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Effects of Pavement Macrotexture Depth and Skid Resistance on Crash Severity Rates

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Abstract

Preventive pavement maintenance decisions in Jordan are normally made based on factors not related to traffic safety in particular. In rare cases, especially when serious crashes occur, such maintenance may be implemented in response to a public outcry. Ideally, it would be beneficial to include frictional and macrotexture measurements. This study aims to identify road sections that are likely to experience severe crash occurrences by using threshold levels of pavement texture and skid resistance. Several road sections with significant crash experience were included in this investigation. Field measurements of Average Pavement Macrotexture Depth (APMD) and British Pendulum Number (BPN) in the wheel path were collected and analyzed. The crash history of these locations in terms of fatal and personal injury accidents was documented. The researchers introduced a crash severity rate in terms of property damage only accidents per million of vehicle miles of travel (VMT). Regression analyses at a significance level of 0.05 were attempted relating crash severity rates (CSR) to the prevailing texture depth and the measured BPN. A CSR of 2.5 property damage only accidents per million vehicle miles of travel was used in this investigation to produce threshold levels of BPN and APMD. The resulting thresholds were a BPN of 40 and APMD of 0.3 mm. The collection of periodic BPN and APMD can be used to identify potential hotspots by predicting the corresponding crash severity rate. Thus, road agencies should be able to make sound decisions regarding corrective maintenance to promote safety in a timely manner.

Keywords

traffic accidents, texture depth, skid resistance, crash severity, British pendulum tester, property damage only

1 Introduction

Several researchers (Athiappan et al., 2022; Chiu, 2008; Slimane et al., 2008) stipulated that skid resistance is a function of texture depth, traffic conditions, pavement age, and bitumen content. Texture depth, surface condition and pavement roughness affect skid resistance of pavements and the corresponding accident rates. The relationship between skid resistance and traffic accidents had been documented. Amini and Beigi (2015) studied the relationship between surface skid resistance and the accident rate at urban unsignalized intersections based on log-linear regression analysis. According to the model it is expected that for each 1% increase in skid resistance, there is a 7.5% reduction in the accident rate and the results showed that the intersections with lower skid resistance experienced higher accident rates, particularly in wet conditions. The relationship between skid resistance and accident rate is significant, as higher skid resistance typically correlates with lower accident rates on urban roads.

Athiappan et al. (2022) and Pitaksringkarn et al. (2018) investigated the correlation between average pavement skid resistance and wet pavement accidents rate in Thailand using non-linear regression analysis to establish a minimum friction threshold known as the Investigatory Level (IL) for various road types. The results showed that pavement skid resistance significantly influences accident rates. Lindenmann (2006), Panagouli and Kokkalis (1998)

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and Pardillo-Mayora and Jurado-Pina (2009) concluded that increasing the pavement skid resistance is vital to reduce traffic accidents, agreeing with the findings of which indicated that identification of spots with low skid resistance helps in reducing accidents rate, significantly. In another study, Tyfour (2009) concluded that loss of skid resistance affects driver's ability to control the vehicle and proved that lower skid resistance reduces steering controllability and increases the braking distance.

Crash experience can be used to make resurfacing decisions related to safety. This investigation attempts to use the Crash Severity Rates (CSR) to identify sections within the roadway network in need of safety enhancing remedies and corrective maintenance. This investigation used the calculated CSR values to determine terminal BPN or SN levels that can be adopted for the case of Jordan.

Several road and transportation agencies in the United States and Europe conduct periodic measurements of skid numbers (SN) within their pavement management systems. A threshold SN of 30 is commonly used to determine the need for corrective surface treatments aimed at enhancing the skid resistance of pavements (Henry, 2000). The researchers have mainly used British Pendulum Numbers (BPN) measurements in this investigation and decided to derive SN measurements from available correlations with BPN similar to those cited by Bazlamit et al. (2022) and Henry and Wambold (1992).

Based on these correlations, the corresponding threshold value of BPN is about 46 to 49. Therefore, most of the sites included in this study are at or approaching minimal skid resistance levels and need surface treatments to enhance their frictional properties.

Athiappan et al. (2022) developed prediction models for skid resistance and texture depth on flexible pavements. The results indicate a significant correlation between texture depth and skid resistance, and there is a significant correlation between texture depth, age of the road and traffic conditions. They suggested that maintaining adequate texture depth is crucial for enhancing road safety and performance. Pranjić and Deluka-Tibljaš (2022) used a pavement texture–friction relationship based on image analysis methods. A mean profile depth (MPD) showed significant correlation with skid numbers. While MPD is a widely used indicator for macro-texture, these studies found that its correlation with pavement friction is not consistent across all conditions.

2 Methodology

A total of eight major arterial roads were included in this investigation. Table 1 presents the summary of these sites and the corresponding operational traffic parameters. The traffic volume in terms Annual Average Daily Traffic (AADT) is believed to affect skid resistance over time significantly (Murad and Abaza, 2006).

These sites had a serious crash history involving fatalities and injuries. On the other hand, these sites were not resurfaced during the crash reporting period. Available crash statistics were documented for these sites and were used in this investigation.

2.1 Field measurements and data collection

Annual traffic crash statistics on these sites were collected form The Jordan Traffic Institute (JTI). Table 2 presents accident statistics, obtained from JTI. These include number of accidents, injuries, and fatalities.

Alam and Tabassum (2023) conducted a hot spot analysis of road traffic crashes in the state of Ohio. They have introduced a crash severity index (CSI) parameter to account for the collective severity of fatalities and injuries resulting from road crashes. A score of 3.0 was used for fatalities, a score of 1.8 for major injuries and 1.3 for minor injuries and a score of 1.0 for property damage only. Therefore, CSI is used to convert crashes into property damage only crashes to allow comparisons based on severity among road sections. In this investigation, accidents statistics on the selected sites included fatalities and injuries. A score of 3.0 was used for fatalities and 1.5 for injuries as presented in Eq. (1).

$$\mathrm{CSI} = 3F + 1.5I \tag{1}$$

Where F is the number of fatalities, and I is the number of injuries.

Table 1 Summary of traffic operational information

Road name	AADT (vpd)	Section length (km)
Queen Rania	62.730	7.4
Yajoz	24.060	9.6
Al Shaheed	60.465	7.8
Jordan	52.425	5.8
Army	86.025	9.8
Airport	44.460	10.7
Circle Belt	85.485	17.2
King Abdullah	48.465	4.8

Table 2 Traffic accidents, crash severity index and crash severity rate

Road name	No. of accidents	No. of injuries	No. of fatalities	CSI	CSR (PDO/106 VMT)
Queen Rania	180	200	13	339	3.2
Yajoz	41	63	2	100.5	1.9
Al Shaheed	92	142	7	234	2.2
Jordan	37	55	0	82.5	1.2
Army	163	288	14	474	2.5
Airport	45	63	6	112.5	1.0
Circle Belt	117	169	13	292.5	0.9
King Abdullah	28	39	2	64.5	1.2

The crash severity rates were calculated to account for crashes per vehicle miles of travel (VMT) as commonly used in similar studies as presented in Eq. (2).

$$\mathrm{CSR} = \mathrm{CSI} \Big/ \left(L \times \mathrm{AADT} \times 365 \times 10^{6} \right) \quad (2)$$

Where CSR is the crash severity rate per million vehicle miles of travel, L is the section length in miles and AADT is the annual average daily traffic in vehicles per day.

2.2 Collection of frictional properties

There are several methods for measuring the skid resistance that vary from one country to another (Murad, 2004). In the USA, for example, the most accepted method for measuring skid resistance is the locked wheel trailer method in accordance with the American Society for Testing and Materials (ASTM) test method ASTM E274/E274M-24 (ASTM, 2024). This test method utilizes a measurement representing the steady-state friction force on a locked test wheel as it is dragged over a wetted pavement surface under constant load and at a constant speed while its major plane is parallel to its direction of motion and perpendicular to the pavement. The result of the test is reported as SN at 40 miles per hour.

Slider devices such as the British Pendulum Tester (BPT) are considered laboratory devices that are used primarily to evaluate the surface frictional properties of road surfaces using core or laboratory-prepared specimens (Henry, 2000). The BPT is a dynamic pendulum impact type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface in ASTM E303-22 (ASTM, 2022). The macro-texture of the pavement can be measured by obtaining the Average Pavement Macro-Texture Depth (APMD). Standards for measuring BPN and the calculation of the (APMD) are described by ASTM test methods in ASTM E1845-23 (ASTM, 2023).

The sections included in this investigation had documented crash experience and no resurfacing. The prevailing geometric features were carefully considered to eliminate any contribution to crash frequency related to unusual geometry such as sharp curves and steep slopes. Such features may affect available sight distances and thus contribute to crash statistics not related to lack of skid resistance.

Periodic measurements of BPN and APMD were collected on a number of randomly selected spots on these sections during the research. These spots were about 200 meters in length. The wet British Pendulum Number (BPN) and the Average Pavement Macro-Texture Depth (APMD) were measured in accordance with ASTM standards including the calibrations. These measurements were taken in the direction of the traffic along the wheel paths. Proper field safety procedures were used to ensure the safety of the field personnel during data collection. Table 3 represents the summary of these measurements.

In general, nearly all sections included in this investigation have lower frictional levels than newly constructed pavements. The exceptionally high AADT values listed in Table 1 may have been the main reason for this difference as traffic repetitions polish aggregates making the pavement surface smoother overtime. Environmental factors such as

Table 3 Summary of crash severity rate and frictional properties

Road name	No. of spots	BPN	APMD
Queen Rania	37	39.6	0.29
Yajoz	48	47.2	0.40
Al Shaheed	39	41.6	0.27
Jordan	29	48.7	0.30
Army	49	40.4	0.27
Airport	53	43.0	0.30
Circle belt	86	47.7	0.34
King Abdullah	24	48	0.36

temperature changes and surface contaminants may have also played a role in reducing pavement skid resistance.

2.3 Thresholds of skid resistance levels

Over forty states in the USA perform skid testing on regular basis in order to employ the results in their pavement management system. The minimum skid resistance (SN) requirement varies among the states from 28 to 41 for interstates, 25 to 35 for primary roads, and 22 to 35 for secondary roads (Henry, 2000; Tobias et al., 2023). Several states have established minimum skid number requirements such as 30 and 35. Currently, there are no specific skid number requirements specified for pavement friction in Jordan.

If the above-mentioned requirements are applied to Jordan, it is clear that estimated SN values for all selected sections in this study are below the threshold levels adopted by many road agencies in the USA. This finding is consistent with that reported by Msallam et al. (2017) who reported that 66% of major and secondary highways included in their skid resistance investigation have skid resistance values lower than minimum acceptable levels when compared with comparable Australian specifications.

3 Results and discussion

Fig. 1 shows a plot between the crash severity rate per million vehicle miles of travel and the measured BPN. The statically significant negative relationship indicates that skid resistance is an important contributing factor in traffic accident causation. This agrees with the findings of other research works stating that lower levels of SN are likely to lead to a higher number of potential traffic accidents (Murad, 2006). The model indicates that improvements in BPN levels would yield a reduction in crash severity rates.

Several regression analyses attempting to relate CSR to BPN and APMD were pursued but did not produce any meaningful outcomes. This was expected since the data from the selected sites did not include sites with higher texture properties and frictional levels. However, the data allowed the research team the ability to zoom in at sites with poor frictional attributes and severe crash experience. The general indication from the available data seems to support the fact that sites with poor texture are also sites with poor frictional properties. Such sites have proven to have alarming crash severity rates. Fig. 1 shows that sites with BPN of 50 would have a CSR value of about 1 while sites with BPN of 40 have a CSR of 2.50. In other words, a 20 percent reduction in BPN is associated with a 150 percent increase in crash severity rate. The road agencies are required to apply prompt corrective actions on sites with poor friction especially those with high traffic volumes. Delaying these corrective measures is likely to be associated with undesirable crash severity outcomes.

Fig. 2 relates BPN to APMD within the sites included in this study. The model was derived based on a linear fit.

$$\begin{gathered}\mathrm{BPN} = 139.26 \times \mathrm{APMD} \\ \left(F\text{-statistics} = 733.516,\ \ p\text{-value} = 1.67E\text{-}07\right)\end{gathered} \tag{3}$$

The only caveat is that the model is primarily valid for sites with APMD between 0.25 mm and 0.5 mm and may not be appropriate for values higher than that. Most sites in this investigation are nearly close to polished surface condition as indicated by low BPN in the range of 40 to 50. These values are associated with texture depths between 0.29 mm and 0.36 mm. The relationship between crash severity rate (CSR) and BPN is as follows:

$$\begin{gathered}\mathrm{CSR} = 95.543\ e^{-0.092\mathrm{BPN}} \\ \left(F\text{-statistics} = 7.379,\ \ p\text{-value} = 0.0348\right).\end{gathered} \tag{4}$$

Based on Eq. (4), a crash severity rate of 2.5 property damage only crashes per million vehicle miles of travel is associated with a BPN of about 40.

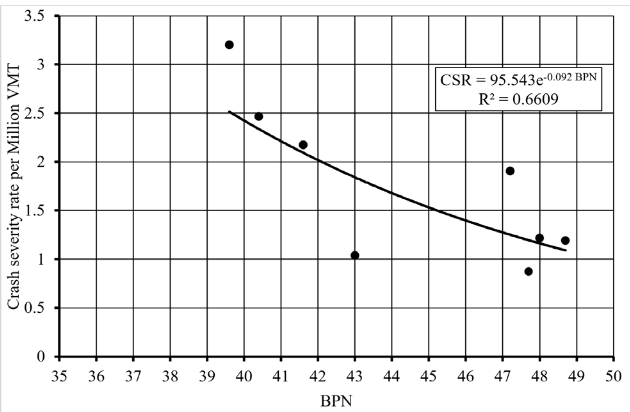

Fig. 1 Crash severity rate versus BPN

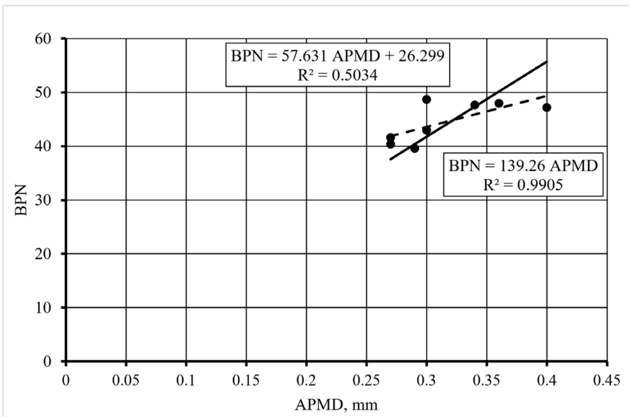

Fig. 2 Variations of BPN with APMD

4 Conclusions and recommendations

The careful analysis of the relationships between the variables in this investigation supports the following conclusions:

1. The results of this study showed that estimated SN levels associated with the sections included in this study do not meet the minimum requirements adopted by many international road agencies in the United States of America, Europe and Australia. Therefore, these sites are regarded as sites with poor frictional performance and technically are due for an immediate corrective surface remedy.
2. Most sections in the facilities studied have considerably poor frictional properties due to the polishing action of the high traffic volumes using them. Newly rehabilitated or constructed sites with such traffic volumes are likely to end up with similar poor frictional properties and crash experiences.
3. Therefore, it is highly recommended that periodic corrective remedies aimed at restoring frictional properties be applied in a timely manner. This should be based on traffic volume prioritization and budget constraints within a comprehensive pavement management system.
4. The researchers have introduced an estimate of crash severity rate (CSR) in terms of property damage only accidents using factors of 3 and 1.5 for fatal and injury accidents, respectively. The CSR showed a significant correlation with frictional properties measured in British Pendulum Numbers (BPN). A CSR of 2.5 property damage only accidents per million vehicle miles of travel was used in this investigation to produce threshold levels of BPN and APMD of 40 and 0.3 mm, respectively. This approach eliminates the need to wait for serious accidents to occur to justify corrective maintenance
5. The investigation showed a strong correlation between frictional levels and crash severity rates. The data showed that the lack of adequate skid resistance would contribute to severe crash experience on heavily travelled road sections. This confirms the findings of other research works stating that lower levels of SN are likely to lead to higher rates of traffic accidents.
6. The research team recommends that future investigations of the relationship of pavement frictional properties and crash experience include a wide range of facilities that include sites with both acceptable and poor frictional levels with properly documented crash experience. It is also recommended that highway agencies in Jordan include periodic measurements of skid resistance of pavements in their pavement management system data collection. This would allow decision makers the ability to monitor the changes in skid resistance over time and make the appropriate corrective decisions in light of available crash records. This investigation can be used to identify hot spots within the roadway network based on periodic collection of friction and corresponding crash history. Recalling that several states use a threshold skid number (SN) of 28 to 43 (Henry, 2000), then the corresponding BPN levels are 43 to 58, respectively (Bazlamit et al., 2022). The sections in this investigation have deteriorated beyond recommended SN thresholds and need corrective maintenance such as resurfacing to restore frictional properties.
7. The crash severity rates associated with the locations in this investigation average about 1.75 property damage only crashes per one million vehicle miles of travel. This is equivalent to an average BPN of about 44 according to Eq. (4). The equivalent SN is close to 28 (Bazlamit et al., 2022).
8. The researchers recommend the adoption of a periodic collection of seasonal BPN and APMD measurements on major arterials within the roadway network. These measurements can be incorporated within the national pavement management system. Corrective maintenance strategies can be triggered by terminal BPN and APMD thresholds adopted by local road agencies.

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