Investigation of the Skid Resistance at Accident Occurred at Urban Intersections

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Abstract: Skid resistance of road surface plays an important role on urban traffic accidents. It is thought that reduction of surface microtexture leads to reduced skid resistance. Hence, it affects driving safety negatively and may cause traffic accidents. This paper is about the effect of skid resistance and intersection safety. Urban four leg signalized intersections were selected from Isparta city. The surface frictional properties were measured and it was tried to find critical skid resistance value with the help of British Pendulum Tester. Macro texture values of the intersections were determined with Sand Patch test and concluded that surface macro texture contributes to skid resistance. An analysis technique based on probability theory has been used. This method is used for expounding the interaction between skid resistance-intersection and accident rates. After the study results are evaluated, it is understood that pavement roughness is very important for urban intersection safety measures.

Key words: Microtexture skid resistance, macrotexture, intersection safety, traffic accidents.

1. Introduction

Traffic accidents are of great concern for road and transport departments around word, because they cause vital loss and dangers for the public. Also, traffic safety is the most important responsibility of anyone involved in urban road transportation. This applies at all stages from initial design, selection of materials, road geometric design to use of the road by the user.

Most of studies proved that extremely many accidents occurred at-grade intersections although intersections cover only a small part of the highway system. From many research studies in the United States, it has been identified that 50% of the total accidents happened at intersections [1]. Also, statistics prepared by the Ministry of Transport in New Zealand show that rural crashes are dominated by loss of control incidents whereas urban crashes are dominated by incidents at intersections [2]. However, according to statistics in Turkey, 40%-60% of traffic accidents are in urban and rural road junctions [3]. So, urban intersection safety research studies are necessary studies for urban transportation systems.

Road engineers and users are also particularly concerned with the safe passage of vehicles that operate over them. One aspect of this safety is that there be adequate traction or friction between tyre and road surface to sustain driving forces and to allow stopping within safe limits [4]. This aspect of safety is tackled under the general designation of skid resistance. The skid resistance of the surface of a pavement is one of the important factors in determining the overall safety of an intersection.

The phenomenon of pavement surface skid resistance involves the complex interaction of pavement, vehicle and environmental factors [4]. In addition to this, intersection accidents are generally uncontrolled events and are dependent on a number of

inter-related factors such as driver behavior, traffic conditions, travel speed, intersection geometry and environmental condition, and vehicle characteristics. So there are many parameters that affect the safety of an intersection.

To investigate the interaction of pavement roughness (micro or macro roughness: skid-resistance or pavement texture depth) and urban intersection safety, all effecting factors about intersection crashes must be considered together or, conversely it can be said that if at selected intersections measured values about affecting factors, excluding skid resistance, are provided as close or same values, it will be possible to identify the relationship between skid resistance and intersection accidents. So, in this study firstly the intersections, whose geometries, approaching speeds and environmental conditions are similar to each other, has been selected.

Then, traffic accident reports were gathered, firstly some geometric and traffic volume measurements were taken from 10 urban signalized intersections in Isparta. Five of these intersections were selected by using the collected data. Microtexture and macrotexture values of these intersections were measured and with probability based approach, it is tried to identify the relationship between skid resistance and intersection crashes.

2. Evaluation of Previous Studies and the Importance of Skid Resistance

At urban road networks, safety characteristics of a pavement is one of the measures of its condition, and in developed countries, highway agencies continually monitor this aspect to insure that roadway sections are operating at the highest possible level of safety. It is an example that the UK skidding policy has been place for the past 40 years and specifies an investigatory level of skid resistance dependant on safety and risk.

A number of devices are used in UK to measure skid resistance. They measure road surfaces using SCRIM (Sideway-Force Coefficient Routine Investigation Machines), Grip Tester or the pendulum. In a laboratory, skid resistance of the coarse aggregate is assessed using the PSV (polish stone value) test with the Wehner Schulze and Road Test Machine devices currently being assessed to assess asphalt mixes [5].

To obtain accurate results from the studies and to give decision about safety at road urban sections, data must be regular. In previous studies according to this aim, different test methods were used for collecting data. For instance, Woodward et al. [6] considered the development of skid resistance for a SMA (stone mastic asphalt) surface using high PSV (polish stone value test) greywacke aggregate and polymer-modified bitumen. The SMA surface has been periodically measured using a Grip Tester to determine how skid resistance has developed from early life through to mid life. They found that the combination of aggregate and bitumen has a significant effect on skid resistance during the early life of asphalt surfacing materials.

In other studies, locked-wheel trailer methods are used to evaluate skid resistance of highway surfaces according to ASTM E274 procedure. From the measured resistance force, the SN (skid number) is calculated. Another skid resistance evaluation procedure is by the use of the yaw mode system. In this system, the wheels are turned at some angle to the direction of motion. The side or cornering forces are measured and transformed into skid numbers [7].

Fenech [4] conducted a study on the nature of skid resistance, with particular reference to the fundamentals of the tyre-pavement friction mechanism and pavement skid behavior. The study concluded that among the characteristics of the road surface, the micro-roughness has most considerable influence on the skid resistance.

The texture at macro scale is required to remove on a wet road surface, especially at higher vehicle speeds, the water from the contact area between the tyre and

the road surface. The macro texture is determined by the size of the aggregate particles at the road surface. The micro texture is determined by the roughness and angularity of the surface of the aggregate particles. The micro texture ensures the removal of the last traces of water from those locations where high contact pressures between the aggregate and the tire are present [8].

In accordance with ASTM Standard E303 the Portable British Pendulum Tester is also commonly used [7, 9] for micro roughness measurements. The British Pendulum Tester is a dynamic pendulum impact type tester which is based on the energy loss occurring when a rubber slider edge is propelled across a test surface. The values measured are referred to as BPN (British Pendulum (tester) numbers) for flat surfaces, and PSVs for specimens subjected to accelerated polishing.

In a region study, adherence test with Vialit plate, Nicholson stripping test, accelerated polishing test (PSV) were carried out on four aggregate samples which were used in seal coats and hot mix asphalt in Afyonkarahisar City. Results were compared with values of specification limits. The results showed that particularly limestone aggregates polishing stone values were poorer than volcanic aggregates sample. Especially, use of aggregates having a good polishing resistance would be an important factor increasing driving safety [10].

There are some studies about effects of skid resistance on road accidents. Şengöz et. al. [11] would like to evaluate the friction characteristics on the urban roads of Izmir by way of Dynamic Friction Tester as well as build a relationship between the traffic accidents and measured parameters. They found that road surface characteristics and traffic safety improvement works have a great importance on traffic safety.

Most of research results are consistent in indicating that wet pavement conditions significantly increase the number of crashes and statistically significant negative correlations of skid resistance values and pavement accident rates have been found [12-15].

Nowadays, vehicle speeds have also increased due to the developing technologies. However, surface texture features are not sufficient for those increasing speeds. The interaction between wheel and pavement (tire-pavement interface) is decreasing as a result of the high speeds, moreover, it vanishes during the rainy weather conditions. A study conducted in England produced that improving skid resistance value of the pavement for 10% provided a 13% reduction in traffic accidents occurring in rainy weather [16]. In other words, the number of accident numbers change as a result of the road surface conditions. Xiao et al. [17] have showed that rising of road surface skid resistance value from 35% to 48% makes a 60% decrease in traffic accidents.

Safety analysis studies show that there are many factors that affect pavement surface friction. It is indicated that traffic level, highway class, pavement age and percent of air voids in the asphalt mix have significant effects on pavement friction. Also, wet pavement has an important effect. Pavement skid resistance is reduced as a pavement gets older. In addition to this, when the water film on a pavement is of a certain thickness, vehicles may hydroplane, i.e., the tires may be separated from the pavement by the water wedge formed between the tire surface and the pavement surface. Total hydroplaning occurs when fluid pressure forces (generated as a result of change in momentum of the fluid particles) in the water-wedged region exceed the total downward load on the tire [18].

The study by Ryell et al. [19] reported that the rate of wet accidents (number of wet-weather accidents per 100 million vehicle-miles) increased from about 27 at an average skid number of about 55, to about 75 at an average skid number of about 25. The results of another study [20] reported the significant reduction in the percent of wet-pavement accidents from 78% to 30% due to increasing the pavement coefficient of

friction from 0.20 to 0.45 by applying surface grooving.

Salt [21] concluded that whilst a surface with a friction coefficient of 0.60 and above might by chance be a scene of an accident in which a vehicle skids in wet weather, the risk that it would be the scene of repeated skidding accidents was extremely small. This risk first became measurable with a coefficient of 0.55 to 0.60 and increased sharply by more than 20 times as the coefficient fell to values of 0.40 to 0.45 and by about 300 times when the coefficient was 0.30 to 0.35. A study conducted on the streets of Muscat indicated minimum skid number of 0.45 on normal sites [22]. Another study [23] concluded that pavement with skid number below 26 were very slippery and had to be corrected.

In Saudi Arabia Al-Mansour [24] investigated the effects of pavement skid resistance on traffic accidents. The analysis included establishing relationships between skid resistance and accident number, accident significance and accident density. It was determined that a decreasing skid resistance leads to an increase in traffic accidents. A critical value of skid resistance was also established based on number, significance and density of accidents. As Al-Mansour [24] indicated, there are no standards agreed upon which define minimum acceptable skid resistance levels. Several studies have been conducted to develop criteria for critical skid resistance levels.

In the study of Piyatrapoomi et al. [25], it is again denoted that the number of crashes increases as the skid resistance of a road decreases. Piyatrapoomi et al. [25] added that regression analysis, correlation analysis and other types of analysis methods including one-table or two table analysis methods commonly used methods for assessing the relationship between road crashes and skid resistance [26-29]. These methods provided mixed results and were not conclusive due to the variation in crash data and skid resistance data and Piyatrapoomi et al. [25] structured their study in two parts. The first part presented the results of regression analysis. The results confirmed

the trend that crashes increased when skid resistance decreased. However, the coefficient of correlation (r^2) values were very low. Thus, it is indicated that as it had been found by previous studies, the regression functions could not be provided confidence in the relationship. In the second part of the study, probability-based method was used and the results of a case study showed the relationship between road crashes and skid resistance.

Generally, most of previous studies included only highways that had a uniform roadway width and shoulders. Also, in these studies as segments with intersections had been excluded from the studies. So although the importance of maintaining adequate levels of pavement friction to safeguard road safety is generally accepted, previous research results on the interaction between skid resistance and urban intersection accidents are scarce.

3. Study Objectives

According to previous studies, the principal measure of pavement safety is skid resistance. In developed countries, skid resistance data are collected regularly to evaluate the effectiveness of a pavement in preventing or reducing skid related accidents. However, in developing countries, skid resistance data are not collected regularly especially at urban intersections.

In Turkey, the effect of surface defects are not determined in urban intersections, also are not included in the accident reports or other urban data collection system. Thus, defects caused by road characteristics are ignored while calculating the accident statistics. According to statistical data in Turkey, it is reported that 1% of the accidents occurred due to the defects of the road and environmental conditions. Yet, in other countries defects of the roads and environment cause 20%-30% of the road accidents, also in the US the percentage rises up to 36% [30]. According to Lum and Reagan [31] about 34% of serious crashes had contributing

factors related to the roadway or its environment. This comparison does not show that road geometries or pavement roughness in our country are much better than in developed countries; Conversely, it reveals the deficiencies about skid resistance and other road geometric measurements.

There is a need for skid resistance studies at intersections which are not enough for developing countries like in Turkey. According to this belief, the main objective of this study is to identify the relationship between skid resistance and urban intersection crashes.

The other objectives of this study are as following:

• to determine the importance of collecting pavement surface measurement data for urban signalized intersection;

• to collect micro and macro texture measurements of pavement from selected intersections using British Pendulum Tester and sand patch method;

• to identify the exact locations of the traffic accidents and to match them with pavement skid resistance measurements.

4. Field Study

It is clear that the skid resistance and safety study

analysis would be complicated due to the quantity and complexity of the variables affecting the intersection accidents. Large number of variables play a significant influence on the values of accident rates. One main difficulty encounters in the analysis is that selecting the intersections which must have the same properties, more than one factor is different for most of intersections so direct judgment is further complicated.

In order to achieve the objective, firstly pavement production dates of intersection were obtained from Isparta Municipal Department of Technical Services (shown in Table 1). Also, some remarkable results have been achieved. Information has been obtained for 10 signalized, four leg intersections whose pavement life were same in Isparta.

Other effective parameters such as intersection traffic value, intersection geometries, intersection approaching speeds and control systems were considered and some geometric measurements were taken from the field of 10 signalized intersections. The intersection traffic volumes were measured with hand cameras, and volumes were evaluated, then the horizontal angles measurements of all for legs, the slope values, traffic island and refuge geometries and

Table 1   Intersection details for analysis (crash rates are only for accident occurred legs from selected intersections for five years period).

Intersection name	Leg number	Pavement type	Pavement age (years)	AADT	Crash Rate (number of crashes/per million veh.)
102-160-180 st.	4	Hot-mix asphalt	6	Leg No. 1: 5,760 veh/day Leg No. 2: 3,460 veh/day Leg No. 3: 7,200 veh/day Leg No. 4: 4,608 veh/day	Leg No. 1: 1.9 Leg No. 3: 1.52 Leg No. 4:0.59
102-103 st.	4	Hot-mix asphalt	6	Leg No. 1: 5,040 veh/day Leg No. 2: 2,520 veh/day Leg No. 3: 6,300 veh/day Leg No. 4: 2,016 veh/day	Leg No. 1: 2.17 Leg No. 3: 6.53
154-109-102 st.	4	Hot-mix asphalt	6	Leg No. 1: 5,440 veh/day Leg No. 2: 2,720 veh/day Leg No. 3: 6,800 veh/day Leg No. 4: 2,176 veh/day	Leg No. 1: 2.01 Leg No. 2: 2.01 Leg No. 3: 1.61
105-135 st.	4	Hot-mix asphalt	6	Leg No. 1: 3,520 veh/day Leg No. 2: 1,760 veh/day Leg No. 3: 4,400 veh/day Leg No. 4: 1,408 veh/day	Leg No. 3: 0.96
110-111-129 st.	4	Hot-mix asphalt	6	Leg No. 1: 3,650 veh/day Leg No. 2: 5,670 veh/day Leg No. 3: 4,900 veh/day Leg No. 4: 2,600 veh/day	Leg No. 1: 0.75 Leg No. 2: 0.48 Leg No. 3: 1.12

approaching speeds were measured. Also environmental conditions of intersections were taken into account. After evaluating measurements, five signalized intersection were selected which have closest measurement values to each other about intersection geometry, approaching speed. Table 1 shows the selected five intersections' characteristics for the analysis. Accidents that have same coordinates for each intersection legs were used for the analysis. Each leg of intersection and their traffic volumes are shown in Table 1 and accident rates were calculated by using Eq. (1). Pline [32] and Koldemir [33] had indicated that this formula could be used for getting accident rates at intersections.

It is important to indicate that selected intersections' capacities are very different each other. It is not possible to find same traffic volumes for each intersection and each leg. To take into account of traffic capacities in five selected intersections, instead of accident numbers, accident rates are used with the help of Eq. (1). Then it became possible to investigate pavement roughness with considering traffic volumes.

$$AR = (AN \times 10^6)/(AADT \times 365) \qquad (1)$$

where, AR, AN and $AADT$ are accident ratio (for million vehicle), annual accident number and annual average daily traffic, respectively.

Traffic accident reports are gathered from City of Isparta Traffic Control Branch Office for five years (2007-2011) and selected intersection accidents were investigated. The types of accidents are fatal, injury and property damage. According to accident reports, the coordinates of accident locations are found. Then the locations of each accident were determined at the selected intersection legs from the accident records.

Generally, recent studies are based on data from a specific road network of the country where the study is performed. The data parameters have been used from international reference. Also, in most published research results refer to the two most common skid resistance measurements: SN and SCRIM [15]. One

of the most popular procedures which are used to evaluate the friction resistance of the road surfaces is the Portable British Pendulum Tester. It gives values in SN (Skid Number) and measures in accordance with ASTM Method E-303. The BPT (British pendulum tester) is a dynamic pendulum impact type tester which is based on the energy loss occurring when a rubber slider edge is propelled across a test surface. While micro roughness of pavement surface texture is measured with BPT, macro roughness of texture is measured using the Sand Patch Method in accordance with ASTM Method E-956 [34] for selected intersection.

Fig. 1 is an example of photos taken while getting measurements. Although in selected intersection legs' pavement ages were same, measured texture values were very different. It is mostly because of the traffic capacities on the intersection legs and shows again the important effect of intersection traffic volume on safety measures. Traffic volume not only directly affects on intersection safety but also affects the pavement texture and to traffic accidents as well. Because of this while analyzing the results, instead of accident numbers, accident rates (accident no per vehicle) have been used.

5. Research Methodology and Analysis

The objective of this study is identifying the relationship between skid resistance and urban intersection crashes. A probability-based method is used for explaining the relation about skid resistance. This method was firstly used by Piyatrapoomi et al. [25] for identifying relationship between skid resistance and road crashes, it was used for a road length of approximately 169.9 km. But they had not used this method for intersections. In this study, probability-based method is used only for urban signalized intersections differently from the study of Piyatrapoomi et al. [25].

For identifying the relationship between road crashes and skid resistance, firstly a common method

Fig. 1   An example of photos taken while getting measurements.

(i.e., regression analysis) is performed. The result of the regression analysis is shown in Fig. 2. This approach has been performed between micro texture measurements (SN values) and intersection accident rate for each leg of selected five signalized intersections which have closest measurement values to each other about intersection geometry and approaching speed. Fig. 2 shows the plots of relationship between intersection crashes occurred on intersection legs for 2007 to 2011 and measured skid resistance values.

In Fig. 2, regression line shows that there is a trend while the skid resistance decreases intersection accidents increase for these five year periods. But, low (r^2) values indicated that there is a high variation in the crashes and pavement roughness data and the relationship between road crashes and pavement roughness cannot show conclusions with confidence, just like the study of Piyatrapoomi et al. [25] as it was told in previous studies Part 2.

After getting this unsatisfactory result, an analysis technique based on probability theory is used. In this analysis, five selected signalized intersections which have very close properties used again, to ensure that

the pavement roughness data can be described by probability distribution.

As it is known it is often helpful to look at probability distribution in graphic form. Instead of probability histogram, in order to interpret effectively, CDF (cumulative distribution function) is used. In probability theory and statistics, CDF describes the probability that a real-valued random variable X with a given probability distribution will be found at a value less than or equal to x as shown in Eq. (2). The cumulative distribution function completely describes the probability distribution of a real-valued random variable, X [35]. For every real number x, the CDF is given by:

$$F(x) = P(X \le x) \tag{2}$$

where, the right-hand side represents the probability that the random variable X takes on a value less than or equal to x. The cumulative distribution is a non-parametric distribution with a wide variety of applications [25, 36] and it is very useful to model an expert's opinion of a variable whose range covers several orders of magnitude in some sort of exponential way, for example, the size of impact on insurers of a large earthquake, the financial impact of
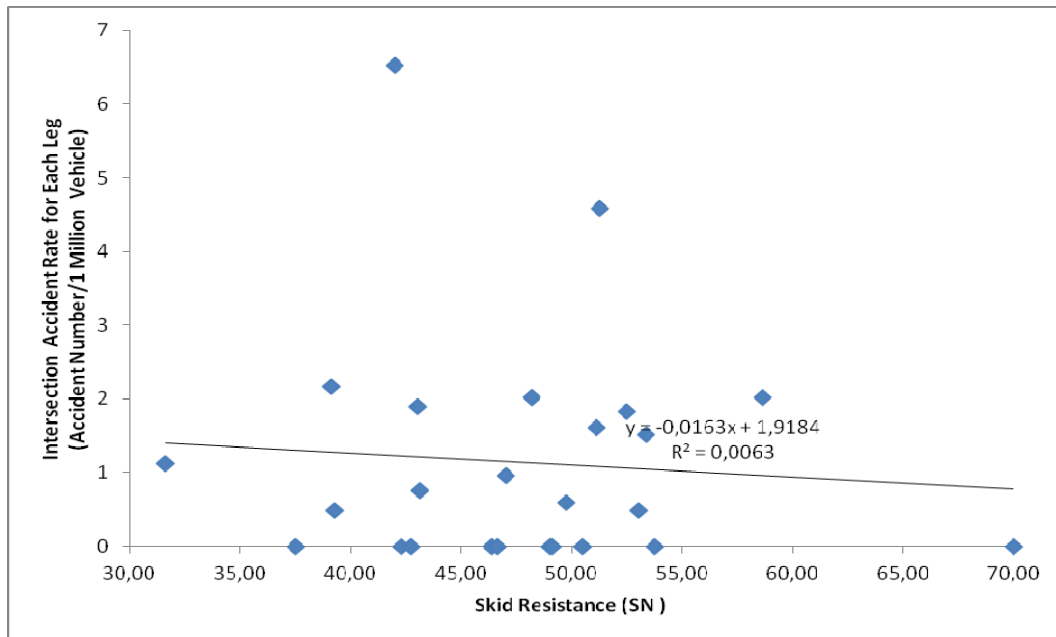
Fig. 2   Relationship between intersection accidents and skid resistance for selected signalized intersections in City of Isparta.

a market crash, or some other extremal event for which that are no relevant data with which to estimate the variable. In such circumstances, it is fruitless to attempt to use a relative distribution directly [37].

Consequently, with this technique it is aimed to assess the degree of variation of skid resistance at intersection legs and assessing this variation characteristic with intersection crashes. So the cumulative probability distribution of five signalized intersections (only accident occurred at legs are selected) for five years, skid resistance data and texture depth values are shown in Figs. 3 and 4.

Variability of skid resistance for each intersection leg is quantified. Then the cumulative probability distributions of accident rates for skid resistance data are showed in Fig. 3. In the light of Fig. 3, acceptable percentage of crash rates can be expounded and can identified the probability distributions of skid resistance. For example, when the skid resistance number is 53.5, probability of accident occurrence rate shall be 15%. Also, while skid resistance number is 38, probability of accident occurrence will be 85%. A thorough analysis can be conducted using the probability distribution method in assessing the

characteristics of cumulative probability distribution of skid resistance and crash risk for different site conditions of intersection approach. Because the results of the analysis show similarities with the previous studies like the study of Ryell et al. [19] that was given in Part 2.

As it is known from the previous studies, macro scale is required to remove on a wet road surface, the water from the contact area between the tyre and the road surface. So it does not directly affect on intersection safety but it affects on pavement friction. Also, friction can be important for intersection approaching speeds. So same analysis was carried out as in Fig. 4 for texture depth data which were gathered from sand patch measurements, and realistic results were gathered. For example, when the average texture depth is 0.75 mm, probability of accident occurrence rate shall be 15%. Also, while texture depth is approximately 0.50 mm, probability of accident occurrence will be 85%.

6. Conclusions and Recommendations

To detect the same type intersections, the number of intersections was selected limited. It was difficult
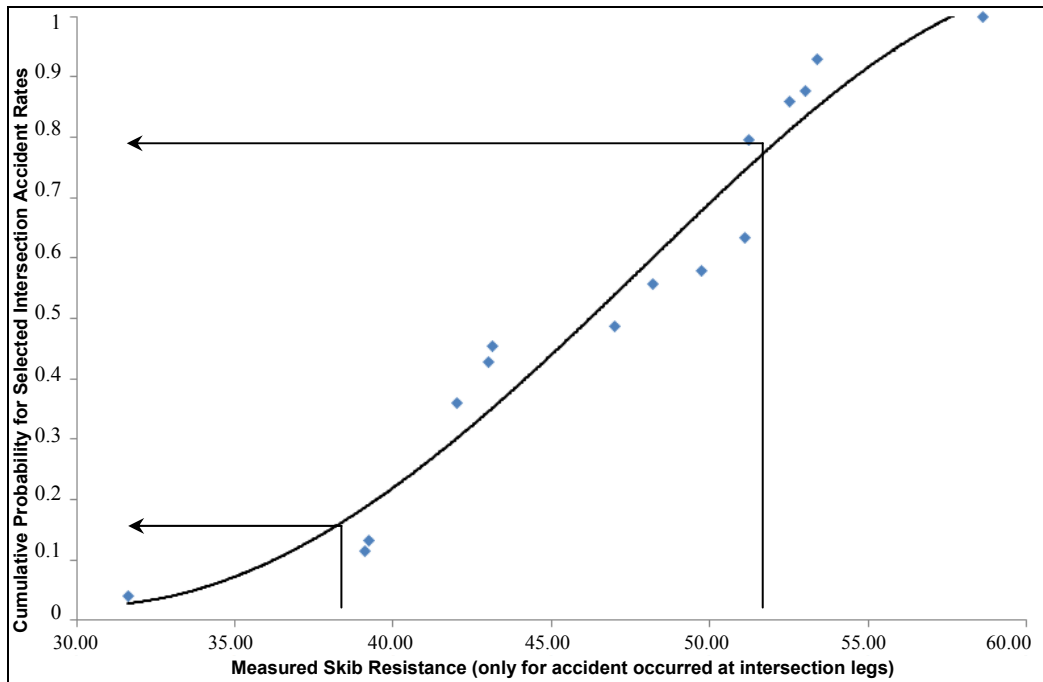
Fig. 3 Cumulative probability distributions of measured skid resistance at accident occurred at intersection legs.
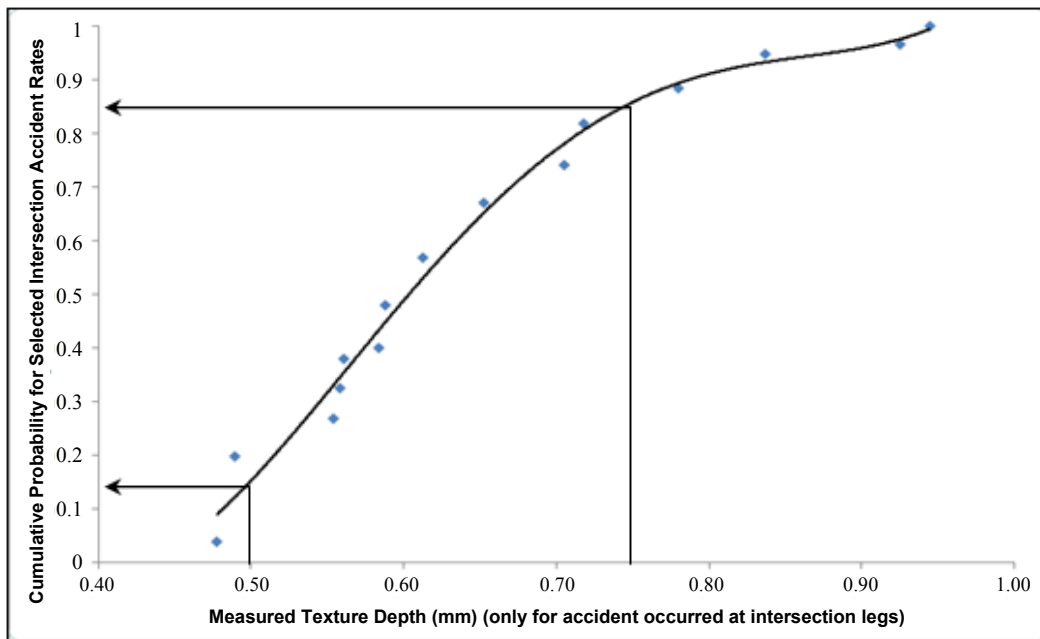

Fig. 4 Cumulative probability distributions of measured texture depth at accident occurred at intersection legs.

to find intersections whose features are same. Despite of this, five signalized four leg intersections which have very close properties were selected. The investigation of the effect of roughness on traffic safety at these urban intersections was performed. When the regression analysis is performed between road crashes and skid resistance, unsatisfactory results are gathered. So an analysis technique based on probability theory has been used. This method is used for expounding the interaction between skid resistance-intersection and accident rates. For example, when the skid resistance number is 53.5, probability

of accident occurrence rate shall be 15% and when the skid resistance number is 38, probability of accident occurrence will be 85% (Fig. 3). Same analysis is carried out for texture depth data as shown in Fig. 4 and results are gathered. For example, when the average texture depth is 0.75 mm, probability of accident occurrence rate shall be 15%. Also, while texture depth is approximately 0.50 mm, probability of accident occurrence will be 85%. With these results, it is indicated that collecting pavement measurement data is very necessary for urban intersections.

In this study, skid resistance values were investigated for evaluating the signalized intersection accidents. Other factors which are effective on intersection accidents are tried to eliminate by selecting same type intersections. So the intersection data were limited.

Being the first study to be carried out locally about signalized intersections and skid resistance in City of Isparta, it is recommended that further skid resistance measurements for the sites can be carried out so as to verify the trends and conclusions accomplished in this study, especially considering with different type of intersections and all intersection effecting parameters together.

Data can be expanded with different pavement combinations. Because after the study results are evaluated, it is understood that pavement roughness is very important for urban intersection safety measures. Different mix performance of different type of pavement can be found for more safe intersections for future works.

Acknowledgments

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