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Impacts of pavement performance indicators on traffic oriented parameters and road safety

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K E Y W O R D S

Pavement Performance Indicators

Traffic Safety

Rutting

Cracking

IRI

Speed

A B S T R A C T

With the passage of time, due to vehicle movement and environmental conditions, the road pavement deteriorates. The accident rate increases if there is no proper maintenance of road deterioration. This study evaluates the safety performance due to the change in pavement performance indicators on the selected roads of Bahawalpur, Punjab Pakistan. Three roads different pavement conditions were selected, based upon their physical inspection, of 5 Km length (each road). The pavement performance indicators used in this study were International Roughness Index (IRI), rutting and cracking. The accident data of last five years (Jan 2015 to April 2019) was used in this study. The pavement performance indicators were measured on site and accident data was taken from emergency service (Rescue 1122). The relationships between pavement performance indicators and accident data were examined. No linear relationship is found between pavement performance indicators and traffic safety, however a parabolic relation is best fitted between these variables. The parabolic models are developed by keeping the pavement performance indicators on independent axis and accident data on dependent axis which can be use by road designers for assessing the value of IRI, rutting and cracking for safe traffic flow. Some values are also suggested which can be used as evaluation criteria that whether the road needs rehabilitation work or not. The suggested values/range for IRI is 1.75-2 m/Km, for rutting 9 – 10 mm and for cracking-Pavement Condition Rating (PCR) 75-80.

1. Introduction/ Background

Traffic accidents are undesirable incidences that make huge misfortune for the individual and complete transportation network. The financial and economic situation of the nation is affected because of the growth in traffic accidents. Traffic accidents result in fatalities and injuries, and it is a major concern for the highway agencies. In 2017 – 2018, almost 14,489 road related injuries and 6,948 fatalities (19 per day) were reported in Pakistan. Number of fatalities is increasing every year as in 2016 – 2017, almost 5047 fatalities (14 per day) were reported. Pakistan Bureau of Statistics claims that in the last decade, a terrible picture has been presented by the traffic accidents in Pakistan, reportedly killing on average 15 people per day in the country wide traffic accidents (Traffic accident report No.388, 2017-18) [1].

The improvement of road safety with the help of well-organized and pavement management system should be the major objective along with effective road maintenance strategies. Investigations and statistical analysis, conducted on the road crashes, demonstrate that there is a relationship between crash frequency and pavement surface characteristics (Noyce et. al., 2007) [4]. Therefore, an investigation is required to find out the possible relationship existing between the pavement surface characteristics and crash frequency. There is also a need to introduce strategies to add the findings in the evaluations of road safety.

Previous works have proven that there are a lot of factors affecting the safety of traffic. The contributing factors for traffic accidents are categorized as driver, vehicle, and roadway, each containing multiple sub-variables. These sub-variables include pavement surface texture, driver/human behavior, Pavement Condition Rating (PCR), International Roughness Index (IRI), cracking, rutting, and speed.

The combined results of these pavement performance indicators give us better understanding of road condition. It also help to determine the factors affecting pavement condition.

On account of that now a days aged pavements are over utilized with presence of lot of defects. The riding quality of the vehicles is directly influenced by the deteriorated structure of pavements. The defects distract the driver and directly affect vehicle activity. This add towards the driving interruptions and mishaps. A road with an bad record of imperfections can make a vehicle to lose control on braking or turning, particularly under unfavorable environmental conditions. Along with other major contributing factors to event of mishaps, the pavement surface condition is a serious concern (Kuleno et al., 2019) [11]. From the studies it is clear that deteriorated pavement condition/structure has contributed in adding the risk to driver and travelers.

Investigations and statistical analysis conducted on the road crashes demonstrate that there is a relationship between crash frequency and pavement surface characteristics (Noyce et. al., 2007). Therefore, there is a need to develop the possible relationship between the pavement surface characteristics and crash frequency. There is need to introduce the related strategies and the findings in the evaluation of road safety.

Road pavement deteriorates with the passage of time due to vehicular loading and environmental conditions. If the deterioration is not addressed timely, it will give rise to frequency of accidents and thus in turn affects road safety. A lot of investigation is required to be done to find out the best possible relationship between pavement performance indicators and roadway safety which will enable us to define the permissible limits of pavement performance indicators and develop models between pavement performance indicators and traffic accidents. These limits will help us in controlling the increase in accident rate by doing maintenance works as and when required.

2. Literature Review

Various studies have been done to find the relationship of pavement performance indicators like roughness, rutting, cracking, macro texture and skid resistance with traffic safety. The summary of some most recent works is discussed below.

The effect of surface defects such as cracking, raveling, potholes, rutting and roughness on crash rate was studied by Kuleno et. al., (2019) [11] for roads of Ethiopia. It was found that effect of cracking and raveling on crash rate was negligible, while rutting and roughness had direct relation with crash rate.

A study investigating the effect of friction on roadway safety of urban roads was done by Najafi et. Al., (2015) [10]. Friction was measured for both wet and dry road condition. It was found in the study that there was no linear relationship between friction and accidents, some regression equations were developed which were recommended to use by designers.

A similar study was done by Al-Masaeid, (2003) [5] using IRI, PSI and road geometry on rural roads. This study showed that by increasing IRI level or by decreasing PSI, single vehicle accident rate will decrease however it would increase multiple vehicle accident rate. This study also showed that by increasing number. of vertical curves and intersection, the multiple vehicle accident rate increases

Relationship between International Roughness Index (IRI) and crash rate was found by Elghriany et. al., (2016) [14] for rigid pavements in the state of Ohio. It was suggested to use the IRI value of 1.5 m/km in road design for safe traffic flow.

Wang et. al., (2006) [2] examined the effect of speed on road safety. It was found that on signalized intersections high speed limits would result in the rear end crashes.

Chan et. Al., (2009) [3] studied the effect of IRI, rut depth and PSI on crash frequency. Total length of road used was 117 kilometers with maximum speed limit of 88 km/h. This study suggested that rut depth model should not be used for predicting accidents, however roughness and PSI models performed well in predicting crash rate.

Saplioglu et. al., (2012) [9] investigated the effect of skid resistance on road accidents at the intersection of the road. This study showed that with decrease of texture depth, the skid resistance also decreased resulting in high chances of the accidents.

Hussein et. Al., (2016) [6] evaluated the effect of rutting, skid resistance and roughness on traffic safety at signalized intersections. Analysis period of 3,4 and 5 year were selected before and after improving the surface condition. It was seen that after the treatment, accidents due to roughness were considerably low.

Cairney et. al., (2008) [8] investigated the relationship between macro texture, rutting and roughness with crashes for rural roads. The decrease in macro texture (below 1.8mm) increase the traffic accidents and with

the increase in roughness crash rate also increased but only when traffic volume was high.

Cenek et. al., (2014) [7] studied the effect of rutting on crash rate for New Zealand state highway network. This study showed that there was no increase in crash rate with increase in rut depth for dry roads but for wet roads crash rate increased with increase in rut depth.

Noyce et. al. (2007) [4] studied the relationship between asphalt mix design, skid friction and roadway safety. This research showed that for a wet pavement, with the decrease in skid friction, crash rate increased.

The correlation between International Roughness Index (IRI), Skid Number (SN) and Rut depth with crash rate was determined by Alhasan et. al., (2018) [12] between 2006 to 2016. A significant impact of skid number on crash rate was observed.

Sarwar et. al., (2017) [13] studied the effect of International Roughness Index (IR), rutting and Pavement Condition Rating (PCR) on crash rate for two scenario, in first scenario no maintenance or rehabilitation was included and in second scenario routine rehabilitation and maintenance was included. It was found that crash rate was reduced around 85% by routine rehabilitation of the road.

The effect of road lighting on traffic safety was studied by Frith and Jacket (2009) [15] for the region of Australia and New Zealand. Significant crash reduction was found by providing proper light system on roads.

Othman et. al., (2009) [16] investigated the parameters of road that influence crash rate the most. He studied more than 3000 accidents from 2000 to 2005. It was shown that rut depth and roughness were the most affecting parameters.

The impact of efficiency of vehicle braking system on accident rate was evaluated by Bogdevicius and Oleg (2006) [17] for rigid pavements. This study showed that braking distance was about 2 meters longer when initial braking velocity was 40 km/h and about 2.5 meters longer when initial braking velocity was 50 km/h.

Korochkin, (2018) [18] examined the impact of rigid pavement in comparison with flexible pavement on traffic safety in Russia. It was observed that pavement condition of rigid pavement remained good for longer time resulting in lesser accidents. As construction cost of rigid pavements in Russia is very high therefore the researcher suggested using asphalt wearing course on rigid pavement, which will result in better performance and lesser accidents.

The effect of pavement condition on road safety was studied by Mohammad et. al., (2015) [19] for roads in Bauchi. No strong relationship was found between pavement condition and traffic safety, however the road geometry played major role in accident rate.

Relationship between IRI and crash rate was determined by Pulugurtha et. al., (2013) [20] for flexible and rigid pavements. Findings from this research validated the general findings from other researchers that targeting and maintaining IRI less than 1.5 m/km will lower crash rate irrespective of pavement type.

Lee et.al., (2015) [21] investigated the relationship between poor pavement conditions and crash rate for low, medium and high speed roads and single/multiple collision cases. Various factors such as roadway, traffic, and environmental factors affecting crash severity were studied. Among these factors, the poor pavement condition increased the severity of multi-vehicle crashes on all three speed-level roads. However, for the low-speed roads, the severity of single-vehicle crashes decreased as pavement condition became poorer.

The reported studies used different pavement performance parameters, road geometry, visibility of driver, speed of the vehicle and different accident causing factors. No matter which factor they used, relationships were found between pavement performance indicators and traffic safety.

3. Data Collection Method

There are many pavement performance parameters that indicate road condition e.g. friction, Present Serviceability Index (PSI), skid resistance, cracking, rutting, International Roughness Index (IRI) and potholes. For this study three parameters were selected including; International Roughness Index (IRI), rutting and cracking.

Two traffic oriented parameters are considered, one is speed and the other is Road User Cost (RUC). RUC is considered only in terms of fuel and vehicle maintenance cost.

The study area for the research is Bahawalpur city, located in Southern part of the Punjab, Pakistan. Three roads are selected based upon their pavement condition ranging from good to bad condition. The selected roads were Jail road (4.5km), Ahmed Pur road (5km) and Dera Bakha road (5km) with conditions as good, fair, and bad, respectively.

There are many advanced methods for calculation of IRI like quarter car vehicle math model but in the study area only available method was topographic survey with the help of auto level. The level reading was taken at every 50 ft interval. For the calculation of IRI, Average Rectified Slope (ARS) is calculated using Reduce Level

(R.L) reading. By taking the difference of two consecutive readings elevational difference or suspension motion of vehicle for these two points was determined. The elevational difference divided by the distance provided ARS. ARS multiply with 1000 gave IRI in m/km. The average IRI values derived from field data collection were 1.88 m/km, 2.31 m/km and 3.43 m/km for Jail road, Ahmed-Pur road and Dera Bakha road respectively as shown in Fig. 1. Some readings taken in field and their collections are shown in Table 1 for the understanding of procedure.

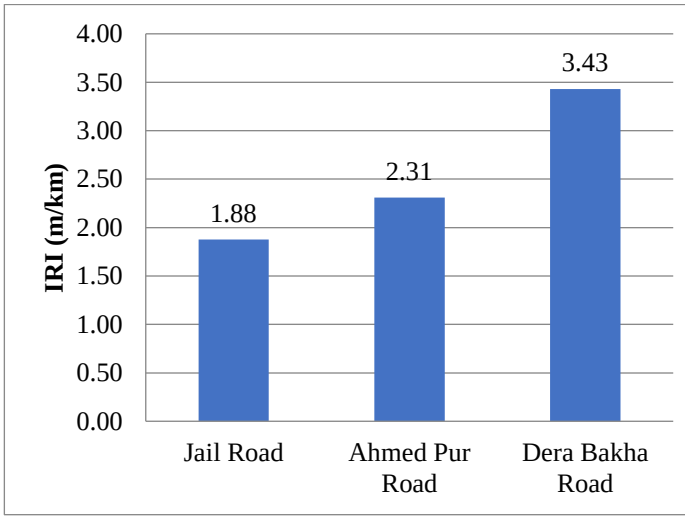

Fig. 1. Avg. IRI values (m/km)

Table 1

IRI values Calculation

R.D	H.I	I.S	R.L	Average Rectified Slope (ARS)	I.R.I (m/km)
	H.I = B.M + B.S		R.L = H.I – I.S	ARS = (Dif of Tw consec. Readings) / 5	I.R.I ARS 1000
	105.86				
0+00		6.68	99.18		
0+50		6.48	99.38	0.00400	4.00
0+100		6.26	99.60	0.00440	4.40
0+150		6.08	99.78	0.00360	3.60
0+200		5.87	99.99	0.00420	4.20

R.D = Reduce Distance **H.I** = Height of Instrument

I.S = Inter Sight **R.L** = Reduce Level

B.M = Bench Mark **B.S** = Back Sight

The rutting was measured using straight edge and inches tape. It was measured at every 50 ft interval. The average rutting values were calculated to be 8.08 mm, 11.06 mm and 19.1 mm for Jail road, Ahmed-Pur road and Dera Bakha road respectively as shown in Fig. 2. Some readings taken in field are provided in Table 2.

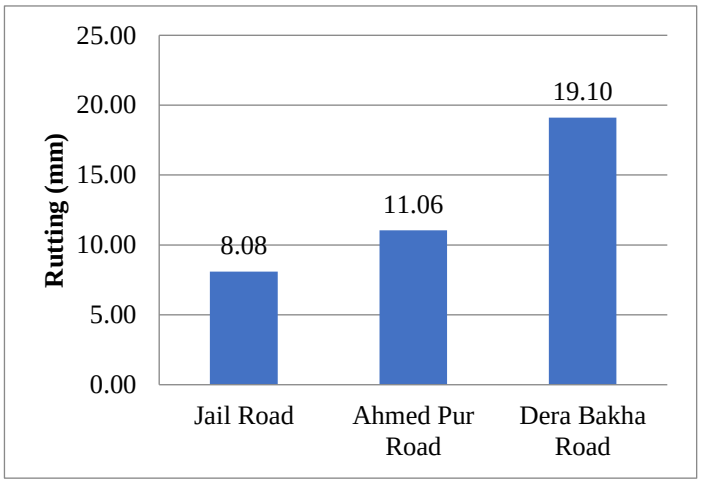

Fig. 2. Rutting values (mm)

Table 2

Rutting values

Sr. Number	R.D*	Rut Depth (mm)	Sr. Number	R.D	Rut Depth (mm)
1	0+00	5	10	0+450	6
2	0+50	3	11	0+500	3
3	0+100	2	12	0+550	6
4	0+150	6	13	0+600	7
5	0+200	4	14	0+650	8
6	0+250	3	15	0+700	5
7	0+300	5	16	0+750	2
8	0+350	5	17	0+800	6
9	0+400	8	18	0+850	8

*R.D = Reduce Distance

The last pavement performance parameter cracking was measured using Pavement Condition Rating (PCR) by visual examination. During visual examination of the road different types of road distresses were observed like rutting, potholes, cracks, wheel track and faulting. The severity and extent of these distresses were examined visually. PCR value ranges from 1 to 100, higher the value better the pavement condition. The calculated values of PCR are 92.7, 64.4 and 40.7 for Jail road, Ahmed-Pur road and Jhangi wala road respectively as shown in Fig. 3. The calculation of PCR values are presented in Table 3 (Annex A).

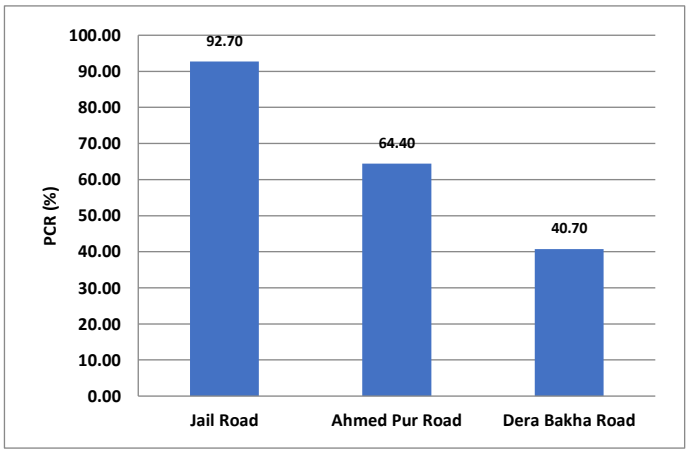

Fig. 3. Pavement condition rating values

After the calculation of pavement performance parameter, the traffic oriented parameters are calculated.

Speed was calculated using a length of 100 ft (30 m) with stop watch and a flag. One observer with a stop watch and other with a flag was standing at the starting and end point. When vehicle passed the first observer, stopwatch was started and when the observer at other end gave the signal with flag, stopwatch was stopped. The time was calculated for different cars and roads. Afterwards speed was calcuated by using the distance and time formula. The average calculated speed values are 45 km/h, 62 km/h and 30 km/h for Jail road, Ahmed Pur road and Dera Bakha road, respectively (Fig. 4).

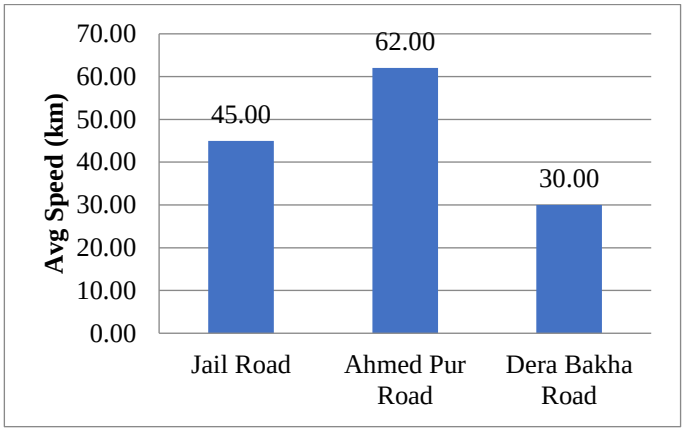

Fig. 4. Average speed values

The Road User Cost (RUC) was used only in terms of fuel cost and vehicle maintenance cost. RUC was determined by using pavement condition, as for good condition vehicle's fuel cost and maintenance cost would be lesser. The road with bad pavement condition, where driver has to apply brakes frequently, the maintenance cost would be higher.

The road accident data was taken from emergency service Rescue 1122 office in Bahawalpur. The data was taken from Jan 2015 to March 2019. The number of accidents for Jail road, Ahmed-Pur road and Jhangi wala road are shown in Fig. 5 and crash trend is shown in Fig. 6.

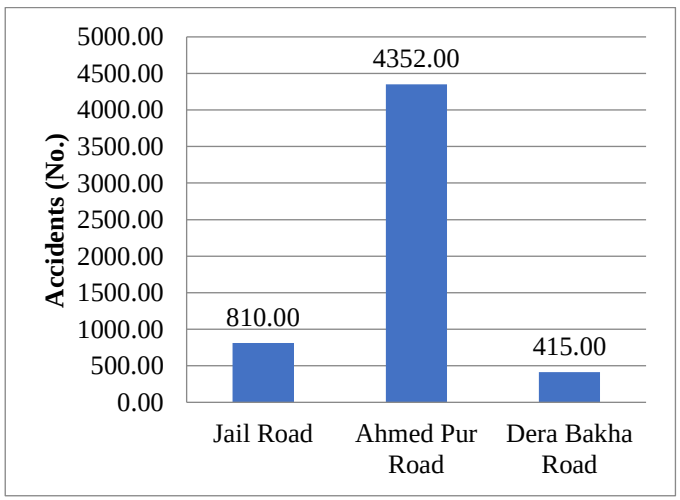

Fig. 5. Number of Accidents

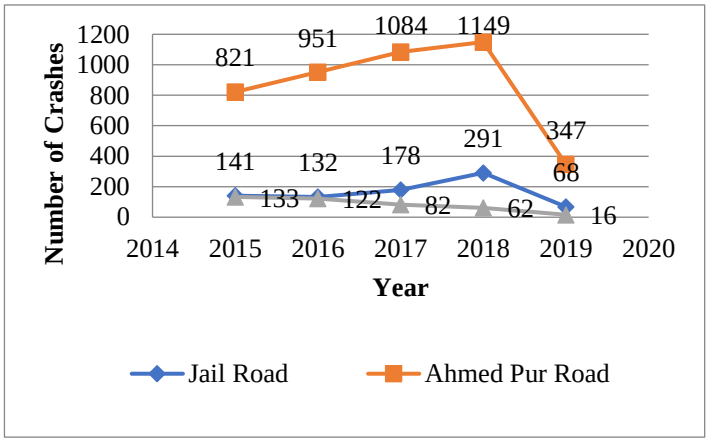

Fig. 6. Crash trend

4. Data Analysis and Discussion

Estimation for determining threshold values of pavement performance indicators for the roads of Bahawalpur, Pakistan has been done in this research paper through its basis on safety and traffic oriented parameters. Three pavement performance parameters; International Roughness Index (IRI), Rutting and cracking and two traffic oriented parameters including Speed and Road User Cost (RUC) are analyzed. The accident data is also considered for determining these threshold values.

Using data calculated for different roads in previous section, comparison models in shape of bar charts and parabolic graphs are developed to link safety, pavement performance indicators and traffic-oriented parameters for better understanding of their relationship.

The comparison between IRI, speed and accident data is shown in Fig. 7, Fig. 8 and Fig. 9 using bar chart and polynomial transformation.

In Fig. 7, for Jail road number of accidents and IRI values are low in comparison with Ahmed Pur road. For Ahmed-Pur road, by increase in the value of IRI there is a drastic increase in accident rate and by further increase in IRI value, number of accidents decreases.

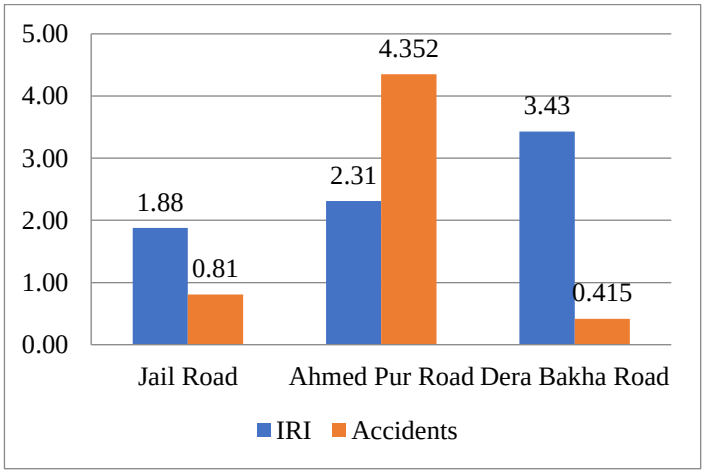

Fig. 7. Bar Chart Comparing IRI and Accident Data (1/1000 Scale)

In Fig.8 with the increase in the value of IRI, the number of accidents also increase but when IRI reaches

the value of 2.65 m/Km number of accidents starts to decrease, forming a parabolic shape curve. This decrease in number of accidents can be due to multiple factors, some of them are discussed below.

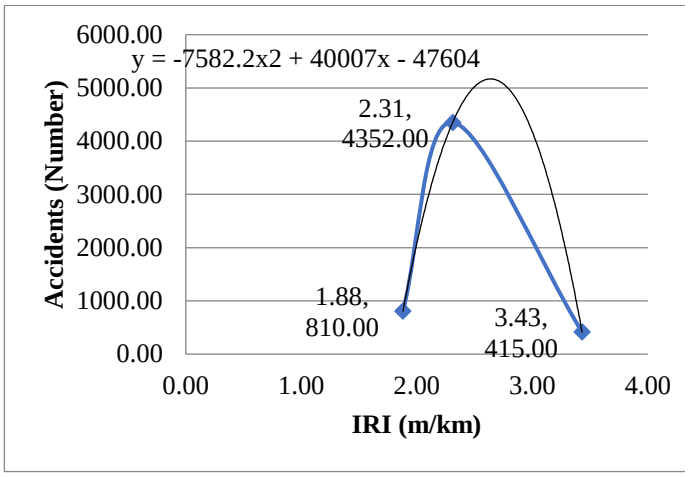

Fig. 8. IRI vs. Accident Data

Dera Bakha road has maximum value of IRI but the number of accidents on this road are minimum. The condition of this road is very bad, and it is full of pot-holes. Due to bad road condition and lesser number of accidents, it can be assessed that driver on these types of roads focus on the obstructions under the wheel which keeps them attentive while driving. When the driver keeps himself attentive while driving, then chances of accident becomes low.

Furthermore, due high number of pot-holes, drivers have to keep the speed of the vehicle very slow (Fig. 10). When speed of the vehicle is slow, driver has more reaction time against the obstruction and requires smaller breaking distance, this results in lesser number of accidents. These two factors explain that this sudden decrease in accident rate is due to driver's behavior on a poor conditioned road but not due to IRI value.

In Fig. 9 a direct relationship between speed and accident rate is found as with the increase in average speed from 30 km/h to 62 km/h, number of accidents increases from 415 to 4352.

There is 0.43 m/km difference between the IRI value of Jail road (1.88 m/km) and Ahmed-Pur (2.31 m/km) road but accident rate difference is very high. Besides that, average speed on Jail road is 45 km/h and on Ahmed Pur road average speed is 62 km/h as shown in Fig 10. From this it is concluded that when IRI value reaches 2.31 m/km and speed of vehicle touches 62 km/h, there is difficulty for drivers to control their vehicle resulting in higher accident rate. Furthermore, as accident rate on Ahmed Pur road is lesser therefore it is concluded that average speed on Ahmed Pur road (45 km/h) is on safer side.

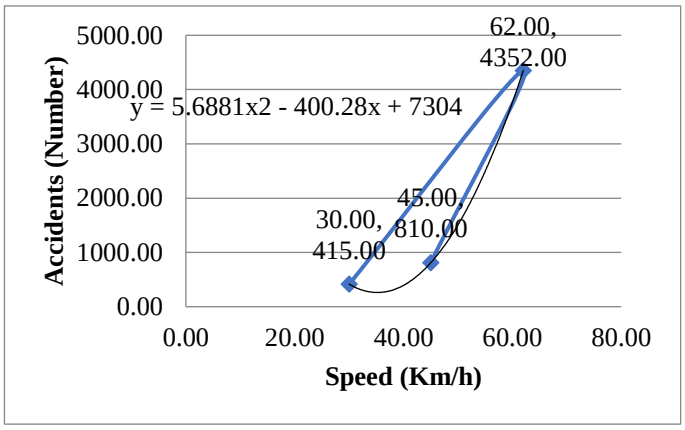

Fig. 9. Speed vs. accident data

The equations derived from Fig. 8 and Fig. 9 are added to develop a new equation (Eq.1) as given below. This equation shows the relationship between IRI, speed and number of accidents.

$$C = -3791.1(IRI)^2 + 20003.5(IRI) + 2.84(V)^2 - 200.14V - 20150 \quad (1)$$

Where

C = Crashes/ Number of accidents

IRI = International Roughness Index (m/km)

V = Speed (km/h)

This equation can be used to determine expected number of accidents of roads having same demographic conditions, by placing the values of International Roughness Index and speed and vice versa.

As an example, assuming that speed is 45 km/h and it is required that number of accidents should not be increased from 200, equation 1 gives the value of IRI 1.78m/km meaning that IRI value should be maintained below 1.78m/km whenever IRI value cross this limit resurfacing should be done for safer traffic flow.

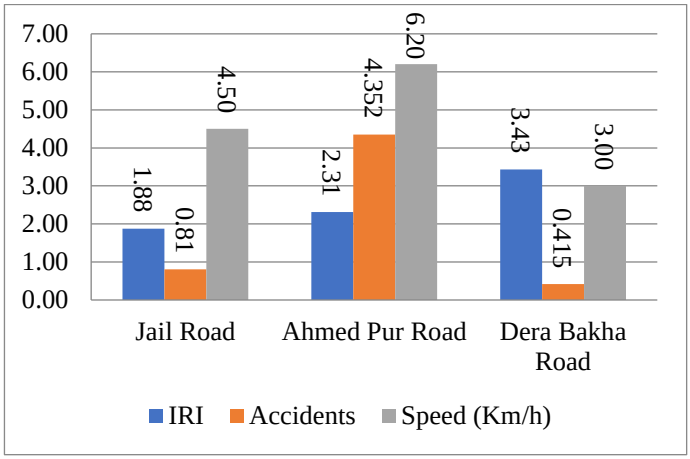

Fig. 10. Bar chart comparing iri, accident data (1/1000 scale) and speed (1/10 scale)

The rutting and accident data is also analyzed as shown in Fig. 11 and 12. From Fig 11, it is shown that for Jail road, Ahmed Pur road and Dera Bakha road rutting values are 8.08 mm, 11.06 mm and 19.10 mm

respectively and their corresponding number of accidents are 810, 4,352 and 415 respectively.

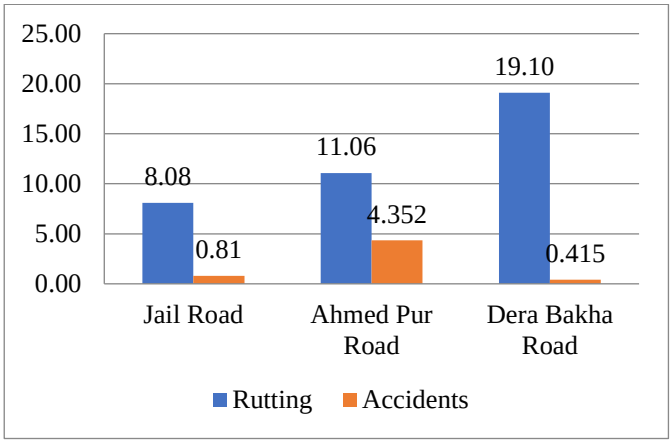

Fig. 11 Bar chart comparing rutting and accident data (1/1000 scale)

A parabolic/ polynomial relationship between rutting and traffic accidents / crash data is depicted in Fig. 12. The rutting values are kept on the independent axis and number of accidents on dependent axis.

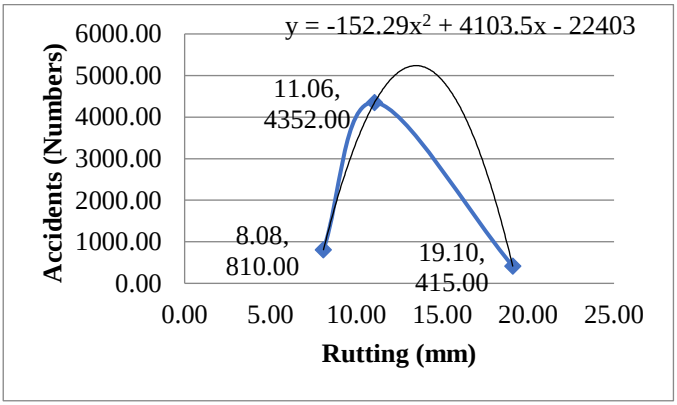

Fig. 12. Rutting vs. accident data

Similar trend is found between rutting and accident data as that of IRI and accident data. The rutting value is increasing as the condition of the road is getting worse.

Starting from Jail road to Ahmed Pur road, number of accident increases with the increase of rutting value. As soon as rutting reaches the value of 13.5 mm, number of accidents starts to decrease with the increase of rutting value which is towards Dera Bakha road. Rutting value of 13.5 mm gives us the maximum number of accidents.

The number of accidents on Jail road are more than that of Dera Bakha road. If number of accidents on Ahmed Pur road are ignored, it can be concluded that number of accidents decreases as rutting increases. This peculiar result on Ahmed pur road may be associated to the fact that Ahmed Pur road is mainly used by passenger traffic, as this road road connects to National Highway 5. The passenger traffic includes vans and buses that travel with higher speed than other type of traffic. It is shown in Fig 13 that average speed on Ahmed Pur road is 62 km/h which is more than allowable speed limit (50 km/h). As the geometry of this road was not designed for the operational speed (62 km/h) therefor number of accidents on this road are more than expected. Also Driver's behavior of this type of traffic is very rash in Pakistan that may result in higher number of accidents.

In order to estimate number of accidents, equations derived from Fig.12 and Fig. 9 are used to develop a new equation (Eq.2). This equation states the relationship between rutting, speed and number of accidents.

$$C = -76.14(R)^2 + 2051.75(R) + 2.84(V)^2 - 200.14V - 7549.5 \quad (2)$$

Where

C = Crashes/ Number of accidents

R = Rutting (mm)

V = Speed (km/h)

Using this equation expected number of accidents can be determined by putting the value of rutting and speed of roads having same demographic conditions and vice versa.

As an example, assuming the same scenario as above, equation 2 gives that rutting value should be maintained under 10mm to meet the required criteria, whenever rutting value will cross this limit, road maintenance/ resurfacing should be required.

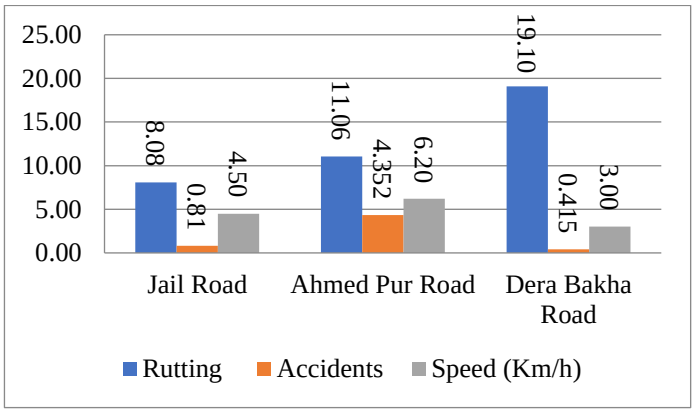

Fig. 13. Bar chart comparing rutting, accident data (1/1000 scale) and speed (1/10 scale)

The comparison between cracks in the form of Pavement Condition Rating (PCR) and accident data is done as shown in Fig. 14 and 15. As show in Fig. 14 PCR value for Jail road, Ahmed Pur road and Dera Bakha road is 92.70, 64.40 and 40.70 respectively.

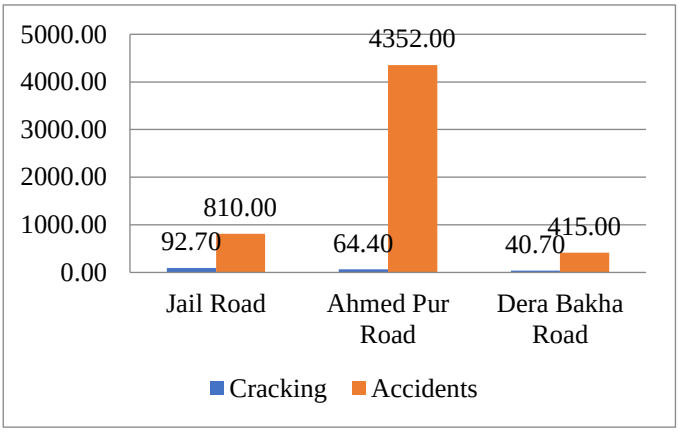

Fig. 14. Comparison of PCR and accident data

The Pavement Condition Rating (PCR) and number of accidents are shown in Fig. 15. Quadratic relationship is found to be fitted between these variables. Initially, with the increase in PCR value, number of accidents is also increased, however when PCR reaches the value of 68, number of accidents starts to decrease with the increase in PCR value.

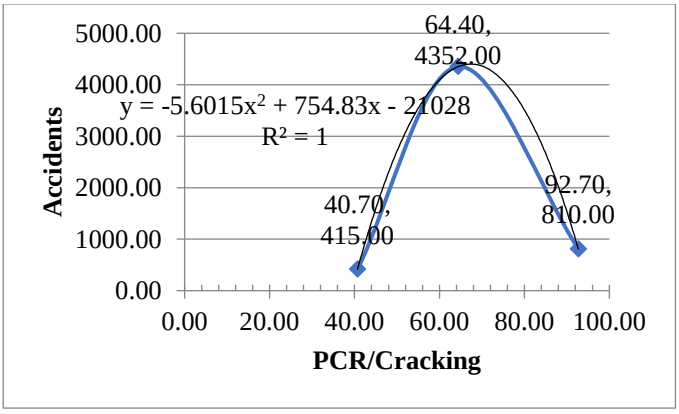

Fig. 15. PCR vs. accident data

This sudden increase in number of accident on Ahmed Pur road can be explained as there is no proper road lighting system on Ahmed Pur road, while Jail road and Dera Bakha road have proper road lightning system. Improper road lighting can be the reason for maximum number of accidents on Ahmed Pur road. It was found by Frith and Jacket (2009) that there is a significant crash reduction by providing proper road light system.

In addition to this, the absence of law enforcement is observed on Ahmed pur road. No traffic warden is found on this road due to which traffic is not organized and it promotes traffic mishaps or roadway accidents.

Hence improper road lighting and absence of law enforcement can be the main reasons for maximum number of accidents on Ahmed Pur raod apart from cracking.

A new equation is developed (Eq.3), by adding the equations derived from Fig. 15 and Fig. 9. This equation shows the relationship between cracking, speed and number of accidents.

$$C = -2.80(PCR)^2 + 377.41(PCR) + 2.84(V)^2 - 200.14V - 6862 \quad (3)$$

Where

C = Crashes/ Number of accidents

PCR = Pavement Condition Rating/ Cracking

V = Speed (km/h)

Using this equation expected number of accidents can be determined by putting the value of PCR and speed of roads having same demographic conditions.

Maximum number of accidents and maximum average speed of traffic was observed on Ahmed Pur Road as shown in Fig. 16 against PCR value of 64.40. PCR value of the road can be sustained by regular maintenance of the road. Higher the PCR value results in better pavement condition. Better pavement condition will result in lesser number of accidents.

By using the equation 3 it is found that PCR value of road should be maintained under 75 for safer traffic flow by regular maintenance work.

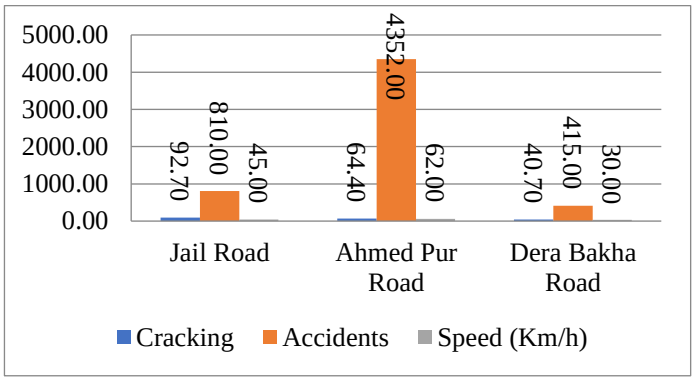

Fig. 16. Bar chart comparing PCR, accident data and speed

5. Conclusions

Relationship between Pavement Performance Indicator (IRI, rutting and cracks), traffic oriented parameters (Speed) and roadway safety are tried to be found in this study. Based upon the analysis, following conclusions can be made. can be concluded

a. A change in crash rate was observed by change in value of pavement performance indicator, Parabolic models/ equations are developed which can be used by the road designers for assessing the value of IRI, rutting and cracking for safe traffic flow.

b. Some values/limits are also suggested for IRI, rutting and cracking which can be used as evaluation criteria whether the road needs rehabilitation or not. If the Pavement Performance Indicators cross these suggested values then road will be needing rehabilitation The suggested values are as follow

   i. IRI = 1.78 m/Km

   ii. Rutting = 10 mm

iii. Cracking (PCR) = 75

c. The speed limit of 45 Km/h is recommended to use on the roads within the city for safe traffic flow.
d. The Road User Cost (RUC) is also affected by the condition of the road; worst the condition higher will be RUC.

6. Recommendations

Specific reason for higher number of accidents cannot be assessed by using only three pavement performance indicators, therefor a vast study needs to be done by using more factors like skid resistance, texture depth, driver/ human behaviour, environmental effects etc.

To find out the more accurate permissible limits of pavement performance indicators similar study needs to be done by using larger number of roads for same pavement condition covering all the traffic type, speed variations etc.

7. References

[1] "Traffic accident report No.388", Government of Punjab Pakistan, Punjab, 2017-18

[2] A. Aty and W. Wang, "Crash estimation at signalized intersections along corridors", Transportation Research Board, pp. 98-111, Dec 2006.

[3] C. Y. Chan, B. Huang and S. Richards, "Effects of asphalt pavement conditions on traffic accidents in tennessee utilizing pavement management system", Advanced Transportation, Vol. 44, pp. 150-161, July 2010.

[4] D. A. Noyce and H.U. Bahi, "Incorporating road safety into pavement management", Dept of Civil Engg., University of Wisconsin., Madison, Report No. MRUTC 04-04, 2007.

[5] H. R. Al-Masaeid, "Impact of pavement condition on rural road accidents", Canadian Journal of Civil Engineering, Vol. 24, pp. 523-531, Jan 2003.

[6] N. Hussein and R. Hassan, "Surface condition and safety at signalized intersections", International Journal of Pavement Engineering, Vol. 10, pp. 83-91, Apr 2016.

[7] P.D. Cenek, A. Henderson and Forbes, "The relationship between crash rates and rutting", NZ Transport Agency, New Zealand, Report No. 545, 2014.

[8] P. Cairney and P. Bennett, "Relationship between road surface characteristic and crashes on victorian Rural roads", in ARRB 23rd Conf., Australia, 2008.

[9] M. Saplioglu, "Investigation skid resistance effects on traffic safety at urban intersections", in 10th international congress on advances in civil engineering, Australia, 2012.

[10] S. Najafi, G.W. Flintsch and A. Medina, "Linking roadway crashes and tire pavement friction", International Journal of Pavement Engineering, Vol. 51, pp. 231-237, Jan 2015.

[11] Kuleno, M. Mena, D.K. Kuma and R.R. Reddy, "Evaluating the impacts of pavement surface defects on traffic safety. A case study between Arba Minch to Zeyise Wozeka road Ethiopia", International Journal of Research and Analytical Reviews (IJRAR), Vol. 6, pp. 1256-1263, Jan 2019.

[12] A. Ahmad, I. Nlenanya, O. Smadi, and C. MacKenzie, "Impact of Pavement Surface Condition on Roadway Departure Crash Risk in Lowa", MDPI Journal / Infrastructures, pp. 3-14, June 2018.

[13] Sarwar, M. Tawfiq and P. C. Anastasopoulos, "Effect of long term non-invasive pavement deterioration on accident injury-severity rates. A seemingly unrelated and multivariate equations approach", Analytic methods in accident research, Vol 13, pp. 1-15, Oct 2017.

[14] A. Elghriany, P. Yi. Ahmed, P. Liu, and Q. Yu, "Investigation of the effect of pavement roughness on crash rates for rigid pavement", Journal of Transportation Safety and Security, Vol 10.1080, Apr 2016.

[15] W.J. Frith, and M. J. Jackett, "Road lighting for safety - a forward looking, safe system based review", Australasian Road Safety Research, pp. 10-13, Nov 2009.

[16] Othman, Sarbaz, R. Thomson, and G. Lannér, "Identifying critical road geometry parameters affecting crash rate and crash type", Association for the Advancement of Automotive Medicine, Vol. 51, Jan 2009.

[17] Bogdevicius, Marijonas and O. Vladimirov, "Efficiency of a braking process evaluating the roughness of road surface", Transport, Vol. 44, pp. 113-119, Mar 2006.

[18] K. Andrey, "Impact of rigid pavements with the asphalt-concrete wearing course on road performance and traffic safety", Transportation research board, Vol. 36, pp. 315-319, Apr 2018.

[19] A. Mohammed, S.Y. Umar, D. Samson, and T.Y. Ahmad, "The Effect of Pavement

Condition on Traffic Safety: A Case Study of Some Federal Roads in Bauchi State", IOSR Journals, Vol. 10.1061, Jan 2015.

[20] Pulugurtha, S. Srinivas, V. Ogunro, M.A. Pando, K.J. Patel, and A. Bonsu, "Preliminary results towards developing thresholds for pavement condition maintenance", safety perspective, Procedia Social and Behavioral Sciences, Vol. 33, Dec 2013.

[21] Lee, Jaeyoung, B. Nam and M.A.Aty, "Effects of pavement surface conditions on traffic crash severity", Journal of Transportation Engineering, Vol. 10.1061, Jan 2015.

[22] A. Wolters and K. Zimmerman, "Implementing pavement management systems for local agencies", illusion center for transportation, Series no. 11-094, pp. 63, 2019.

Table 3

PCR values

Reprinted from “Pavement condition rating form” by Angela Wolters and Kathryn Zimmerman, Implementing Pavement Management Systems for local agencies, 2011 illusion center for transportation series no. 11-094 pp. 63, Fig. 45.

AHMED PUR ROAD, BAHAWALPUR - LENGTH 5KM

Distress Type	Distress Weight	Severity			Extent			Total
		L	M	H	O	F	E	
Raveling (Flexible / Composite)	10	0.3	0.6	1	0.5	0.8	1	0
Bleeding (Flexible / Composite)	5	0.8	0.8	1	0.6	0.9	1	0
Corrugations (Flexible)	5	0.4	0.8	1	0.5	0.8	1	0
Rutting (Flexible / Composite)	10	0.3	0.7	1	0.6	0.8	1	5.6
Potholes / Debonding (Flex. / Comp.)	10	0.4	0.7	1	0.5	0.8	1	2
Patching (All Pavement Types)	5	0.3	0.6	1	0.6	0.8	1	0.9
Settlement (All Pavement Types)	10	0.5	0.7	1	0.5	0.8	1	2.5
Crack Seal Deficiency (Flex. / Comp.)	5	1	1	1	0.5	0.8	1	5
Wheel Track Cracking (Flexible)	15	0.4	0.7	1	0.5	0.7	1	7.35
Longitudinal Joint Cracking (Flex.)	5	0.4	0.7	1	0.5	0.7	1	2.45
Longitud. Cracking (Comp. / JC / CRC)	5	0.2	0.6	1	0.4	0.8	1	0
Edge Cracking (Flexible)	5	0.4	0.7	1	0.5	0.7	1	2.45
Random Cracking (Flexible)	5	0.4	0.7	1	0.5	0.7	1	2.45
Block and Transverse Cracking (Flex.)	10	0.4	0.7	1	0.5	0.7	1	4.9
Transverse Crack (Comp. / JC / CRC)	15	0.4	0.7	1	0.5	0.8	1	0
Pumping (Comp. / JC / CRC)	15	0.4	0.7	1	0.3	0.7	1	0
Faulting (Jointed Concrete)	10	0.4	0.7	1	0.5	0.8	1	0
Surface Deterioration (JC / CRC)	10	0.4	0.7	1	0.6	0.8	1	0
Total Deduct								35.6
100 - Total Deduct = PCR								64.4