Identifying Relationship between Skid Resistance and Road Crashes using Probability-based Approach

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ABSTRACT

Road crashes are of great concern for road and transport departments around world, because they cause tremendous loss and dangers for the public. Reducing crash rates and crash severity are imperative goals that governments, road and transport authorities, and researchers aim to achieve. In Australia, road crash trauma costs the nation A$15 billion annually. Five people are killed, and 550 are injured every day. Each fatality costs the taxpayer A$1.7 million. Serious injury crashes can cost the taxpayer many times the cost of a fatality. Crashes are in general uncontrolled events and are dependent on a number of inter-related factors such as *driver behaviour, traffic conditions, travel speed, road geometry and condition, and vehicle characteristics (e.g. tyre type pressure and condition, and suspension type and condition)*. Skid resistance is considered one of the most important surface characteristics as it has a direct impact on traffic safety.

Attempts have been made worldwide to study the relationship between skid resistance and road crashes. Most of these studies used the statistical regression and correlation methods in analysing the relationships between skid resistance and road crashes. The outcomes from these studies provided mixed results and are not conclusive.

The objective of this paper is to present a probability-based method of an ongoing study in identifying the relationship between skid resistance and road crashes. Historical skid resistance and crash data of a road network located in the tropical east coast of Queensland were analysed using a probability-based method. Analysis methodology and results of the relationships between skid resistance, road characteristics and crashes are presented.

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1. INTRODUCTION

Skid resistance is an important feature of road pavements. Skid resistance refers to a condition parameter which characterises the contribution that a road makes to the friction between a road surface and a vehicle tyre during acceleration, deceleration and cornering or turning (Weligamage, 2006). Vehicles need friction to accelerate, decelerate or change direction. During these manoeuvrers, the friction generated between the vehicle's tyres and the road surface provides the force necessary to change the speed or course of the vehicle. Road surfaces must provide adequate levels of skid resistance for the vehicles travelling on them to facilitate safe manoeuvres in all conditions. In Australia, Austroads (the Association of Australian and New Zealand Road Transport and Traffic Authorities) published a guideline for the management of road surface skid resistance in 2005 and urged road Authorities in Australia and New Zealand to review their skid resistance management practices (Austroads 2005). The Austroads guideline has led the Queensland Government Department of Main Roads (QDMR) to review its skid resistance management practice (Weligamage 2006). In consequence, a joint research project including QDMR, Queensland University of Technology (QUT) and the Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM) was established. The research project aims at investigating whether there is a significant relationship between road crashes and skid resistance on Queensland's road networks. If the relationship exists, the current skid resistance management practice of QDMR will be reviewed and appropriate skid resistance investigatory levels will be recommended for managing skid resistance on Queensland road networks to minimise road crashes with skid resistance as a contributing cause.

Current practice in managing skid resistance in road authorities is largely based on comparing the actual skid resistance with established standard skid resistance levels called "investigatory levels (IL)" or "skid number (SN)". The standard level or investigatory level is an indicator to trigger site investigation. When measured skid resistance is below the investigatory level, a site investigation is conducted to identify whether further action should be taken (e.g. providing site treatment to increase the skid resistance). The UK Highway Agency Standard (HD15/87) introduced the concept of skid resistance investigatory levels rather than intervention levels. According to the standard, at any location on the road network where the skid resistance became equal to or fell below the investigatory level, an investigation was required to determine if treatment to improve its skidding resistance was justified (Sinhal, 2005).

Skid resistance may be measured by the Sideway-force Coefficient Road Inventory Machine (SCRIM) and Norsemeter Road Analyser and Recorder (known as ROAR). The SCRIM and ROAR units are widely used in Europe, the UK, Australia and New Zealand (Fulop et al., 2000, Weligamage, 2006, Soet & Barnsley, 2005, Austroads, 2005). Table 1 shows skid resistance investigatory levels used in Queensland, Australia.

Table 1: Norsemeter ROAR Investigatory levels used by Queensland Government Department of Main Roads in Australia

Skid Resistance Demand Categories	Description of Site	Investigatory levels*
High	Curves with radius ≤100 m Roundabouts Traffic light controlled intersections Pedestrian / school crossing Roundabout approaches	0.30
Intermediate	Curves with radius ≤ 250 m Gradients ≥ 5% and ≥ 50 m long Freeway and Highway on/off ramps Intersections	0.30
Normal	Manoeuvre-free areas of undivided roads Manoeuvre-free areas of divided roads	0.25

*These base levels are for a 60 km/hr slip speed (appropriate for 60 - 80 km/hr speed)

The number of crashes increases as the skid resistance of a road decreases as indicated by existing International research studies. Regression analysis, correlation analysis and other types of analysis methods including one-table or two-table analysis methods are commonly used methods for assessing the relationship between road crashes and skid resistance (Viner et. al. 2005, Seiler-Scherer 2004, Kuttesch 2004, Cenek & Davies 2003). These methods provided mixed results and were not conclusive due to the variation in crash data and skid resistance data. These research studies are briefly discussed below.

Network crash analysis and its relationship with skid resistance were undertaken on a network of approximately 5,800 km in the UK (Viner et. al. 2005). Viner et. al. 2005 plotted the relationship between mean crash risk and skid resistance. The study indicated that crash risk was found statistically significant at locations with lower skid resistance for single and dual carriageways non event category. Non-event category refers to sites where there are no junctions, crossings, notable bends or gradients, but may have commercial or residential accesses. For major junctions, and roundabouts the result indicated that crash risk was greater than the non-event site categories, but also indicated variation in the results (Viner et. al. 2005).

Regression analyses were conducted to establish the correlation between skid resistance and crash frequency in a skid resistance study for Switzerland’s national highway. Data for the period 1994-1998 were collected and classified according to number, severity, crash in dry and wet pavement, and crash type. The lowest skid resistance value for each 500 metre segment was assigned to the segment. The crash level was determined across the network in 500 metre intervals. The study found no quantifiable correlation between crashes and skid resistance (Seiler-Scherer 2004).

An extensive study was undertaken to quantify the relationship between skid resistance and wet weather crashes for data from Virginia (Kuttesch 2004). The data for the period 2000-2003 were aggregated into 3,243 one-mile sections. The lowest value of skid resistance was selected for use in the analysis for each section. A total of 3,243 data records were developed which included crash data, skid resistance data and traffic data (AADT). There were 22,232 crashes at the study sites. The total crash rate per 10 million vehicle-miles travelled (VMT) and the wet crash rate per 10 million VMT were calculated for each site. The study indicated that there was a statistically significant effect of skid resistance on wet crash rate, i.e. wet crash rate increased with decreasing skid number and that skid resistance information by itself did not explain the variability in the wet crash rates.

In New Zealand, Cenek and Davies (2003) conducted a study that combined detailed information of road geometry (i.e. horizontal curvature, gradient and cross-fall), road surface condition (i.e. roughness, rut depth, texture depth and skid resistance), carriageway characteristics and crash data in crash risk analysis. For the analysis, data from annual surveys of 22,000 lane-km of New Zealand's State Highway network since 1997 was used. The study employed one and two-way tables and Poisson regression modelling to identify critical variables and their relationships with crashes. The critical variables included traffic flow (ADT), horizontal curvature, skid resistance and to a lesser extent lane roughness, which are common to all crash types (Cenek & Davies 2003). One-way tables compared crashes with one critical variable, whilst the two-way tables compared crashes with two critical variables. The study indicated that in the one-way table, crash rates increased as horizontal curve radius decreased; crash rates increased as skid resistance values decreased; and crash rate increased whilst traffic volumes decreased. In addition, for the final situation, low ADT suggested more challenging roads with narrower lanes, more tortuous alignment than roads with high volumes of ADT, hence leading to higher crash rates.

The results using the two-way tables showed the trend of all crashes when compared with critical variables. Cenek and Davies (2003) indicated that there was a trend of wet crashes with horizontal curvature and SCRIM skid resistance coefficient. The crash rate increased as the curve radius decreased. However, the apparent effect of ADT was reduced when the horizontal curvature was considered in the two-way table study. Crash rate increased as the skid resistance deceased and when the horizontal curve radius decreased. The crash rate for the wet condition showed greater statistical error because crash numbers were smaller than when all crashes were considered (Cenek & Davies 2003).

The outcome of the above studies provided inconclusive results. However, attempts had been made in this joint QDMR, QUT and CIEAM research to use the method that has been employed by previous studies (i.e. regression technique) in assessing the relationship between road crashes and skid resistance for Queensland road networks. This paper is structured into two parts. The first part presents the results of the regression analysis. The results confirm the trend that crashes increase when skid resistance decreases. However, the coefficient of correlation (r^2) values were very low. Thus, as found by previous studies, the regression functions could not provide confidence in the relationship. Theoretically, when the (r^2) values approach unity, the relationship is strong, when the (r^2) values approach zero, it implies no relationship. The second part presents the proposed probability-based method and results of a case study identifying the relationship between road crashes and skid resistance.

2. PART 1: REGRESSION ANALYSIS IN IDENTIFYING RELATIONSHIP BETWEEN ROAD CRASHES AND SKID RESISTANCE

An attempt was conducted to use the common method (i.e. regression analysis) in identifying the relationship between road crashes and skid resistance. This section presents result of the regression analysis in identifying the relationship between road crashes and skid resistance for Queensland national highway located on non-reactive soils in the tropical north east of Queensland. Table 2 shows the road characteristics for the analysis. As mentioned, road geometry (e.g. curves, intersections, etc.) is an important parameter contributing to road crashes. However, currently road geometry information is not available. QDMR is collecting the road geometry information and this is expected to be completed in 2008. When road geometry information is available, it will be included in the analysis.

The skid resistance collecting data program for QDMR started in 2003 and the data are currently very limited. The relationships between road crashes and skid resistance between 2003 and 2005 where skid resistance data were available were studied. Skid resistance data are available for 69.9 km, 169.1 km and 35.0 km for 2003, 2004 and 2005 respectively for the road category considered. All skid resistance data was captured using a Norsemeter ROAR measuring device.

In this analysis, the total road length was divided into small segments of 3 km. Road crashes were determined across the total length of the road category in 3 km intervals. The average of skid resistance of the segment of 3 km was assigned to the segment. For this road category, the skid resistance data Figures 1, 2 and 3 show the plots of relationship between road crashes and skid resistance for 2003 to 2005. The regression lines show that there is a trend when the skid resistance decreases road crashes increase for these three year periods. However, (r^2) values were calculated to be 0.0547, 0.0647 and 0.0506 for 2003, 2004 and 2005, respectively. These very low (r^2) values indicated that there is high variation in the crashes and skid resistance data and the relationship between road crashes and skid resistance cannot draw conclusions with confidence. To this end, a new analysis technique based on probability theory has been developed and the outcome of the analysis is presented in the next section.

Table 2: Road details for analysis

	Road category				
Year of Data	Seal Types	Seal Ages (years)	AADT	No. of crashes	Total road length (km)
2003	Spray seal	0-5	3,000 -10,000	23	69.9
2004	Spray seal	0-5	3,000 -10,000	61	169.1
2005	Spray seal	0-5	3,000 -10,000	23	35.0
	Total			107	274.0

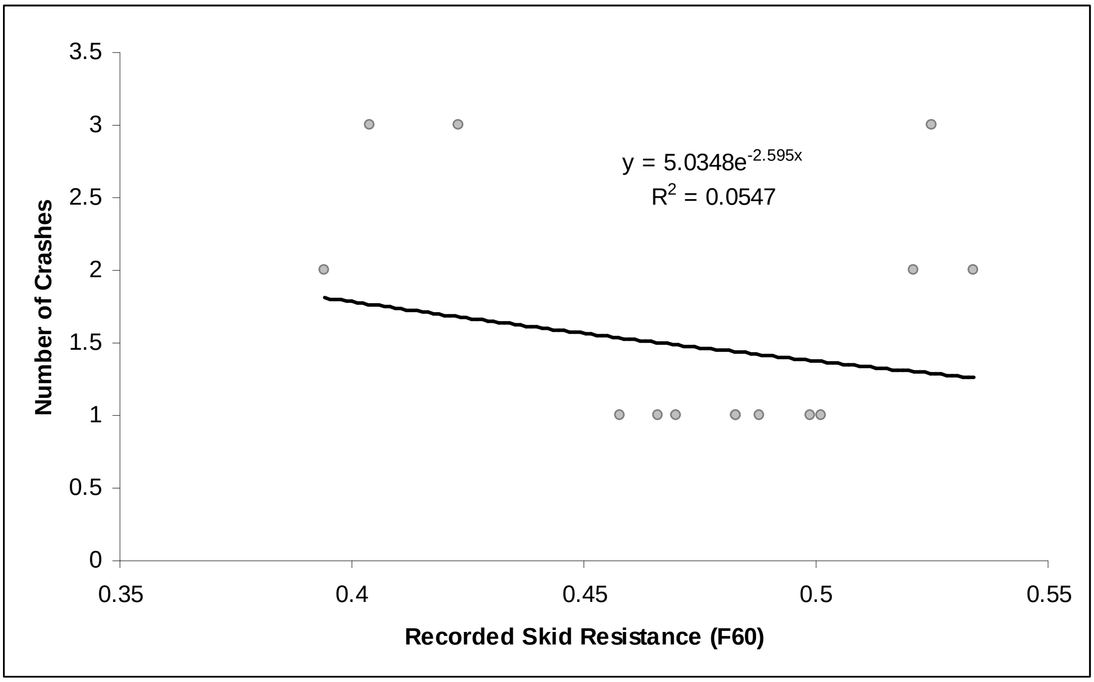

Figure 1: Relationship between road crashes and recorded skid resistance for 2003 for a road category of spray seal, seal age between 0 and 5 years and AADT between 3,000 and 10,000.

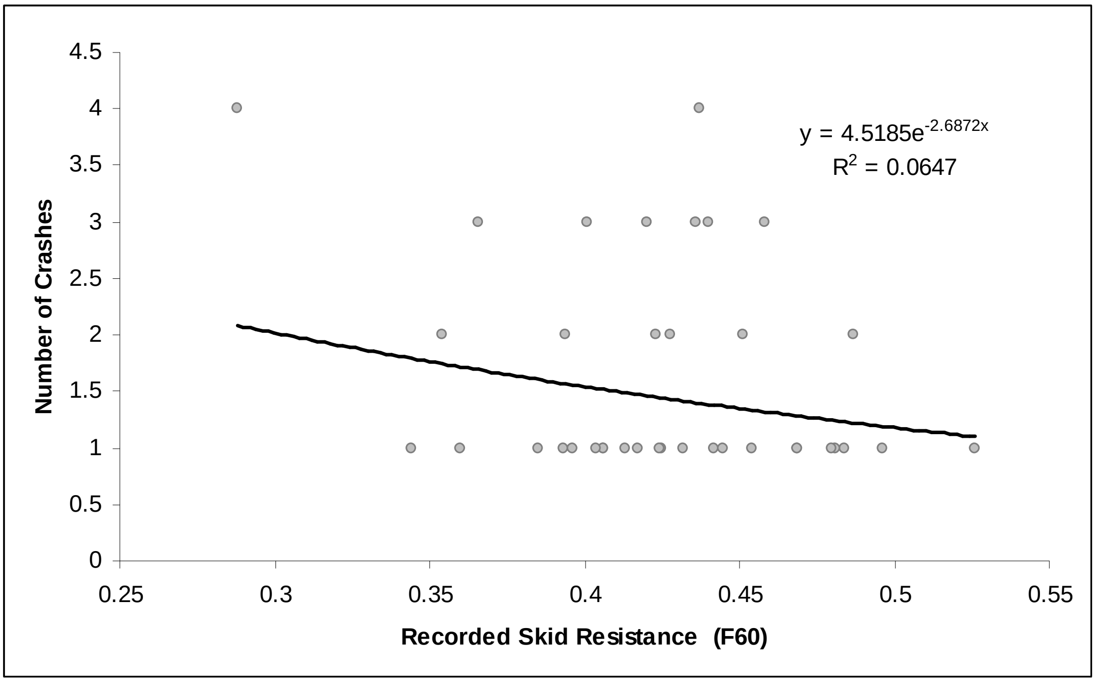

Figure 2: Relationship between road crashes and recorded skid resistance for 2004 for a road category of spray seal, seal age between 0 and 5 years and AADT between 3,000 and 10,000.

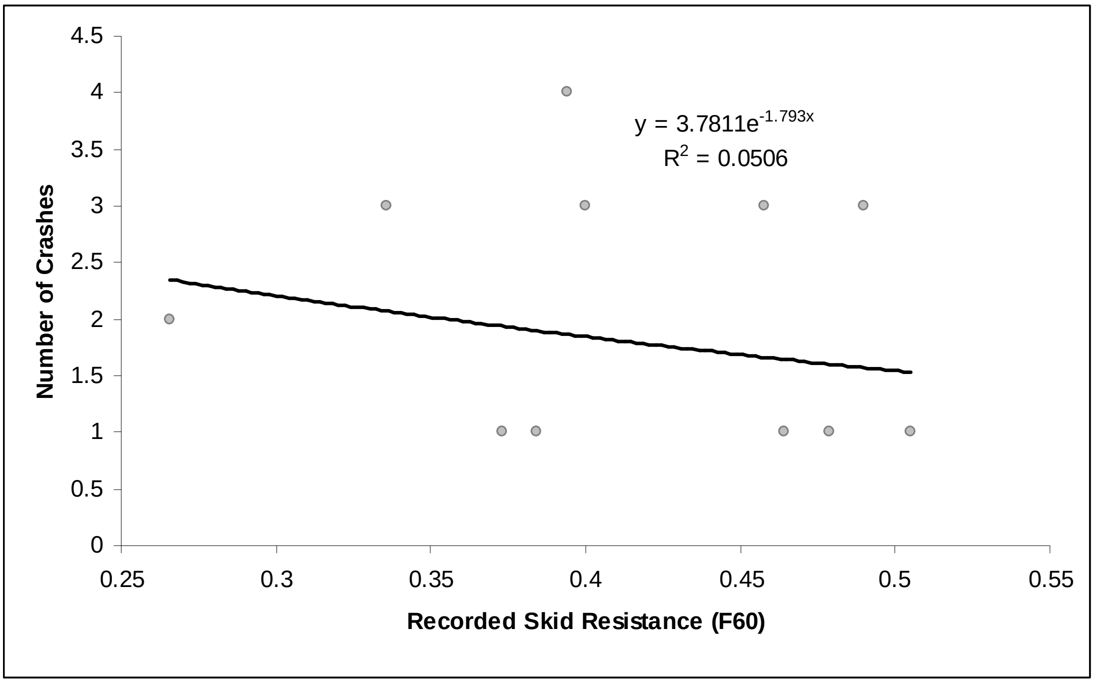

Figure 3: Relationship between road crashes and recorded skid resistance for 2005 for a road category of spray seal, seal age between 0 and 5 years and AADT between 3,000 and 10,000.

3. PART 2: IDENTIFYING RELATIONSHIP BETWEEN ROAD CRASHES AND SKID RESISTANCE USING A PROBABILITY-BASED TECHNIQUE

This section presents a new technique based on probability theory in analysing the relationship between road crashes and skid resistance. Road crash data, skid resistance and road category of spray seal, seal age between 0 and 5 years, annual average daily traffic between 3,000 and 10,000 vehicles with the length of approximately 169.9 km were used to demonstrate the application of the proposed technique. The steps in the analysis include:

Step 1: Categorise road site condition: This step aims at categorising road site condition according to road geometry, pavement type, annual average daily traffic, etc.

Step 2: Obtain historical road data of road crashes and skid resistance.

Step 3: Divide total road length into small road segments.

Step 4: Count road crashes and identify segments where crashes occur.

Step 5: Quantify the variability of skid resistance within the small road segments by probability distribution: This step aims at assessing the degree of variation of skid resistance of the small segments and assessing this variation characteristic with road crashes.

In this analysis, the total road length was divided into small segments of 3 km. The 3 km segment was selected to ensure that the skid resistance data can be described by a probability distribution. Figure 4 shows the cumulative probability distributions of small segments of 3 km for skid resistance data for 2004.

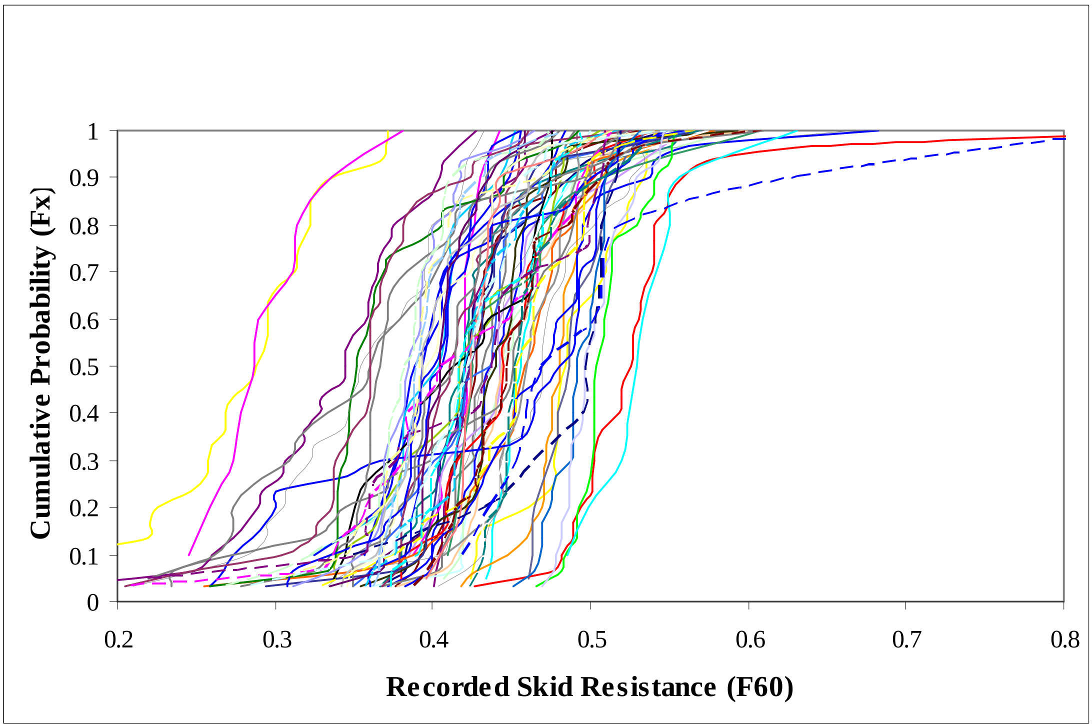

Figure 4: Cumulative probability distributions of recorded skid resistance (F60) for 2004 of 169.9 km for a road category of spray seal, seal age between 0-5 years and AADT between 3,000 to 10,000 vehicles

Step 6: Identify road segments where crashes occurred and count the number of crashes: This step identifies the probability distributions of the skid resistance where road crashes occur, and counts the number of crashes.

Step 7: Calculate percentages of crashes and identify the probability distributions of an interested crashes percentage:

Step 8: Identify an acceptable percentage of crashes. For demonstration, Figure 5 shows two cumulative probability distributions which are the boundaries that 70% crashes occur.

Step 9: Test goodness of fit of the two cumulative probability distributions obtained in Step 7: Figure 6 and Figure 7 show that the two cumulative probability distributions are in goodness of fit with theoretical probability distributions. Figure 8 shows the two theoretical cumulative probability distributions.

Step 10: Identify acceptable percentage of crashes and the probability distribution of skid resistance: Figure 8 indicates that 15% of crashes occur on the road surfaces that having the cumulative probability distribution of skid resistance greater than the cumulative probability distribution of F(x2). Seventy percentage of crashes occurred within the boundary of the two cumulative probability distributions of F(x1) and F(x2). Or 85% of crashes occurred on the road surface that having the cumulative probability distribution of skid resistance below the cumulative probability distribution of F(x2).

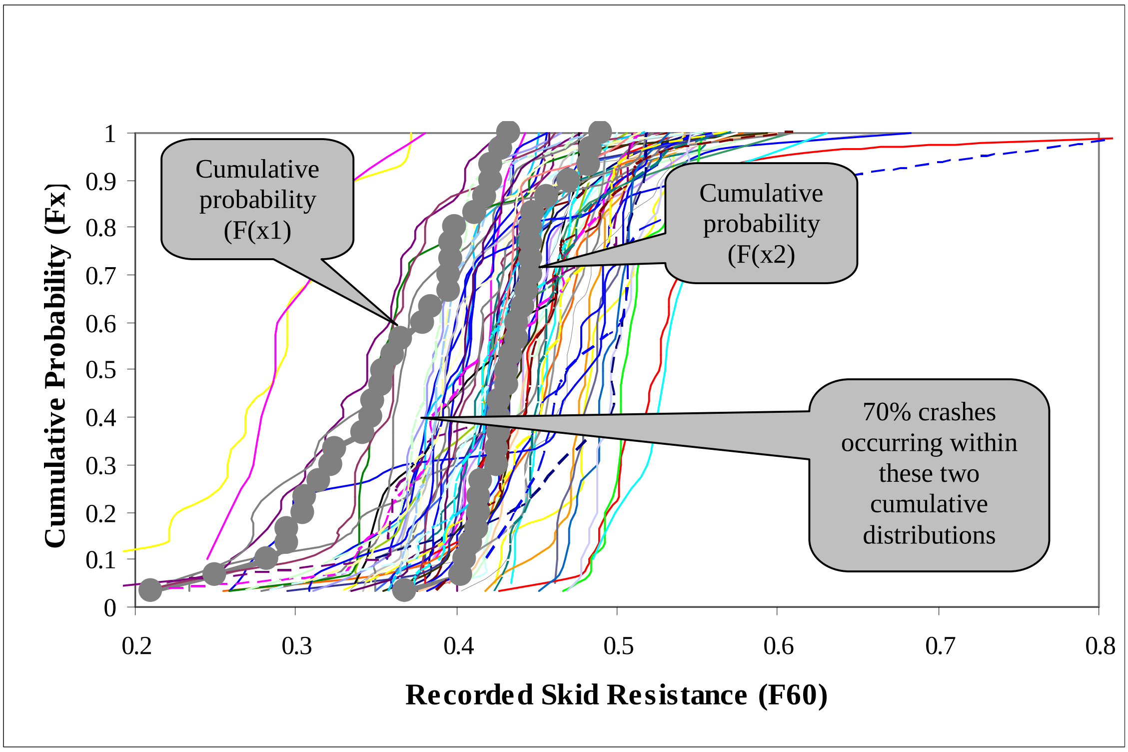

Figure 5: Two cumulative probability distributions of recorded skid resistance (F60) that divide road crashes into 15% crashes, 70% crashes and 15% crashes

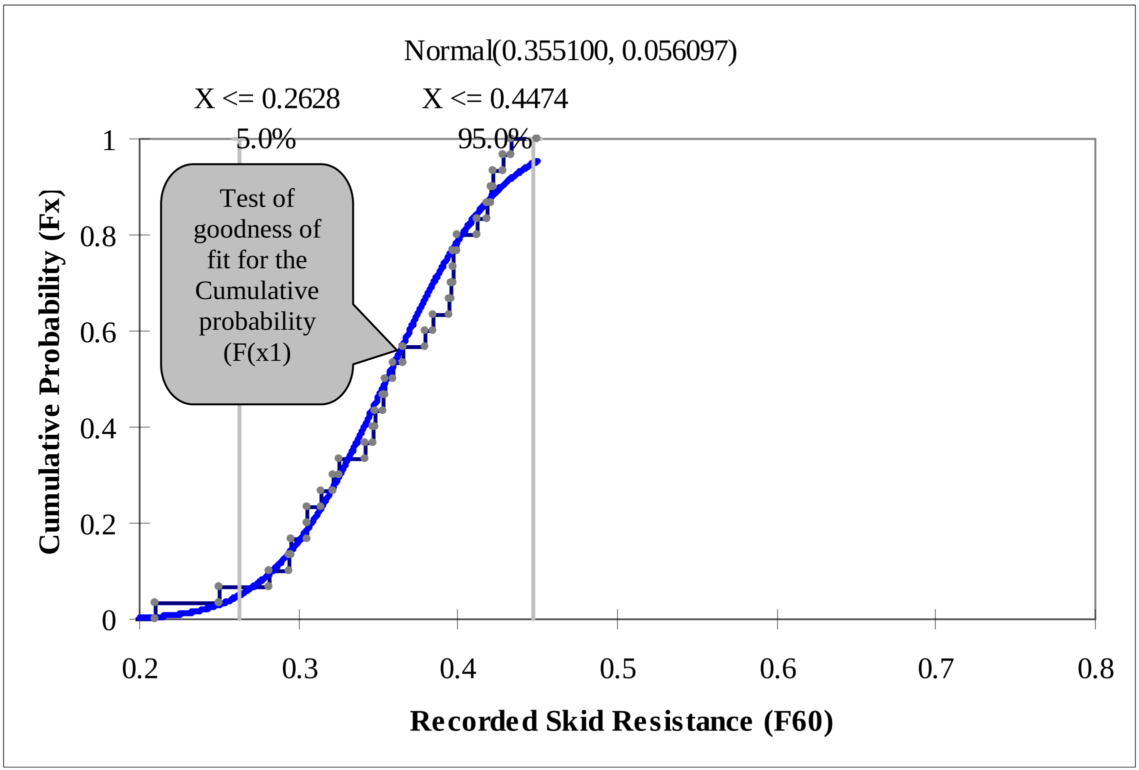

Figure 6: Test of goodness of fit for the cumulative probability distribution for F(x1)

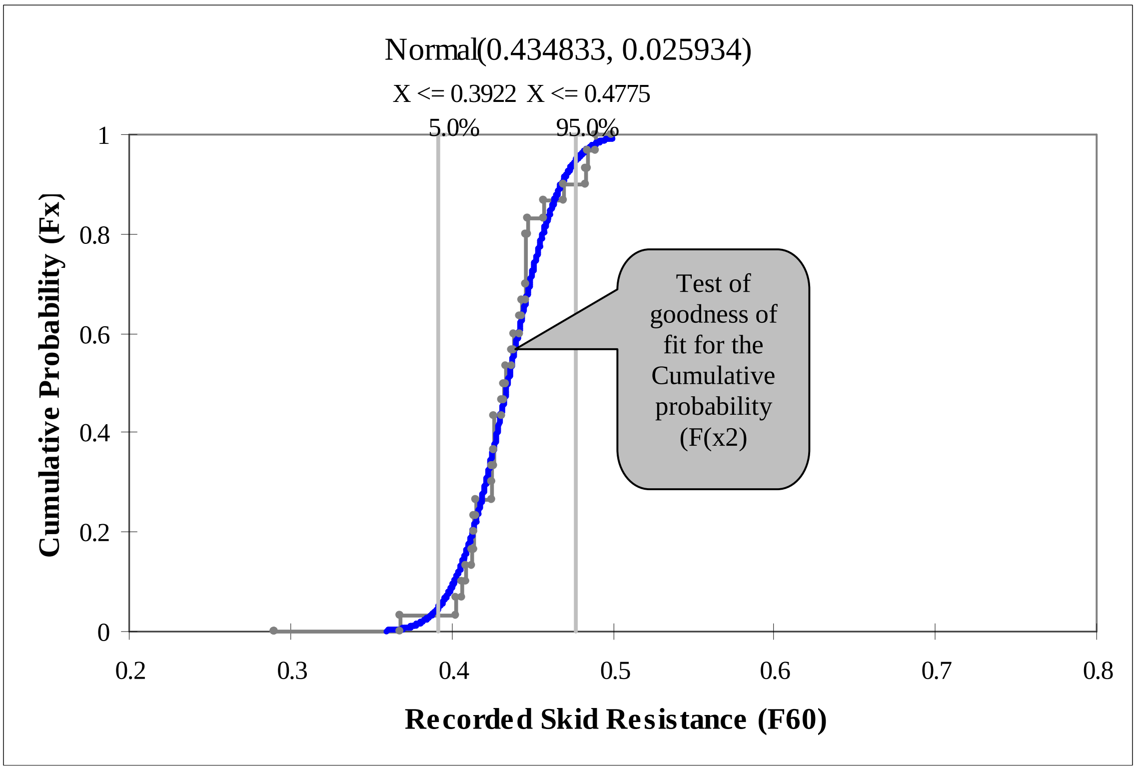

Figure 7: Test of goodness of fit for the cumulative probability distribution for F(x2)

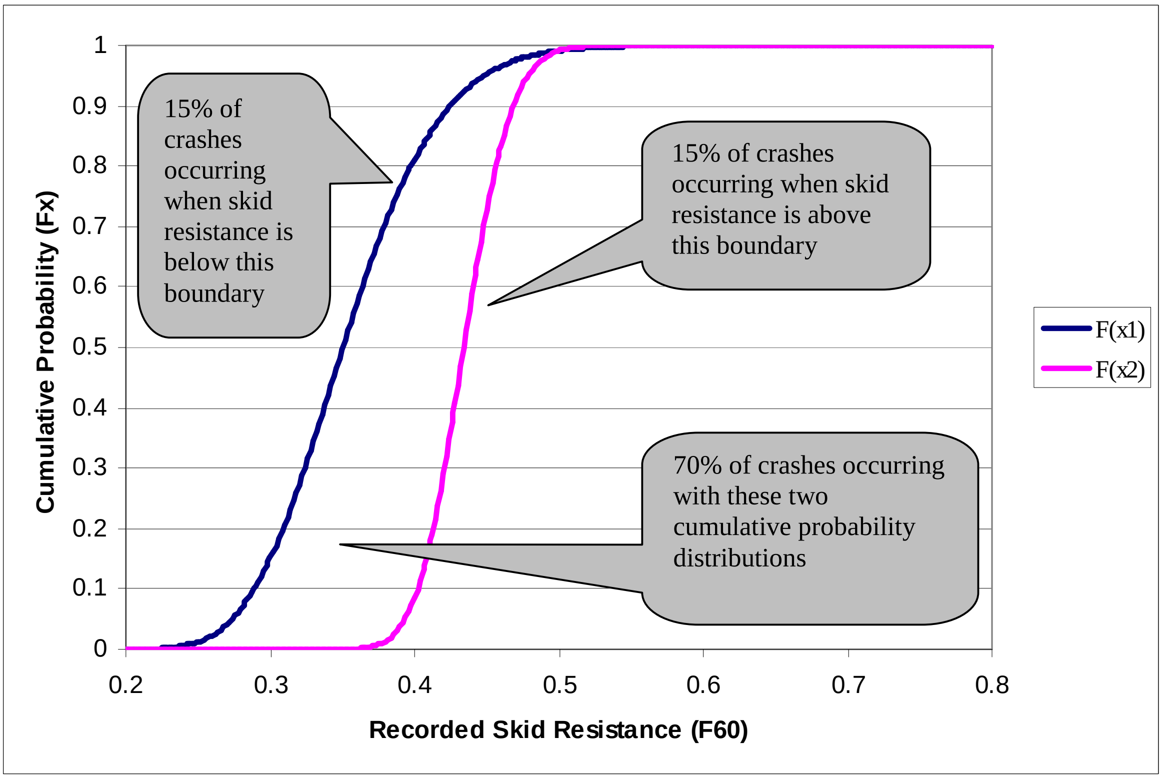

Figure 8: Two theoretical probability distributions of F(x1) and F(x2) that divide road crashes into 15% crashes, 70% crashes and 15% crashes

The cumulative probability distributions shown in Figure 8 can be used as criteria in selecting the skid resistance levels for managing the skid resistance of the road network. For example, the cumulative probability distribution of F(x2) of the skid resistance may be adopted since it has been shown that only 15% of road crashes occurred where the skid resistance was greater than this skid resistance level. A thorough analysis can be conducted using the suggested method in assessing the characteristics of cumulative probability distribution of skid resistance and crash risk for different site conditions of the road network. Appropriate cumulative probability distributions of skid resistance can be selected for an identified acceptable crash risk. For managing skid resistance, actual skid resistance measured from different sites will be compared with the identified cumulative probability distributions. It must be noted that the skid resistance values that are measured at a road site will be transformed into a cumulative probability distribution and compared with the established cumulative probability distribution. In this method the variability of skid resistance is managed and controlled within the identified cumulative probability distribution. Road authorities can ensure consistent levels of skid resistance are provided using the suggested technique analysis and management.

4. CONCLUSIONS

Due to high variations in recorded crash and skid resistance data, the common methods such as regression analysis or correlation analysis cannot be directly employed in assessing the relationship between road crashes and skid resistance. Previous studies using these methods provided mixed and inconclusive results. This paper presented a probability-based method in assessing the relationship between road crashes and skid resistance. The step-by-step methodology was presented in this paper. In this method, the total road length is divided into small segments of an equal length. A road length of approximately 169.9 km located in wet and non-reactive soil in the tropical east coast of Queensland was used to demonstrate the method. This road length was selected from a road category of spray seal, seal age between 0 and 5 years, AADT between 3,000 and 10,000 vehicles. In this method, the variability of skid resistance of each small segment is quantified by a cumulative probability distribution. The cumulative probability distributions of the skid resistance of the small road segments where crashes occurred are identified and the crash numbers are counted. The percentages of crashes from the total crashes for each of the small segments that crashes occur are calculated. The cumulative probability distribution of skid resistance which is the boundary of high risk crashes is identified. For instance, a cumulative probability distribution of the skid resistance which is the boundary of the 85% road crashes can be identified as high risk. It means that 85% of road crashes occur on road surfaces where the skid resistance values are lower than the boundary cumulative probability distribution of the skid resistance. Thus, the level of crash risk (expressed in terms of percentage) and the level of skid resistance (expressed in terms of the cumulative probability) is identified simultaneously. This information will assist road engineers to identify the level of risk and the characteristic of skid resistance for that particular risk level. A thorough analysis can be conducted in assessing these characteristics. Appropriate skid resistance levels expressed in terms of the cumulative probability distribution for an acceptable percentage of crashes can be identified. The skid resistance can be managed by comparing the cumulative probability distributions of actual skid resistance with the established cumulative probability distribution of skid resistance. In this method, the variability of the skid resistance can be managed and controlled which provides more consistency in the skid resistance level.

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