Pavement Condition and Traffic Safety: A Comprehensive Review of the Literature

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1. Introduction

Traffic safety as one of the important topics in the field of Transportation Engineering plays a pivotal role in saving lives of people who are using roads and highways in their daily trips. In 2017, the National Vital Statistics Reposts revealed that the third leading cause of death in US is accident [1]. To this end, many researchers are focusing on different aspects of traffic safety to analyze, predict, detect, and prevent different types of accidents. Accordingly, finding out the critical factors which are influential in occurrence of accidents is of great importance since they can be further studied in order to decrease accidents. Among the effective factors on traffic accidents including drive awareness, driver behavior, maneuvering, speeding, weather, environment effects, vehicle conditions, and pavement condition [2] one of the substantial one is pavement condition due to the fact that deterioration and defects on pavement can cause skidding, driving off tracks, improper maneuvering. In addition, poor surface macrotexture and microtexture lead to hydroplaning and inconsistency tyre pavement contact and also reduction in tyre gripping the pavement which eventually can cause accident.

2. Pavement defect and failure

Harsh weather condition, lack of appropriate maintenance, and heavy daily traffic can cause adverse impacts on pavement condition. In this section, different types of defected pavement and their impact on accidents are pointed out.

One important type of the most important defect of pavement if roughness which is some irregularities on the surface of pavement that decrease ride quality by increasing vehicle vibration and decreasing operation speed. It can also damage the tyre of vehicle and increase operating cost of vehicle. In order to measure the roughness of pavement, International Roughness Index (IRI) obtained from measured longitudinal road profiles is used. IRI can be categorized into difference groups 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). However, traffic accident usually occurs in the fair and poor pavement conditions [3]. Another important defect of pavement is rutting which is a depression or groove worn into a road or path by the travel of wheels or skis. Pavement friction is also found to have significant association with accidents. pavement friction includes microtexture which is collative term for a

material's crystallographic parameters, macrotexture which is family of wave-shaped road surface characteristics, skid resistance which is the force developed when a tyre that is prevented from rotating slides along the pavement surface.

3. Accident and pavement condition

There are many researches showing that pavement condition can significantly increase chance of accident on different road types. That means, cities with extreme cold and hot weather condition should consider continuous maintenance of pavement condition to prevent accidents. In China, it is shown that two substantial factors which are leading to fatal accidents are traffic flow condition and pavement condition [4]. Similarly, other researchers proved that pavement condition is one of the leading factors in accident occurrence in freeways [5].

Several studies showed the impact of different pavement condition on accidents. In one study, it was shown that increasing IRI can increase accident rate by 95.72% of the road segment [6]. It is also shown that rut depth can also increases accident rates in 94.27% road segment. Interestingly, another study showed that while increasing road roughness decreases single-vehicle accidents due to reduced speed, it increases multiple accidents because of lateral shifts and speed differentials between road users [7]. It is worth noting that decrease in roughness by 1m/km can cause 1 percent decrease in the tyre wear for passenger cars which eventually save 321 million dollars per year [8].

A decrease in roughness by 1m/km resulted to 1 percent decrease in the tyre wear for passenger cars could save 321 million dollars per year [8]. Figure 1 shows is captured from [3] which is displaying the relationship between Annual Average Daily Traffic (AADT) and accident frequency under the influence of IRI. Based on this figure, increasing AADT with higher IRI value causes higher accident frequency.

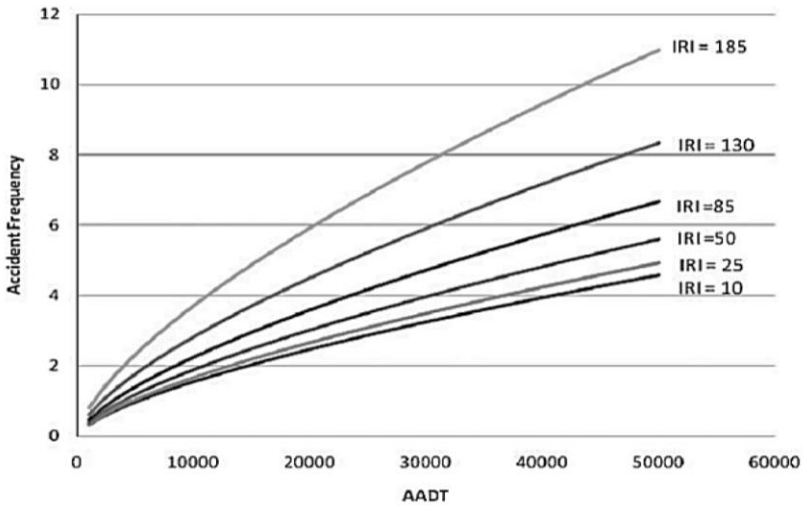

Figure 1 All accident IRI model [3]

Rutting in the pavement is another significant cause of accidents. Researchers showed that lower rutting depth decrease accident rates [6], however, accidents increase as the rut depth gets greater than 7.6mm (0.3in) [9]. It is also shown that severe rutting can distract the drivers and make them steer abruptly to avoid the defects which result in collision or running off track [10]. In addition, nighttime and rainy weather conditions are two important factors which are increasing impact of rutting pavements on accident occurrence significantly [3].

Regarding pavement friction, different studies considered impact of friction on accidents. To this end, it is shown that higher macrotexture cases safer highways and reduces accident rate [11]. However, macrotexture increase noises generated from tire-pavement friction due to high texture depth of macrotexture [11]. Similarly, higher skid resistance value decreases accident risk on dry roads due to sufficient friction force develops within tyre and road thus increases the road safety [2]. In a study conducted in 1750 km of two-lane rural road of Spanish National Road System, skid resistance measured with SCRIM and influence of pavement conditions on safety was investigated. It is shown that both wet- and dry-pavement crash rates have decreasing trend as skid resistance increased. In addition, pavement friction improvement schemes showed significant reductions of 68% in wet-pavement crash rates [12].

In another study, relative risk for different skid-resistance are calculated and plotted in the Figure 2 in which the curve was obtained by taking the ratio of the percentage of results from the skidding-

accident sites in each range of values of skid-resistance to the corresponding figure from the random sample sites and plotting it against skid-resistance [13].

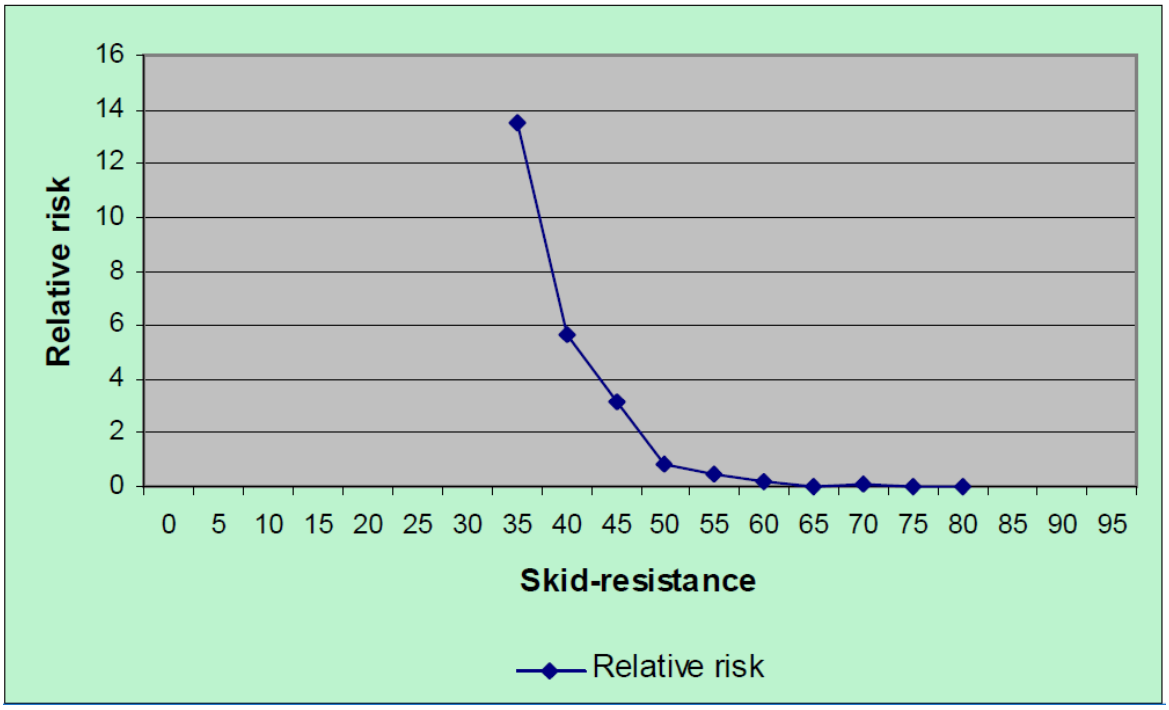

Figure 2 Relative rate of skidding-accident for different skid-resistance [13]

Based on Figure 2, the rate is measurable for the values below 65 and it increases significantly for the values below 50 to 55. Regarding the form of this curve, values below 55 are most likely to be accepted on roads with easy traffic conditions, and values below 45 might show potentially slippery conditions whatever the road layout and traffic conditions. Through a study about influential factors on accident rates impact of different conditions were investigated which are shown in Table 1. Based on this table, roadways with ice, hoarfrost, packed snow, loose snow, and black ice in ruts have the most negative impacts on traffic safety and increase the accidents, respectively [13].

Table 1 Accident rates (personal injuries per million vehicle km) and roadway condition [13]

Roadway condition	Accident rate
Dry bare roadway, winter	0.12
Wet bare roadway, winter	0.16
Slush	0.18*
Loose snow	0.30
Ice	0.53
Hoarfrost	0.53
Packed snow	0.31
Bare ruts	0.12*
Black ice in ruts	0.30*
Dry bare roadway, summer	0.14
Wet bare roadway, summer	0.18

In addition, accident rates were calculated for different friction intervals which are categorized in four categories comprised of less than 0.15, 0.15-0.24, 0.25-0.34, 0.35-0.44. Results of this study are displayed in Table 2.

Table 2 Accident rates (personal injuries per million vehicle km) and friction interval [13]

Friction interval	Accident rate
< 0.15	0.80
0.15 – 0.24	0.55
0.25 – 0.34	0.25
0.35 – 0.44	0.20

4. Accident severity and pavement condition

There are many studies which are showing the significant impact of surface condition on accident occurrence based on different measures. However, there are some other researchers who are

focusing on impact of pavement condition on severity of accidents. To this end, in 2015, a series of six Bayesian ordered logistic regression models were employed to investigate impact of different factors such as roadway, traffic, and environmental factors on crash severity. Among these factors, poor pavement condition is found to increase the severity of multi-vehicle crashes on different speed-level roads. Accordingly, poor pavement can increase the severity of single-vehicle crash on high-speed roads. However, in the low-speed roads, severity of single-vehicle crashes decreases for poor pavement conditions. Based on the results of this study, the severity of most crash types can be reduced when the pavement condition is well maintained such as minimum pavement condition of 2.0 or higher [14]. Another study categorized pavements into Asphaltic concrete pavement (ACP), continuously reinforced concrete pavement (CRCP), and jointed concrete pavement (JCP), and then investigated effects of pavement conditions on accident severity. The correlation between several pavement condition ratings, or scores and crash severity showed that crashes on JCP pavements are most likely to be more severe than on ACP or CRCP pavements, especially on two-lane highways in Texas. In addition, the results of ride score and IRI score suggested that higher ride and IRI cores result in more severe crashes [15].

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