SKID RESISTANCE PERFORMANCE PROFILES

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ABSTRACT

Managing skid resistance is an essential part of Queensland Department of Transport and Main Roads' (TMR) responsibilities to ensure traffic safety. TMR released its skid resistance management plan (SRMP) as a central strategy for managing skid resistance. In managing skid resistance on Queensland state-controlled road networks, a Road Analyser and Recorder (ROAR) device had been used in monitoring skid resistance. TMR endeavours to provide proactive approaches in managing skid resistance. However, it is extremely difficult to predict skid resistance deterioration rates in future so that skid resistance treatments could be planed ahead. With the availability of skid resistance data at the network level, TMR wishes to make use of these data to find ways to predict skid resistance performance in future. A cooperative research project was established between TMR and Australian Asphalt Pavement Association (AAPA) to analyse these skid resistance data and to develop skid resistance performance profiles (i.e. skid resistance deterioration rates) for its road network. Skid resistance data collected between 2004 and 2007 were used in the analysis. This paper presents a proposed methodology employed in developing skid resistance performance profiles.

INTRODUCTION

Skid resistance of the Queensland state-controlled road networks is managed through skid resistance element management. Queensland Department of Transport and Main Roads (TMR) has three key documents to control skid resistance management, namely:

- Skid Resistance Management Plan (SRMP)
- Skid Resistance Element Management Plan Part 1 (EMP Part1)
- Skid Resistance Element Management Plan Part 2 (EMP Part 2)

Skid Resistance Management Plan (SRMP) describes actions necessary to implement the strategy and establishes initial measurement regimes for skid resistance at the network and project levels (Weligamage 2006).

Element Management Plan (EMP) sets out processes used to determine state-wide funding for managing skid resistance. EMP Part 1 sets out scopes, requirements, roles and responsibilities of the skid resistance element management. EMP Part 2 sets out targets to achieve based on available funding provided through Queensland Road Performance Plan (QRPP).

TMR endeavours to reduce road crashes on the state-controlled road network which have low skid resistance as a contributory cause. An important piece of information that TMR requires is to predict deterioration rates of skid resistance that would occur in future. However such deterioration models are not available for Queensland condition. TMR adopts a proactive means to manage skid resistance and to predict risks in providing inappropriate levels of skid resistance on its road networks. Given the availability of skid resistance data that had been recorded for a number of years on the Queensland state-controlled road networks, this cooperative research project with Australian Asphalt Pavement Association (AAPA) attempted to study skid resistance performance at the network levels and to develop skid resistance deterioration models for Queensland road network conditions. The skid resistance deterioration model presented in this paper is a function of seal ages. Skid resistance data measured using International Friction Index (F60) were used in the analysis.

SKID RESISTANCE

The skid resistance of a road surface is a condition parameter which quantifies the roads' contribution to friction between the surface and a vehicle tyre. There are two main components of the physical road surface that contribute to the level of skid resistance it provides, namely; the micro-texture and macro-texture of the surface. These surface characteristics depend on the type, size and shape of aggregate used in construction of the road, and also the actual construction process, as shown in Figure 1 below. Micro-texture refers to tiny irregularities in the aggregate surface, providing a pathway for adhesion (chemical bonding) between the tyre and aggregate.

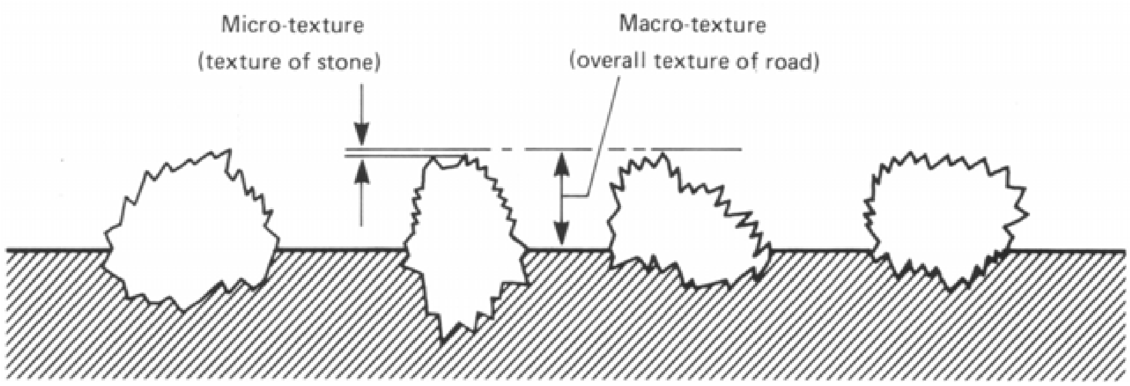


Figure 1: The micro-texture and macro-texture components of the road surface. Here the aggregate is partially embedded in the road surface

This phenomenon provides a large proportion of the skid resistance in dry conditions, but its contribution is dramatically reduced in wet conditions. In wet conditions, it also increases the chance of hydroplaning, at which point the tyre is fully supported by water, losing contact with the road surface (Austroads, 2005).

In wet conditions, the macro-texture of the road surface becomes important in vehicle control during manoeuvres. The macro-texture refers to the deviations and channels between aggregate components in the road surface. Its primary roles are to allow hysteresis, produced by the deformations in the tyre from contact with the aggregate particles in the road, and also to allow water to channel and escape from the road – tyre interface. This is very important as it allows more contact between the micro-texture of the road and the tyre surface, increasing adhesion and, therefore, the ability to reduce the chance of skidding. It also reduces the chance of hydroplaning, at which point the tyre is fully supported by water, losing contact with the road surface.

SKID RESISTANCE DATA COLLECTION

For skid resistance testing, TMR utilised the Norsemeter ROAR (Road Analyser and Recorder) to perform network data collection and project level data collection for Queensland.

Since 2003 extensive skid resistance data capture programs had been undertaken to allow determination of the overall network condition with respect to its skid resistance properties. The skid resistance data obtained from the friction factor at a 60 km/hr slip speed (F60) were measured. For other speed zones or higher speed zones, slip speeds were adjusted according to the slip speeds given in Table 1. The skid resistance data at F60 were adjusted (as less skid resistance is available at higher slip speeds) using the following relationship:

$$F(S) = F60e^{(S-60)/Sp}$$

Where: S = adopted slip speed; Sp = speed number (speed dependency of friction measure), is a function of macrotexture and the measurement methodology. Figure 2 shows an example of skid resistance values obtained from different test devices.

Table 1: Slip speeds for different speed zones

Gazetted speed (km/hr)	110	100	90	80	70	60	50	40
Adopted slip speed (km/hr)	80*	80*	70*	60*	60*	60	50	40

**assume good visibility and some speed reduction occur before panic breaking*

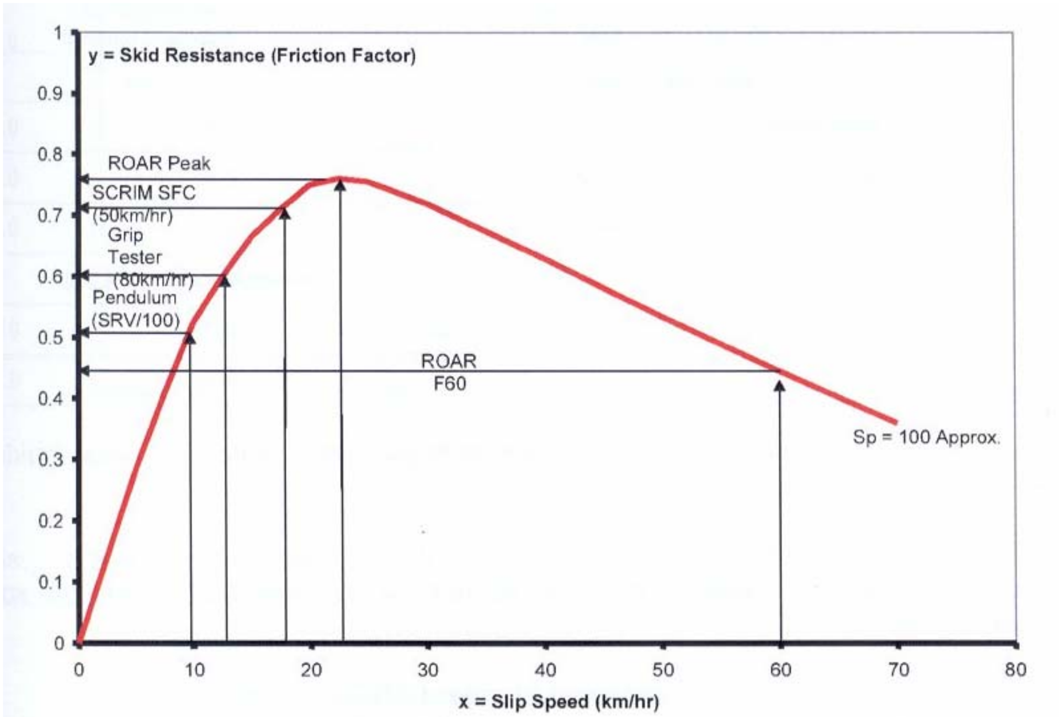


Figure 2: Slip speed and speed number (Baran, 2009)

Due to occasional breakdowns of ROAR device, around 2007 ROAR ceased its operation for skid resistance data collection for the state-controlled road network. TMR's Skid Resistance Steering Committee decided to adopt SCRIM (the Sideways-force Coefficient Routine Investigation Machine) for skid resistance data collection at the network level. A SCRIM data collection program at the network level was first conducted in 2010 on the Queensland state-controlled road of Queensland. SCRIM data are very limited covering only a one year period and therefore were not used in this study.

Given the availability of F60 data that have been collected for a number of years using ROAR device, a methodology for establishing skid resistance deterioration profiles was developed. The same methodology would be expected to be applicable for establishing skid resistance deterioration profiles for SCRIM data in future.

NORSEMETER (ROAR) FOR SKID RESISTANCE DATA COLLECTION

TMR employed a Norsemeter Road Analyser and Recorder or ROAR as it is most commonly known for network skid resistance data collection. The friction coefficients recorded from ROAR tests are for longitudinal friction on a wet surface and are expressed in terms of the International Friction Index (IFI). ROAR can be operated by fixed or variable slip methods. TMR operated the ROAR device in the variable skid mode. Figure 3 shows a Norsemeter (ROAR) used by TMR. However, ROAR ceased its operation for skid resistance tests at the network level after 2007 due to occasional breakdowns of the device. The first SCRIM test on TMR's network was conducted in 2010.

Figure 3: Norsemeter Road Analyser and Recorder or ROAR used by TMR (Baran, 2009)

METHODOLOGY FOR DEVELOPING SKID RESISTANCE DETIORATION PROFILE

Piyatrapoomi & Weligamage (2010) presented at the 2010 ARRB Conference a probability-based method for developing pavement strength deterioration models as a function of pavement ages. A similar methodology was employed in developing skid resistance deterioration models. For skid resistance, a skid resistance deterioration model is a function of seal ages. Details of the methodology are given below.

- Step 1: Skid resistance data of F60 were grouped based on seal types, e.g. spray seal (SS), dense graded asphalt (DG), open graded asphalt (OG), and so on.
- Step 2: For each seal type, skid resistance data were grouped according to seal ages.
- Step 3: Statistically analyse skid data for each seal age group for a particular seal type and conduct the degree of goodness-of-fit test with a theoretical probability distribution.
- Step 4: Select the probability distribution that gives the best degree of goodness-of-fit to represent the probability distribution of the skid data for that particular seal age and seal type.
- Step 5: Repeat the statistical analysis of steps (3) and (4) for skid data of other seal ages.
- Step 6: From the probability distributions obtained from step 5 all seal ages for a particular seal type, select a skid resistance value from the probability distribution for a seal age to represent a percentile of interest. For instance, select a skid resistance value at the 15th percentile if the 15th percentile were of interest.
- Step 7: Repeat step (6), i.e. select skid resistance values to represent a percentile of interest from the skid resistance probability distributions of other seal ages.
- Step 8: Plot the selected skid resistance values of the percentile of interest against seal ages.
- Step 9: Conduct a regression analysis of the skid resistance values and seal ages given in step (8).

- Step 10: Test the R2 value of the regression line. Should R2 value be acceptable, the regression line could become a skid resistance deterioration model.

It must be noted that a selected percentile represents a probability of occurrence of skid resistance. If a 15th percentile value were selected, it is implied that there would be an 85% probability that skid resistance data for each seal age had values above the regression line, and 15% probability of the skid resistance values could be below the regression line.

STEP BY STEP ANALYSIS

Skid resistance F60 data collected in 2007 were presented to demonstrate the proposed methodology. It must be noted skid resistance deterioration rates may be different for different aggregate sources. Differences in aggregate sources were not identified in this analysis. Once the methodology has been accepted, the aggregate sources will be identified and skid resistance performance profiles can be refined in future studies. Skid resistance data tested on spray seal surfaces were used for this demonstration. Skid resistance data were recorded at 100 metre intervals. A step by step analysis is given below.

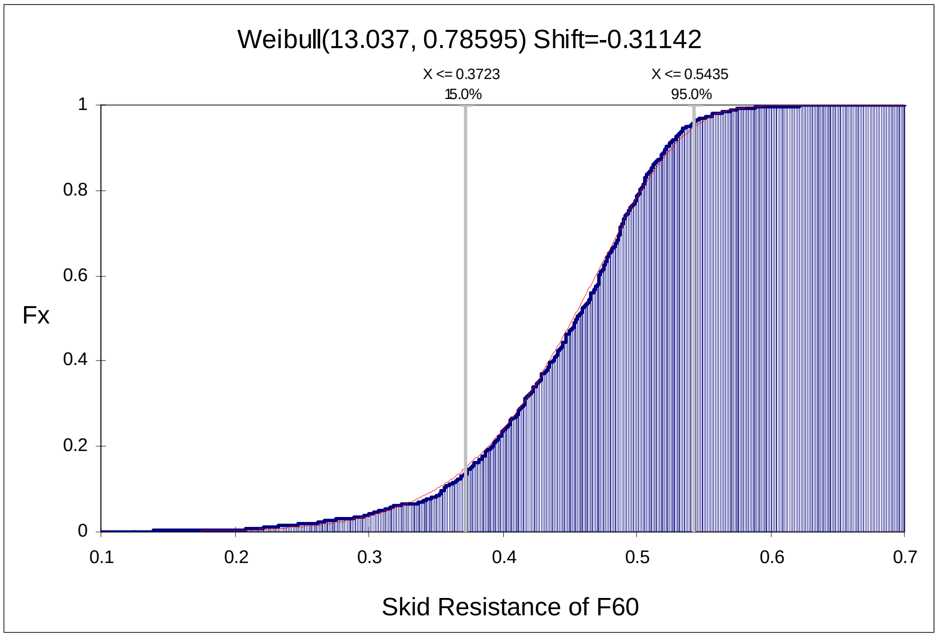
Step 1: Skid resistance data were grouped according to surface types. In this case, skid resistance data tested on spray seal surfaces were used in the analysis.

Step 2: For each seal type, skid resistance data are grouped according to seal ages.

Step 3: Statistically analyse skid data for each seal age group of a particular seal type and conduct a test of the degree of goodness-of-fit with a theoretical probability distribution. Figure 4 presents an example of skid resistance data shown in the cumulative probability distribution. The figure also shows the test of the goodness of fit of which a Weibull distribution provides the best goodness of fit to the skid resistance data.

Step 4: Select the probability distribution that gives the best degree of goodness-of-fit to represent the probability distribution of the skid data for that particular seal age and seal type. Figure 4 shows that Weibull probability distribution gives the best goodness-of-fit to the skid resistance data recorded on spray seal surfaces having 4 years of age. The Weibull probability distribution was selected to represent the theoretical probability distribution of the skid resistance data for this particular seal age.

The Kolmogorov-Smirnov (K-S) Goodness-of-fit-test method was used to quantify the statistical information and probability distribution of the skid resistance (F60) data for each seal age group. The Kolmogorov-Smirnov (K-S) method (Ang & Tang 1975, Piyatrapoomi et. al. 2003) involves a comparison between the cumulative distribution of sample data and the cumulative distribution of an assumed theoretical probability distribution function as shown in Figure 4. In this study, commercial software @Risk was used in assessing the statistical information and the probability distribution of the skid resistance (F60) data (Palisade 2005). The Kolmogorov-Smirnov (K-S) best goodness-of-fit to the skid resistance (F60) data of each seal age group given by the @Risk software was chosen as the probability distribution of the skid resistance (F60) for that seal age group. The mean, standard deviation and percentile values were calculated from the identified probability distribution.



Note: Fx = cumulative probability

Figure 4: Cumulative probability of skid resistance data of F60 and a test of degree of goodness-of-fit with Weibull probability distribution for skid resistance data recorded on spray seal surfaces having 4 years of age

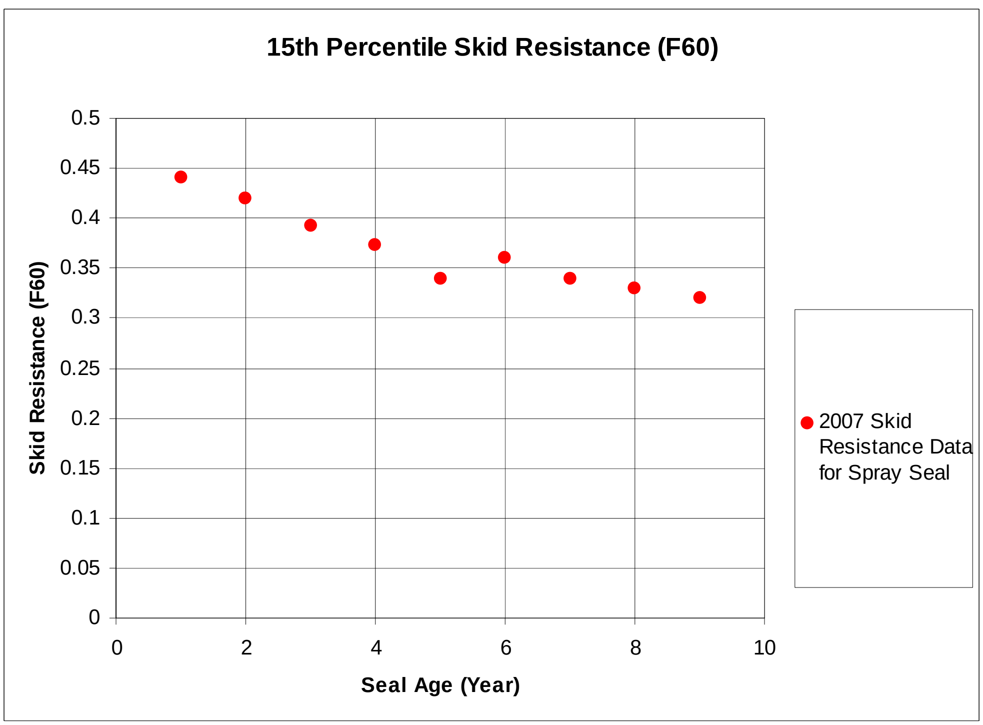


Figure 5: 15th percentile values of skid resistance (F60) for different seal ages of spray seal surfaces for skid data tested in 2007

Step 5: Repeat the statistical analysis of steps (3) and (4) for skid data of other seal ages.

Step 6: From the probability distributions obtained from step (5) of all seal ages for a particular seal type, select a skid resistance value from the probability distribution for a seal age to represent a percentile of interest. For instance, select a skid resistance value at the 15th percentile if the 15th percentile were of interest.

Step 7: Repeat step (6), i.e. select skid resistance values to represent a percentile of interest from the skid resistance probability distributions of other seal ages.

Step 8: Plot the selected skid resistance values of the percentile of interest against seal ages.

Step 9: Conduct a regression analysis of the skid resistance values and seal ages given in step (8).

Step 10: Test the R2 value of the regression line. Should R2 value be acceptable, the regression line could serve as a skid resistance deterioration model.

Figure 6 shows the 15th percentile values of skid resistance (F60) and a regression line with R2 value of 0.9554.

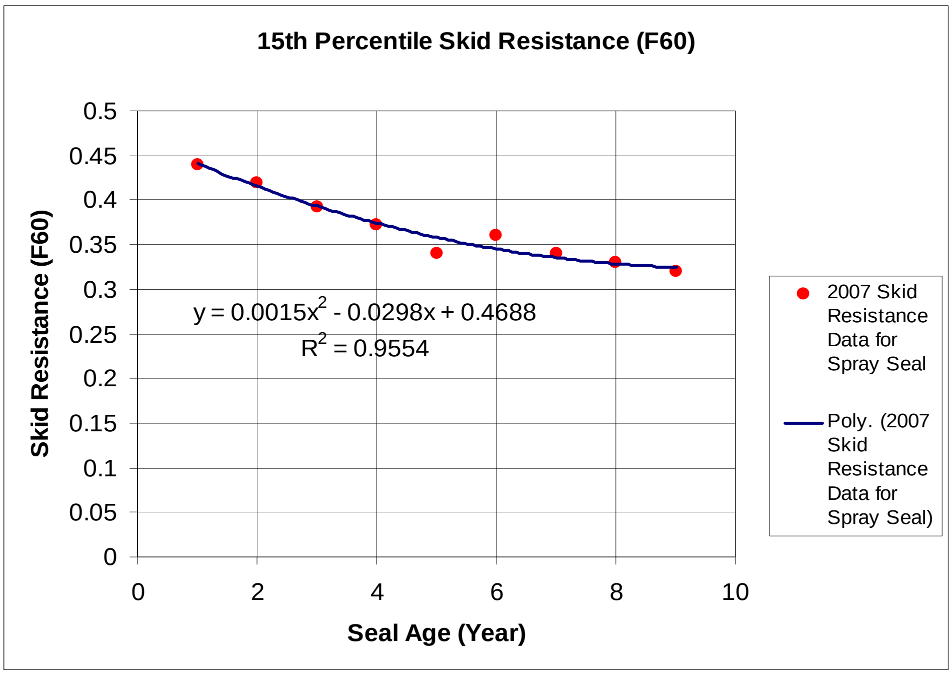


Figure 6: 15th percentile values of skid resistance (F60) for different seal ages of spray seal surfaces for skid data tested in 2007 and its regressed line

Based on the analysis method given above, skid resistance deterioration profiles for different percentiles were developed. Figure 7 shows the deterioration profiles of skid resistance (F60) for different percentile levels, namely; 1st, 5th, 15th, 30th, 50th percentile levels. The Y-axis denotes skid resistance of F60 values, whilst the X-axis denotes seal ages. Figure 7 gives the probabilities of skid resistance (F60) that would have values below the regressed lines. For instance, the regressed line of the 1st percentile level indicates that there is a 1% probability that the skid resistance (F60) would have values less than the regressed line (the 1st percentile curve); the regressed line of the 5th percentile indicates that there is a 5% probability that skid resistance values would be less than the regressed line and the like for other percentiles. The selection of a skid resistance deterioration profile may need to consider the risk of having skid resistance values below a selected skid resistance deterioration profile. Skid resistance values above the 50th percentile were shown to be high in values, therefore skid resistance deterioration curves above the 50th percentile level may not need to be examined.

Figures 8, 9 and 10 show comparison of skid resistance deterioration profiles for different percentile values. The 1st percentile values could be used to identify the lower bound level of skid resistance on the network. The lower bound could be interpreted as that it would be unlikely that skid resistance (F60) values would be less than the lower bound curve. The lower bound curve can be interpreted as the lowest skid resistance (F60) values. However as mentioned, it must be noted that there would be a one percent probability that the skid resistance values would be less than the lower bound curve (i.e. the 1st percentile curve). Skid resistance values above the 50th percentile were shown to be high in values, and hence, skid resistance deterioration curves above the 50th percentile level should provide good friction. The risk of having low skid resistance values below the 50th percentile should be examined thoroughly. A skid resistance deterioration profile could be selected based on an acceptable probability of having skid resistance values below a selected deterioration profile. The selection of an acceptable probability depends on risk levels that road authorities would take. However, more research should be conducted to assess what the risk levels would be, say, a 5% probability of skid resistance would be less than a selected 5th percentile skid resistance deterioration profile.

Figure 8 shows the 1st, 5th and a 50th percentile deterioration curves. The bands between the 1st and the 5th percentile curves and between 5th and 50th percentile curves show how skid resistance values are spread out between these deterioration profiles. Figure 9 shows the bands between the skid resistance deterioration profiles for the 1st, 15th and 50th percentile curves. Figure 10 shows the bands for the skid resistance profiles between the 1st, the 30th and the 50th percentile curves. Examining these bands would assist in foreseeing unacceptable skid resistance values or a very low value prior to selecting an appropriate skid resistance deterioration profile.

More research studies with more skid resistance data need to be conducted to assess the skid resistance deterioration profiles and whether there are any changes in the profiles before a skid resistance deterioration profile could be established. However, as mentioned risk levels of having skid resistance values below a selected percentile of skid resistance deterioration profile also need to be assessed against wet crashes to determine what risk levels are associated with which selected percentile levels.

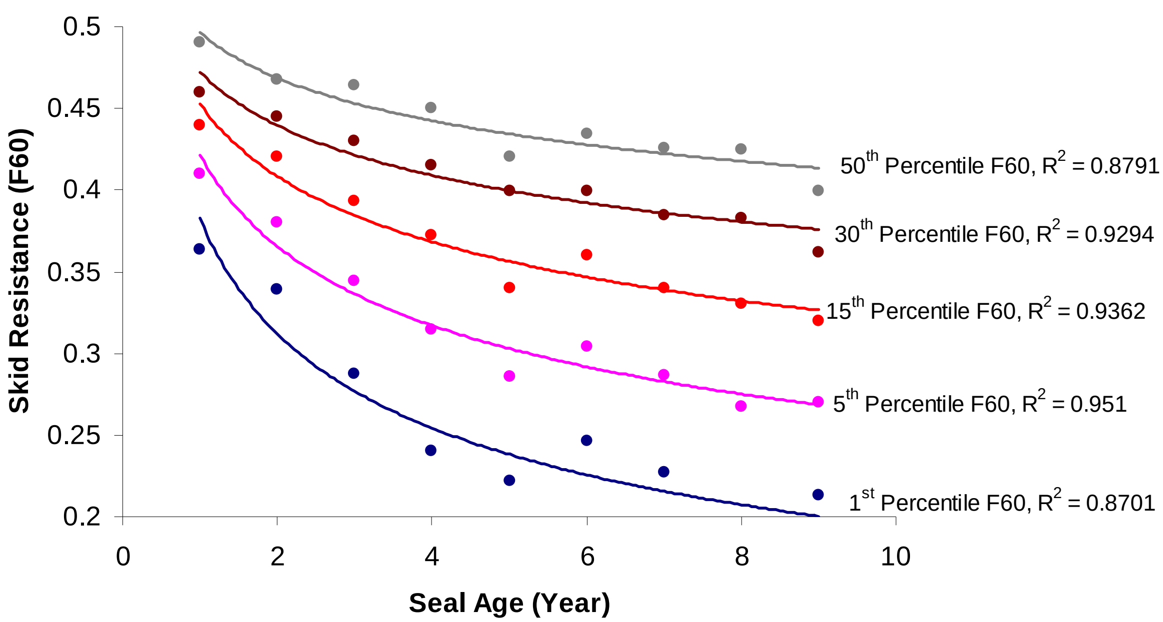


Figure 7: Regressed lines representing 1st, 5th, 15th, 30th and 50th percentiles of skid resistance (F60)

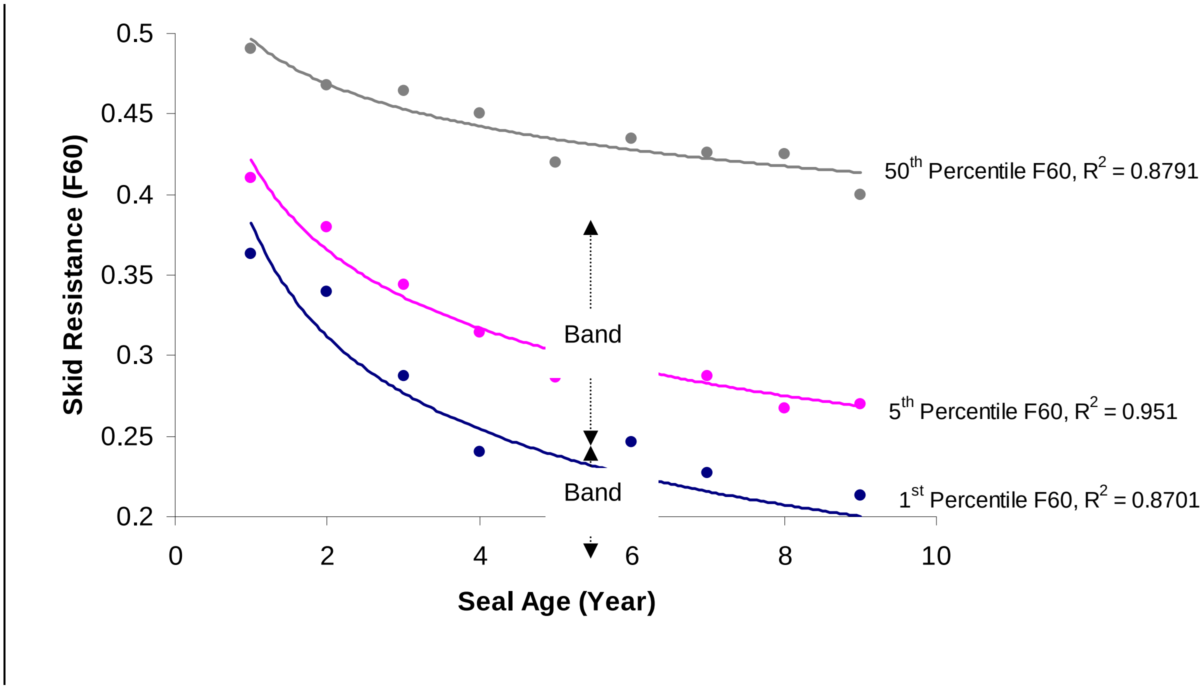


Figure 8: Regressed lines representing 1st, 5th, and 50th percentiles of skid resistance (F60)

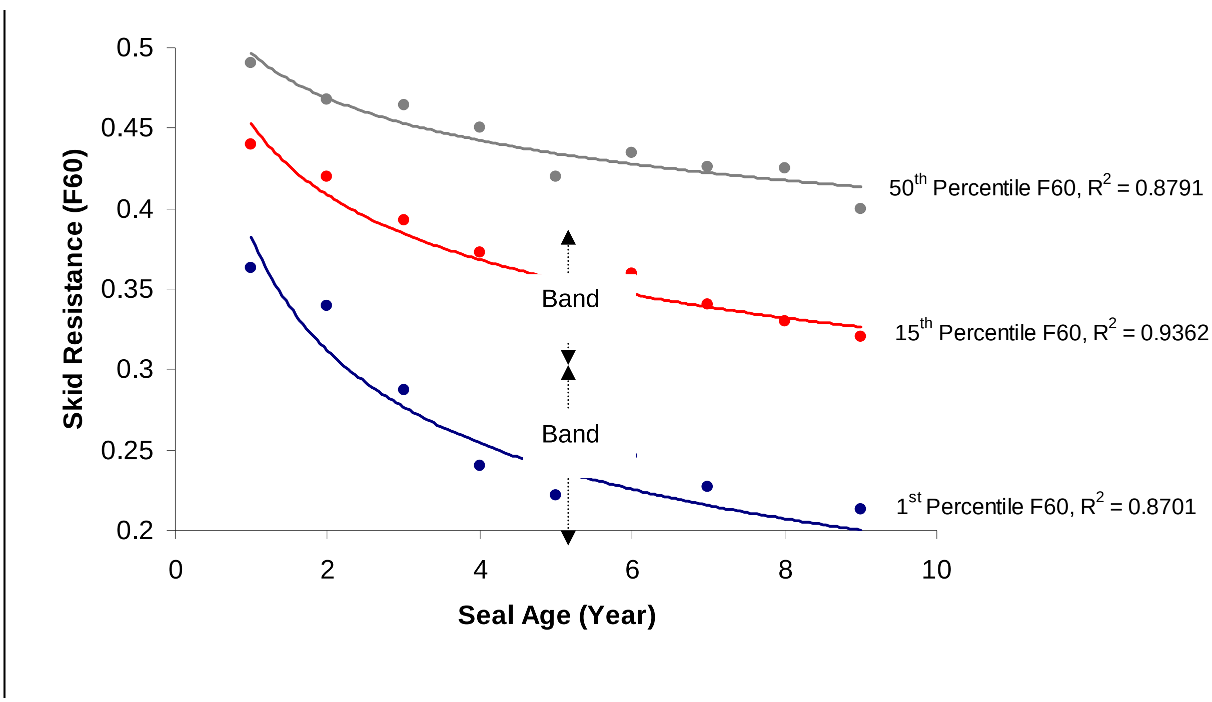


Figure 9: Regressed lines representing 1st, 15th, and 50th percentiles of skid resistance (F60)

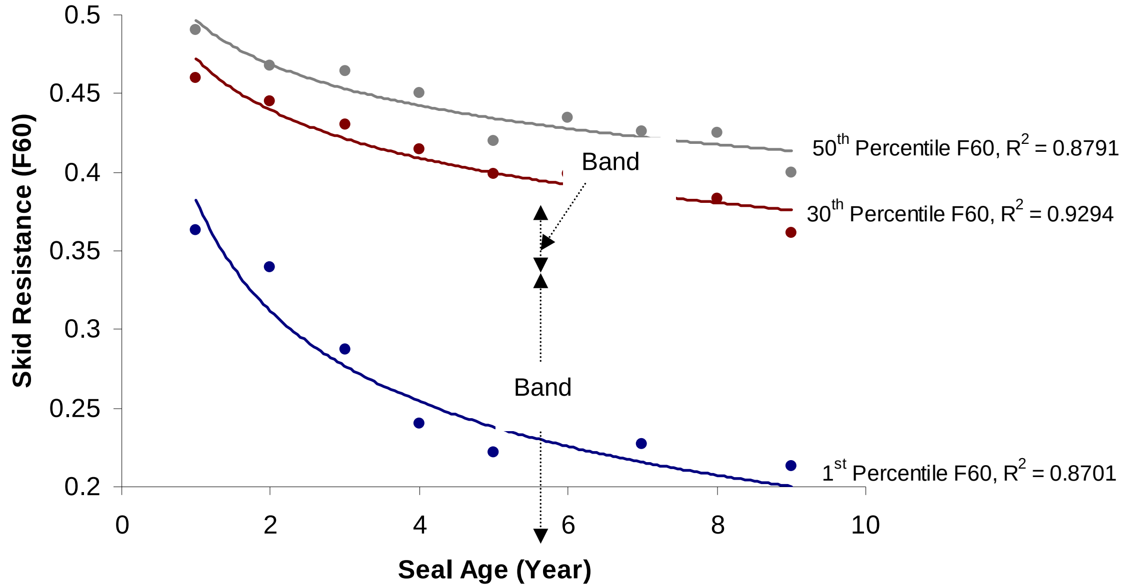


Figure 10: Regressed lines representing 1st, 30th, and 50th percentiles of skid resistance (F60)

ANALYSIS OF HISTORICAL SKID RESISTANCE DATA

Skid resistance data (F60) tested between 2004 and 2007 on Queensland state-controlled road networks were used in the analysis. Skid resistance data (F60) tested on spray seal surfaces were sufficient to develop probability distributions for different seals, and hence to develop skid resistance deterioration profiles. The analyses were conducted with skid resistance data tested for a 4 year period. Skid resistance deterioration profile developed for each year was compared with other years. Comparisons of the 15th and 30th skid resistance deterioration profiles for 2004 to 2007 for spray seal surfacing are presented in Figures 10 and 11. Both figures give empirical functions representing skid resistance profiles for each year of skid data.

Figures 10 and 11 show that skid resistance data for 2006 and 2007 give higher values in the deterioration profiles than skid resistance data for 2004 and 2005. It can be observed that the 15th percentile skid resistance deterioration profiles show more discrepancies among the 4-year period than those of the 30th skid resistance deterioration profiles. However, the 4-year data showed similar trends of skid resistance deterioration. More trend lines should be developed with more skid resistance data for other years. Appropriate skid resistance deterioration profiles could be developed with confidence once more trend lines with more data have been developed.

The methodology in developing skid resistance deterioration profiles is generic and can be used with SCRIM data. TMR endeavours to use SCRIM data to develop skid resistance profile at the network level as well as for project levels.

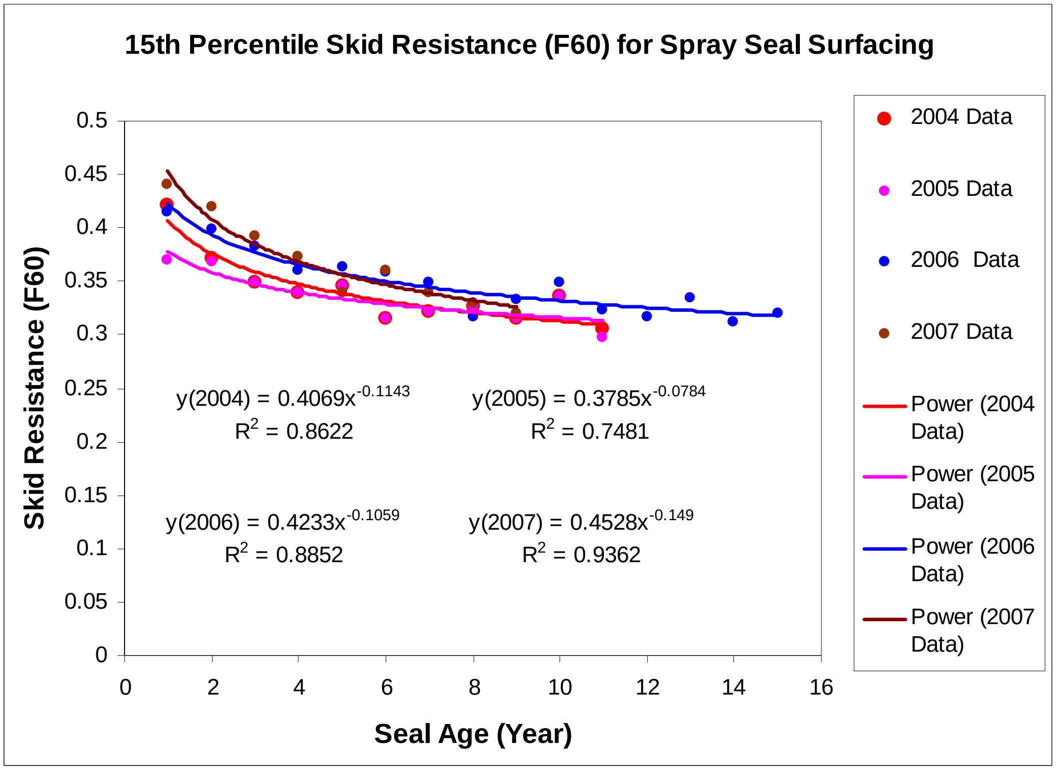


Figure 11: 15th percentile skid resistance deterioration profiles obtained from skid resistance data (F60) tested between 2004 and 2007

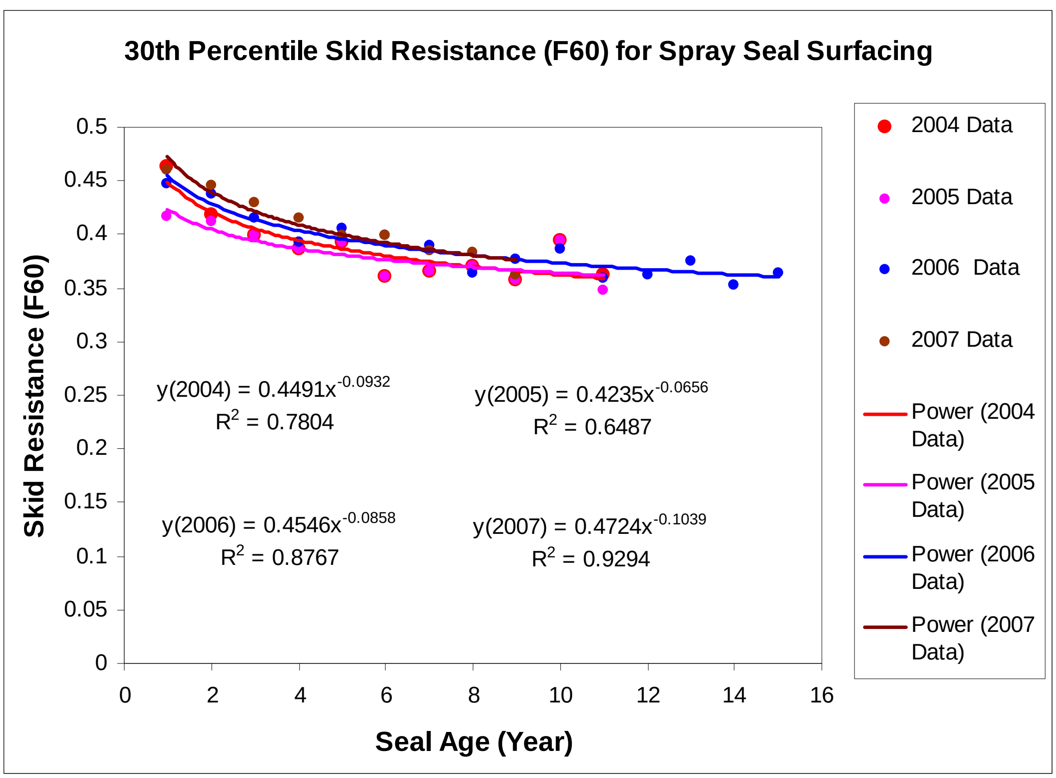


Figure 12: 30th percentile skid resistance deterioration profiles obtained from skid resistance data (F60) tested between 2004 and 2007

CONCLUSIONS

This paper presented a methodology for developing skid resistance deterioration profiles. The proposed methodology was developed through probability-based theory. Deterioration profiles for skid resistance (F60) data collected between 2004 and 2007 on Queensland state-controlled road networks were also analysed and presented in the paper. A skid resistance deterioration profile could be selected based on an acceptable percentile level such as 15th or 30th percentile. Adopting a skid resistance deterioration profile with a known percentile level would provide information on the probability of skid resistance values that are lower in value than those for the deterioration curve. Ideas and concepts which could be used in examining skid resistance deterioration curves and in selecting skid resistance deterioration profiles were discussed. The 1st percentile could be used as the lower bound levels (or the lowest skid value on the network) of the deterioration profile. Other percentile curves could be compared with the lower bound curve to identify a range of skid resistance values between a selected deterioration profile and the lower bound curve. Decision-makers could foresee the level of skid resistance having the values below a selected deterioration profile. The methodology is generic and can be used develop skid resistance profiles where other units of measuring skid resistance are available.

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Justin Weligamage is currently Manager Road Asset Strategy with the Department of Transport and Main Roads, Queensland, Australia. He has over 25 years of consulting, research and industry experience in the areas of road and civil infrastructure. Justin has been involved in several initiatives for developing and implementing road asset management initiatives, including the publication of "Asset Maintenance Guidelines", “Skid Resistance Management Plan”, Strategic application of the Highway Development and Management System, or HDM-4 within Queensland Main Roads, and road investment decision support research within the Cooperative Research Centre for Construction Innovation. He also wrote a number of research papers and technical reports, and these research works have been published and presented at various refereed international conferences.

Rob Vos has been the Queensland Executive of the Australian Asphalt Pavement Association for the past decade, working with the industry and government to improve the performance of bituminous products. He has been involved in the roads industry for 35 years since graduating from the University of Cape Town, South Africa with Civil Engineering degree. He is a member of the UK and South African Institution of Civil Engineers and is a UK Chartered Engineer. His experience covers 13 years with a State Road Authority in South Africa and 10 years as the Technical Director to the Southern African Bitumen Association. Rob has written, co-authored and presented papers to local and international conferences in Africa, USA and Europe.