# INFLUENCE OF SEASONAL TEMPERATURE ON PAVEMENT RELIABILITY PERFORMANCE: A CASE STUDY

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## ABSTRACT

This exploratory study analyzed crash and pavement data to examine pavement reliability performance (PRP) for seasonal temperature changes in U.S. State Y. The term PRP is a general term, and the NCHRP 500 report series were used for this study. (1) PRP was examined for three pavement types:

- Pave 1– asphalt overlay on flexible pavement
- Pave 2 – asphalt overlay on rigid pavement
- Pave 3 – jointed plain concrete.

Study results showed that in warm seasons, the pave1 odds ratio (OR) for crashes had a 17 to 100 percent increase compared to pave2 and pave3 OR in the following categories: overall Single Vehicle Run-Off-Road (SVROR), SVROR/Fail to Control Vehicle, SVROR/Overturn, and SVROR/Curve.

Pave1 OR crash trends for SVROR/ Exceeding Speed Limit and SVROR/Alcohol related crashes did not show an increase compared with pave3 OR in warm seasons.

Pave1 showed clear differences in warm and cold seasons for crash rate distributions per categories of Log10 annual average daily traffic (AADT) with significantly higher (p-value equal to.04) SVROR crashes for Log10 AADT less than or equal to 7,900.

This study recommends further research for asphalt surface property sensitivity to temperature, and the impact of pavement surface temperature on pavement reliability using analysis of crash data.

## INTRODUCTION

Anyone who has walked barefoot across a parking lot on a hot summer day knows that asphalt concrete (AC) or “blacktop” is exceptionally good at soaking up the sun's warmth. (2) The AC surface is dark and this characteristic contributes significantly to receiving a large amount of energy through radiation heat transfer. There is objective evidence that AC surface friction increases in early spring and decreases in early fall. The variation of skid number between early spring and early fall depends on the type of pavement, pavement design, material, and geographical location. Because, AC is a viscoelastic material, it is difficult to believe that its high surface temperature will not impact its surface properties to some small extent.

A Federal Highway Administration (FHWA) study produced a model that determines the changes in asphalt stiffness, resilient modulus, and poison's ratio of the base, subbase, and subgrade with time. Material properties, pavement geometry, and other required data for input were provided by CMS (Climatic-Materials-Structural) Model. This study developed a model to study the temperature profile on asphalt surface and changes. However, there is no model to study influence of temperature on AC surface where it relates to tire-surface friction.

It would be a difficult and an expensive task to test the above empirical knowledge on a national scale, however, the usage of crash data analysis may serve as a feasibility study for starting a set of statewide validation studies for influence of seasonal temperature on PRP.

This study has provided methodology for using statistical analysis of crash and pavement data files for influence of seasonal temperature on PRP where data was available.

Transportation Research Board's National Cooperative Highway Research Program (NCHRP) NCHRP Report 500 Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: Volume 6: A Guide for Addressing Run-off-Road Collision, and Volume 7: A Guide for Reducing Collision on Horizontal Curves (1) were used as guidance to isolate crash variables in warm and cold seasons for analysis from data files. The following areas of concern were examined.

For pave1 through pave3, the comparison of crash trends and how the seasonal temperatures influence their PRP.

1. SVROR/Fail to Control Vehicle
2. Multivehicle crashes on Road (MVOR) versus SVROR
3. SVROR/Overturn
4. SVROR/Curve
5. Curve/SVROR/Overturn

Also, data analysis was performed to answer the following questions:

- Does PRP vary according to pavement type, and its AADT for each season?
- Are there more speeding-related crashes in warm versus cold seasons?
- Are there more alcohol-related crashes in warm versus cold seasons?
- Are there more fatality crashes in warm versus cold seasons?

From the State Y crash and pavement data file, a sample of 101,271 crashes for primary vehicle, nonintersection, no pedestrian, no bicycle, no animal, no railroad, no work zone, no school, etc., were used for of the years 2005-2009 (5 years).

This study report contains the following sections:  Background, Methodology, Data Management, Tools, Results and Discussion, Summary and Conclusion, Recommendation, References, and Acknowledgment.

# BACKGROUND

According to a 2006 study by Miller and Zaloshnja, roadway condition was a contributing factor in 31.4 percent of all crashes, 52.7 percent of the annual 42,642 fatalities, and 38 percent of the 5,746,231 non-fatal crashes. These motor vehicle crashes cost the U. S. economy more than $217 billion each year. This is about three and a half times the annual U.S. Government investment of $59 billion in roadway capital improvements (3)

According to the National Highway Traffic Safety Administration (NHTSA), Fatality Analysis Reporting System (FARS), from 1994 to 2009 (16 years of data; mean equals 41,338, standard deviation (SD) equals 2,434.7, Minimum (Min.) equals 33,808, and Maximum (Max.) equals 43,510), a total of 661,403 people died in vehicle crashes in the United States of America. Using any conservative estimate and certainly less than 52.7 percent in the Miller and Zaloshnja study, pavement texture and friction condition may have contributed to a noticeable number of fatalities each year.

The FHWA 1993 study An Integrated Model of the Climatic Effects on Pavements used sunshine percentage, wind speed, air temperature, and solar radiation to develop a CMS Model to compute temperature profile throughout the asphalt pavement. (4) This CMS model determines the changes in asphalt stiffness, resilient modulus, and poison's ratio of the base, subbase, and subgrade with time. Material properties, pavement geometry, and other required data for input were provided by the CMS Model. However, this study developed a model to study the temperature profile on asphalt surface and changes in its properties. However, influence of temperature on AC surface where it relates to tire-surface friction is not a known phenomenon.

Asphalt tends to absorb heat much better than concrete. So much so, that a study by Mallick et al presented the concept of extracting heat energy from asphalt pavements. This study involved experiments with finite element modeling and testing with small and large scale asphalt pavement samples. Water flowing through copper tubes inserted within asphalt pavement samples was used as heat exchangers. The rise in temperature of water as a result of flow through the asphalt pavement was used as the indicator of efficiency of heat capture. Results for small scale testing showed that the use of highly conductive aggregate can significantly enhance the efficiency of heat capture. The efficiency can also be improved by using a reflectivity reducing and absorptivity increasing top layer over the pavement. Tests carried out with large scale slabs showed that a larger surface area results in a higher amount of heat capture, and that the depth of heat exchanger is critical. An effective heat exchanger design will be the key to extracting maximum heat from the pavement. (5)

"The data collected on six hot mix AC pavements located in different climatic zones in Texas demonstrates that the seasonal variation of skid numbers is not a phenomenon that is limited to northern states only. The variations observed followed the same general trend that has been described in previous research studies. Accordingly, the maximum skid numbers were measured during the winter and early spring and the minimum skid numbers were measured during the summer. The maximum variation in skid numbers that were measured at bi-weekly intervals was10-12 skid numbers. The difference in the average skid numbers measured in winter and summer was about 6. Seasonal variation of skid numbers was found to be very significant in comparison with those associated with other factors that contribute to such variation such as longitudinal variation, variation between different skid trucks, different operators, etc." (6).

Hall et al. classified the variables that affect tire-pavement friction into the following categories: 1) pavement surface characteristics (i.e., microtexture and macrotexture), 2) traffic variables (e.g., slip speed), 3) tire properties (i.e., foot print and inflation pressure), and 4) environment (i.e., climate, wind, temperature, precipitation, and contaminants). In particular, environmental (climatic) factors can have both short-term and long-term effects. (7)

Tests carried out at a series of trial sections between 1988 and 1992 in New Zealand showed very pronounced seasonal changes in skid resistance, with minimum summer values being approximately 30 percent lower than peak winter values. (8)

# METHODOLOGY

The first part of this study was designed to examine the State Y PRP, using *NCHRP Report 500*, *Volume 6: A Guide for Addressing Run-off-Road* (ROR) *Collision*, and *Volume 7: A Guide for Reducing Collision on Horizontal Curves*.

*NCHRP Report 500*, Volume 6 states, "ROR crashes involve vehicles that leave the travel lane and encroach onto shoulder and beyond and hit one or more on any number of natural or artificial objects such as bridge wall, poles, embankments, guardrails, parked vehicles, and trees."

Generally, most crashes occur between two vehicles or more on roadways. The proportions of SVROR are much lower than MVOR crashes on safer roadways. A roadway or system is considered to have higher risk factors for SVROR when its SVROR crash proportion gets closer to, or greater than its MVROR crash proportion.

*NCHRP Report 500*, Volume 6, Objective 15.1 A7, states that "providing skid- resistant surface may reduce SVROR effectively." Objective 15.1 B recognizes that Overturn crashes are more likely for SVROR.

*NCHRP Report 500*, Volume 7, Objective 15.2 A7 identifies providing *skid-resistance pavement surfaces* as a possible effective countermeasure for reducing likelihood of SVROR crashes.

*NCHRP Report 500*, Volume 7, Objective 15.2 B1 identifies *overturn* as an adverse consequence of SVROR on curves.

*NCHRP Report 500*, Volume 7, objective 15.2 B2-B5 identifies *fixed objects on roadside* create hazardous roadway conditions on curves.

Based on the *NCHRP Report 500* guides, the following questions were designed to examine PRP for pave1 through pave3 State Y.

How will the following crash trends compare in warm versus cold seasons, and how will seasonal temperatures influence their PRPs:

1. SVROR/Fail to Control Vehicle?
2. Multivehicle crashes on Road (MVOR) versus SVROR?
3. SVROR/Overturn?
4. SVROR/Curve?
5. SVROR/Exceeding Speed Limit?
6. SVROR/Alcohol?
7. SVROR/Killed?

Generally, higher AADT in congestion hours is associated with reduced level of service (lower velocity) that may be protective (not a risk factor) for SVROR crashes. The following question is designed to examine seasonal PRP per different level of AADT for pave1 through pave3.

Does PRP vary according to pavement type and its AADT for each season?

For question 1 through 7, each type of pavement has variables such as Federal HWY Classification, number of lanes, lane and shoulder widths, pavement thicknesses, ages, conditions, AADTs, pavement designs, geometric designs, etc. For comparing pavement types in this type of analysis, crash data needs to be adjusted for all the above variables. OR is an effective and efficient method that can be used to compare three pavement types' PRP performance for areas of concern. Proper samples were isolated for each pavement type, and they were analyzed independently, and pave1 OR was compared to the other ORs to determine which pavement has a higher risk factor compared to pave1.

U.S. State Y is a northern State, which assures that pavements were exposed to two extreme seasonal temperatures. In Table 1, the months of December through March were selected for the cold season, and June through September was selected for the warm season.

**Table 1: State Y monthly temperature per National Weather Channel. (9)**

| Cold Season | | | Warm Season | | |
|---|---|---|---|---|---|
| Monthly Average Temp. (°F) | | | Monthly Average Temp. (°F) | | |
| **Months** | **High** | **Low** | **Months** | **High** | **Low** |
| Dec | 32 | 12 | Jun | 80 | 53 |
| Jan | 27 | 5 | Jul | 84 | 58 |
| Feb | 33 | 10 | Aug | 82 | 56 |
| Mar | 45 | 22 | Sept | 74 | 47 |
| Mean | 34.25 | 12.25 | Mean | 80 | 53.5 |
| (SD) | 7.63 | 7.14 | (SD) | 4.32 | 4.8 |

A sample of 101,265 crashes (Sample 1) from State Y data was isolated and linked to its pavement data file for the period of 2005-2009 (5 years.) These crashes were non-intersection and primary vehicle crashes (vehicles identified to have caused the crash.) Passenger data were omitted from this file, as they are not relevant. Intersection crashes were omitted because there are many variables involved in intersection crashes that may overshadow the pavement related variables.

Most, 87.3 percent, of the crashes occurred on three different types of pavements with a total of 12,900 miles. Per Sample 1, these pavements types with their corresponding lengths are listed in Table 2. Other type of pavements did not have large enough crashes to be included in this study.

**Table 2: State Y crash percent and crash per mile by pavements, type, length, and thickness.**

| State Y Non-Intersection Crashes<br>Omitted: pedestrian, bicycle, train, animal, work zone, other irrelevant crashes,<br>Sample 1= 101,262 crashes & Period: 2005-2009 | | | | | | |
|---|---|---|---|---|---|---|
| **Pavement Type** | **Freq.** | **%Crash of Sample1** | **Length* (mile)*** | **Estimated Crash/Mile** | **Type** | **Thickness** |
| Asphaltic Overlay on Flexible Pavement (pave1) | 26,734 | 26.40% | 7,300 | 3.7 | HMAC* | min. 2.5" |
| Asphaltic Overlay on Rigid Pavement (pave2) | 40,810 | 40.30% | 3,200 | 12.8 | HMAC* | min. 2.5" |
| Jointed Plain Concrete (pave3) | 20,861 | 20.60% | 2,400 | 8.7 | PCC***e | Variable |
| Total | 88,404 | 87.30% | 12,900 | 6.9 | | |

**Length were provided by the State Y *Hot Mixed AC ***Portland Cement Concrete*

Table 3 shows different pavement types with their corresponding functional classes and lengths for the State Y.

**Table 3: Pavement length per each type and Functional Classification*.**

| State Y Pavement Length per Type and Functional Classification | | | |
|---|---|---|---|
| **Functional Class** | **Flexible Length (pave1) (mile)** | **Composite Length (pave 2) (mile)** | **Rigid Length (p** |
| Rural Interstate | 95 | 197 | 18 |
| Urban Interstate | 26 | 164 | 75 |
| Rural NHS other high type | 1,383 | 636 | 42 |
| Urban NHS other high Type | 120 | 349 | 52 |
| Other Rural Federal Aid | 13,540 | 2,235 | 22 |
| Other Urban Federal Aid | 3,679 | 813 | 1,17 |
| Total | 18,843 | 4,394 | 2,60 |

***Highway Statistics 2008***

A harsh cold climate, includes 1) many hours of snow and ice on the pavement, 2) more hours of wet pavement condition due to snow and ice melting than the wet pavement hours in warm season, and 3) many hours of frozen moisture on the pavement (black ice) with freezing temperatures at night, dawn, early morning, and even during the day.

To eliminate any bias from the data due to the above three factors, only “dry” pavement condition was used. Crashes for months of December, January, February, and March for the cold season, and June, July, August and September for the warm season were used. The months of September and May were added to increase sample size, many crashes were eliminated in order to reduce bias in the sample.

Normally, lower posted speed limits are protective for SVROR crashes in areas with road friction issues. Based on this fact, crashes with higher speed were selected for PRP analysis. SVROR crashes that occurred on roads with posted speed limits of 55 mph (miles per hour) and 65 mph for cold and warm seasons were compared for each type of pavement.

To examine PRP concerning question 8 in this section, crash Rate for 100 Million Vehicle Miles (RMVM) was calculated for each segment of road for each type of pavement. (10) RMVM standardizes crash frequencies for each road segment (or entire road or system) for its length, AADT, and number of days in the study period. This standardization is required so that road segments can be compared for each type of pavement.

**RMVM= no. of crashes*10**8/(segment length*AADT*days*no. of years)**

For each season, crash frequencies were normalized by their total number of crashes to overcome sample size differences. This results in crash proportions for each category of AADT. The traditional RMVM formula was used as the measure for safety reliability performance for categories of AADT, but instead of using actual frequencies in the formula, crash frequency proportion was used for each season. In this study, the reliability performance measure is crash Proportion Rate for 100 Million Vehicle Miles (PRMVM.)

**PRMVM = no. of crashes*10**8/(segment length*AADT*days*no. of years* season sample size),**

Days in warm season =122, and days in cold season days=121.

Season sample size= total number of crashes that occurred in each season (warm or cold) for period of five years.

Considering a wide range of AADT (150-200,000) in State Y data, Log10 (AADT) categories were used to provide two histograms for PRP PRMVM measures for cold and warm seasons.

For each crash datum, State Y provided segment length with its corresponding AADT that was adjusted per month of year by State Y crash data managers. This was done to address the concern that there may be more traffic on the roads during the warmer months. It is not known how accurately these adjustments reflect the actual monthly fluctuations in AADT by roadway type.

The IBM SPSS Statistics software 15.0 was used to calculate PRMVM for each road segment and PRMVM were added up for each Log10 (AADT) category separately. Pavements' PRMVMs histograms were plotted per pavement Log10 (AADT.)

# DATA MANAGEMENT

To prepare the data for analysis and to reduce biases, to the extent possible, the following steps were followed. Using Sample 1, omitted cases involving:

1. Wet pavements in warm and cold seasons
2. Ice, snow/slush condition in cold season
3. All other surface condition like sand, and mud
4. Weather conditions for snow, rain, fog, and etc, and kept only clear, and cloudy weather condition
5. Dark/lighted, dark/not-lighted, dawn and dusk
6. Omitted cases for months of; April, May, October, and November.
7. Omitted hours of 4:30 p.m. to 9:00 a.m. to avoid dealing with nighttime crash variables, and black ice in cold season (77 percent of all crashes in cold season, and 74 percent of all crashes in warm season occurred between 9:00 a.m. to 4:30 p.m.)

Subset-1a with 15,097 crashes resulted after step 7.

1. Omitted all crashes for two or more vehicles involved, and only kept single vehicle crashes
2. Omitted crashes for years 2005 through 2007 and used only 2008 and 2009 crashes (with more recent AADT) for examining seasonal temperature impacts on pavement safety versus AADT

Subset-1b with 5,540 (5 percent of Sample 1) crashes resulted for period of 2008 through 2009 after step 9. Used Sample 1 and followed steps 1 through 5, plus the following:

1. Omitted all crashes that were multivehicle and were not ROR crashes. Single vehicle "crash types" involving collision with bridge parapet end, bridge rail, bridge/pier/abutment, culvert, curb, ditch, embankment, fence, guardrail end, guardrail face, jackknife, luminary light support, mailbox, median barrier, other fixed object, other post, traffic sign post, traffic signal, and tree, and utility pole were kept, as these crashes are all ROR types of crashes.
2. Omitted Crashes that occurred on the road with posted speed limit of 25 to 50 mph, and kept crashes that occurred on roads with 55 mph and 65 mph posted speed limit.

Subset-1c with 4,051 crashes (4 percent of sample 1) resulted after step11.

1. Omitted cases for months of; April, May, October, and November.

Subset-1d with 2,686 crashes (3 percent of sample 1) resulted after step 12.

This study used (literally) attribute and variable names as stated in State Y crash file. In following statistical analysis; Subset-1a, Subset -1b, Subset-1c, and Subset-1d were used.

# TOOLS

For the statistical analysis the following tools were used: SPSS 15.0, Statistix 9.0, and Excel 2010.

# RESULTS AND DISCUSSION

SUBSET-1 WAS USED TO DETERMINE HOW MVOR VERSUS SVROR OCCURRED ON PAVE1 THROUGH PAVE3, and how seasonal temperature affects these crashes on each type of pavement. If these pavements are to be compared for any concern, it is very difficult to find statistical methodologies that can normalize crash data for the three types of pavements in this study.

Two by Two Association Test was used to determine crash variables' OR in warm versus cold season. To compare Pave1 OR to Pave2 and Pave3 OR the following formula was used.

**%Increase in Pave1 Risk Factor= 100x(OR1-ORi)/ORi**

OR1 is pave1 OR, and ORi is the other type pavement OR (pave2 or pave3).

For questions #1 through #4 in the Methodologies section, Table 4 Shows OR and percentage increase in pave1 OR compared to pave2 and pave3.

**Table 4: Odds ratio for Various crash variables in warm vs. cold season*.**

| Pavement | Season | Attribute: Driver Contribution | | Two by Two Association | | Pave1 % Increase for OR in Warm Season |
|---|---|---|---|---|---|---|
| | | Variable: SVROR/Fail to Control | Variable: SVROR/Other Actions | Odds Ratio | P-Value | |
| Pave1 | Warm | 299 (54%) | 251 | 1.31 | 0.09 | - |
| | Cold | 106 (48%) | 117 | | | |
| Pave2 | Warm | 234 (54%) | 196 | 0.86 | 0.34 | 53% |
| | Cold | 146 (58%) | 105 | | | |
| Pave3 | Warm | 93 (47%) | 107 | 0.75 | 0.25 | 74% |
| | Cold | 53 (54%) | 46 | | | |
| **Pavement** | **Season** | **Attribute: Crash Type** | | **Two by Two Association** | | **Pave1 % Increase for OR in Warm Season** |
| | | **Variable: SVROR** | **Variable: Motor Veh. In Transport** | **Odds Ratio** | **P-Value** | |
| Pave1 | Warm | 972 (41%) | 1375 | 0.89 | 0.14 | - |
| | Cold | 435 (44%) | 550 | | | |
| Pave2 | Warm | 696 (24%) | 2172 | 0.75 | 0.00 | 19% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Cold | 422 (30%) | 992 | | | |
| Pave3 | Warm | 316 (28%) | 832 | 0.70 | 0.00 | 27% |
| | Cold | 200 (35%) | 371 | | | |
| **Pavement** | **Season** | **Attribute: Crash Type** | | **Two by Two Association** | | **Pave1 % Increase for OR in Warm Season** |
| | | **Variable: SVROR / Overturn** | **Variable: SVROR / Nonoverturn & Fixed Object** | **Odds Ratio** | **P-Value** | |
| Pave1 | Warm | 217 (25%) | 665 | 1.63 | 0.00 | - |
| | Cold | 66 (17%) | 330 | | | |
| Pave2 | Warm | 130 (22%) | 469 | 1.40 | 0.06 | 17% |
| | Cold | 58 (17%) | 292 | | | |
| Pave3 | Warm | 94 (34%) | 186 | 1.20 | 0.37 | 36% |
| | Cold | 53 (30%) | 126 | | | |
| **Pavement** | **Season** | **Attribute: Crash Type** | | **Two by Two Association** | | **Pave1 % Increase for OR in Warm Season** |
| | | **Variable: SVROR / Curve** | **Variable: SVROR / Straight** | **Odds Ratio** | **P-Value** | |
| Pave1 | Warm | 325 (37%) | 555 | 1.28 | 0.06 | - |
| | Cold | 124 (31%) | 271 | | | |
| Pave2 | Warm | 90 (15%) | 508 | 0.64 | 0.01 | 100% |
| | Cold | 76 (22%) | 274 | | | |
| Pave3 | Warm | 52 (19%) | 228 | 0.74 | 0.21 | 72% |
| | Cold | 42 (23%) | 137 | | | |

** Subset-1a and Subset-1d were used for this table.*

Table 4 shows that in the period of this study;

1. SVROR/Fail to Control Vehicle:
    a. On pave1 was 1.31 times more likely to occur in warm season than cold season
    b. On pave2 was 0.14 times less likely to occur in warm season than cold season
    c. On pave3 was 0.25 times less likely to occur in warm season than cold season

In warm season, pave1 SVROR/Fail to Control Vehicle OR had a 53 percent increase compared to pave2, and had a 74 percent increase compared to pave3.

2. SVROR versus MVOR:
    a. On pave1 was 0.11 times less likely to occur in warm season than cold season
    b. On pave2 was 0.25 times less likely to occur in warm season than cold season
    c. On pave3 was 0.30 times less likely to occur in warm season than cold season

In warm season, pave1 SVROR versus MVOR OR had a 19 percent increase compared to pave2, and had a 27 percent increase compared to pave3.

3. SVROR/Overturn:
    a. On pave1 was 1.63 times more likely to occur in warm season than cold season
    b. On pave2 was 1.40 times more likely to occur in warm season than cold season
    c. On pave3 was 1.20 times more likely to occur in warm season than cold season

In warm season, pave1 SVROR/Overturn OR had; a 17 percent increase compared to pave2, and had a 36 percent increase compared to pave3.

4. SVROR/Curve:
    a. On pave1 was 1.28 times more likely to occur in warm season than cold season
    b. On pave2 was 0.36 times less likely to occur in warm season than cold season
    c. On pave3 was 0.26 times less likely to occur in warm season than cold season

In warm season, pave1 SVROR/Overturn OR had a 100 percent increase compared to pave2, and had a 72 percent increase compared to pave3.

For questions #5 through #8, table 5 shows OR and percentage increase in pave1 OR compared to pave2 and pave3.

**Table 5: Odds ratios for various crash variables in warm versus cold season*.**

| **Pavement** | **Season** | **Attribute: Crash Type** | | **Two by Two Association** | | **Pave1 % Increase for OR in Warm Season** |
|---|---|---|---|---|---|---|
| | | **Variable: SVROR / Exceeding Speed Limit** | **Variable: SVROR / Not Exceeding Speed Limit** | **Odds Ratio** | **P-Value** | |
| Pave1 | Warm | 46 (5%) | 836 | 1.31 | 0.37 | - |
| | Cold | 16 (4%) | 380 | | | |
| Pave2 | Warm | 26 (4%) | 573 | 1.01 | 0.97 | 29% |
| | Cold | 15 (4%) | 335 | | | |
| Pave3 | Warm | 17 (6%) | 263 | 1.86 | 0.19 | -30% |
| | Cold | 6 (3%) | 173 | | | |
| **Pavement** | **Season** | **Attribute: Alcohol Flag** | | **Two by Two Association** | | **Pave1 % Increase for OR in Warm Season** |
| | | **Variable: SVROR / Alcohol Flag** | **Variable: SVROR / No Alcohol** | **Odds Ratio** | **P-Value** | |
| Pave1 | Warm | 48 (5%) | 834 | 0.85 | 0.54 | - |
| | Cold | 25 (6%) | 371 | | | |
| Pave2 | Warm | 19 (3%) | 580 | 0.64 | 0.19 | 33% |
| | Cold | 17 (5%) | 333 | | | |
| Pave3 | Warm | 11 (4%) | 269 | 1.01 | 1.00 | -15% |
| | Cold | 7 (4%) | 172 | | | |
| **Pavement** | **Season** | **Attribute: Crash Severity** | | **Two by Two Association** | | **Pave1 % Increase for OR in** |
| | | **Variable:** | **Variable:** | **Odds Ratio** | **P-Value** | |

| | | SVROR / Killed | SVROR / Not Killed | | | Warm Season |
|---|---|---|---|---|---|---|
| Pave1 | Warm | 12 (1%) | 870 | 1.81 | 0.35 | - |
| | Cold | 3 (1%) | 393 | | | |
| Pave2 | Warm | 10 (2%) | 589 | 1.96 | 0.30 | -8% |
| | Cold | 3 (1%) | 347 | | | |
| Pave3 | Warm | 4 (1%) | 276 | 1.28 | 0.77 | 41% |
| | Cold | 2 (1%) | 177 | | | |

** Subset-1d was used for this table.*

Table 5 shows that in the period of this study:

1. SVROR/Exceeding Speed Limit:
    a. On pave1 was 1.31 times more likely to occur in warm season than cold season
    b. On pave2 was 1.01 times more likely to occur in warm season than cold season
    c. On pave3 was 1.86 times more likely to occur in warm season than cold season

In warm season, pave1 SVROR/ Exceeding Speed Limit OR had a 29 percent increase compared to pave2, and had a 30 percent decrease compared to pave3.

2. SVROR/Alcohol related crashes:
    a. On pave1 was 0.15 times less likely to occur in warm season than cold season
    b. On pave2 was 0.26 times less likely to occur in warm season than cold season
    c. On pave3 was 1.01 times more likely to occur in warm season than cold season

In warm season, pave1 SVROR/ Alcohol OR had a 33 percent increase compared to pave2, and had a 15 percent decrease compared to pave3.

3. SVROR/Killed:
    a. On pave1 was 1.81 times more likely to occur in warm season than cold season
    b. On pave2 was 1.96 times more likely to occur in warm season than cold season
    c. On pave3 was 1.28 times more likely to occur in warm season than cold season

In warm season, pave1 SVROR/Killed OR had an 8 percent decrease compared to pave2, and had a 41 percent increase compared to pave3.

To answer question#8 about whether PRPs vary differently for each season by pavement type and AADT:

Subset-1b was used for the analysis and crash frequencies were normalized by PRMVM in relation to AADT as shown in table 7. From Subset 1b two independent samples were prepared for warm and cold seasons. Crash proportions were calculated for each road segment in the sample (proportions total is equal to 1) and these proportions were used to calculate PRMVM.

Because PRMVM has a cumulative property, all segments' PRMVMs were added for each Log10 (AADT) category. Results are presented in histograms presented in figures 1 through 3. Histograms (descriptive analysis) serve as an effective tool to compare the two independent distributions for the warm and cold seasons. Statistical tests were used to determine if there were significant differences between them.

PRP (PRMVM) is presented for pave1, pave2, and pave3 for categories of Log10 (AADT), as shown in table 6. Corresponding histograms are presented in figures 1, 2, and 3.

**Table 6: Crash Proportion Rates for 100 Million Vehicle Mile per Log10 (AADT), Subset-1b.**

| **Pavement Reliability Performance (PRMVM) per $Log_{10}$ (AADT)**<br>**Warm and Cold Seasons**<br>**Dry Roads, Daytime, 9:00 am to 4:30 pm**<br>Sample: 5,540 crashes & Period:2008-2009 | | | | | | |
|---|---|---|---|---|---|---|
| **Log10 (AADT)** | **Pave1 PRMVM** | | **Pave2 PRMVM** | | **Pave3 PRMVM** | |
| | **Cold** | **Warm** | **Cold** | **Warm** | **Cold** | **Warm** |
| 2.2 | | 2.964 | | | | |
| 2.3 | 1.64 | 0.86 | | | | |
| 2.4 | | 2.711 | | | | |
| 2.5 | | 1.358 | | | | |
| 2.6 | | 0.484 | | 0.507 | | |
| 2.7 | 2.06 | 1.988 | | 0.564 | | |
| 2.8 | 2.25 | 5.54 | | | | |
| 2.9 | 2.92 | 4.064 | | 0.632 | | 0.159 |
| 3.0 | 2.44 | 6.311 | | | | |
| 3.1 | 1.78 | 3.431 | 4.75 | 0.108 | 0.49 | |
| 3.2 | 3.77 | 9.05 | | 0.878 | | |
| 3.3 | 7.42 | 5.532 | 1.14 | 0.662 | 0.15 | 0.346 |
| 3.4 | 4.04 | 7.213 | 2.38 | 1.94 | 0.24 | 0.614 |
| 3.5 | 5.57 | 6.553 | 2.32 | 1.519 | 0.35 | 0.22 |
| 3.6 | 4.86 | 8.109 | 1.20 | 2.318 | 0.83 | 0.88 |
| 3.7 | 9.24 | 7.653 | 3.21 | 3.147 | 0.87 | 1.025 |
| 3.8 | 3.69 | 5.248 | 3.08 | 2.265 | 3.53 | 2.047 |
| 3.9 | 6.31 | 5.23 | 3.07 | 5.176 | 2.68 | 1.236 |
| 4.0 | 3.86 | 3.418 | 4.91 | 5.515 | 2.70 | 3.12 |
| 4.1 | 3.26 | 3.944 | 5.09 | 5.568 | 5.13 | 4.963 |
| 4.2 | 2.36 | 2.376 | 4.15 | 5.181 | 3.96 | 4.569 |
| 4.3 | 1.07 | 2.834 | 3.65 | 3.056 | 2.39 | 2.062 |
| 4.4 | 0.67 | 0.323 | 3.04 | 2.747 | 1.03 | 1.377 |
| 4.5 | 0.14 | 0.426 | 2.44 | 1.516 | 0.94 | 0.983 |
| 4.6 | 0.08 | 0.021 | 1.31 | 1.415 | 0.38 | 0.37 |
| 4.7 | 0.01 | 0.019 | 0.53 | 0.427 | 0.54 | 0.433 |
| 4.8 | | 0.003 | 0.43 | 0.254 | 0.098 | 0.084 |
| 4.9 | 0.02 | 0.021 | 0.45 | 0.269 | 0.166 | 0.094 |
| 5.0 | 0.00 | 0.008 | 0.328 | 0.317 | 0.074 | 0.074 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5.1 | 0.17 | 0.134 | 0.30 | 0.368 | 0.198 | 0.161 |
| 5.2 | 0.03 | 0.019 | 0.90 | 1.027 | 0.013 | 0.014 |

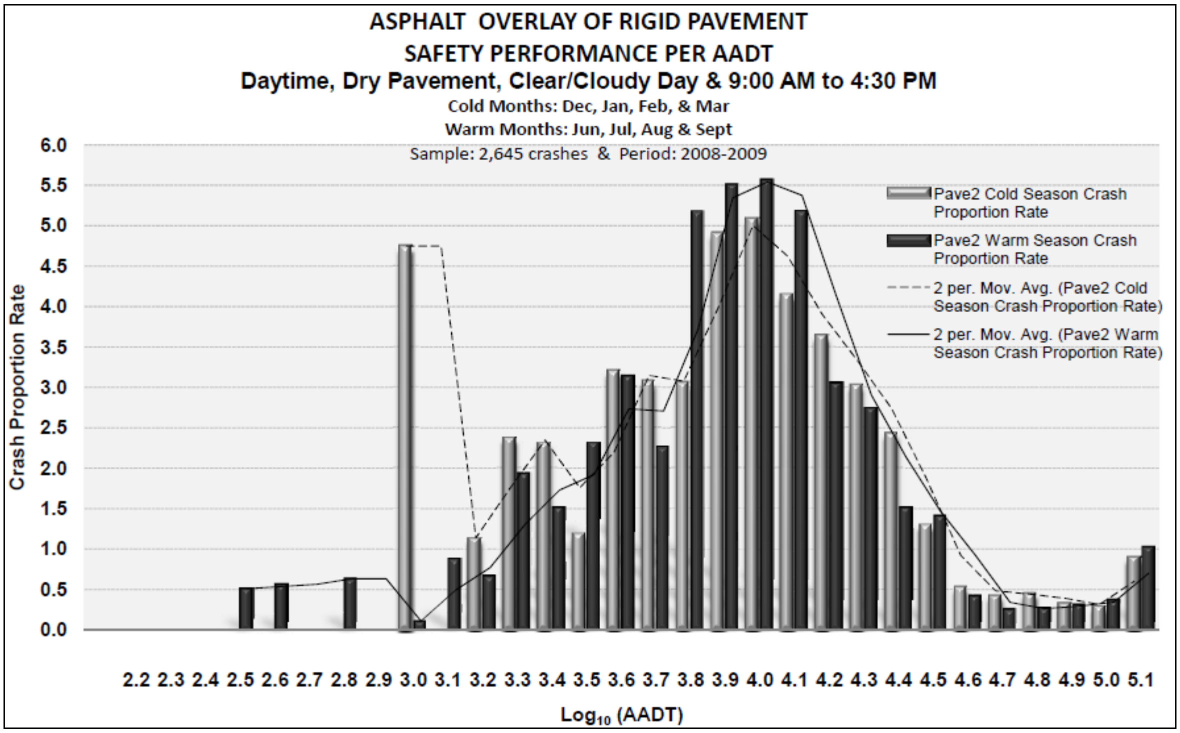


***Figure 1: Pave1 PRP (PRMVM) per Log10 (AADT).***

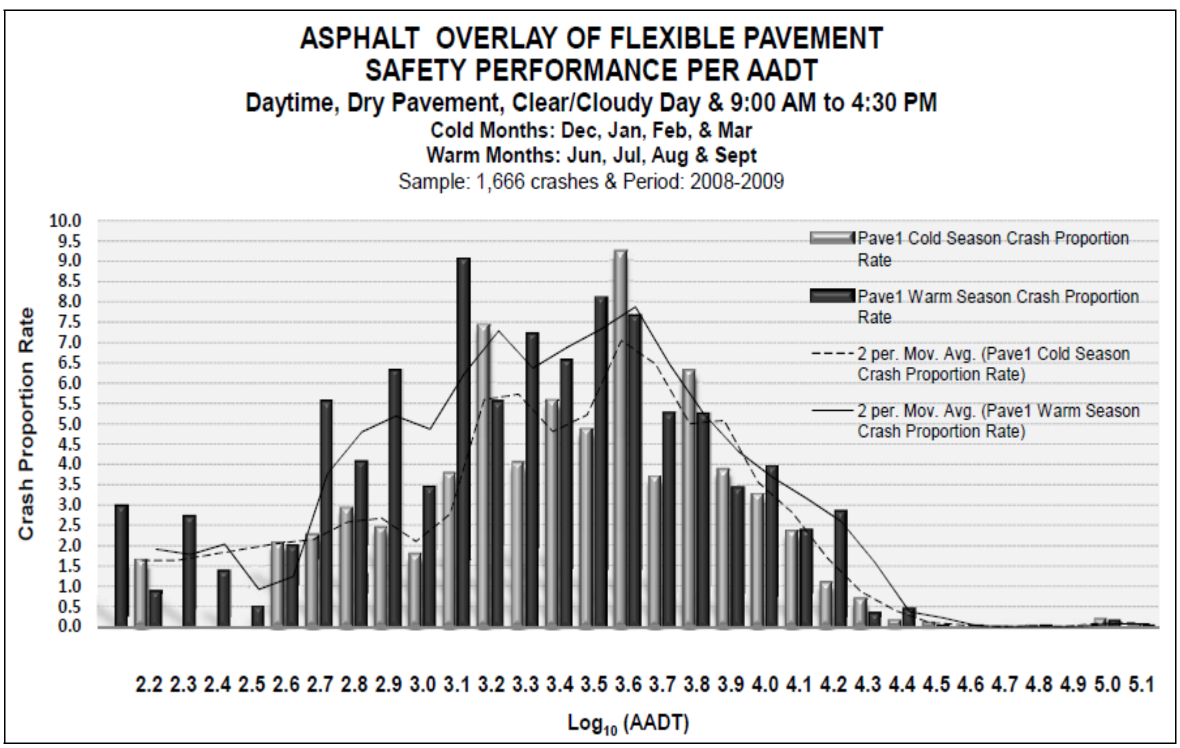

***Figure 2: Pave2 PRP (PRMVM) per Log10 (AADT).***

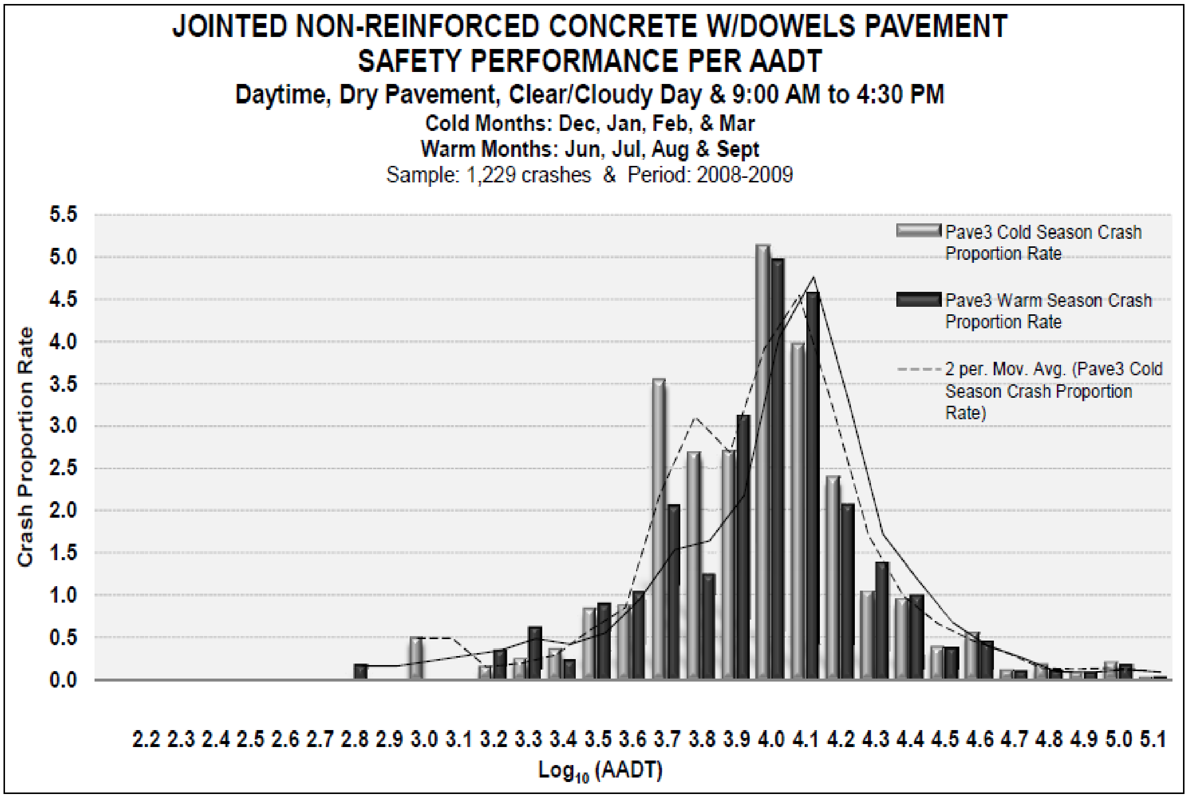


***Figure 3: Pave3 PRP (PRMVM) per Log10 (AADT).***

Per the histograms in fiqures 1 through 3, there are clear differences in the warm and cold weather crash rate (RPMVM) distributions per categories of Log10 (AADT)

Because PRMVMs decreased for higher values of Log10 (AADT) in all three pavements types (figures 1 through 3), each pavement distribution was considered for Log10 (AADT) equal to or greater than 3.9 as shown in table 7.

The reduction of PRMVMs in higher AADTs could be because of congestion on the road. Congestion could be a protective factor for reducing ROR crashes. If congestion related crashes are included in this analysis, they may mask pavement safety issues in this study. Pave1 has higher proportions for SVROR crashes than pave2 and pave3 in cold and warm seasons as shown in table 7. The two samples for warm and cold seasons were tested using the Two-proportion Z-Test methodology.

**Table 7: Two Proportion Z-Test for PRP (PRMVM) per AADT, Subset-1b.**

| Pavement | Seasonal Frequency Proportion for; SVROR crashes Sample: 2,686 crashes & Period:2005-2009 | | Two Proportion Z-Test | |
|---|---|---|---|---|
| | Log10 AADT=< 3.9 | | | |
| | Cold Season | Warm Season | Z value | P-value 2-sides |
| Pave1 | 0.86 | 0.90 | 2.01 | 0.04 |
| Pave2 | 0.21 | 0.25 | 1.57 | 0.12 |

| | | | | |
|---|---|---|---|---|
| Pave3 | 0.08 | 0.11 | 1.14 | 0.25 |

Pave1 SVROR crash frequency for Log10 AADT=< 3.9 is 86% in cold season, and 90% for warm season.

Also, table 8 shows where SVROR crashes occurred on different highway classifications. This information may hint toward pavement age, management and/or maintenance issues.

**Table 8: Crash percentage on 4-lane roads per highway classification for each pavement type, Subset-1b.**

| Pavement | SVROR Crash Percentage Per Highway Classification<br>Sample: 2,686 crashes & Period:2008-2009 | | | | | |
|---|---|---|---|---|---|---|
| | Interstate Hwy<br>Rural | Interstate Hwy<br>Urban | State Highway<br>Rural | State Highway<br>Urban | Town Road<br>Rural | Total |
| Pave1 | 5% | 15% | 64% | 9% | 91% | 48% |
| Pave2 | 64% | 77% | 20% | 78% | 9% | 35% |
| Pave3 | 31% | 8% | 16% | 14% | 0% | 17% |
| Totals | 100% | 100% | 100% | 100% | 100% | 100% |

Subset-1c for SVROR crash data (table 9) was prepared for all 12 months and was used for generating a chart for RMVM distribution per 12 months for each pavement type.

**Table 9: Yearly crash distribution per month, Subset-1c.**

| Crash Frequency Distributions for 12 Months of Year<br>Single Vehicle ROR Crashes<br>Dry Roads, Daytime, 9:00 am to 4:30 pm, and Posted Speed Limit 55 and 65<br>Sample:4,051 crashes & Period:2005-2009 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pave** | **Yr** | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** | **Total** | **% Total** |
| Pave1 | 2005 | 18 | 27 | 22 | 26 | 43 | 48 | 66 | 40 | 31 | 30 | 18 | 17 | 386 | 20 |
| | 2006 | 22 | 33 | 21 | 35 | 41 | 48 | 51 | 39 | 36 | 29 | 29 | 24 | 408 | 21 |
| | 2007 | 26 | 13 | 20 | 26 | 43 | 44 | 43 | 46 | 57 | 35 | 34 | 15 | 402 | 21 |
| | 2008 | 18 | 14 | 22 | 24 | 35 | 43 | 51 | 52 | 30 | 34 | 21 | 7 | 351 | 18 |
| | 2009 | 16 | 16 | 27 | 26 | 51 | 39 | 42 | 38 | 39 | 28 | 21 | 18 | 361 | 19 |
| | Total | 100 | 103 | 112 | 137 | 213 | 222 | 253 | 215 | 193 | 156 | 123 | 81 | 1908 | 100 |
| | % Total | 5 | 5 | 6 | 7 | 11 | 12 | 13 | 11 | 10 | 8 | 6 | 4 | 100 | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pave2 | 2005 | 17 | 17 | 22 | 33 | 28 | 32 | 46 | 29 | 31 | 32 | 15 | 19 | 321 | 22 |
| | 2006 | 20 | 17 | 23 | 26 | 26 | 36 | 31 | 40 | 23 | 34 | 25 | 17 | 318 | 22 |
| | 2007 | 21 | 20 | 17 | 16 | 29 | 34 | 41 | 23 | 27 | 33 | 26 | 17 | 304 | 21 |
| | 2008 | 13 | 15 | 15 | 23 | 29 | 24 | 29 | 20 | 17 | 23 | 19 | 14 | 241 | 17 |
| | 2009 | 19 | 14 | 18 | 20 | 26 | 29 | 35 | 29 | 23 | 19 | 20 | 15 | 267 | 18 |
| | Total | 90 | 83 | 95 | 118 | 138 | 155 | 182 | 141 | 121 | 141 | 105 | 82 | 1451 | 100 |
| | % Total | 6 | 6 | 7 | 8 | 10 | 11 | 13 | 10 | 8 | 10 | 7 | 6 | 100 | |
| Pave3 | 2005 | 8 | 8 | 5 | 13 | 13 | 11 | 14 | 20 | 15 | 12 | 13 | 11 | 143 | 21 |
| | 2006 | 12 | 6 | 10 | 14 | 10 | 20 | 12 | 17 | 6 | 11 | 9 | 6 | 133 | 19 |
| | 2007 | 13 | 7 | 8 | 9 | 15 | 13 | 17 | 14 | 13 | 12 | 12 | 9 | 142 | 21 |
| | 2008 | 9 | 12 | 11 | 9 | 13 | 14 | 10 | 17 | 15 | 16 | 10 | 6 | 142 | 21 |
| | 2009 | 15 | 6 | 9 | 13 | 13 | 10 | 8 | 18 | 16 | 6 | 10 | 8 | 132 | 19 |
| | Total | 57 | 39 | 43 | 58 | 64 | 68 | 61 | 86 | 65 | 57 | 54 | 40 | 692 | 100 |
| | % Total | 8 | 6 | 6 | 8 | 9 | 10 | 9 | 12 | 9 | 8 | 8 | 6 | 100 | |

Table 10 shows the crash frequencies in table 9 that were normalized using the RMVM relation (page 7).

**Table 10: Monthly PRP (RMVM) for SVROR crashes, Subset-1c.**

| **SVROR Crash Rates per 12 months of Year<br>Dry Pavement, Daytime 9:00 am to 4:30 pm,<br>Clear/Cloudy Weather, and Posted Speed Limit 55 & 65 mi/h**<br>Sample: 4,051 crashes & Period:2005-2009 | | | | | |
|---|---|---|---|---|---|
| **Month** | **Pavement's Crash Rates (RMVM) (all road segments for the duration of study)** | | | | |
| | **Average °T Temperature (°F)** | **Pave1** | **Pave2** | **Pave3** | **Total Crashes Rates RMVM** |
| Jan | 15 | 27,862 | 4,644 | 3,754 | 36,260 |
| Feb | 20 | 28,643 | 7,358 | 1,665 | 37,665 |
| Mar | 32 | 27,750 | 5,025 | 2,300 | 35,075 |

| | | | | | |
|---|---|---|---|---|---|
| Apr | 44 | 48,578 | 8,357 | 3,380 | 60,315 |
| May | 57 | 62,624 | 9,960 | 4,026 | 76,609 |
| Jun | 66 | 74,849 | 12,905 | 3,071 | 90,825 |
| Jul | 70 | 84,965 | 12,053 | 2,430 | 99,448 |
| Aug | 68 | 86,720 | 11,713 | 3,801 | 102,235 |
| Sept | 59 | 75,952 | 7,466 | 3,487 | 86,905 |
| Oct | 47 | 45,772 | 14,656 | 2,301 | 62,729 |
| Nov | 33 | 34,432 | 7,445 | 2,792 | 44,669 |
| Dec | 20 | 21,477 | 4,852 | 1,441 | 27,770 |

RMVM and average monthly temperature distributions in table 10 were plotted over 12 months below.

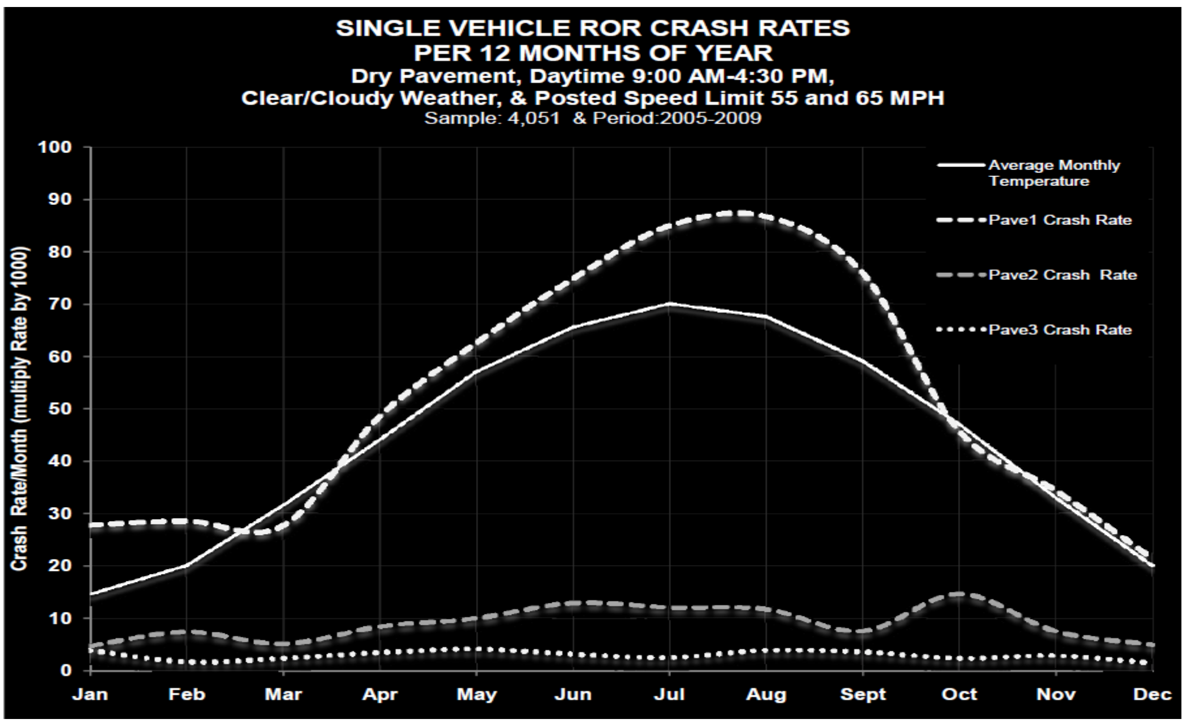


***Figure 4: Pave1 through Pave3 monthly PRP (RMVM) for SVROR crashes, Subset-1c.***

## SUMMARY AND DISCUSSION

Although, there are many studies that have examined the relationship between pavement reliability and seasonal temperature changes, there are no studies that establish the existence of this relationship with objective measures using statistical analysis of crash data. Most importantly, there are no guidelines or directions for how to determine PRP related to seasonal temperature changes.

The results for the first part of this expletory study showed that in warm season the pave1 variable for:

- SVROR/Fail to Control Vehicle OR had a 53 percent increase compared to pave2, and had a 74 percent increase compared to pave3
- SVROR versus MVOR OR had a 19 percent increase compared to pave2, and had a 27 percent increase compared to pave3
- SVROR/Overturn OR had a 17 percent increase compared to pave2, and had a 36 percent increase compared to pave3
- SVROR/Overturn OR had a 100 percent increase compared to pave2, and had a 72 percent increase compared to pave3
- SVROR/ Exceeding Speed Limit OR had a 29 percent increase compared to pave2, and had a 30 percent decrease compared to pave3.
- SVROR/Alcohol OR had a 33 percent increase compared to pave2, and had a 15 percent decrease compared to pave3.
- SVROR/Killed OR had 8 percent decrease compared to pave2, and had a 41 percent increase compared to pave3.

In the second part of the study, histograms in fiqures 1 through 3 showed clear differences in the warm and cold weather crash rate (RPMVM) distributions for the categories of Log10 (AADT) pave1 had a significantly higher (p-value equal to 0.04) SVROR crashes for Log10 AADT less than or equal to 3.9.

Figure 4 for RMVM distribution per 12 months showed increase in SVROR crash rates in warm season for pave1 compared to pave2 and pave3. This distribution closely follows the average monthly temperature distribution in figure 4.

Based on the above results, this study shows that pave1 PRP possibly was more influenced negatively by warm season temperature.

## CONCLUSION

The finding of this exploratory study show that an average temperature difference of 44°F between warm and cold seasons may increase percentage of crash OR for certain variables in warm seasons. Due to the scope of this study, we could not determine if reduced friction and/or other factors are causing the increase in crash OR for asphalt overlay on flexible pavement.

It was found that overall SVROR OR for pave1 was increased in warm season. In warm season, SVROR crash trends for driver contribution/fail to control vehicle, crash type/overturn, and road horizontal characteristic/curve were increased from 17 percent up to 100 percent for pave1 compared to pave2 and pave3. Also, it was found that in warm season pave1 OR for SVROR/exceeding speed limit, and alcohol related crashes are not increased compared to pave3. Pave1 SVROR/killed OR increased 41 percent compared to pave3 for warm seasons.

Pave1 histograms for crash rate vs. Log10 (AADT) showed clear differences in the warm and cold weather crash rate distributions for categories of Log10 (AADT.) pave1 had a significantly higher (p-value equal to 0.04) SVROR crashes for Log10 (AADT) less than or equal to 3.9.

Statistical analysis of State Y crash and pavement file was shown to be an effective and efficient way to study pavement reliability performance.

## RECOMMENDATION

The findings of this study are not intended to represent the final ruling on the relationship between seasonal changes and the reliability of these pavement types. This is especially true because the conclusions were drawn from an analysis of one State’s data. Geographic locations, weather, pavement design, aggregate type and quality, and standards for production, construction, and maintenance may vary from one State to another, thus resulting in a different relationship between crash frequency and seasonal change for these pavement types.

In future studies, pave1 PRP requires a closer examination for major contributing factors beside warm season temperature influence.

This study recommends further research in areas of pavement heat transfer, and how temperature affects viscoelastic material properties for rubber tire and hot-mix asphalt to reduce ROR crashes. SVROR crashes are among the most severe types of crashes, and it would be beneficial to the United States economy to reduce their frequency and severity.

Furthermore, it may be worthwhile to use crash data for PRP and pavement design in order to open new doors for future pavement research, technology, and resources that result in lives saved. To support this goal, it is highly recommended that each State or network that shares common attributes of geographical location, climate, and aggregate and material resources be studied individually. This is particularly important because findings, and subsequent countermeasures, while reliable and effective in one State, may not be applicable in another.

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