Investigation of Hot Mix Asphalt Surfaced Pavements Skid Resistance in Maryland State Highway Network System

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Abstract:

In this paper, authors conducted extensive statistical analysis on the data from the Maryland State Highway Administration (MDSHA) Pavement Management System (PMS) to investigate the possible correlations between skid resistance indicator (friction number) and influential factors for Hot Mix Asphalt (HMA) surfaced pavements, which account for 98% of the MDSHA network. The factors considered include pavement surface age, pavement location (urban or rural), traffic intensity, aggregate properties, application of slurry seal treatments and climate-related factors such as temperature and rainfall. Regression analysis was used to quantify the significance of these factors. Particularly, the difference of friction between urban roads and rural roads reveals that traffic fashion (speed, stopping frequency and etc.) would play a more important role than traffic intensity in the polishing of surfaces. It is also found that the network average friction would be influenced by the average daily temperature and rainfall. This paper also discussed the implication and potential uses of these findings. The results presented in this paper would be useful for pavement skid resistance evaluation and improvement in pavement maintenance practices.
INTRODUCTION

Wet accidents have been a critical safety issue for highway agencies and the inadequacy of pavement surface skid resistances has been criticized as one of the major reasons for wet accidents (1, 2). Nowadays the monitoring of pavement skid resistance plays an increasingly important role in evaluating pavement quality, planning pavement rehabilitation, and determining rehabilitation alternatives.

It is well known that the pavement skid resistance is determined by the interaction between pavement surface and vehicle tires. The pavement surface texture characteristics such as microtexture and macrotexture have significant influence on the pavement skid resistance (3-5). Researches also found that the interactions between pavement surface and tires were affected by climate related factors such as temperature and rainfall (6-10).

Many efforts have been made to relate the pavement friction performance to influential factors. However, relatively few researches have been done on a network level. In this paper, authors conducted extensively statistical analyses on the data from the Maryland State Highway Administration (MDSHA) Pavement Management System (PMS) to quantitatively evaluate the factors that might affect the pavement skid resistance on a network level. The MDSHA PMS covers a total of 15,000 lane-miles of mainline roadway network, as shown in Figure 1. The network consists of 61% flexible pavements, 2% rigid pavements and 37% composite pavements that are original rigid pavements with Hot Mixture Asphalt (HMA) overlays. Overall, HMA surfaced pavements account for 98% of the network.

![FIGURE 1 the MDSHA pavement network and the BWI.](image)

In order to monitor pavement frictional performance, the MDSHA has been conducting annual network level pavement friction testing from March to November. The survey is conducted using a locked-wheel skid trailer with ribbed tires, which provides a coefficient of wet-friction known as friction number (FN) or skid number (SN). The survey is conducted on the
outside lane for all sections at approximately 0.3 miles intervals. The skid trailer is calibrated every 4 to 6 weeks with 10 tests on HMA surface and 10 tests on Portland Concrete Cement (PCC) surfaces. Other pavement characteristics including construction history, traffic, location, and etc. are also collected and stored in the PMS.

The factors considered in this paper include surface ages, pavement location (rural and urban), traffic information, treatment type (slurry seal and others), aggregate properties, air temperature, and rainfall. Aggregate properties include the grain size gradation and the polishing resistance of the aggregates measured as Polish Value (PV). In this paper, the aggregates are divided into 4 groups (4.75mm, 9.5mm, 12.5mm and 19mm) based on the nominal maximum size. The traffic intensity in terms of Annual Average Daily Traffic (AADT) per lane is considered as a traffic influence factor. The pavement sections are also categorized as urban or rural based on location. The weather data is obtained from the Baltimore Washington International airport (BWI) station of National Weather Service Forecast Office (http://www.erh.noaa.gov). The BWI station is located at the center area of the Maryland and its weather data covers a large portion of the MDSHA pavement network (Figure 1).

It is found that the skid resistance reaches a steady state in about one year after resurfacing. A study of the influence of traffic intensity and pavement location shows that traffic pattern might play a more important role than traffic intensity on friction. The application of HMA overlays using aggregates with high PV (> 6) can improve FN by 3 units on the average and slurry seals could improve FN by 5 ~ 8 units. A study of climate-related factors reveals that 1 degree (°F) increase of average daily temperature during survey period can lead to 1 unit decrease of the network average FN; 0.1 inches increase of daily average rainfall could lead to 1.26 units increases of the network average FN.

**DATA ANALYSIS**

Friction numbers measured by a trailer are highly influenced by the testing speed. The FN can be related to the testing speed by following equation (6):

\[
FN = FN_0 * e^{PNG \cdot S / 100}
\]  

(1)

Where,

- \(FN_0\) is the intercept of FN at zero speed;
- \(S\) is the speed; and
- PNG is the percent normalized gradient given by:

\[
PNG = -100 \frac{d\mu}{\mu \cdot ds}
\]  

(2)

Where

- \(\mu\) is the friction coefficient; and
- \(\frac{d\mu}{ds}\) is the gradient of friction with speed.
As shown in Figure 2, 81% of friction numbers in the MDSHA pavement survey were obtained at speeds between 38 and 42 mph. Therefore, it is reasonable to conclude that this paper is based on data for friction resistance measured at 40 mph. Although this paper focuses on the data obtained in a narrow range of vehicle speeds, the results obtained in this paper could be extended to other vehicle speeds using Equation 1.

The most recent pavement survey data (the year of 2004) in MDSHA is used for the investigation of the influence of pavement characteristics on the pavement skid resistance. The annual network average frictions from year 1998 to 2004 are used to investigate the relationship between pavement skid resistance and climate-related factors. The network average friction is obtained by averaging the sections across the network.

**Pavement location (Urban or Rural)**
Based on the land use zone, pavements are categorized as urban or rural which accounts for 31% and 69% of the network respectively. Comparing to rural roads, urban roads generally experience a more frequent stop-and-go traffic due to higher traffic volume, lower speed limit, more traffic lights and caution zones. Pavement surfaces are more likely to be polished under a frequent stop-and-go traffic because the interaction between surface and tire is much greater when a vehicle is being accelerated or decelerated than when it is at a constant speed. The data shows that the average friction number of rural roads and urban roads are 48.5 and 42 respectively - about 6.5 higher on rural roads.

**Age of surfaces**
It is known that skid resistance reaches its maximum in a few weeks after resurfacing and gradually reaches a steady level in approximately two years (5). As shown in Figure 3, one year after new surfacing, the skid resistance continues to deteriorate although the deterioration rates are relatively slow. Regression analysis shows that on average the deterioration rates of rural pavements and urban pavements are 0.22 and 0.26 FNs per year respectively, and FNs of rural roads are 6 ~ 8 units higher than those of urban roads.

The regression curves in Figure 3 also indicate that the difference in friction between rural and urban roads appears one year after resurfacing and after two years the difference does not change significantly. Considering that no statistically significant difference between rural roads and urban roads exist right after resurfacing, it is reasonable to say that a considerable amount of deterioration would happen on urban roads in the first year. It can be further concluded that the friction reaches its steady state in about one year after resurfacing since the deterioration rate later on is quite small comparing to in the first year.

**FIGURE 3 Friction over surface age by rural and urban roads.**
The pavement surfaces aged from 1 to 12 years account for 81.8% of the network (Figure 4) and the variation of frictions is comparatively small within this range of ages. Therefore, the remaining analyses include only pavements 1 to 12 in age to minimize the confounding effects related to the age.

**Traffic**

In general, pavement friction deteriorates with increasing traffic intensity (4, 5). In this paper, the natural logarithm of AADT per lane (Log(AADT/lane)) for each section are grouped into intervals with 10th of Log(AADT/lane) increment.

Figure 5 illustrates the distribution of Log(AADT/lane) by urban and rural roads. It can be seen that Log(AADT/lane)s of urban pavements are approximately normally distributed in a range of 7 to 10 comparing to a range of 5.5 to 10 of rural pavements, which indicates that traffic intensity on urban roads is higher than that on rural roads.
It can be observed in Figure 6 that a linear relationship exist between friction and Log(AADT/lane) of rural pavements. However the correlation for urban roads is quite weak. When Log(AADT/lane) is less than 9.5, for the same traffic intensity, rural roads virtually have a higher friction than urban roads, and the difference decreases with traffic intensity. When Log(AADT/lane) is larger than 9.5, the rural roads have similar frictions as urban roads. The possible explanation is that when traffic intensity reaches a certain level, the traffic fashion on rural roads exhibits similar traits as on urban roads. This observation leads us to believe that
traffic fashion (speed and stopping frequency, etc.) would have a more significant influence than traffic intensity on pavement friction.

**Aggregate properties**

In the MDSHA, the frictional resistance of aggregates is measured by a specific equipment called “circular test track”, which uses two wheels roll over the surface of sample aggregates that are arranged in a circular track to a certain number of times to polish aggregates and then uses another test wheel to measure the friction of aggregates. The result is indicated by the Polish Value (PV) that reflects aggregates’ frictional resistance. A higher PV shows a higher frictional resistance and a PV larger than 6 is regarded as acceptable in most circumstances. It can be seen in Figure 7 that the friction number decreases with the increase of the traffic intensity (Log(AADT/lane)). In addition, regression curves show that aggregates with PV ≥ 6 provide an approximately 3 higher friction number than aggregates with PV < 6. However, the deterioration rates over traffic intensity for both types of aggregates are similar.

![Figure 7](image)

**FIGURE 7** Friction over traffic intensity by aggregates with PV larger than or equals 6 and aggregates with PV less than 6.
Figure 8 presents the friction changes over Log(AADT/lane) by different Superpave aggregate gradations: 4.75mm, 9.5 mm, 12.5mm and 19.0mm. It is found that 4.75mm aggregates are mostly used for comparatively low traffic (Log(AADT/lane < 7.7) and 19.0mm aggregates are used for comparatively high traffic (Log(AADT/lane>8.8). Aggregates in categories 9.5mm and 12.5mm are used in a relatively wide traffic intensity range. Regression curves indicate that 9.5mm provides a higher friction number than 12.5mm especially when the Log(AADT/lane) is low. This difference gradually decreases with increasing traffic intensities.

**Slurry seals**

The slurry seal provides a thin surface treatment with mixtures composed of crushed aggregates, asphalt emulsion and fillers. It is widely used as a preventive or corrective treatment to extend the life of pavements. Figure 9 shows the differences of the slurry seal treatment and other treatments (most are overlays) on friction numbers. Regression curves indicate that the slurry seal treatment provides a higher friction number than other treatments by 5~8 units when Log(AADT/lane) is in a range of 5.3 to 10.3.
Climate-related factors
Most investigations on climate-related variations of skid resistance were conducted through
aperiodical (on monthly or daily basis) measurements on selected sections with well recorded
climate information (6-10). However, in the MDSHA network inventory friction survey, each
section is tested once a year and the real time weather condition is not recorded. As a result, it is
difficult to correlate a friction number survey to the weather condition for a specific section.
However, if one considers the MDSHA roadway network as a whole unit, a correlation between
the annual variation of network average friction number and the annual variation of the weather
could be studied.

The FN for the entire network is calculated by averaging all sections in a given year. The
average daily temperature and rainfall during survey (from March to November) are used to
represent the weather condition in that year. Figure 10 presents the average daily temperature
and average friction number of the network from year 1998 to 2004. It can be seen that the
average daily temperature has an opposite relationship with the friction (a higher average daily
temperature corresponds to a lower friction number). Figure 11 confirms this observation and
shows that a strong linear correlation exists between the average daily temperature and the
average FN: One degree ($^\circ F$) increase of temperature leads to one unit decrease of FN.
FIGURE 10 Year trends of average daily temperature and network average friction.

FIGURE 11 Friction variations with average daily temperature.
As shown in Figure 12, the average friction number is also influenced by the average daily rainfall. The friction number tends to increase with increasing rainfalls however the correlation is not as strong as that of temperature (Figure 13).

![Figure 12](image1.png)

**FIGURE 12** Year trends of daily average rainfall and network average friction.

![Figure 13](image2.png)

**FIGURE 13** Friction variations with daily average rainfall.

In the MDSHA, the comparison of network skid resistance between years is a procedure to monitor highway safety and to examine the effectiveness of skid resistance improvement efforts. Considering that the climate has significant influences on the pavement friction numbers,
climate-related influences should be eliminated before examining the effectiveness of skid resistance improvement efforts. The climate information should be incorporated into the PMS and pavement skid resistance analysis to help decision makers make a well-informed judgment of engineering efforts.

CONCLUSION

In this paper, authors investigate the possible correlations between frictional resistance (friction number) and influential factors of HMA surfaced pavements in the MDSHA pavement network. The influential factors include pavement surface age, pavement location (urban or rural), traffic intensity, aggregate properties, slurry seal treatments and climate-related factors. Even though the observations are made from year 2004 friction survey data, authors’ preliminary studies showed that similar trends could be obtained from previous years’ survey with minor variations of parameters in regression equations.

The following conclusions are drawn and corresponding further studies are suggested from the findings:

- Skid resistance of HMA pavements is affected by the pavement locations (urban or rural) due to the different traffic fashions (speed and stopping frequency, etc.). The friction number on rural roads is higher than that on urban roads by 6~7 units on the average.
  
  It would be of interest to further quantify the influence of the traffic fashion, which could be expressed in terms of average traveling speed of vehicles and stopping frequency.

- The friction number on roadways seems to reaches a steady state condition in about one year after resurfacing. At the steady state condition, the skid resistance deteriorates with ages at a relatively low rate: 0.22 FN decrease per year on rural roads and 0.26 on urban roads. In addition, urban roads seem to experience a considerable amount of polishing in the first year after resurfacing.

  In order to quantify the friction loss in the early stage (the first year), it is suggested that the initial friction numbers be measured right after rehabilitation.

- The influence of traffic intensity depends on the pavement location. On urban roads, the correlation between friction and traffic intensity is quite weak. On rural roads, the friction decreases linearly with the natural logarithms of AADT per lane. When Log(AADT/lane) is less than 9.5, urban roads generally have a lower friction than rural roads for same traffic intensity. However, when Log(AADT/lane) is above 9.5, both roads have similar frictions.

- Application of aggregates with high PV can improve skid resistance by 3 friction numbers on the average.

- Application of slurry seals can improve skid resistance by 5~8 friction numbers on the average.
The network average friction number would be affected by the average daily temperature and rainfall during survey. 1 degree \( ^\circ F \) increase of average daily temperature could lead to a 1 decrease in FN and a 0.1 inches increase of daily average rainfall could lead to a 1.26 increases in FN. Therefore, climate related influences would be considered before evaluating the pavement network friction between years.

**DISCLAIMER**

The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of policies of the Maryland State Highway Administration. This paper does not constitute a standard, specification, or regulation.

**REFERENCE**