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ACCIDENT DUE TO PAVEMENT CONDITION – A REVIEW

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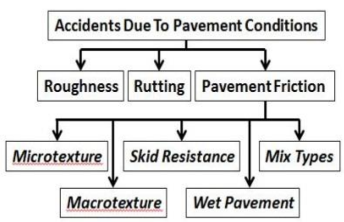
Graphical abstract



Abstract

Accidents are a never ending issue and have been in the rise for the past decades. It has been a significant contributor towards death of human which is alarming yearly with the increase of road users and also with the large construction of road pavement around the globe. This paper is intended to provide an overview regarding the rate of accident and pavement conditions. Human factors has been widely known and established as one of the main contributor to road accidents. This study therefore will be focusing more on to pavement conditions, where its relation with accidents needs to be further explored. Macrotexture, microtexture and surface roughness plays an important role in providing an acceptable and ideal pavement condition. Higher friction between the tire and pavement should be established in order to resist skid and rutting effects. In order to solve problems related to accidents, the causes of accidents has to be further analyzed. A review on pavement conditions and accidents will be discussed further in this paper.

Keywords: Accidents, motorcyclist, road condition, human factor, fatality, unevenness; road friction

1.0 INTRODUCTION

More than 1.3 million people died and about 50 million are injured every year in traffic accident worldwide[1]. This results to major socioeconomic problem with increasing number of death annually. Traffic accident is defined as an occurrence event which involves one or more vehicle collision that resulted to damage, injuries or death. Table 1 shows the road fatality per 100000 inhabitants and per billion vehicle-km for major countries with large and extensive road network. It can be observed since 1990 till 2012, ASEAN countries and South America recorded highest death rates compared to other counterparts of the world. Malaysia has the highest road fatality among all other countries which recorded 24 deaths per 100000 inhabitants followed by Cambodia and Colombia. However, Europe countries such as United Kingdom, Iceland, Norway and Denmark show improvement in reduction of death rates. Serious attention and short term action has to be taken onto ASEAN countries in order to curb the death toll[2].

There are many factors which contribute to accidents such as drive awareness, driver behavior, maneuvering, speeding, pavement conditions, weather, environment effects and vehicle conditions [3]. However, this paper will only focus on pavement conditions related to accidents due to the fact that deterioration and defects on pavement leads to skidding, driving off tracks, improper maneuvering to avoid the road defects and also prolonged driver braking distance which need serious attention by traffic authorities. Besides that, poor surface macrotexture and microtexture could lead to hydroplanning and inconsistency tyre pavement contact and also reduction in tyre gripping the pavement which eventually causes accidents. This review paper will focus more on the pavement friction, rutting and pavement roughness to understand better on the mechanism pavement texture and the pavement contacts.

Table 1 Death per 100000 inhabitants and per billion vehicle-km [2]

Country	Killed per 100 000 inhabitants						Killed per billion v-km					
	1970	1980	1990	2000	2010	2012	1970	1980	1990	2000	2010	2012
Malaysia	-	-	22.7	25.9	23.8	23.6	-	-	-	26.3	16.2	13.4
Cambodia	-	-	-	-	12.7	13.4	-	-	-	-	-	-
Colombia	-	-	-	16.5	12.1	12.7	-	-	-	-	-	-
UK	14	11	9.4	6.1	3.1	2.8	37.4	21	12.8	7.4	3.8	3.6
Iceland	9.8	11	9.5	11.5	2.5	2.8	-	26.5	14.9	13.8	2.5	2.9
Norway	14.5	8.9	7.8	7.6	4.3	2.9	41.7	19.3	12	10.5	4.9	3.3
Denmark	24.6	13.5	12.3	9.3	4.6	3	50.5	25	17.3	10.7	5.6	3.4

2.0 ACCIDENTS DUE TO PAVEMENT CONDITIONS

Road accidents are caused by more than one factor such as the accident location, the road condition inclusive of road types and surface condition, driver's behavior and also weather condition [4]. For an instance, when an accident takes place during wet weather condition, the impact of wet weather and the road condition together with the adequacy of road geometry design also need to be looked into besides the drivers' factor itself.

According to the statistics provided by the Ministry of Public Security in China, high fatality rates were observed in freeway than in urban roads due to the higher speed by vehicles. Two contributing factors for fatal accidents in freeway in China are the condition of traffic flow and the effect of pavement conditions [5]. This has been supported by the findings done by Karlaftis and Golias [6] where the pavement conditions are important factor affecting accidents for two-lane freeways.

Pavement conditions can be classified into different category namely mild, moderate and severe pavement conditions. Examples of poor pavement conditions are rutting, depression, polished surface, unevenness and potholes.

2.1 Roughness

Pavement roughness is the irregularities on pavement surface that affect the ride quality of vehicles, the vehicles vibrations, operating speed, the wear and tear of tyre and also the operating cost of the vehicle. The measurement for the roughness in determination of the acceptable road condition is known as International Roughness Index (IRI). IRI is measured by using the Australian Road Research Board (ARRB) walking profiler (WP) along the pavement lanes [7]. The Public Works Department of Malaysia or also known as Jabatan Kerja Raya (JKR) recommended the IRI value of 1.6m/km for four lane highways, 2.5m/km for two way highways and 8m/km for minor roads [8]. FHWA suggests that the threshold of 2.7 m/km is recommended for acceptable ride quality [9].

Over the years, Forsberg and Magnusson [10] has perceived the importance of road roughness towards driving comfort. Comfort does not only depend on the road roughness subjectively but also depend on many other factors such as vehicle type, alignment of the road, crossfall and also road environment. An illustration on the factors that contributes to comfort is shown in Figure 1[10].

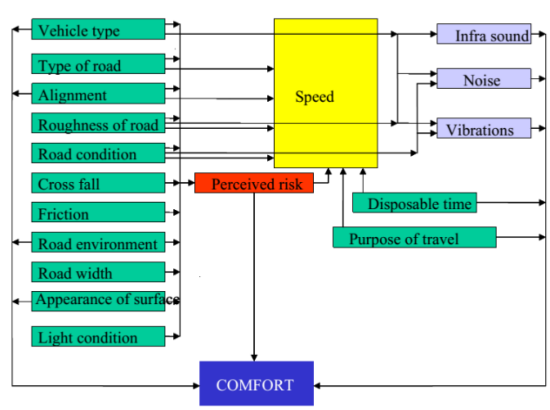


Figure 1 Factors contributing to ride comfort and their relationship [10]

In a study by Anastasopoulos *et al.* [11] the increase in IRI increases the accident rates by

95.72% of the roadway segment. They carried out his studies using two parameter models which are random parameters and fixed parameter tobit model. They also found that high in rut depth also increases accident rates in 94.27% road segment of his study. Al- Masaeid [12] found that the road roughness will decrease single-vehicles accidents but increases the multiple-vehicle accidents rate. The single-vehicle accident rate decreases as the pavement roughness increases due to reduced speeds. The multi-vehicle accident rate increases due to lateral shifts and speed differentials between road users.

A decrease in roughness by 1m/km resulted to 1 percent decrease in the tire wear for passenger cars could save 321 million dollars per year[13]. IRI up to 4 m/km increases the cost of repair and maintenance of 10% for passenger cars and heavy trucks. At the IRI of 5 m/km, the increase of repair and maintenance will increase up to 40% for passenger cars and 50% for heavy trucks [13]. Inadequacy of roughness during wet pavement also increases the IRI value as there is a decrease in friction. The risk of getting involved in skidding related to wet-pavement crashes increases when Skid Number is below 40, while the risk is low when Skid Number is above 60 [13].

Pavement Condition Index (PCI) related to distress in pavement surface has a direct influence on the smoothness (IRI) which is the surface irregularities that affect the ride quality of road users. Study by Park shows that the lower the IRI value, the flatter the profile will be. IRI of 0.0m/km means it is perfectly flat profile while IRI above 8m/km is impossible to travel [14].

IRI is categorized into three difference categories which are the good (IRI < 1.5 m/km), the fair (1.5 m/km< IRI < 2.7 m/km), and the poor (IRI >2.7 m/km). Traffic accident usually occurs for the fair and poor pavement conditions [15]. Pavement irregularities range from 0.1 ≤ λ≤ 100 m wavelength using the road micro-profiler. IRI shows the spectrum of height of road irregularities per one meter or kilometer per length of the measured road section. It is expressed by a vertical summative displacement of a standard vehicle suspension driving at the speed of 80 km/h and the ratio of the travelled distance [16].

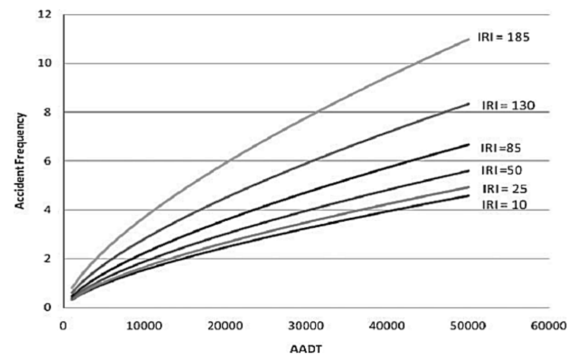


Figure 2 All accident IRI model [15]

Figure 2 above shows the relationship between Annual Average Daily Traffic (AADT) and accident frequency with the influence of IRI. An increase in the AADT with a higher IRI value led to higher accident frequency. IRI with 2.9 m/km exhibits beyond the maximum poor rating of 2.7 m/km subjecting the tyre to lose its contact with pavement and eventually crash[15].

2.2 Rutting

Pavement rutting is a longitudinal permanent deformation along its surface. It is a deformation which was created by repetitive vehicle loading along the wheel path. Accumulation of water on the rut surfaces reduces the skid resistance and increase the hydroplaning. The rutting which is not maintained can lead to cracking and disintegration from the pavement structure.

Strat *et al.*[17] quantifies that rut accidents will increase as the rut depth gets greater than 7.6mm (0.3in). Anastasopoulos *et.al* [11] findings revealed that lower rutting depth decrease accident rates through her modeling utilizing random-parameter model. Another study revealed that severe rutting might distract the driver from driving normally causing them to steer avoiding the defects which resulted into collision or running off track [18].

Chan *et al.* [15] mentioned that the occurrence of accidents increases significantly by the rutting and roughness during night and under rainy weather conditions. A study carried out in Turkey proved that rutting is the most important road defect that relates to traffic accidents through t-test shown in Table 2 [19].The greater the magnitude of t value, the greater the evidence against the null hypothesis. The results of t value at 19.202 indicated that rutting has stronger evidence among the road defects towards road condition.

Table 2 Statistical evaluation of traffic accident parameter [19]

Parameters	Non-Standardized coefficients		Standardized coefficients	t-value	p-value
	Beta	Standard error	Beta		
Constant (α)	1.292	0.061	1.292	21.190	0.000*
Pothole (VPD)	0.673	0.045	0.645	14.907	0.000*
Seasonality (D_1)	-0.040	0.032	-0.027	-1.269	0.209
Road depressions (RDD)	0.002	0.001	0.058	2.388	0.020**
Loose material(LMD)	0.003	0.001	0.158	3.441	0.001*
Undulation (UD)	0.010	0.003	0.106	3.527	0.001*
Deficient road marking (RMD)	0.003	0.001	0.078	2.668	0.010*
Rutting (RD)	0.001	0.000	0.483	19.202	0.000*
Soft shoulder (SSD)	0.199	0.017	0.334	11.753	0.000*
n: 72	k: 8		sd.: 63		
R^2: 0.973	F_h: 316.79		F_c: 2.10		

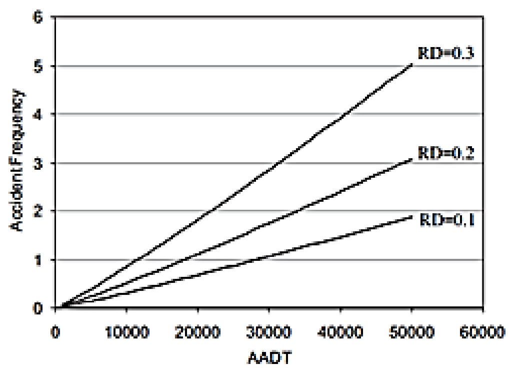


Figure 3 (a) RD models for predicting accidents occurring in nighttime conditions[15]

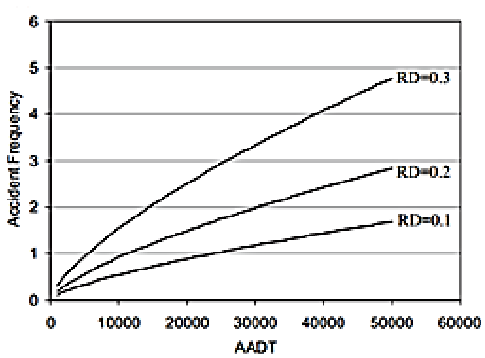


Figure 3 (b) RD models for predicting accidents occurring in rain conditions[15]

Chan *etal.* [15] in their study indicated that the Rut Depth (RD) was significant during nighttime and rain condition as shown in Figure 3 (a) and(b). Both conditions increase the accident frequency with the increase of AADT. Rut on roads is visible during daytime and during normal weather conditions where driver may decelerate and safely steer to avoid the rut zone. However, rut path are not observed during night and wet weather usually when water film present which may impose accidents due to unawareness of the drivers. This led to hydroplaning phenomena as well. From Figure 3 (a) and (b) above, RD with increase of only 0.1 inches (2.5 mm) creates a major change in accident frequency.

2.3 Pavement Friction

Pavement friction is the force that resists the relative motion between the contact of tyre and pavement surface. This friction force is generated as the tire is in motion moving along the pavement surface. Pavement friction depends largely on the microtexture and macrotexture of the pavement eventhough the properties of the tyre, vehicle speed and weather effect also plays role in friction [20]. Microtexture is the small textures on aggregates that control the contact of tyre and pavement surface while the macrotexture is in a larger scale which is more related to the aggregates arrangement that controls the water film under the tyre to reduce the skid resistance. A good pavement friction is usually achieved at the early stage of construction and it is worn due the traffic over time. Figure 4 shows the schematic diagram for the microtexture and macrotexture [21].

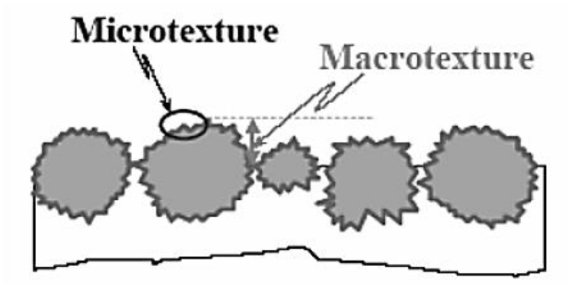


Figure 4 Microtexture and Macrotexture [21]

2.3.1 Microtexture

Microtexture is influence by the surface aggregate properties. The mineralogy, aggregate composition, structures, angularity, shape, texture and its polished characteristics does affect the microtexture of the pavement. Microtexture properties on aggregates functions to provide the best pavement friction at a lower speed [21].

Microtexture increases on dry weather friction which is good in braking effect and for deceleration of vehicles [22]. Microtexture provides spaces for tyre contact towards the pavement surface which produces a strong gripping effect when the vehicle is in motion. The microtexture also plays an important role to ensure that the tyre has a strong bonding with the surface to resist skid. It is designed to provide adequate skid resistance at speed of less than 48 km/h [22].

2.3.2 Macrotexture

The macrotexture on pavement possess strong effect on wet conditions than in dry condition. Macrotexture increases the wet weather friction which in return provides enough depth for contact between the tire and pavement in wet road conditions. The macrotexture also reduces water splash and spray whereby drivers trailing behind will have a clearer vision. Higher mactotexture led to a safer driving amongst the road users which will eventually reduce the accident rate. However, macrotexture also creates tire-pavement noise since the macrotexture has a high texture depth [22].

A study done in Australia on the Great Eastern Highway on Prince Highway West[23] indicated that the macrotexture and accidents relationship are more significant in urban areas compared to rural area. In contrast, on Dukes Highway, it was observed that the accidents and macrotexture more obvious noted on rural sections compared to urban roads. The study reveals that lower macrotexture were observed at the urban areas along the Prince Highway West which led to high significance between macrotexture and accidents in urban areas compared to the rural areas. For the Dukes Highway, very little urban roads were observed along its routes which make the accident more significantly happens in rural road due to macrotexture. Overall, the study proves that there was significant association between accidents and low macrotexture at most of the sites.

International Friction Index (IFI) measures both the macrotecture and friction on wet pavements with a speed remain at constant at 60 km/h. The IFI is based on the assumption that the friction is a function of speed and macro texture. Friction Number (F60) and Speed Constact (Sp) is considered in the IFI measurement. F60 indicates the fricition at slips speed of 60 km/h and Sp indicates the speed dependency of the friction coefficient. Assumptions of the IFI also include the reduction in friction values as the speed increases[24]. The IFI is obtained through the British Pendulum Tester and also the Dynamic Friction Tester.

2.3.3 Skid Resistance

Pavement has to be designed in a way that the sufficient pavement friction must be available throughout the entire life of the pavement and must be able to withstand wet weather condition. This again depends on the microtexture and macotexture of the pavement design in order to enhance pavement durability through increasing on its textures [22]. Skid resistance depends on surface microtexture (texture wavelength of <0.5 mm and amplitude of <0.2 mm) and macrotexture (wavelength of 0.5 mm–50 mm and amplitude of 0.1 mm–20 mm)[25]. A lower skid resistance value increases accident risk on wet roads due to insufficient friction force develops within tyre and road. A pavement with higher skid resistance minimizes the skidding thus increase the road safety [3].

Loss of skid resistance affects driver's ability to control vehicle. A lower skid resistance also reduces the steering controls by driver where braking and steering directly depends on the friction develop from tire and pavement which will eventually resulted to increased stopping distance while braking. The skid resistance on a contaminated up-gradient was found to be lower than the contaminated down-gradient of the same traffic density [26]. Water, clay, dust, dry sand, oil and grease on the pavement surface are the few factors which cause skidding. These materials on the pavement surface causes reduction in contact between tyre and pavement surface [27]. Different pavement types have different skid resistance properties. Open texture pavement has a better skid resistance property than the stone mastic asphalt pavement [24]. This is due to the thick binder film on the Stone Mastic Asphalt surface preventing the exposure of aggregate texture.

2.3.4 Wet Pavement

Hydroplanning effect is a phenomenon that takes place when there is a certain water film thickness between the tire and the pavement. Maximum hydroplaning happen when fluid pressure forces exceeded the load of tyre and the vehicle weight itself. Consequently, this may lead to driver involving into accident [28]. Three different category of hydroplaning which are the viscous hydroplaning, dynamic hydroplaning and tire-tread rubber reversion hydroplaning. The differences between these three category are the viscous hydroplaning happens when there are a thin water film layer and little microtexture on the road, dynamic hydroplaning is considered when there is very little time to remove water under the tires due to the high speed and the tire-tread rubber-reversion hydroplaning takes place when the vehicles lock it tyres at high speed [29].

Studies have shown that the skidding accident rate during wet weather condition is much higher compared to dry weather condition. For example, accidents of wet pavement in Jordan comprise of 20% of total accidents stating that insufficient of skid resistance leads to road accidents [30]. Young[31] and Hosking [32] found that a reduction of 45% and 37% respectively in wet skidding rates for an increase of 0.1 in friction coefficient. Half of road accidents during wet weather were actually due to skidding. Magnitude of skid resistance was affected based on the tire inflation pressure, wheel load, water film thickness and sliding speed. Simulation on sliding speed revealed that sliding speed lower than 20km/h is sufficient because there would be enough time for the water to escape thus providing grip to the pavement [33].

Wet pavement skidding contributes to 13.5% of fatal and 25% of all accidents [34]. In France, 14% of all injuries took place during rainy weather for the period of 1990 to 2000 [27]. Inadequate pavement texture can lead to skidding of vehicles due to the water film which creates a gap between tire and the pavement. The unavailability of irregularity pavement texture causes vehicle to loss its grip with pavement when in contact through the tires. A good surface texture usually consists of good aggregate mineralogy, various aggregate sizes, have a good gradation in the surface mix, low surface wear and suitable pavement finishes and texturing techniques.

The quality of aggregate is one of the factors that determined the skidding on wet weather. Texture depth and ribbed tyre proved to increase with the increase in coarse aggregate content but the voids in mineral aggregate (VMA) or air voids (AV) shown no correlation with the skid resistance. Inadequate surface friction actually lead to poor visibility due to splash and spray eventually led to uncontrolled skidding are the main causes of wet weather crashed. The splash and spray according to Hoerner and Smith [35]that contribute to 10% of wet weather accidents can also be minimized with deeper textures. According to Larson *et al.*[36], 70% of the wet weather crashes are preventable with improved texture or friction on pavement surfaces.

Figure 5 below shows the relationship of different water film thickness between skidding number (SN) travelling speed. It can be observed that the skidding number decreases with thicker water film depth at speed from 30 km/h to 120 km/h[37].

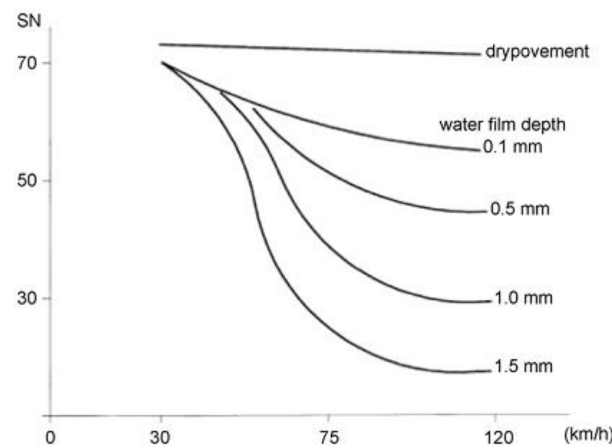


Figure 5 Influences of water film depth and vehicle speed on skid resistance [37]

2.3.5 Mix Types

A study by Henderson[38] shown that higher percentage of crushed chips in mix provides a higher skid resistance as the crushed chip increases the skid friction up to 25% by providing greater microtexture which has more angularity and irregularity. This indicates that the quality of aggregate is very important factor in achieving good surface friction properties.

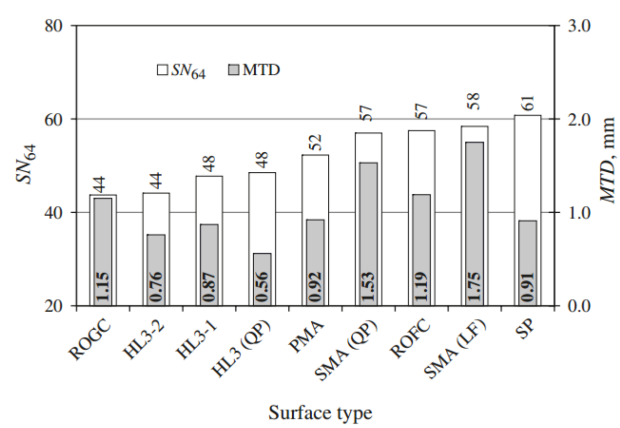


Figure 6 Comparison of texture and skid resistance on various AC pavement [39]

Figure 6 shows that the Stone Mastic Asphalt (SMA) pavement shown a good Skid Number with high Mean Texture Depth (MTD). Superpave mix pavement has the greatest SN with low MTD. This is due to the location of site with higher dust deposition. Higher binder content and bigger stone to stone contact in SMA mixer was predicted to provide higher SN value since the MTD shows the highest. However, the lower SN reading for the SMA mixes compared to Superpave was because of constant tyre deformation beyond certain texture depth. Rubberized Open Friction Course (ROFC) also apparently provides a higher SN value even with lower MTD. The results from the study indicated that the quality of aggregates is the most important factor to achieve a surface with high skid resistance [39].

3.0 METHODOLOGY

Accident data and also pavement condition data as mentioned above will be collected from the Malaysian local authority involving Polis Diraja Malaysia (PDRM), Jabatan Kerja Raya (JKR) and also Malaysian Institute of Road Safety Research (MIROS). The pavement condition data will be obtained during occurrence of accident at the particular location. This is to provide the relationship of accident and pavement condition. A series of historical accident and pavement condition data required to determine the probability of accident to happen and also the prediction of accidents to occur in future based on a developed model. This model will help the Malaysian local authority involving road accidents to plan and recommend measures to mitigate road accidents in the future.

4.0 EXPECTED FINDINGS

Models on accident and pavement conditions will be developed to determine the relationship and also to predict the accident trend in the future. The findings will indicate the types of road and its surface condition that highly contributes to accidents. Besides that, the type of pavement condition that contributes the most towards the pavement condition has to be addressed first. It is expected that there is a strong relationship between the road accident and pavement conditions.

5.0 CONCLUSION

Pavement condition is an important factor in reducing accidents especially in tyre pavement friction. Macrotexture, microtexture and surface roughness plays an important role in providing an acceptable and ideal pavement condition. Higher friction between the tire and pavement should be established in order to resist skid and rutting effects. Nevertheless, the potential in reduction of aquaplaning phenomenon can be achieved with a good pavement texture. Roads free from rutting, undulating and unevenness are essential to facilitate safe driving condition. Therefore, pavement condition needs to be given attention in order to curb accidents thus to increase road user safety. Accidents can be prevented if road users have more awareness on the safety and also if the roads are well maintained according to its service life.

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