference in snow/ice-to-dry ratios between rural and urban freeways. Because the analyzed database did not contain a sufficient number of urban freeway mileage,[3] the following presentation is based on state-wide crash data.[4] Such data were available for 1998, 1999 and 2000 (years 1999 and 2000 are not included anywhere else in this report).

Tables E5-E7 present state-wide non-deer crashes for years 1998-2000, respectively. Based on information presented on **tables E8-E10** and summarized below, wet-to-dry (Wet/Dry) ratios for urban and rural freeways do not show the dramatic differences that exist between snow/ice-to-dry (Fzn/Dry) ratios.

	Urban		Rural		
	Wet/Dry	Fzn/Dry	Wet/Dry	Fzn/Dry	
1998	0.36	0.10	0.21	0.68	n = 6017
1999	0.28	0.19	0.21	0.93	n = 6762
2000	0.43	0.31	0.25	1.29	n = 7981

The dramatic differences between urban and the rural environment Fzn/Dry ratios seems to suggest that the identified differences in Fzn/Dry ratios and FSR for rural freeways[5] are, perhaps, not mainly due to pavement surface texture, but may be overwhelmingly due to the level of winter maintenance operations. Aggressive snow plowing, salt and abrasives spreading on urban freeways melt frozen precipitation promptly, avoiding the devastating effects observed on rural freeways. Thus, contrary to rural freeways where safety issues are predominant when frozen precipitation is present, the main safety issue on urban Wisconsin freeways seems to occur in the presence of wet, not frozen precipitation. However, investigation of this winter maintenance hypothesis is beyond the scope of the present effort.

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[3] The interested reader may find this limited information in **Tables D2** (rural ADT 60K+) **and D4** (urban ADT 60K+).
[4] The rest of the present report is based on data from I-90, I-94, I-794 and I-894, for pavement sections constructed after 1978. See **Appendix C** for a detailed description of analyzed crashes.
[5] (based on the analyzed 1991-1998 data summarized in **Appendices C and D**)

Table E1. Weather Station Information.

ST	WMOID	WBAN	CALL SIGN	STATION NAME	COOP ID
CA	72 4800	23157	KBIH,	BISHOP	40822
	72 2950	23174	KLAX,	LOS ANGELES INTL	45114
	72 4940	23234	KSFO	FRISCO	47769
WA	72 7930	24233	KSEA,	SEATTLE/TACOMA	457473
	72 7850	24157	KGEG	SPOKANE	457938
IL	72 5300	94846	KORD,	OHARE	111549
	72 4390	93822	KSPI	SPRINGFIELD	118179
MN	72 6580	14922	KMSP	MINNEAPOLIS/ST PAUL	215435
MI	72 6380	94814	KHTL,	HOUGHTON LAKE	203936
	72 5390	14836	KLAN	LANSING	204641
UT	72 5720	23127	KSLC	SALT LAKE CITY	427598
NC	72 3140	13881	KCLT,	CHARLOTTE	311690
	72 3060	13722	KRDU	RALEIGH	317069
WI	72 6400	14839	KMKE	MITCHELL	475479
VA	72 4010	13740	KRIC,	RICHMOND	447201
	72 4030	93738	KIAD	DULLES	448903
WA	72 4050	13743	KDCA	WASH NATL WSCMO	448906

Table E2. Available Hourly Weather Observations (NOAA file TD 3280).

STA_ID Milwaukee

		MONTH											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count
YEAR	1991	744	672	744	720	744	720	744	744	720	744	720	744
	1992	744	696	744	720	744	720	744	744	720	744	720	744
	1993	744	672	744	720	744	720	744	744	720	744	720	744
	1994	744	672	744	720	744	720	744	744	720	744	720	744
	1995	744	672	744	720	744	719	742	744	720	721	720	732
	1996	703	517	717	720	702	717	742	744	714	744	719	739
	1997	743	672	744	720	742	719	744	742	720	731	718	736
	1998	739	664	744	720	744	719	744	744	720	744	720	743

Table E2. Available Hourly Weather Observations (NOAA file TD 3280). (Continued)

STA_ID Minneapolis

		MONTH											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count
YEAR	1991	744	672	744	720	744	720	744	744	720	741	720	744
	1992	744	696	744	720	744	720	744	744	720	744	720	744
	1993	744	672	742	720	744	720	744	741	720	744	720	744
	1994	744	672	744	720	744	720	744	744	720	744	720	744
	1995	744	672	744	720	744	720	744	744	720	744	720	744
	1996	742	696	744	720	744	701	744	744	720	741	714	744
	1997	743	672	744	720	744	720	743	744	720	744	719	727
	1998	744	672	744	720	744	719	744	744	720	737	718	740

Expected number of observations per month:

- Jan, Mar, May, Jul, Aug, Oct, Dec: 24 hours x 31 days = 744 hours / month.
- Apr, Jun, Sep, Nov: 24 hours x 30 days = 720 hours / month.
- Feb: 24 hours x 28 days = 672 hours, except in 1992 and 1996: 696 hours.

Table E2. Available Hourly Weather Observations (NOAA file TD 3280). (Continued)

STA_ID Bishop CA

		MONTH											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count
YEAR	1991	744	671	744	717	743	718	744	733	719	744	720	694
	1992	744	696	370	679	726	720	744	743	716	248	235	243
	1993	242	224	245	238	248	240	247	248	239	248	240	240
	1994	648	670	738	720	744	704	744	744	720	743	708	730
	1995	686	658	740	719	744	720	744	744	720	744	720	715
	1996	744	695	744	697	731	646	743	731	717	742	720	744
	1997	731	672	744	714	739	674	722	729	720	744	720	744
	1998	742	672	742	720	741	720	742	743	696	743	720	743

Table E2. Available Hourly Weather Observations (NOAA file TD 3280). (Continued)

STA_ID Los Angeles CA

		MONTH											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count
YEAR	1991	744	672	744	719	744	720	744	744	720	744	720	744
	1992	744	696	744	719	744	720	744	744	720	744	720	744
	1993	744	672	744	720	744	720	744	744	720	744	720	744
	1994	744	672	744	720	744	720	744	744	720	742	720	743
	1995	744	672	744	720	744	720	744	744	720	744	720	743
	1996	744	696	744	720	744	720	744	744	720	744	720	744
	1997	744	672	743	717	738	718	687	743	720	740	718	744
	1998	744	672	744	720	744	720	744	744	713	738	720	743

Expected number of observations per month:

- Jan, Mar, May, Jul, Aug, Oct, Dec: 24 hours x 31 days = 744 hours / month.
- Apr, Jun, Sep, Nov: 24 hours x 30 days = 720 hours / month.

Feb: 24 hours x 28 days = 672 hours, except in 1992 and 1996: 696 hours.

Table E2. Available Hourly Weather Observations (NOAA file TD 3280). (Continued)

STA_ID San Francisco CA

		MONTH											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count	Count
YEAR	1991	744	672	744	720	744	720	744	744	720	744	720	744
	1992	744	696	744	720	744	720	744	744	720	744	720	744
	1993	743	672	744	720	744	720	744	744	720	744	720	744
	1994	742	672	744	720	744	720	744	744	720	744	720	744
	1995	744	672	744	720	744	720	744	744	720	744	720	744
	1996	744	695	744	720	744	720	736	739	719	741	719	743
	1997	744	672	743	720	743	720	742	744	707	741	709	744
	1998	744	672	743	716	744	718	744	744	717	744	720	738

Expected number of observations per month:

- Jan, Mar, May, Jul, Aug, Oct, Dec: 24 hours x 31 days = 744 hours / month.
- Apr, Jun, Sep, Nov: 24 hours x 30 days = 720 hours / month.
- Feb: 24 hours x 28 days = 672 hours, except in 1992 and 1996: 696 hours.

Table E3. Wisconsin Liquid and Frozen Precipitation Summary

Year	% Time Dry	% Time Liquid	% Time Frozen	Dry/Liquid	Dry/Frozen
1991	0.866	0.074	0.060	11.68	14.48
1992	0.858	0.076	0.066	11.29	13.03
1993	0.848	0.078	0.074	10.91	11.49
1994	0.883	0.056	0.061	15.87	14.43
1995	0.872	0.067	0.061	12.95	14.28
1996	0.896	0.051	0.053	17.59	16.91
1997	0.899	0.050	0.050	17.83	17.83
1998	0.903	0.058	0.040	15.70	22.86

Table E4. California Liquid and Frozen Precipitation Summary

Year	% Time Dry	% Time Liquid	% Time Frozen	Dry/Liquid	Dry/Frozen
1991	0.952	0.045	0.002	21.01	393.21
1992	0.955	0.043	0.002	22.46	394.37
1993	0.948	0.050	0.002	19.00	391.33
1994	0.963	0.035	0.002	27.64	397.55
1995	0.940	0.058	0.002	16.12	451.77
1996	0.952	0.047	0.001	20.48	686.65
1997	0.965	0.032	0.003	30.61	287.98
1998	0.939	0.058	0.003	16.20	315.09

Table E5. Wisconsin State-Wide Crashes, 1998 (Deer crashes excluded).

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	CITY STREET URBAN	44075	41.5	41.5	41.5
	CITY STREET RURAL	4211	4.0	4.0	45.5
	TOWN ROAD RURAL	8886	8.4	8.4	53.8
	COUNTY TRUNK RURAL	9000	8.5	8.5	62.3
	STATE HIGHWAY URBAN	16395	15.4	15.4	77.8
	STATE HIGHWAY RURAL	17037	16.0	16.0	93.8
	INTERSTATE HWY URBAN	3469	3.3	3.3	97.1
	INTERSTATE HWY RURAL	3122	2.9	2.9	100.0
	Total	106195	100.0	100.0	

Table E6. Wisconsin State-Wide Crashes, 1999 (Deer crashes excluded).

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	BLANK	1	.0	.0	.0
	CITY STREET URBAN	45203	41.3	41.3	41.3
	CITY STREET RURAL	4483	4.1	4.1	45.4
	TOWN ROAD RURAL	9381	8.6	8.6	53.9
	COUNTY TRUNK RURAL	9410	8.6	8.6	62.5
	STATE HIGHWAY URBAN	16122	14.7	14.7	77.2
	STATE HIGHWAY RURAL	17546	16.0	16.0	93.3
	INTERSTATE HWY URBAN	4247	3.9	3.9	97.1
	INTERSTATE HWY RURAL	3144	2.9	2.9	100.0
	Total	109537	100.0	100.0	

Table E7. Wisconsin State-Wide Crashes, 2000 (Deer crashes excluded).

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	CITY STREET URBAN	49343	41.5	41.5	41.5
	CITY STREET RURAL	4659	3.9	3.9	45.4
	TOWN ROAD RURAL	10400	8.7	8.7	54.1
	COUNTY TRUNK RURAL	10036	8.4	8.4	62.5
	STATE HIGHWAY URBAN	17328	14.6	14.6	77.1
	STATE HIGHWAY RURAL	18580	15.6	15.6	92.7
	INTERSTATE HWY URBAN	4711	4.0	4.0	96.7
	INTERSTATE HWY RURAL	3982	3.3	3.3	100.0
	Total	119039	100.0	100.0	

Table E8. Wisconsin Urban and Rural Wet-to-Dry and Snow/Ice-to-Dry ratios, 1998.

				Count
TYPE OF HIGHWAY	INTERSTATE HWY URBAN	ROAD SURFACE CONDITION	Dry	2230
			Wet	792
			Snow/Slush/Ice	215
	INTERSTATE HWY RURAL	ROAD SURFACE CONDITION	Dry	1476
			Wet	306
			Snow/Slush/Ice	998

Table E9. Wisconsin Urban and Rural Wet-to-Dry and Snow/Ice-to-Dry ratios, 1999.

				Count
TYPE OF HIGHWAY	INTERSTATE HWY URBAN	ROAD SURFACE CONDITION	Dry	2669
			Wet	751
			Snow/Slush/Ice	508
	INTERSTATE HWY RURAL	ROAD SURFACE CONDITION	Dry	1321
			Wet	280
			Snow/Slush/Ice	1233

Table E10. Wisconsin Urban and Rural Wet-to-Dry and Snow/Ice-to-Dry ratios, 2000.

				Count
TYPE OF HIGHWAY	INTERSTATE HWY URBAN	ROAD SURFACE CONDITION	Dry	2495
			Wet	1085
			Snow/Slush/Ice	783
	INTERSTATE HWY RURAL	ROAD SURFACE CONDITION	Dry	1428
			Wet	353
			Snow/Slush/Ice	1837

Figure E1. California Snow Routes. Source: CalTRANS.

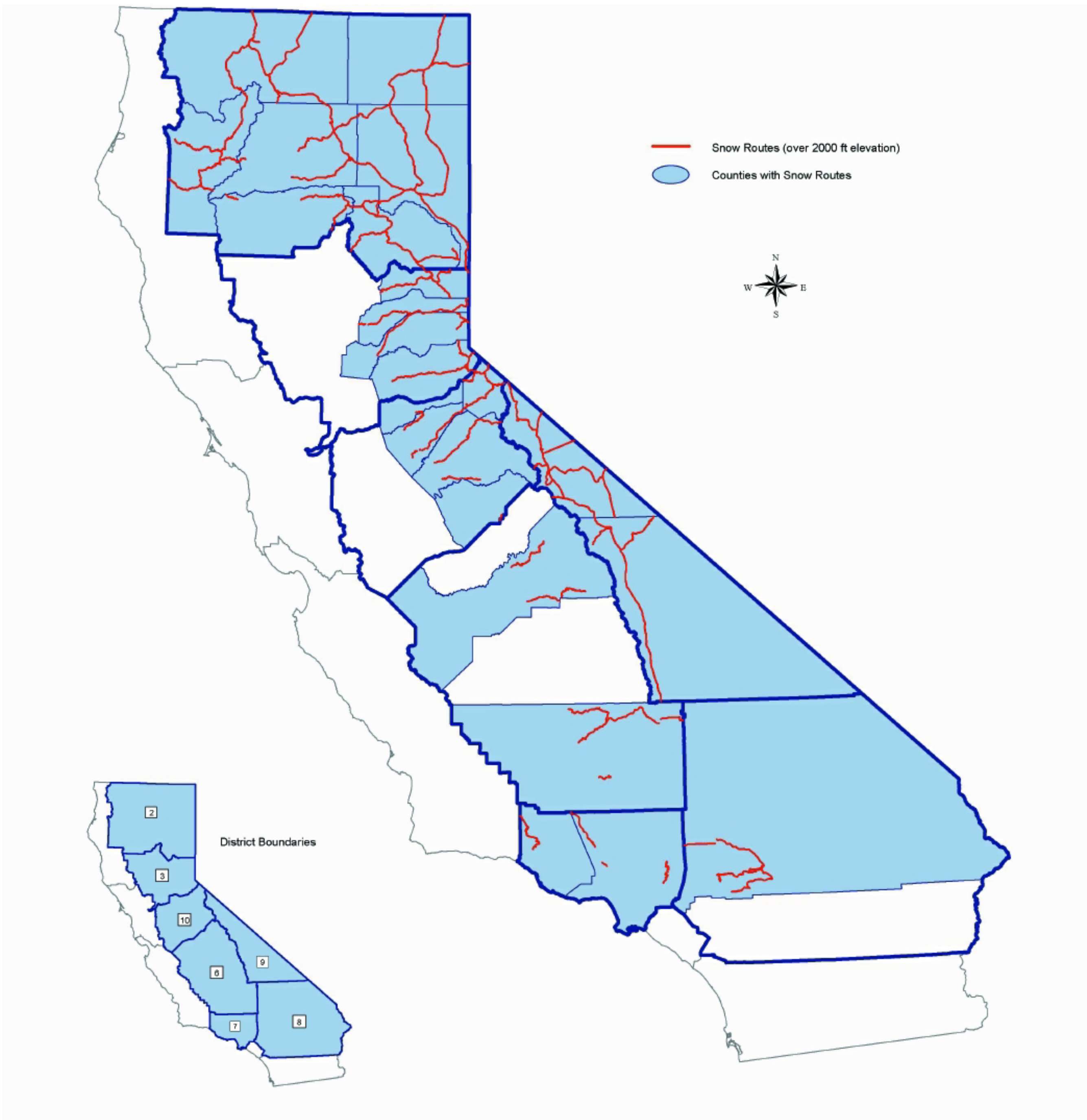


Figure E2. Analyzed Wisconsin Snow/Ice crashes 1998.

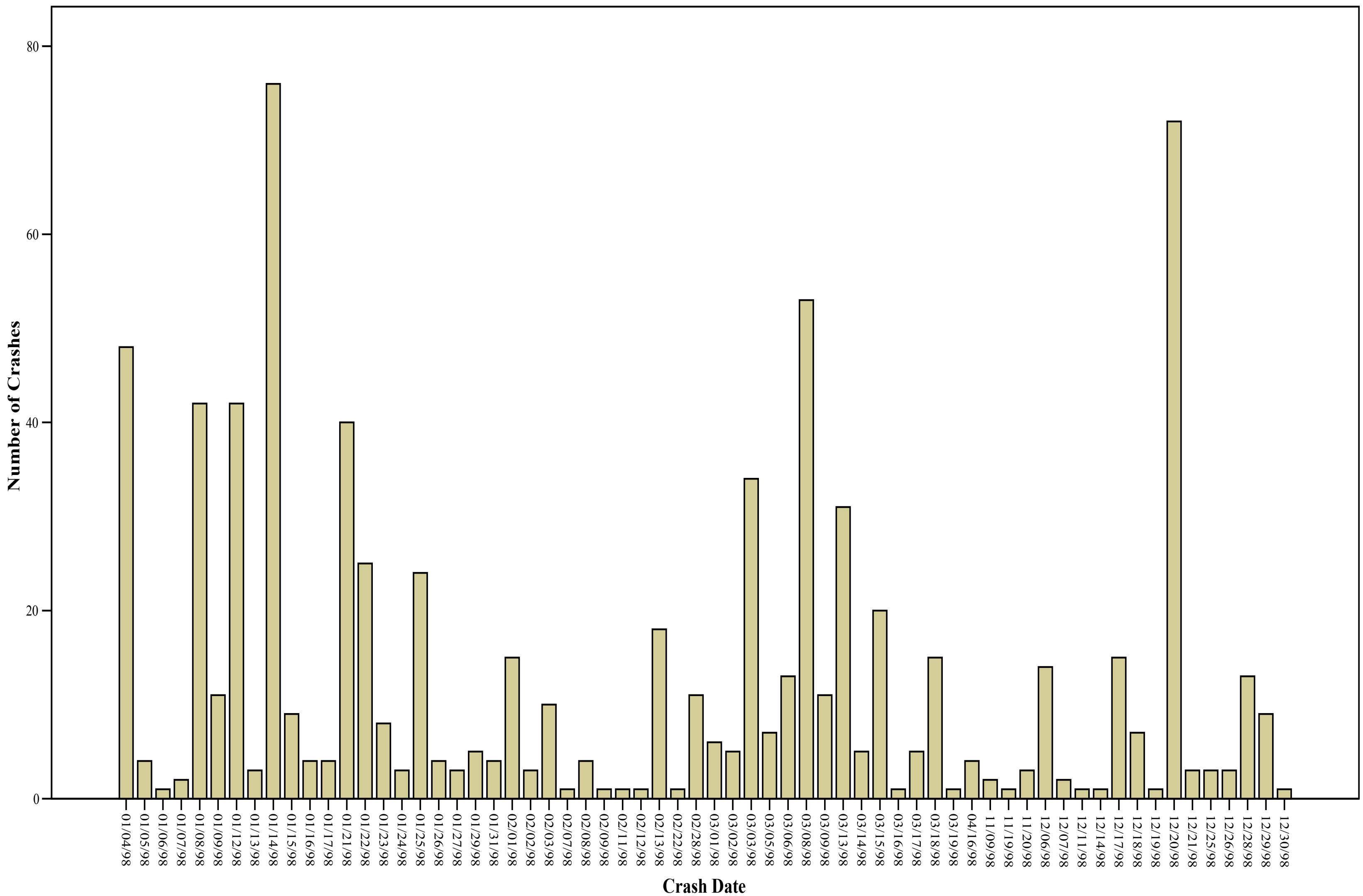


Figure E3. Analyzed Wisconsin Freeway Crashes. Number of Snow/Ice Pavement Crashes per Day, 1998.

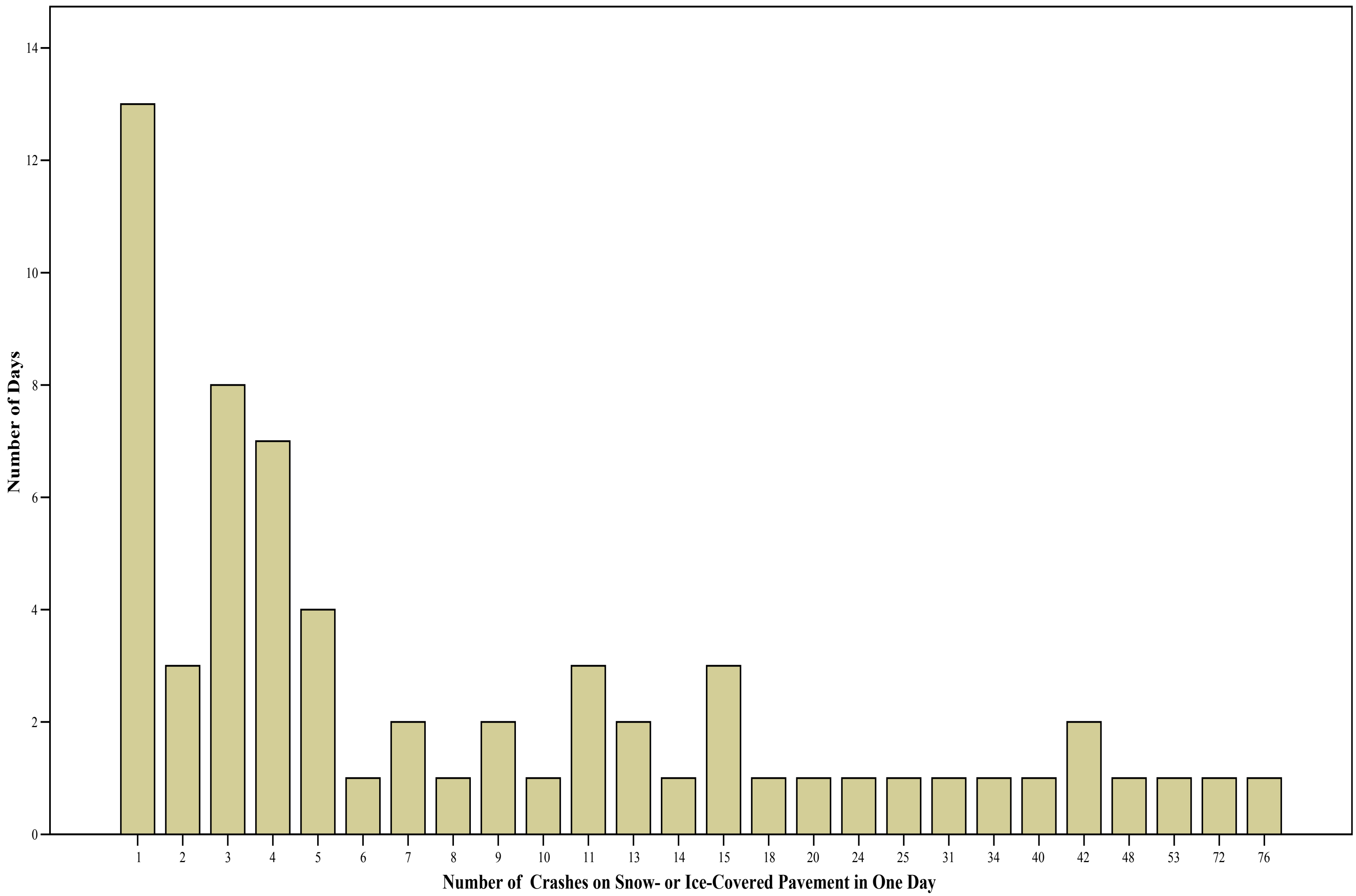
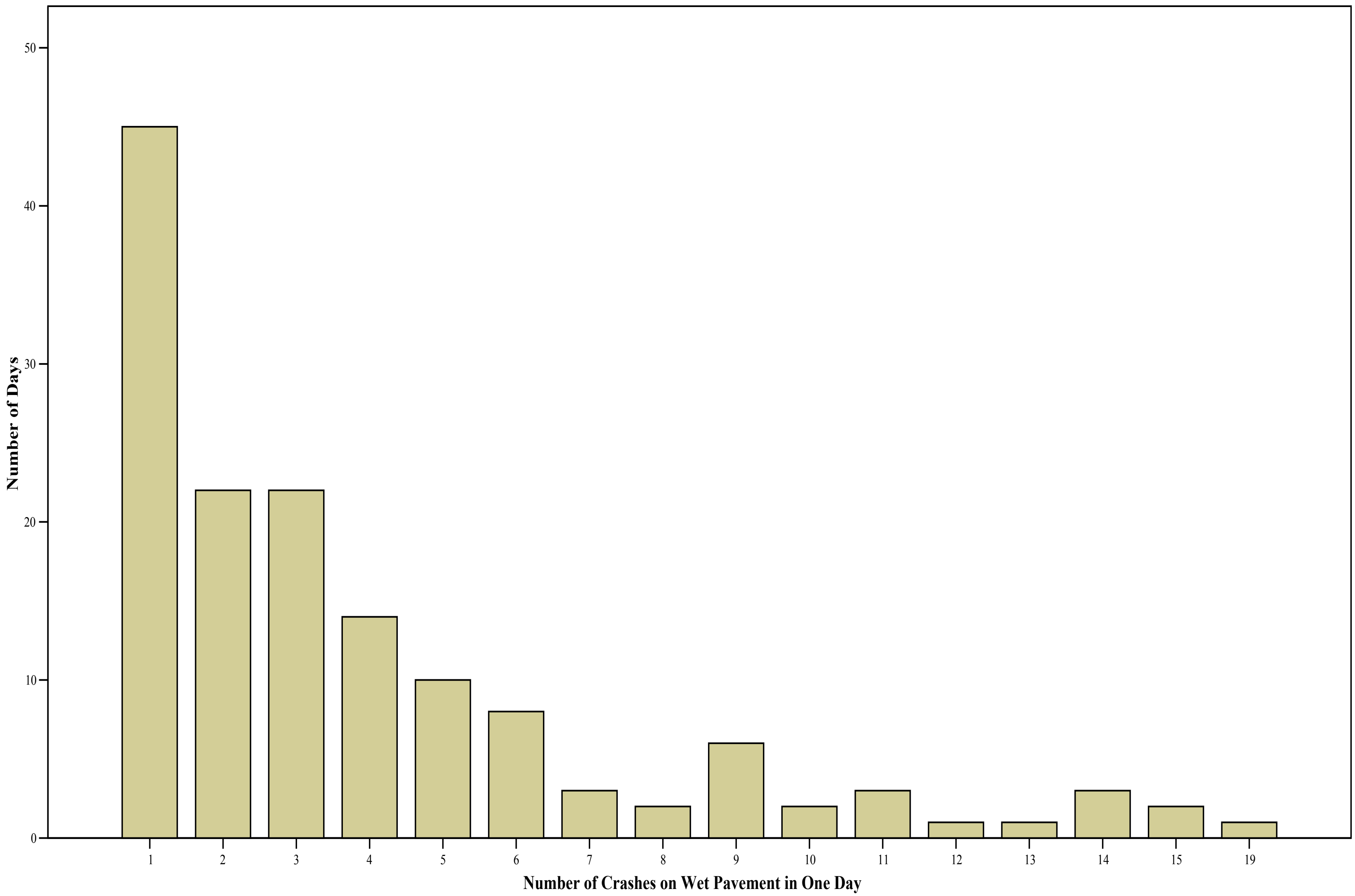


Figure E4. Analyzed Wisconsin Freeway Crashes. Number of Wet Pavement Crashes per Day, 1998.



APPENDIX F

ANALYZED WISCONSIN FREEWAYS

INTRODUCTION

Pavement data were extracted from the “Metamanager” WisDOT database. The database provided pavement materials information (PCC or asphalt), the date a pavement surface was constructed, travel information (freeway segment length and ADT) and freeway type (urban or rural). The mid-1999 Metamanager edition was used in order to include the pavement surface construction dates relevant to all analyzed segments.

The pavement database was queried and freeway pavement segments constructed within a range of years was identified (starting after 1978 and ending on a specific year between 1990 and 1997). Selection of pavement construction dates after 1978, the first year that all new PCC freeway pavements were required to have a TT texture, guaranteed that all identified PCC surfaces were transversely tined. Crashes were matched to travel information on the pavement section on which they occurred and crash statistics were calculated (see **Table C2**). The exact pavement selection and crash matching methodology is described in detail in **Appendix C**.

Table F1 provides pavement mileage and type for pavement for pavements constructed after 1978 along the analyzed freeways I-90, I-94, I-794 and I-894. The first such construction occurred in 1982. All rural mileage shown on **table F1** for years 1982 – 1990 adds up to 279 miles; urban mileage adds up to 33 miles; the total (based on rounded mileage) is 312 miles, shown on **page C6** that summarizes 1991 crash experience. In 1991, 55.07 rural miles and 2.49 urban miles were added to the analyzed database, as can be verified on **page C7** showing 334 rural miles, 36 urban miles and a total of 370 miles for the 1992 crash summary.

Table F1. Pavements Constructed After 1978 on Analyzed Freeways.

				Roadway Classification	
				Rural Freeway	Urban Freeway
				Length	Length
Year	1982	Wear Surface	Asphalt	.	.72
			Tined PCC	.	.
	1983	Wear Surface	Asphalt	12.11	2.48
			Tined PCC	13.40	.
	1984	Wear Surface	Asphalt	.	.
			Tined PCC	18.97	.
	1985	Wear Surface	Asphalt	.	4.19
			Tined PCC	13.40	.
	1986	Wear Surface	Asphalt	13.34	18.73
			Tined PCC	32.16	.
	1987	Wear Surface	Asphalt	24.08	5.12
			Tined PCC	14.12	.
	1988	Wear Surface	Asphalt	41.31	.
			Tined PCC	4.73	.
	1989	Wear Surface	Asphalt	27.39	.
			Tined PCC	16.33	.
	1990	Wear Surface	Asphalt	40.71	.
			Tined PCC	7.14	2.20
	1991	Wear Surface	Asphalt	53.41	2.49
			Tined PCC	1.66	.
	1992	Wear Surface	Asphalt	18.98	.87
			Tined PCC	45.41	.
	1994	Wear Surface	Asphalt	.	3.18
			Tined PCC	18.76	.
	1995	Wear Surface	Asphalt	23.77	2.71
			Tined PCC	11.28	3.23
	1996	Wear Surface	Asphalt	49.76	25.73
			Tined PCC	22.89	4.07
	1997	Wear Surface	Asphalt	37.53	22.31
			Tined PCC	13.99	.
	Total	Wear Surface	Asphalt	342.39	88.53
			Tined PCC	234.24	9.50

APPENDIX G

HIGHWAY SAFETY INFORMATION SYSTEM
&
HSIS GUIDEBOOK FOR THE CALIFORNIA DATA FILES
(VOLUME I)

HIGHWAY SAFETY INFORMATION SYSTEM

The Highway Safety Information System is a multi-state database that contains crash, roadway inventory, and traffic volume data for a select group of States. The HSIS is operated by the University of North Carolina Highway Safety Research Center (HSRC) and LENDIS Corporation, under contract with FHWA.1

California database:

• First Year Available: 1991
• Average Crashes/Year: 160,000
• Roadway Mileage: ***15,300***

Available files:

Crash - Contains basic accident, vehicle, and occupant information on a case-by-case basis. Typical data include type of accident, type of vehicle, sex and age of occupants, fixed-object struck, accident severity, and weather conditions.

Roadway Inventory - Contains information on roadway cross-section and the type of roadway. Data include the number of lanes, lane width, shoulder width and type, median width, rural/urban designation, and functional classification.

Traffic Volume - Contains annual average daily traffic (AADT) data. Additional data on hourly volumes and percentage of trucks is also available in selected States and/or locations.

Intersection - Contains information on highway intersections. Data include traffic control type, intersection type, signal phasing, and turn lanes.

Interchange/Ramp - Contains information on highway interchanges. Data include interchange type and ramp characteristics.

1 Source: http://www.hsisinfo.org// Friday, June 04, 2004, 2:07 AM

HIGHWAY SAFETY INFORMATION SYSTEM GUIDEBOOK

FOR THE CALIFORNIA DATA FILES

Volume I

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November, 1995

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INTRODUCTION

The California database incorporated into the HSIS system is derived from the California TASAS (Traffic Accident Surveillance and Analysis System). The system, maintained by the Traffic Operations Office of CALTRANS, is a mainframe-based system based on COBOL programming. The Traffic Operations Office (TO) provides the data to HSIS in the form of two different data files. These contain:

Accident data (including accident, vehicle and occupant data)

Roadway inventory data (including intersection and interchange ramp data, and Average Daily Traffic counts)

Raw file data is provided to the Highway Safety Research Center where they are retained as backup information. The documentation (variable listings, definitions, etc.) for these raw files and for the SAS files that are developed from them are available at FHWA offices. The conversion programs developed by HSRC and LENDIS to convert the files into SQL and SAS formats are included in the Programmer's Guidebook, which is available at the HSIS offices at FHWA.

Beginning in 1994, the HSIS system was converted to a relational database for internal use. This database, using a SYBASE system, stores the data received from California and other states, and the data files for a given state are linked and manipulated using SQL language. However, this conversion from the original SAS-based system to the newer relational system is somewhat transparent to the end-user of the data since the output files produced by SYBASE for modelling and analysis will be SAS formatted. As in the past, we have continued to produce SAS format libraries for each of the variables in each of the files. Because it is envisioned that the majority of analyses will utilize these SAS files and formats, this Guidebook will concern these SAS files -- their formats, completeness, and quality. Single variable tables for key variables from each file will continue to be published in a separate Volume II document.

As noted above, the California SAS accident data is divided into three separate subfiles, the first containing the basic accident information on a case-by-case basis, the second containing information on up to nine vehicles in each accident (including driver information), and the third containing information on up to seventy occupants in each crash. The HSIS accident and vehicle data are extracted directly from the TASAS by the Traffic Operations staff. The occupant data, including data on the driver, are not included in TASAS, but are in the California Highway Patrol's SWITRS (Statewide Integrated Traffic Records System) file. This latter file is acquired from California by the US DOT National Highway Traffic Safety Administration (NHTSA) each year, and HSRC staff obtains copies of this file from NHTSA and merges it with the TASAS data.

Unlike the accident file which is referenced to a point on the roadway, each record in the Roadlog File contains information on a homogeneous section of roadway (i.e., a stretch of road which is consistent in terms of certain characteristics, with a new section being defined each time any of the characteristics changes). Each record contains current characteristics of the roadway system and includes such variables as traveled way width, number of lanes, paved and total shoulder width, median type, and other variables. Traffic information in the form of Average Annual Daily Traffic (AADT) and Daily Vehicle Miles of travel is included for each section. As will be noted below, unlike most other HSIS state inventories, this file also contains information on terrain, design speed, and special features such as auxiliary lanes. There is no horizontal or vertical alignment information in the files.

While intersections were included as part of the basic TASAS roadway inventory record, a separate Intersection File has been created in the HSIS system. Each record on the file contains information on both the mainline route and the crossing route. The information includes such items as intersection type, traffic control type, lighting, channelization, and ADT for both the mainline and cross street.

In similar fashion, an Interchange Ramp File has been developed which contains information on approximately 14,000 individual ramps. While there is no way to tie these ramps to one of the approximately 3000 associated interchanges in the state, the file does contain information on ramp type (e.g., diamond, slip, direct left-turn connector, etc.), ADT, and whether the crossing road is a state route or not.

DETAILS OF MAJOR FILES

The Accident Files

The state agency responsible for statewide accident data collection is the California Highway Patrol (CHP). The CHP is responsible for investigating crashes on all freeways (urban and rural) and on other state routes and county roads outside municipal areas. They are also responsible for the collection and computerization of crash data from all investigating agencies in the state. The CHP investigates approximately two-thirds of all accidents occurring on state routes. The remainder are reported by municipal police. The general accident reporting threshold used by the CHP is currently $500 or personal injury. This threshold is felt to be fairly consistently used by all CHP personnel in terms of filing crash reports. Conversations with the CHP indicated that while minor (non-towaway) crashes will be reported, they are reported on a "short form." In approximately 50 percent of these minor cases, the officer will not provide information on uninjured passengers.

However, neither the report form used nor the reporting threshold followed is consistent across the many local municipalities in the state. Unlike the other HSIS states, accident data are not collected statewide by all police departments on a standard form. While some municipalities use the standard CHP form, many have developed their own form, including major cities such as San Jose, San Diego and Los Angeles. Currently, the CHP is "recruiting" these cities to adopt the standard form, and hope that they will begin using a revised version of the form in 1996. Other cities and towns may or may not follow suit. Even though these cities use non-CHP forms, their data are "converted" to CHP format by accident coders to the extent possible. They are ultimately key-punched into the CHP's data system, known as SWITRS (Statewide Integrated Traffic Records System).

In addition to differing forms, it also appears that different municipalities follow different reporting thresholds, with some reporting only towaway crashes, many reporting crashes with damage of greater than $1000, and some not reporting PDO crashes at all. Some information on the level of PDO reporting can be gleaned from CHP's "Annual Report of Fatal and Injury Motor Vehicle Traffic Accidents." This publication, available at the FHWA HSIS office, provides a city-by-city breakdown of fatal, injury, and PDO crashes reported. In general, if reported to a moderately low threshold, 55-70 percent of the total crashes should be no-injury (PDO) crashes.

Cities which don't show such a ratio are more than likely not fully reporting these non-injury crashes.

Thus, in general, while injury and fatal data is felt to be accurate for both the CHP and most municipalities, PDO crashes (and thus total crashes) are most accurate for the Highway Patrol. Crashes investigated by the Patrol can be identified by using the variable CHP_IND. In terms of rate development, this means that rates developed for freeways (urban and rural) and for other rural roads (outside municipalities) where accidents are reported by the CHP would be accurate. Total accident rates developed for urban areas should be considered somewhat suspect, or the analyst must determine which cities should be included in the rate based on reporting ratios or other information.

It is estimated that there are over 500,000 accidents in the entire state each year. Approximately 150,000 of these are investigated by the California Highway Patrol on state routes (where TASAS inventory information is available). As noted above, all forms (regardless of form type) are sent to the CHP for processing. The CHP then separates the forms into those occurring on state routes (including the urban areas using their own forms) and those on non-state routes, and sends the state-route hard copies to the Traffic Operations Office (TO) for location coding. Of the 500,000 total accidents that occur each year, approximately 150,000 occur on the state system and are location-coded by the TO.

The location coding is done by coding staff using maps, straight line diagrams, reference marker location logs and other aids. In addition to the standard coding done by other states, all accidents which occur on interchange ramps are located to the specific interchange ramp on which they occur. (See specifics under later discussion of "Interchange ramps.")

The mile-posting of all accidents is based on the investigating officer's location-related information and on his/her narrative and sketch. Each officer is instructed to provide a distance to a reference point measured in .01 miles in rural areas or feet in urban areas. Unlike other states, the officer attempts to give distances to reference markers in both directions from the point of the crash. All routes on the state system (Interstate, US, and State numbered highways) have both regularly spaced reference markers as well as markers on many different objects along the roadway (e.g., bridges, culverts, boundary signs). By 1995, approximately 13,000 call boxes with reference numbers will be added on the suburban and urban state system.

In summary, given the reference markers, locations procedures, and coding procedures used, it is felt that the location coding for the 150,000 state-route accidents per year is probably as accurate as would be found in any state in the U.S., with over 90% of the urban and rural accidents being located to within .01 miles. TO staff estimate that there are problems in location provided by the officers in less than two percent of the accidents that the staff codes. These are sent back to the police officers for correction.

In addition to the location coding, the TO staff also code additional variables related to fixed objects struck (up to four in sequence), location of collision by lane, and movement and direction of travel prior to collision. These codes are then returned to the CHP along with the location codes and hard copies.

All codes are then keypunched by the California Highway Patrol and entered into SWITRS. Once keypunched and entered, the complete computer file is sent back to the TO office for their use. The complete annual file is "closed out" around April of the following year.

The TASAS system retains up to ten years of accident data. The HSIS system currently contains accident data for 1991-1994.

The Accident Subfile contains over 40 variables and approximately 150,000 crash records per year. It contains basic variables describing the overall crash (i.e., time and location, weather, lighting, collision severity, accident type, etc.). The file does not include a “first harmful event” variable or a "most harmful event." It also does not contain speed limit or vehicle damage or point of contact. More specific variables related to contributing factors, object struck, and vehicle movements are included in the Vehicle Subfile.

While the Accident Subfile does not contain a "sequence of events" variable, the Vehicle Subfile does contain a type of sequence for fixed-object impacts. Here, the CHP coders enter up to four fixed objects (and their locations) in the order they are struck. One of the fixed object codes is "rollover," which will allow meaningful analysis of roadside hardware and fixed object impacts.

The Vehicle Subfile contains over 30 variables and approximately 300,000 vehicle records per year. It contains information on up to nine vehicles in the crash. In addition to the fixed-object sequence, the file contains specific information on vehicle type, an indication of "direction of travel," contributing factors, vehicle maneuvers and pedestrian locations prior to the crash, and the number of injured and killed occupants. As noted above, specific driver information related to injury, restraint use, sex, and physical condition/drug use are extracted from a separate CHP file and attached to this file. (It is noted that approximately two percent of the vehicles could not be matched with the SWITRS file. This occurs because the Traffic Operations staff manually enters some city reports and some late CHP reports which are not included in the SWITRS file.) The truck information on the file contains some detail on the basic configuration -- whether van or tanker and how many trailers are being pulled. The NGA elements are not on the report form or the file, but will be collected by the CHP on a supplementary form in the future. A complete form revision which will include the NGA elements, and added variables on pedestrian accidents and traffic control devices, is expected in 1/1/96.

The HSIS Occupant Subfile contains information on up to seventy occupants per crash. As noted above, it is not part of TASAS, but is extracted from the CHP file. It contains information on occupant type, sex, age, seating position, injury class, safety equipment use, and ejection for approximately 200,000 occupants per year. Of these, approximately 140,000 are injured and uninjured passengers. However, as noted above, information on uninjured passengers is not captured in approximately 50 percent of the minor (non-towaway) crashes. If one passenger is injured, data is captured on all other passengers whether injured or not. Thus, the file is biased to some extent toward more serious (injury-producing) crashes. The remaining 60,000 records concern injured (but not uninjured) drivers. Information on uninjured (and injured) drivers is found in the Vehicle Subfile.

In order to assess the accuracy of accident variables, we both questioned the California DOT Traffic Operations staff concerning their feelings of variables that were incompletely coded or might be inaccurate, and examined a series of single-variable tables for key variables in each of the subfiles. The Operations staff indicated that virtually all variables on the Accident and Vehicle Subfiles seem to be coded correctly, especially by the Highway Patrol. (They do not use the occupant data in the CHP files, and thus have no knowledge of its accuracy.) They do feel that the information concerning whether an accident occurred in a construction zone (which is part of a "road condition" variable) is less than accurate. (Based on a recent HSIS staff analysis of work zone accident data in other HSIS and non-HSIS states, this problem is common across almost all states.)

In addition to information received from the TO staff, single variable tabulations were run to examine the questions of reporting completeness and data accuracy for these accident subfiles. (As noted earlier, single-variable tables for key variables are provided in Volume II of the Guidebook.) Here, study of percent of "unknown," "not applicable," and "not stated" values for over 50 key variables indicate that, in general, the data in the Accident and Vehicle Subfiles are coded to a high degree of completeness. With very few exceptions, these data also appear to be quite consistent across years, and similar variables appear to have similar values. The exceptions are noted under pertinent variables in the later format section.

As noted above, the major exception to this is in terms of completeness and accuracy of the Occupant Subfile data. First, the file contains data that are biased to some extent toward the more severe accidents, since some significant proportion of the uninjured occupants in non-towaway, property-damage-only crashes do not get entered into the file. Second, there are some differences in the type/seating of occupants between the two variables related to OCC_TYPE (Occupant Type) and SEATPOS (Seating Position). This is due to the fact that the Occupant Type variable combines all uninjured occupants into one code, and that while report forms used by California cities all contain some type of information on drivers, all do not contain a variable on seating position. It is again noted that the most complete information on drivers can be found in the Vehicle Subfile. Other data issues are noted with the specific variable in the later format section.

Except for these Occupant Subfile problems, based on both the interviews and the data comparisons conducted, the majority of the data appear quite accurate.

The Roadway Inventory Files

The California roadway inventory system, taken directly from TASAS, contains current characteristics of the state road system. It is divided into three files within the HSIS system. The first is a basic roadway characteristics file (i.e., the "Roadlog") containing information on the roadway mainline cross section. The second is an Intersection File which contains information on the characteristics of approximately 20,000 intersections and their approach roadways. The third is an Interchange Ramp File, describing the basic characteristics of over 14,000 separate ramps of interchanges.

All three inventory files were developed from inventory information originally collected through a series of field surveys and from construction drawings. Updates to the file is now done on a routine basis by the TO inventory staff based on new construction drawings. The only updates that would be missed by the TO staff are new intersections build at the district level when new development (e.g., a shopping center) occurs. These are sometimes reported by the district office and sometimes not. Often, during accident plotting procedures, these come to the attention of the TO staff, who then request information from the district office. In general however, the Operations staff feel that the inventory information is quite accurate.

The Roadlog File

As shown in Table 1 below, the basic Roadlog File contains information on approximately 15,200 miles of mainline (non-ramp) roadway. This includes all functional classes of roads within the state system -- Interstate, U.S. and state routes. This file contains information on approximately 2,450 miles of Interstate, 11,000 miles of other primary highway, and 1,700 miles of secondary/county/township roads. California has a higher proportion of freeway mileage than do the other HSIS states, particularly urban freeway. Currently, there are two roadway inventory files in the HSIS system, 1993 and 1994. Because a new record is generated each time any of the items on the file changes, the sections that are generated are fairly short, resulting in a large number of individual records. The 15,200 miles of basic inventory information is divided into approximately 50,000 records, resulting in an average section length of 0.3 miles.

The file contains information on route descriptors (including functional class) and general terrain, and cross-section information related to traveled way width, number of lanes, paved and total shoulder width, median type, and other variables. Unlike most state inventories, it also contains information on design speed, special features such as auxiliary lanes, and detailed information on median barriers. The original TASAS file does not contain specific information on the type of shoulder (e.g., earth, sod, gravel, paved). However, California staff note that two variables related to total shoulder width and treated shoulder width can be used to infer whether part or all of a shoulder is paved.

Table 1. HSIS roadway mileage by roadway category (1994 data).

Roadway Category	**Mileage**
Urban freeways	2,205.36
Urban freeways < 4 Lanes	43.08
Urban multilane divided non-freeways	732.55
Urban multilane undivided non-freeways	185.15
Urban 2 lane highways	640.60
Rural freeways	1,846.95
Rural freeways < 4 lns	96.42
Rural multilane divided non-freeways	589.89
Rural multilane undivided non-freeways	408.50
Rural 2 lane highways	8,496.75
Total	15,245.25

The original TASAS file contains groups of variables for "right roadbed" and "left roadbed." Since the definition of each type of roadbed can change depending on whether or not the roadway is divided, the data has been converted to more standard HSIS definitions. After conversion (and as in other HSIS states), "Road 1" is either the full roadway for undivided sections, or the right-hand roadway in the direction of inventory for divided sections. "Road 2" only exists for divided roadways, and is the left-hand roadway in the direction of inventory. There are a few variables which were left in the original "roadbed" format (e.g., right and left roadbed "special features"). These are noted in the format section of this Guidebook.

Traffic information in the form of Average Daily Traffic is included for each section, along with Daily Vehicle Miles of travel. However, truck percentages are not included in the basic inventory file. A detailed description of the basis for these traffic variables is included below.

Finally, unlike most states, the California Roadlog file contains some information concerning changes that occurred to the roadway elements. With some programming, this should allow "before/after" analysis for specific roadway changes. Unlike the Washington State HSIS file, this is not a "date of last change" for each variable. Instead, using a "history indicator" flag and an "effective date" variable, one can determine whether a change has occurred since the preceding year within a group of variables. These flag and date variables exist for groups of variables related to the access control, AADT, median, right roadbed, and left roadbed. To determine the specific variable that changed, and the change in that variable, one must compare the current group of variables to the same group in the preceding year's file. (As noted in the format section under these flag and date variables, this is somewhat difficult to do since the roadbed designations for most variables except for these "history" variables have now been converted to the more conventional "Road 1/Road 2" definitions.) It is also noted that both the history indicator and the effective-date variable must be used in identifying changes. The history indicator variable will remain "on" after the first change, and thus will not indicate whether a subsequent change has occurred. However, the effective date will indicate when the current roadway characteristics became "open to traffic."

In order to assess the accuracy of roadway inventory variables in this Roadlog file and the related files concerning intersections and ramps, we again questioned the California DOT

Traffic Operations staff and examined a series of single-variable tables for key variables in each of the files. The Operations staff feel that the overall quality of the variables in all three files is very high. As noted above, the information in the files is updated in an ongoing effort based on construction plans and maintenance effort reports.

In addition to information received from the TO staff, single variable tabulations were run to examine the questions of reporting completeness and data accuracy. (Again, single-variable tables for key variables are provided in Volume II of the Guidebook.) Here, study of percent of "unknown," "not applicable," and "not stated" values for over 40 key variables in the Roadlog File indicate that, in general, the data is coded to a high degree of completeness. For most variables, there was no missing data. For the remainder, missing data was found in less than 1.5% of the cases. The data also appear to be quite consistent across years, and similar variables appear to have similar values.

In general, from the interviews and the data comparisons conducted, the data appear quite accurate. In the limited number of cases where possible inaccuracies were found or where more detailed definitions might be critical in future analyses, they are noted in the later formats section under the specific variables.

The Intersection File

As noted earlier, intersection-related information for approximately 20,000 intersections has been extracted from the TASAS roadway inventory file and placed in a separate HSIS Intersection File. This file contains more detail on intersections than do most state inventory files, describing both the mainline route and the intersecting route.

In the development of this file, the original TASAS roadway record was used to generate an intersection record each time a state route crosses either a state or non-state route. Thus, during the development process, two (duplicate) records would be generated each time two state routes crossed. (Only one record would be generated when a state route crossed a non-state route since the non-state route would not be inventoried in the roadway file.) A given state route would appear as "mainline" in one of these records, and as "intersecting street" in the second record. To reduce computer storage requirements, the original TASAS file only carries the full set of intersection variables on the record with the lower route number. For example, for an intersection of US 100 with California State Route 2, the data would be retained on the record in which CA 2 was the mainline. The higher number route record would only contain reference data pointing to the other record. For ease of use in the HSIS file, these higher-numbered route records have been deleted from the file. The intersecting route can still be matched with other files since the location (milepost) information is retained on the intersection record, along with the mainline location information.

For each intersection record, specific inventory variables for the mainline include variables related to intersection type, whether the mainline is divided or undivided, traffic control type (with information on whether the signals are semi-actuated or fixed time) intersection lighting, presence of signal mastarm, the presence of left-turn channelization, the presence of right-turn channelization, the type of traffic flow (e.g., two way verses one way with left turns permitted or not permitted), the number of through lanes, and the mainline ADT. It is noted that the channelization and traffic flow information is in the record only once for the mainline (and once for the intersecting street), meaning that the incoming and outgoing legs of each roadway are assumed identical with respect to these variables. In addition to the general information and the information on the mainline legs, cross-street variables include information on the traffic signal mastarms, left and right turn channelization, type of traffic flow, ADT and the number of through lanes.

Finally, as with inventory variables on the Roadlog File, there are a series of "history" and "effective date" variable that will help the analyst determine whether a change has occurred to the intersection in the past year. There are separate history variables for the entire intersection, traffic control, and lighting, and separate history variables for mainline and cross street ADT, and for the groups of variables describing the mainline and cross street (including channelization, mastarm, and traffic flow type). Again, as discussed above, both variables must be used in determining when a change has occurred.

In terms of data accuracy and completeness, examination of tables for the 20 key variables in the file indicate very little missing data (i.e., less that 4% for any variable, and no missing data for most variables). The values for all variables appear logical, and no problems were indicated by California Traffic Operations staff.

The Interchange Ramp File

As with the intersection data, information on approximately 14,000 ramps has been extracted from the TASAS roadway inventory file and placed in a separate HSIS Interchange Ramp File. It is noted there is no “unifying number” which would allow one to group ramps which would be in the same interchange. Thus, an analysis can be done on a ramp basis rather than interchange basis. It is estimated that these 14,000 ramps represent approximately 3,000 interchanges statewide.

Specific variables on the file include the general type of ramp (on or off), the basic ramp design (e.g., diamond, direct, slip, loop, etc.), the ADT on the ramp, whether a median is present on the roadway where the ramp begins, and whether the crossroad on which the ramp terminates is a state or non-state ("area 4") route. Again, a separate pair of history variables are present for both the general descriptive information and for the ADT information.

As was noted earlier under the accident section, individual accidents are located to the ramps on which they occur by a unique ramp identification number. If an accident occurs in the speed change lane prior to the gore area, it is coded to the mainline rather than the ramp. If after the gore and prior to the ramp terminal, it is coded to the ramp. If the ramp terminal is an intersection (as in a diamond interchange), and the accident occurs in the crossroad/ramp intersection or is near enough to be judged as being affected by the ramp terminal (usually 150 ft), there are two different ways of locating the crash depending on the type of crossroad. If the crossroad is a state route, then the crash is coded to the state route. If, on the other hand, the crossroad is non-state route, the accident is coded to the ramp, but is designated in the accident file under INT_RMP ("Intersection/Ramp accident location") to be a "ramp area, intersecting street" location. This is referred to as "area 4" by California staff. As noted above, there is also a code on the Interchange Ramp File defining whether an "area 4" exists for a given ramp (i.e., whether the crossroad is a non-state route.) For non-state routes, "area 4" would also include any crashes occurring between the two ramp terminals (i.e., on or near the overpass).

In terms of completeness and accuracy, examination of tables for the five key variables in the file indicate missing data in less than one percent of the records. Values appear logical, and no problems were indicated by California Traffic Operations staff.

Traffic Information in the Roadway Inventory Files

As indicated in the preceding three sections, all three inventory files contain Annual Average Daily Traffic (AADT) information. In addition, the Roadlog File contains information on Daily Vehicle Miles, which is computed as the product of the section length and section AADT estimate.

In California, the twelve district offices have the responsibility of collecting traffic data and developing the AADT estimates for each road section within their district. The Division of Traffic Operations of CALTRANS' central office oversees the operation, and attempts to maintain consistency in the methods and data across all districts as much as possible. If requested, Traffic Operations personnel will assist a district in calculating the AADT estimates. The Division also maintains all count data on an on-line computer file for the districts' use.

There are approximately 2,100 permanent count stations on mainline highways operated by CALTRANS in California. Of these, approximately 400 are permanent, continuous counting control stations that operate continuously each day in a given year. Every major state-administered route is counted each year. The 400 permanent continuous count stations form a network that covers all major routes. The remaining control stations are permanent, quarterly counting control stations, i.e., in-pavement loops to which a counter/recorder device is attached for 7 to 14 days during each quarter. CALTRANS also collects count data at approximately 700 of these quarterly counting control stations once every three years. In a given year, there are approximately 1,000 permanent quarterly counting stations where count data are not collected. California has determined that the AADT estimates which are derived from the simple average of the four (unadjusted) quarterly counts does indeed account for seasonal fluctuations without further adjustment based on nearby permanent counters. Consequently, there are no additional adjustments or corrections applied to the AADT's estimated from the quarterly counts.

In addition to the permanent control stations, approximately 1,000 coverage counts are collected annually. The intent is to collect coverage counts on a 3-year cycle (for a total of approximately 3000 coverage counts), although conditions may force longer intervals in certain districts at times. A coverage count is basically a 24-hour to 1-week count.

Coverage counts are expanded to AADT estimates using factors derived from the combined continuous counts and quarterly count data. For road sections which are not counted in a given year, it is the responsibility of the districts to develop these AADT estimates. In some cases, the districts reply on overall traffic growth trends within the district. However, in most cases, the AADT assigned to the section is developed by studying the traffic growth in counts falling on each side of the section.

It is also noted that 24-hour to one-week coverage counts are collected on approximately 3,200 on- and off-ramps per year. These ramp counts are manipulated through ramp balancing to reflect continuity of flow on mainline freeways.

Finally, vehicle classification data are collected at approximately 70 permanent stations across the state. Additional classification counts are collected on an as-requested basis, typically at locations where traffic count data is being collected. Since this is district-based, there is no reliable estimate on how many additional classification counts are collected across all twelve districts per year. Finally, there are approximately 45 weight-in-motion stations statewide which provide speed, volume, and the “13-bin” vehicle classification information.

Issues Related to Developing and Merging Files

As noted above, the accident data are subdivided into three subfiles -- accident, vehicle and occupant. The Accident and Vehicle Subfiles can be linked together using the accident report number (i.e., CASENO). When linking the occupant subfile, the additional linking variable related to vehicle number (i.e., VEHNO) must match so that the occupants are associated with the vehicle in which they were traveling. To link vehicles with accidents, first sort both subfiles by CASENO. To link the Occupant file with the other two subfiles, first sort both the Vehicle subfile and Occupant subfile by case number and vehicle position number. Next sort the Accident subfile by case number. Alternatively, the separate subfiles can be linked by specifying an SQL JOIN operation with the constraining condition that case number and vehicle number from each table are equal. SQL processing does not require the data to be presorted and the output will not be in any particular sort order unless ORDER BY is specified.

The Accident Subfile can be linked to Intersection and Interchange Ramp Files using the two variables related to county/route (i.e., CNTY_RTE) and MILEPOST. Using the same CNTY_RTE and MILEPOST variables, the Accident Subfile can be linked to the Roadlog File using the CNTY_RTE and BEGMP and ENDMP variables.

To prepare the Accident Subfile for linking with the Roadlog File using a SAS data step process, the analyst must sort both the Accident and the Roadway File into location order by

CNTY_RTE and MILEPOST on the Accident file and by CNTY_RTE and BEGMP on the Roadlog File. Similar sorts would be done with other files to be merged. For the alternative SQL join, the analyst must specify an exact match on CNTY_RTE and a range match where MILEPOST occurs between BEGMP and ENDMP. (Programs to accomplish this merging and division are documented in the HSIS Programmer's Guidebook, available at FHWA.)

Finally, where appropriate and possible, a format which defines categories within a given variable has been developed for HSIS SAS variables. These categories are shown in the pages below. These formats have been saved in a format library which can be provided to the user. As a naming convention, the "format name" is the same as the variable name, with the only exception being for certain character variables (in contrast with numeric variables). More specifically, a SAS format name has to be preceded by a "$" if the variable is character in nature. There is an 8-character length limit on both variable name and format name. In cases where the variable name is already eight characters in length, the addition of the preceding "$" would make the format name one character too long. In these cases, the format name is the same as the variable name except the final character of the variable name is dropped.

California Contacts

State Liaison [2]-- Lynn Seamons (916-654-4318) -- Mr. Seamons is our main contact in the California DOT when questions arise concerning the California data files in general. He is the Manager of the Accident Surveillance and Coding Branch of the CALDOT Division of Traffic Operations, and is the primary custodian of the TASAS system. He should be the first contact on all questions related to all accident and roadway inventory files. He is assisted by Robert (Bob) Brown (916-654-2215), who can answer questions on all files in Mr. Seamons absence.

Traffic Counts -- Joe Avis (916-654-3072) -- Mr. Avis is the traffic count specialist within the Division of Traffic Operations. He is responsible for headquarters coordination and storage of the traffic counts collected by the district offices, and forwards the ADT to Mr. Seamons for inclusion in TASAS.

California Highway Patrol Accident Data -- Bev Christ (916-657-7432) -- Ms. Christ is the Governmental Program Analyst with the California State Highway Patrol. She works with the

2 Liaison was Janice Benton 916 654 7271 (Sept. 2001) (Author’s note)

SWITRS data which is the basis for the HSIS driver information in the Vehicle Subfile and the Occupant Subfile. She can answer questions related to these data and to the overall nature of data collection by the State Highway Patrol and city agencies. (However, accident-related questions should be posed to Mr. Seamons first, as our main point of contact.)

APPENDIX H

DATA COLLECTION AND USE SUMMARY

INTRODUCTION

Many State Departments of Transportation were contacted in the course of the present effort. The purpose of these contacts was to inquire about the availability of crash, pavement texture, Friction Number, travel, roadway classification and other data relevant to the present effort. This effort sought to identify reliable multi-year state-wide databases that could readily be integrated and analyzed. Any identified databases would also have to be compatible across states, in order to allow direct comparisons with Wisconsin data.

This was a time-consuming process requiring repeated contacts by phone or e-mail; it produced results piecemeal. It was unknown at the outset whether the pieces would fit together when they were all finally gathered. Most information ended up not being used because data integration and testing would exceed the resources available for the present effort. An inventory of gathered information is presented in this Appendix for the purpose of facilitating future investigators who may be after similar types of information. **Appendix I** presents a list of the persons within each organization that provided the information described herein.

CALIFORNIA

HSIS:	1991-1998 crashes, roadway inventory, 1997 intersection information.
Caltrans:	Contacts relating to freeway operation under winter weather conditions with District 3.
Disposition:	Used crash and roadway inventory.
Reasoning:	State-wide, multi-year information on longitudinal texture, some information on transversely tined pavements. Intersection information not used to avoid influence of extraneous variables on safety performance.

COLORADO

No data gathered.

Disposition:	Not used.
Reasoning:	Inadequate sample for safety performance evaluation—longitudinal texture was applied only recently.

ILLINOIS

HSIS:	1991-1998 crashes, roadway inventory. No information on pavement surface texture.
ILDOT:	No additional pavement data gathered.
Disposition:	Not used.
Reasoning:	Only transversely tined pavements used. No information on rehabilitated sections or use of grinding.

IOWA

No data gathered.

Disposition:	Not used.
Reasoning:	Limited use of longitudinal texture.

MAINE

HSIS:	1991-1998 crashes, roadway inventory. No information on pavement surface texture.
MDOT:	No additional data.
Disposition:	Not used.
Reasoning:	State mainly uses 8”-9” Asphaltic Concrete (AC) on Interstate highways; PCC has not been used since 1975-6. About 72 lane-miles of remaining PCC were to be overlaid with AC. Transversely tined PCC used on bridge decks.

MICHIGAN

HSIS:	1991-1998 crashes, roadway inventory
MDOT:	Construction year, year of pavement improvement, low Friction Number, high Friction Number, average Friction Number, lane in which FN was collected, FN test date.
Disposition:	Not used
Reasoning:	Not clear which pavement surface texture was in place each year.

MINNESOTA

HSIS:	1991-1998 crashes, roadway inventory. No information on pavement surface texture.
MNDOT:	No information on which PCC pavements were longitudinally ground.
Disposition:	Not used.
Reasoning:	No information on pavement surface texture.

NORTH CAROLINA

HSIS:	1991-1998 crashes, roadway inventory. No information on pavement surface texture.
NCDOT:	No additional data.
Disposition:	Not used.
Reasoning:	Only about 200 miles of exposed PCC pavement available. Transversely tined surface treatment. Information on its location would have to be gathered by contacting each of NCDOT divisions 4, 5, 7, 9 and 10. Difficulty in identifying PCC sections.

UTAH

HSIS:	1991-1998 crashes, roadway inventory.
UDOT:	No accurate surface texture database available. PCC pavements (a total of approximately 1,200 miles) transversely tined. Some diamond grinding performed on less than 10% of this mileage as rehab. Some grinding project limits identified by Region Materials Engineers. Skidabraider was also used in a couple of projects.
Disposition:	Not used.
Reasoning:	Extent of grinding not clear—some projects were in one direction only. Grinding project dates varied through the evaluation period complicating the evaluation. No established database to track pavement texture.

VIRGINIA

VDOT:	1992-2000 crashes (1996 data not complete); Traffic volumes 1996-2001; skid data; concrete pavement inventory (235 miles of longitudinally tined pavements, few transversely tined pavements, several hundred miles of milled pavements)—pavement section lengths varying from a few miles to over 30 miles in length; friction information (VDOT uses the ASTM E274 friction device and correct the Skid Number to 40 mph); pavement age.
Disposition:	Preliminary analysis for 1997-2000 data. Not used in this report.
Reasoning:	Many compatibility issues with HSIS data; difficult identification of highway class; some very short segments; scattered locations.

WASHINGTON STATE

HSIS:	1991-1998 crashes, roadway inventory
WADOT:	Inventory of rehabbed freeway segments (1993-2001)--grinding applied mostly to right lane.
Disposition:	Not used.
Reasoning:	Limited database consisting of transversely tined texture. Rehabilitation occurred at different times during the analysis period, complicating the analysis.

WISCONSIN

WisDOT	1991-1998 freeway crashes on I-90, I-94, I-794 and I-894. 1998-2000 statewide crashes. 1975-1994 Friction Number database. Metamanager mid-1999 roadway inventory (pavement type, travel information, urban/rural freeway classification).
Disposition:	Used crash, Metamanager and Friction Number data.
Reasoning:	State-wide multi-year information available. Reliable integration of crash and roadway data.

APPENDIX I

AGENCY CONTACTS

INTRODUCTION

The present Appendix contains the names and contact information of persons that provided the data listed in **Appendix H.**

CONCRETE PAVING ASSOCIATION OF MINNESOTA

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