VIRGINIA DEPARTMENT OF TRANSPORTATION

2007 WET ACCIDENT REDUCTION PROGRAM (WARP) REPORT

BY

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EXECUTIVE SUMMARY
The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) strive to improve highway safety in the United States. The Virginia Department of Transportation (VDOT) has taken several initiatives to improve highway safety; one initiative focuses on reducing the traffic fatality rate. As part of the highway safety program, VDOT’s Materials Division started the Wet Accident Reduction Program (WARP) in the early 1970s. This program is focused on reducing highway crashes by facilitating pavement friction characteristics improvement at known wet accident occurrence locations. The purpose of WARP is to improve the highway safety during wet conditions by identifying potential locations with known high occurrences of wet accidents. Subsequent friction testing at these locations allows the districts to take necessary measures to improve friction on the roadway sections that may not offer adequate friction during wet conditions.

The locations where a higher number of wet weather related accidents occur compared to dry accidents in a given calendar year are identified as Potential Wet Accident Hotspot (PWAH) sites by VDOT. Under WARP, Materials Division performs friction testing on these PWAH sites and reports the friction test results to the district pavement management personnel. The district pavement management staff considers short and long term action for correcting pavement friction at the sites with low friction numbers. A friction number of 20 had been historically used as a cut off number to flag sites for low friction. This report summarizes the 2007 WARP test data and provides some historical comparison.

Based on 2007 calendar year’s accident data provided to VDOT by DMV around middle of 2008, 366 sites were identified as PWAH sites by VDOT and subsequently tested by Materials Division under WARP in the latter part of 2008. Out of these, 34 sites were found to have a friction number less than 20. Between the years 1999 and 2007, the number of total accidents (Dry and Wet) and dry accidents have increased almost 13% and 17%, respectively while the number of wet accidents have decreased by about 7%. In contrast, the number of PWAH sites has decreased almost 27% between the years 2002 and 2007. The number of low friction sites also reduced in 2007 when compared to 2006. The reduction of wet accidents compared to dry accidents across the state of Virginia is possibly indication of good pavement friction on Virginia’s road.
INTRODUCTION

The Federal Highway Administration (FHWA) is encouraging each highway agency to develop and manage a skid accident reduction program to reflect the individual needs and conditions within the State\(^1\). The purpose of a wet accident reduction program is to minimize wet weather related accidents through: i) identifying and correcting sections of roadway with high or potentially high wet skid accident incidence, ii) ensuring that new surfaces have adequate, durable skid resistance properties, and iii) utilizing resources available for accident reduction in a cost-effective manner\(^1\).

In recent years, there has been a major effort initiated by FHWA and American Association of State Highway and Transportation Officials (AASHTO) to improve highway safety in the United States. In each year there are about 43,000 deaths, 3 million injuries, and 6 million crashes in the United States with an estimated associated cost of $230 billion\(^2\). In December 2003, AASHTO launched a new effort to lower the nation’s highway fatality rate to 1.0 per 100 million vehicle miles of travel, compared to the fatality rate of 1.48 per 100 million vehicle miles of travel recorded in 2003\(^2\).

In 2007, Virginia had 145,407 crashes of which 940 were fatal involving 1,026 deaths\(^3\). Virginia Department of Transportation (VDOT) has taken several steps to reduce the number of highway fatalities. The number of traffic accident related fatalities in Virginia has dropped to 822 in 2008 compared to 1,026 in 2007\(^4\).

Poor pavement friction or surface texture increases the risk of crashes. Such risk is significantly higher during wet conditions resulting in increased fatalities, more serious personal injuries, and significant traffic delays\(^2\). To minimize the number of wet accidents, VDOT Central Office Materials Division initiated WARP in the early 1970’s as part of the highway safety program. Virginia DOT is aiding to reduce the number of traffic accidents and the fatality rate by administering and maintaining the WARP.

**Pavement Friction**

Pavement friction is the force that resists the relative motion between a vehicle tire and a pavement surface. This resistive force is generated when the tire rolls or slides over the pavement surface. The factors that primarily influence pavement friction forces are pavement surface characteristics, vehicle operational parameters, tire properties, and
environmental factors. Pavement friction is reported as a skid number (SN) or friction number (FN). The skid number is determined from the force required to slide the locked test tire at a stated speed, divided by the effective wheel load and multiplied by 100. The SN is calculated using the following equation:

\[ SN = 100 \times \mu = 100 \times \frac{F}{W} \]

Where, 
- \( SN \) = Skid number at the measured speed
- \( \mu \) = Coefficient of friction.
- \( F \) = Tractive horizontal force applied to the tire, lb
- \( W \) = Vertical load applied to the tire, lb

The reporting values of SN range from 0 to 100, with 0 representing no friction and 100 representing complete or full friction.

Friction measurements are obtained by locking the test tire (ribbed or smooth) on a wetted pavement surface while traveling at a specified speed of 40 mile/hour, which is the standard speed specified in AASHTO T242. The smooth tire is more sensitive to pavement macro-texture, while the ribbed tire is more sensitive to micro-texture changes in the pavement. Macro-texture is the most important element affecting friction resistance at a higher speed or under wet conditions.

SN values are generally designated by the speed at which the test is conducted and by the type of tire used in the test. For example, \( SN_{40R} = 36 \) indicates a friction value of 36, as measured at a test speed of 40 mile/hour (64 kilometer/hour) and with a ribbed (R) tire. Similarly, \( SN_{40S} = 30 \) indicates a friction value of 30, as measured at a test speed of 40 mile/hour and with a smooth (S) tire.

**Wet Accident Reduction Program (WARP)**

The purpose of WARP program is to identify locations with high incidence of wet weather accidents and lower surface friction so the appropriate corrective measures can be taken. WARP is an important function performed by VDOT since it is related to travelers’ safety on Virginia’s highways. WARP uses accident data provided by Virginia Department of Motor Vehicles (VDMV) each calendar year to identify locations on Virginia’s interstate and primary routes that may have inadequate surface friction properties. Each year DMV provides VDOT’s Traffic Engineering Division with the preceding year’s accident data.
Under WARP, a methodology has been developed to identify locations with a higher frequency of wet accidents than dry condition accidents in any given year by using traffic accident data. Such locations are called Potential Wet Accident Hot Spots (PWAHS). The following data elements are retrieved and used for this purpose: total accidents (rate), wet weather accidents (rate), dry accidents (rate), and the wet accident to dry accident ratio. This information is stored in the Highway Traffic Records Inventory System (HTRIS). Upon notification from the Traffic Engineering division, Pavement Design and Evaluation (PD&E) section of Materials Division downloads the PWAHS separately for Interstate and Primary routes. Skid testing is to be performed on these sites. Currently DMV takes about 5 to 7 months to provide previous year's traffic accident data. 2007 accident data was provided to VDOT around May of 2008 and friction testing on PWAHS was performed during the remainder of 2008 calendar year.

This list is forwarded to the District Pavement Maintenance Engineers. The skid testing crew also contacts the District Pavement Management personnel before performing skid testing to identify the sites that are under construction or have already been corrected late last season, or that are scheduled to be corrected during the current season. These sites are excluded from testing schedule. Skid testing is performed at the remaining locations.

Once skid testing is complete, PD&E provides the skid results to Central Office Virginia Information Technology Agency (CO VITA) to upload into HTRIS. After the completion of the upload, PD&E downloads the PWAHS sites with skid results based on route type (i.e., Primary and Interstate) and forwards to District Pavement Maintenance staff for further review. The sites where the skid number falls below 20 are flagged for special attention. Historically, a skid number of 20 had been used as a cut off number to flag sites with low friction which is consistent with some other agencies. However, a more recent study performed by VTRC and VA Tech has recommended the use of a higher value (25 to 30) for this purpose.

BACKGROUND

History of WARP in VDOT

In the late 1950’s, the Virginia Highway Transportation Research Council (VHTRC) and VDOT’s Equipment Division built a new skid test trailer which measured pavement
friction while traveling with a constant rate of speed without traffic control. In 1958, VHTRC planned and hosted the first International Skid Conference, and recommended the formation of ASTM Committee E17 on skid resistance. In the 1960’s, the committee developed E 274, a specification for building skid trailers. At that time, a mid sized sedan was equipped to record the distance required to stop upon panic braking on either wet or dry pavement.

WARP currently used in VDOT dated back late 1970’s. In the early 1970’s, the VHTRC developed a structured WARP for the Department to perform extensive skid tests. In 1974 the Materials Division purchased the first ASTM E-274 trailer which was equipped with ribbed tires (SN40R). By 1976, VDOT had adopted a policy of resurfacing pavements that had experienced wet weather accidents and had a mean trailer skid number less than 40 when tested at a speed of 40 mph (SN40R) with a ribbed tire. However, a procedure for systematically identifying and evaluating wet accident sites or low skid number sites had been proposed by S. N. Runkle and D. C. Mahone in 1976 which served as the basis for the current WARP. Today, all routine skids testing in Virginia is performed at a test speed of 40 mph with a smooth tire (SN40S).

As of today, two ASTM E-274 skid trailers are in operation within the Commonwealth. The skid testing units are stationed at the Lynchburg district office with other NDT testing equipments. The central Office Pavement Design and Evaluation (PD&E) section operates and oversees the program statewide.

**WARP Sites Testing Guidelines**

The following guidelines are followed for testing WARP Sites in Virginia.

- For all routes, testing shall be conducted at a minimum frequency of one test for every 0.10 mile. For sites less than one mile, as many tests as possible are conducted, up to one test for every 0.05 mile.
- Each section is to have a minimum of three tests, evenly spaced at 0.1 mile interval (both before and after) beyond the limit of the referenced site, provided a jurisdictional boundary or construction project does not interfere with testing. Each of these tests must have a tested skid number greater than 24 prior to proceeding. If skid number below 24 is encountered in these “run-in” or “run-out” sections, the
limit of the respective “run-in” or “run-out” sections are extended to get three consecutive skid numbers greater than 24. These “run-in” and “run-out” tests ensure that any questionable areas have been accurately identified and are in addition to the section limits.

- Wherever possible, a minimum of one test is conducted prior to an intersection with a stoplight or stop sign. This test is conducted within 200 feet (0.04 miles) of the stoplight or stop sign.
- Data is reported by county-relative mileposts. Straight line diagrams from HTRIS are used by the operator for reference and locating starting nodes in the field.
- At the completion of testing for a district, the WARP data is uploaded to the HTRIS server by CO VITA.

EQUIPMENT AND OPERATOR

Skid Testing Equipment and Operator

The keys to collecting quality skid data are experienced operators and good equipment. VDOT owns and operates two ASTM E-274 trailer units. Each unit includes force and speed transducers, a control system, a record system, and a pavement wetting system. Test wheels are incorporated into the trailer. The test tire is a standard smooth tire. VDOT equipment operators have many years of experience using skid trailers.

Equipment Calibration/ Verification

VDOT’s skid units are routinely (weekly, monthly & yearly) calibrated following the manufacture’s recommendations. Virginia DOT has a comprehensive calibration and verification program to ensure the successful collection of skid testing data. Inherit in this process is quality control and assurance processes. The verification procedures apply to the load and traction forces unit and the distance measuring instruments. These procedures are part of a three-tier process- weekly, quarterly, and annually. These checks are designed for collecting the highest quality skid data.

2007 WARP RESULTS

This section of the report provides the summary statistics of friction testing under WARP. Also presented are some associated traffic accident statistics. The reader may find this
information helpful along with the WARP testing data presentation of which is the sole purpose of this report. The analysis of the traffic accidents and possible cause for any apparent trend are beyond the scope of this report.

**Potential Wet Accident Sites Results for 2007**

Table 1 shows the district-wide number of PWAH sites for the year 2007 for both primary and interstate routes. The total number of PWAH sites identified in 2007 is 366 of which 164 and 202 sites are on interstate and primary routes, respectively. Northern Virginia district has the highest number of total PWAH sites followed by Richmond district.

**Table 1: PWAH Results for 2007**

<table>
<thead>
<tr>
<th>Name of District</th>
<th>IS</th>
<th>Primary</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bristol</td>
<td>8</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>Hampton Roads</td>
<td>45</td>
<td>11</td>
<td>56</td>
</tr>
<tr>
<td>Staunton</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Culpeper</td>
<td>1</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Lynchburg</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Fredericksburg</td>
<td>16</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Nova</td>
<td>41</td>
<td>104</td>
<td>145</td>
</tr>
<tr>
<td>Richmond</td>
<td>37</td>
<td>50</td>
<td>87</td>
</tr>
<tr>
<td>Salem</td>
<td>12</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>164</td>
<td><strong>202</strong></td>
<td><strong>366</strong></td>
</tr>
</tbody>
</table>

**Skid Testing Results for 2007**

Table 2 shows the number of sites on interstate and primary routes which have a low skid number (less or equal to 20). There are 34 low skid sites across the state in 2007. Northern Virginia and Fredericksburg district have the highest number of low skid sites on primary and interstate routes, respectively.
Table 2: Skid Testing Results for 2007

<table>
<thead>
<tr>
<th>District</th>
<th>IS: No of sites (SN&lt;=20)</th>
<th>Primary: No of sites (SN&lt;=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bristol</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Salem</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Lynchburg</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Richmond</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Hampton Roads</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Fredericksburg</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Culpeper</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Staunton</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NOVA</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>22</td>
</tr>
</tbody>
</table>

Traffic Accident Results for 2007

Figure 1 represents the district-wide number of wet and dry accident sites for the year 2007 for both primary and interstate routes. From Figure 1, it can be seen that Nova district has the highest number of accidents in 2007 followed by Richmond district.

Figure 1: District wide Accident Data for 2007
HISTORICAL TREND

Comparison of 2007 and 2006 Skid Testing Results

Figure 2 shows the low friction sites (i.e., the sites with friction number less than or equal to 20) for the last two years (e.g., 2006 and 2007). The number of low skid sites on the interstate within the WARP limit is 12 in 2007 compared to 10 in 2006 and the number of low skid sites on primary within the WARP limit is 22 in 2007 compared to 34 in 2006. In 2007, the total number of low skid sites has been reduced by almost 23%.

![Skid Testing Results Comparison between 2007 & 2006](image)

**Figure 2: Comparison of Number of Low Friction Sites in 2006 and 2007**

Comparison of 2007 PWAH with Historical Results

Figure 3 represents the statewide number of PWAH sites for interstate, primary, and total through the years 2002 and 2007. There is an increase in the number of total PHWA sites...
between 2002 and 2004 and a decrease thereafter. The primary routes have higher number of PWAH sites compared to interstate routes.

Figure 3: Statewide Historical PWAH Results

**Comparison of 2007 Traffic Accident with Historical Results**

Figure 4 shows the statewide total number of traffic accidents on primary and interstate routes for the years 1999 through 2007. There is a steady increase of the number of total accidents through 1999 and 2004 and a slight drop in 2005. In 2006, the total number of accidents increases suddenly and again decreases sharply in 2007. The number of traffic accidents for both primary and interstate routes follows the similar trend for total accidents.
Figure 4: Statewide Historical Traffic Accident Results

Figure 5 shows wet to dry accident ratio for primary, interstate, and total through the year 1999 and 2007. The Wet to dry accident ratio in Figure 5 follows the similar fashion for the primary and interstate route and so does the total accident. Overall, the interstate routes have a higher wet to dry accident ratio when compared to primary routes. The wet to dry accident ratio number has been reduced both in primary and interstate routes in 2007 when compared to 1999.
<table>
<thead>
<tr>
<th>Year</th>
<th>Wet and Dry Accident Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>0.12</td>
</tr>
<tr>
<td>1999</td>
<td>0.16</td>
</tr>
<tr>
<td>2000</td>
<td>0.20</td>
</tr>
<tr>
<td>2001</td>
<td>0.24</td>
</tr>
<tr>
<td>2002</td>
<td>0.28</td>
</tr>
<tr>
<td>2003</td>
<td>0.32</td>
</tr>
<tr>
<td>2004</td>
<td>0.36</td>
</tr>
<tr>
<td>2005</td>
<td>0.32</td>
</tr>
<tr>
<td>2006</td>
<td>0.28</td>
</tr>
<tr>
<td>2007</td>
<td>0.24</td>
</tr>
<tr>
<td>2008</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Figure 6 shows the number of PWAH sites per million vehicle miles traveled on interstate routes between 2002 and 2007\(^\text{10}\). The figure shows that the number of PWAH sites per million vehicle miles increases between years 2002 and 2003, and decreases between the years 2004 and 2007. The number of PWAH sites is 0.006 per million vehicle miles in 2007 compared to 0.009 in 2003 and 2004 on interstate routes. The lower ratio is an indication of fewer PWAH sites and hence it can be a result of improved friction characteristics of Virginia’s highways.

**Figure 5: Wet and Dry Accident ratio**
The factors that influence pavement friction forces are pavement surface characteristics, vehicle operating parameters, tire properties, and environmental conditions. Pavement surface characteristics are a function of micro and macro texture, material properties, and temperature. Pavement surface texture influences many different pavement tire interactions. Good skid resistance results from controlling the micro texture and macro texture of Hot Mix Asphalt Concrete (HMAC) pavement surfaces. Safe, skid-resistant HMAC pavement surfaces can be created by using good-quality, polish-resistant materials combined in a way that provides appropriate aggregate gradation and mix stability.\(^{11}\)

Once a section has been identified as being at or below a friction threshold level, steps should be taken to improve the friction deficiency. Steps could include cautioning highway users by installing appropriate warning signs (e.g. slippery when wet, reduced speed) and then proceed with developing a short term and long term friction improvement plan. The plans are

\[\text{Figure 6: PWAH Sites per Million Vehicle Miles Traveled on Interstate Route}\]
• Short-term remedial (maintenance) work.
• Comprehensive restoration treatment (e.g., diamond grinding, cold milling, thin overlays, chip seals) aimed directly at improving friction.

For asphalt pavement, micro surface treatments are widely used to restore pavement which has inadequate friction characteristics. It provides excellent ride quality, good pavement friction characteristics and low noise levels. Seal coats or Chip seals are also used to restore pavement friction characteristics and extend the life of pavements. Pavement preservation activities also provide an opportunity to improve both the pavement condition and surface characteristics in a very cost-effective manner. Depending on the pavement distress condition, the section could also be overlaid.

For Portland Cement Concrete (PCC) pavements, diamond grinding increases concrete pavement friction by enhancing surface macro texture. Adequate macro texture reduces the potential for hydroplaning. Saw cut grooving is used traditionally to restore adequate frictional characteristics of PCC pavements. Grooving could be either longitudinal or transverse.
CONCLUSIONS AND RECOMMENDATIONS

- Between the years 2002 and 2007, the total number of traffic accidents and the number of dry accidents in Virginia have increased almost 13% and 17%, respectively while the number of wet accidents has decreased almost 7% during the same period. The wet to dry accident ratio has also decreased from 0.182 to 0.145 at the same period.

- Total number of Potential Wet Accident Hotspot sites has reduced almost 27% between 2002 and 2007. The number of PWAH sites in million vehicle miles traveled was also reduced from 0.009 to 0.006 in 2007.

- The low skid number site (skid number less than or equal to 20) has reduced in 2007 when compared to 2006.

- As wet accidents are directly related to pavement friction; the decreasing trend of wet accidents, PWAHs, and low skid sites despite an increase of total accident could be indicative of good pavement friction on Virginia’s primary and interstate routes.

- WARP has been a valuable tool to assess the risk of having wet accidents on Virginia’s highways and thereby put effort to minimize such risk.

- WARP Program should be continued as an ongoing assessment of Virginia roads that may be at risk for having wet accidents so the preventative measures could be performed at the sections found to have low surface skid characteristics. WARP is expected to increase the safety of the public traveling on Virginia’s roadways.

ACKNOWLEDGEMENTS

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NDT Unit (Lynchburg) for their efforts in the data collection
Respective Central Office VITA, Traffic Engineering Division and DMV Personnel for collecting, processing and uploading/downloading related data.
District Pavement Personnel that analyze WARP data and make appropriate measures to address any deficiency in pavement surface friction of tested roadways.
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