Effect of pavement surface conditions on road traffic accident - A Review

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Abstract. This study aims to establish an overview of the state-of-the-art relationship between accident risks and pavement surface conditions. The symptoms of pavement surface failure are indicated by roughness, rutting, and skid resistance. To analyse the relationship between traffic accident and pavement surface conditions, an extensive review of the literature was conducted on the related titles. The findings showed that pavement surface conditions have a strong positive effect on accident risks. Pavement surface distresses directly affect ride comfort and indirectly cause distraction to the driver resulting in loss of control of the vehicle, which may lead to injuries or deaths. The ranges of acceptable pavement surface conditions were also presented.

1 Introduction

Road accidents are now the leading cause of injuries and deaths globally, causing approximately 1.25 million deaths and 20-50 million long-term disabilities each year [1]. By 2030 it is predicted that highway crashes will be the fifth leading cause of deaths globally unless preventative measures are taken to curb this global challenge [2]. In Malaysia, traffic accidents are the fourth leading cause of death after ischemic heart disease, pneumonia, and cerebrovascular disease [3]. Over the past decade, the number of road accidents in Malaysia has been increasing meanwhile, the mortality rate has shown a steady reduction from its peak in 2016. The number of road accidents and fatalities has dropped by 26% and 25% respectively in 2020 compared to 2019 (Fig. 1) due to the Movement Control Order (MCO) imposed during the COVID-19 pandemic which resulted in lesser traffic [4]. According to these statistics, road accident imposes serious problem to the society in terms of human, medical, and property damage [5]. The research on the causes of road traffic accidents (RTAs) is now very crucial and has attracted great attention in the literature. Numerous researchers have explored the relationship between road characteristics and road accidents. One of the key elements of road characteristics is the pavement conditions. This paper aims to establish as objectively as possible an overview of the state-of-the-art relationship between accident rates and road pavement conditions. The focus would be to identify and analyse the causes of RTAs and their impacts on road users. The findings of this research will enable pavement engineers to identify potential measures required to minimize road traffic accidents.

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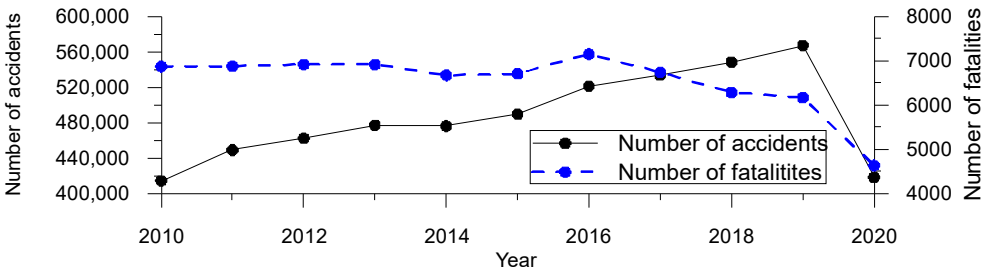

Fig. 1. Number of road accidents and fatalities in Malaysia (2010-2020).

2 Causes of road traffic accidents

The causes of road accidents can be broadly categorised as due to human error, road conditions, and vehicle conditions. However, the percentage for each factor can vary significantly from country to country as shown in Table 1, depending on the country's level of awareness about road safety, the strictness of the law enforcement, and engineering aspect (vehicle design and road infrastructure) [6]. Human error is the leading cause of road traffic accidents in all countries, followed by either road or vehicle conditions. Since human error is hard to control thus, the government and transport authorities have focused more on the road condition as a measure to improve traffic safety [7]. Hence, the following sections will discuss on pavement surface conditions in relation to RTAs.

Table 1. Causes of road traffic accidents.

Causes of Road Accident (%)					Reference
Human error	**Road Condition**	**Vehicle Condition**	**Other factors**	**Country**	
75.4	14.5	10.2	-	South Africa	[8]
85.5	2.9	5.1	6.4	Kenya	[9]
80	12.7	7.8	-	South Africa	[10]
90	4	8.4	-	Ghana	[11]
75.7	2.9	17.1	-	Congo	[12]
80.6	13.2	6.2	-	Malaysia	[13]
67	29	4	-	Saudi Arabia	[14]
29	64	7		Malaysia	[3]

3 Pavement surface conditions

It has been reported that the second highest cause of road accident in Malaysia is due to pavement conditions [15]. Interestingly, 64% of the total road accidents in Sarawak, East Malaysia, were caused by unsafe road conditions. This percentage is higher than the national record due to uneven road surface and improper geometric design at the studied area**.** Pavement distresses are caused by combined actions of traffic loading and environmental conditions [16]. The three most important pavement surface condition characteristics are roughness, rutting, and skid resistance [17, 18]. The relationship between the aforementioned pavement surface conditions and traffic safety is discussed in the following section.

3.1 Relationship between roughness and Safety

Pavement roughnesses are irregularities or deviations from the intended longitudinal profile of the road surface that affects vehicle ride-ability [18]. Roughness is related to serviceability and results to inadequate skid resistance, which in turn affects the dynamics of the moving vehicle and operating speed [19]. International roughness index (IRI) is the most common parameter used to measure the response of pavement roughness [16]. Many studies have shown a strong correlation between pavement irregularities (roughness) and traffic accidents [16, 19-31, 34]. For resistance, a study done by Chan et al. [19] who investigated the effect of pavement distress variables on accident frequency. The results showed that crash rate increases with the increase in IRI values. However, the effect was more pronounced at night and during wet weather because such adverse conditions usually impair visibility. Thus, increasing the potential for accidents. Contrary, Hussein and Hassan [26] found the effect to be higher during the day on a dry pavement surface than during the night on a wet pavement surface. The reason being traffic volume during dry days is higher than during wet nights. Identically, King [20] also reported that an increase in pavement roughness increases crash rates. However, the effect was significant for light vehicles compared to heavy freight vehicles. Various researchers [16, 21-23, 27, 28, 34] also observed a significant positive relationship between IRI values and accident frequency. These studies revealed that roads with small IRI values had fewer accidents compared to similar roads with high IRI values. Contrary, Al-Masaeid [24]; Karan et al. [29] investigated the effect of pavement roughness on single-vehicle and multiple-vehicle crash rates. The results showed that single-vehicle crash rate decreases when roughness increases. This is because drivers tend to be extra careful on a very rough road and they often reduce operation speed which in turn reduces accident risk. This finding coincides with the results obtained by Tsubota et al. [25]; Buddhavarapu et al. [30]. However, the multiple-vehicle crash rate increased with an increase in IRI values agreeing with the previous studies. Interestingly, very good pavement conditions were also associated with high crash rates as well as high severity outcomes because very good pavement conditions induce speeding behaviour [30, 31]. Fig. 2 provides the summary of the relationship between roughness and safety for different studies. It should be noted that the weather and environmental conditions might be different when compiling the graphs.

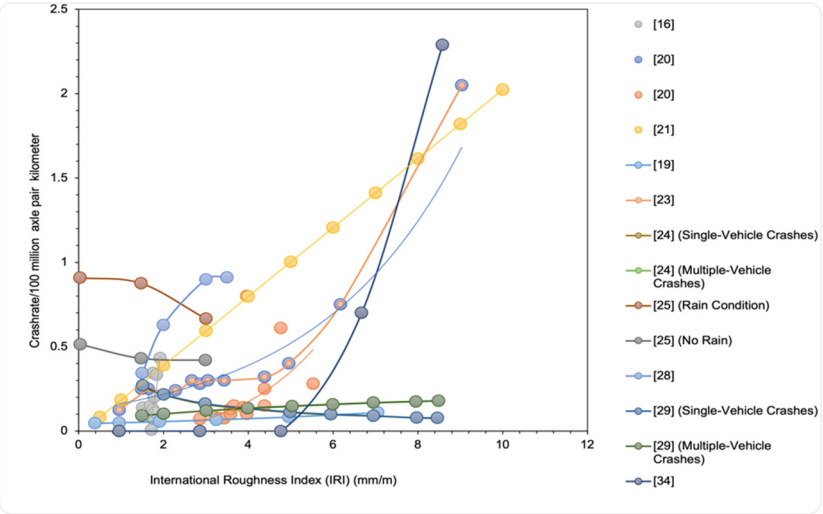

Fig. 2. The relationship between roughness and crash rate.

3.2 Relationship between rutting depth and safety

Rutting is defined as the longitudinal plastic deformation of the roadway along the path of the wheels formed by repetitive loading and consequential material failure [25]. A large rut depth can be difficult to manoeuvre and may need extra driver's effort to escape it. A rut can collect water during rainfall leading to hydroplaning and loss of skid resistance [32]. Hydroplaning is a dangerous situation whereby water on the pavement surface causes the tires of the vehicle to lose contact with the road surface. Thus, riding on top of the water film, leading to loss of control of the vehicle [33]. There are limited studies that have investigated the relationship between rut depth and accident risk who successfully found a strong positive correlation [19, 25, 34]. According to Fig. 3, the studies by Chan et al. [19]; Tsubota et al. [25]; Mamlouk et al. [34] suggested that increase in rut depth also increased crash rate. However, the effect was more pronounced at night-time and during rainy weather. In general, rut zones are not visible at night or when covered with water during rainfall. Thus, the driver may not be aware of the potential hazard ahead of him/her and may fail to adjust speed in time to safely manoeuvre out of a rut zone resulting to an accident. These results are in agreement with the results obtained by Hollo and Kajtar [35] who also reported a significant increase in accidents at night during wet weather than daytime under dry weather. In addition, the crash rate for Chan et al. [19] was much greater compared to Tsubota et al. [25], Mamlouk et al. [34] since the plotted values corresponded to annual average daily traffic of 50,000 veh/day. It's worth mentioning that the weather and environmental conditions might be different when compiling the graphs. Contrary, studies done by [23, 26, 36] have found that there is no any clear relationship between rut depth and crash rate. Similarly, Ihs et al. [37] found rut depth to be the least predictor of crash rate and less useful for generating maintenance and rehabilitation rules.

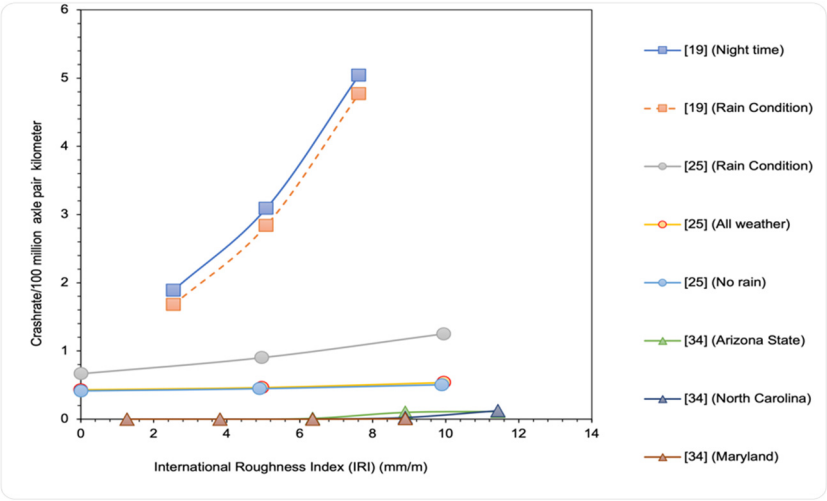

Fig. 3. The relationship between rut depth and crash rate.

3.3 Relationship between skid resistance and safety

Skid resistance of the wet pavement is of vital importance since many studies have reported that almost 20% of the total road accidents occur on the wet pavement [38]. The higher the friction force at the tire-pavement interface the more the driver can control the vehicle. Several studies have demonstrated a link between skid resistance and crash risk. Many of them have focused more on showing how wet pavement condition strongly affects traffic

safety. For example, Crisman and Roberti [39] stated in their study that, pavement with high skid resistance has proved to decrease the likelihood of accidents risk since sufficient skid resistance helps drivers to have full control of the vehicle. In another study conducted by Mayora and Piña [40] who investigated the effect of skid resistance on traffic safety under wet pavement conditions. The results revealed that both wet and dry pavement accidents rates decreased with increasing values of skid resistance. However, wet weather accident risk was significantly higher in curves than in tangents whereas, for the dry pavement the risk was similar on both. Wet pavement accident rate was higher because of the lubricating action of the water film which reduced friction force. The study further showed that the application of pavement friction improvement schemes resulted in a reduction of wet pavement accidents by 68%. These findings were consistent with the results obtained by [38, 41], which investigated the influence of skid resistance on crash rate for both dry and wet conditions and the impact was also severe during wet conditions. Comparable findings were reported by Alhasan et al. [42] whereby, an increase in pavement friction resulted in decreasing crash severity. Similarly, Hussein and Hassan [26] reported that both wet and dry crash rates decrease with an increase in pavement skid resistance. In another related study by Al-Mansour [43] the results also showed that as skid number increases accident rate decreases. The author further stated that pavements with skid number less than 0.35 had the highest accident risk whereas the risk was constant for pavement with a skid number greater or equal to 0.45.

4 Range of acceptable pavement surface conditions

The threshold values of acceptance for the pavement conditions characteristics are classified based on the engineering judgment or past practical experience [32]. It is important to define threshold values for pavement characteristics below which crash rate can be minimized and riding comfort increased [44]. Lack of uniformity in the methodology for assessing minimum thresholds has led to the existing differences among the proposed values [45]. Tables 2, 3 and 4 show variations in the critical rut depth, roughness, and skid resistance values for different countries. Considering all the values in the table, threshold values can be taken as an average of all cases [34]. Therefore, pavement is considered as a poor pavement surface and prone to accidents if it has a rut depth exceeding 23.5 mm and an IRI value greater than 3.2 m/km. However, the skid resistance threshold value was inconclusive, because each country had its own instrument and method for measuring pavement friction force. Thus, the friction values recorded were not directly comparable.

Table 2. Rut depth severity level.

Severity level (mm)			Country	Reference
Low (Good)	**Medium (Fair)**	**High (Poor)**		
< 6	6 - 25	> 25	India	[46]
< 6	7 - 12	> 13	USA	[47]
6.35 - 12.7	12.7 - 38.1	> 38.1	USA	[48]
3.18 - 9.53	9.53 - 19.05	> 19.05	USA	[49]
5.1 - 12.5	12.7 - 25.2	≥ 25.4	USA	[50]
7.62	Not ranked	15.75	USA	[51]
< 10	10 - 20	> 20	Canada	[52]
(2.5 - 9.6)	(9.6 - 23.5)	(> 23.5)	-	Average (Rounded)

Table 3. Roughness severity level.

Severity level (km/m)			Country	Reference
Low (Good)	**Medium (Fair)**	**High (Poor)**		
2 - 3.9	4 -5.9	6 -10	Australia	[53]
< 1.5	1.5 - 2.7	>2.7	U.S.A	[54]
≤ 3.9	3.9 - 4.4	> 4.4	China	[55]
< 1.5	1.5 - 2.7	>2.7	U.S.A	[56]
0.95 - 1.48	1.50 - 1.88	>2.7	U.S.A	[57]
< 1.5	1.5 to 2.1	>2.1	Canada	[58]
1.0 to 1.5	1.5 to 2.0	> 2.0	Canada	[59]
0.6 – 2.2	2.2 - 3.2	> 3.2	-	Average (Rounded)

Table 4. Skid resistance thresholds values.

Road Type/Geometry	Skid Resistance Value	Country	Reference
Freeways and two-lane highways	SFC[1] = 0.40/0.45	Chile	[60]
All road types	SN40S[2] = 32, SN40R[2] = 23	USA	[61]
Undivided and divided highways	SN40R[2] = 30/25	USA	[62]
Regional network	SFC[1] = 0.45 – 0.55	UK	[63]
Curves with radius less or greater than 500 m	SCRIM[3] = 55/60	Spain	[40]
Malaysian Roads	SRV[4] = 55	Malaysia	[64]

[1] Sideway force coefficient.
[2] Skid numbers measured at 64 km/h (40 mph) in accordance with ASTM standard method E274 (ASTM E274/E274M–11).
[3] Sideway-force Coefficient Routine Investigation Machine.
[4] Skid Resistance Value

5 Conclusion

This study analysed the correlation between the key pavement conditions and the number of crashes. In general, the findings revealed that as rut depth and pavement roughness increases, so does the accident rate. On the other hand, when skid resistance increases, accident risk decreases. The effect was more pronounced during rainy weather and at night-time. Pavement is considered as a poor pavement surface and prone to accidents if it has a rut depth exceeding 23.5 mm and an IRI value greater than 3.2 m/km. However, skid resistance threshold value was inconclusive due to an absence of a uniform global methodology. These results provided an insight on the relationship existing between pavement conditions and accident rates which may be valuable for engineers during pavement design and maintenance in traffic safety improvement.

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