Linking Road Traffic Accidents With Skid Resistance – Recent UK Developments

Authors: H E Viner[1], R Sinhal[2] and A R Parry[1]

[1]*TRL Limited, UK*
[2]*Highways Agency, UK*

ABSTRACT

When, in 1988, the UK Department of Transport first introduced requirements for skid resistance on its trunk road network, it introduced the concept of "investigatory levels" to be compared with measurements from routine skid resistance surveys. At the heart of this process was a link between the risks of wet skidding accidents occurring and the levels of measured skid resistance on the road. Initially, this was based upon a survey of a sample of the network at which the time was limited by survey capacity and computing power. The skidding standards have recently been revised and as part of this process, a new assessment of the link between accident risk and skid resistance has been made. This has involved a study of the whole Trunk Road network. This paper will review the historic background and then describe in more detail the recent study and its findings, how the results compare with the historic work and the changes that were shown to be appropriate for application in the revised standard introduced in August 2004.

1. INTRODUCTION

The skid resistance policy for trunk roads was introduced in January 1988 through the standard HD28 in the Design Manual for Roads and Bridges. This standard was based on research, carried out over a number of decades, that had pieced together the influence of road surface condition on accident risk and introduced a strategy for managing the skid resistance of trunk roads to deliver predictable levels of friction that are adequate for the majority of manoeuvres.

While this approach was still valid, there have been a number of important developments since 1988 that meant it was appropriate to review how the detailed outcomes of the policy are achieved. The trunk road network has changed to some extent in terms of length and geometry, traffic flows have increased, new types of surfacing materials have been introduced and vehicle and tyre technology has improved. Research into skid resistance has also progressed (e.g. Roe, Parry and Viner, 1998) and it was recognised that there were areas in which the implementation of the policy needed to be improved. Therefore, the Highways Agency decided to review the policy and standard for today's conditions.

As part of this review, TRL was commissioned by the Highways Agency to conduct a network level analysis of the influence of skidding resistance on accident risk. As a result of this, some changes were recommended to the way the network is categorised and the required levels of skid resistance are determined. This paper outlines the historical background to the introduction of the standard, the results of the new accident study and the conclusions reached which led to changes to the standard that was introduced in 2004.

2. BACKGROUND

Drivers need friction to accelerate, decelerate or change direction. During these manoeuvres, 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. The manoeuvre being attempted by the driver and certain characteristics of the vehicle define the magnitude of the friction force that will be required to complete it successfully. If the friction generated is not sufficient, the tyre(s) will start to skid, with potential for subsequent loss of control.

The friction available is influenced by several different factors, which makes analysis complicated. The condition of the road surface is one factor, which is particularly important in wet conditions. This led to the concept of measuring "skid resistance", whereby factors such as the vehicle and tyre were standardised to provide a method of assessing the contribution of the road surface to the available friction.

Early research in the 1930s showed that skid resistance:

- was different on different types of road surface,
- decreases with increasing speed,

- varies during the course of the year, and
- was lower during the first rainfall after a long dry spell.

Between the 1930s and the 1960s a range of different devices were developed in the UK for measuring skid resistance, culminating in the development of the SCRIM (Sideway-force Coefficient Routine Investigation Machine), by the early 1970s (Hosking and Woodford, 1976). This was the first device capable of large scale routine surveys, having been fitted with a water tank that greatly extended its range compared with the earlier test equipment. It had better facilities for entering markers for location referencing and an on-board paper tape punch to allow direct entry of the data to a computer for processing. Apart from changes to the vehicle chassis and updates of the data recording system, SCRIM has remained essentially the same until the development of the dynamic vertical load measurement system reported in a separate paper (Roe and Sinhal, 2005).

In parallel to the development of measuring equipment, research was also carried out to determine the levels of skid resistance appropriate. Again, in early work it was recognised that different levels of skid resistance might be appropriate, depending on the location and the local traffic conditions (Bird and Scott, 1936). These concepts were developed through the 1950s to 1970s (e.g. Giles, 1957 and Salt and Szatkowski, 1973) to the idea of different levels of skid resistance for “Most difficult sites” (e.g. roundabouts and sharp bends), “Average sites” (e.g. motorways and high speed roads; heavily trafficked urban roads) and “Other sites” (e.g. mainly straight roads with easy gradients and curves and no junctions). This also introduced the ideas of different levels of risk for different sites within the same category and the concept of equalising accident risk across the network.

A larger-scale study of the link between skid resistance and personal injury accidents, based on 1000km of road network (Rogers and Gargett, 1991), confirmed the different levels of accident risk for different types of road site and the increase in risk for sites with lower skid resistance. Some results from this work are reproduced in Figure 1.

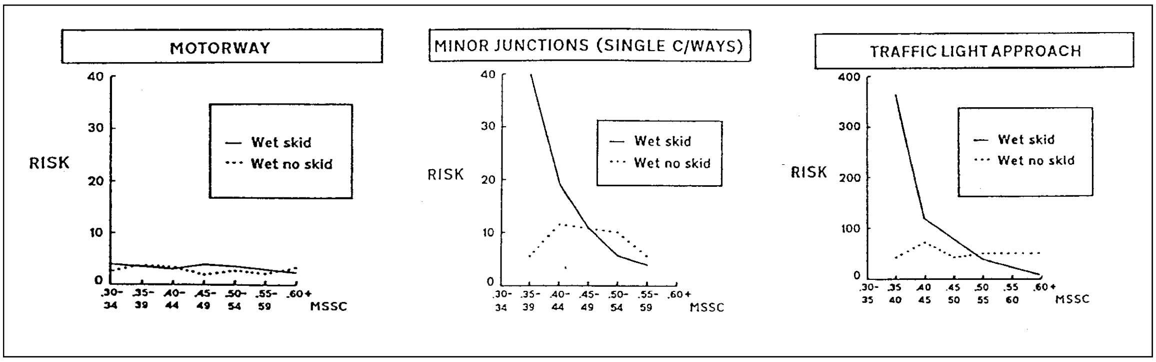

Figure 1 Risk of accidents on wet roads and Mean Summer SCRIM Coeffcient (MSSC) from Rogers and Gargett (1991)

To avoid the misinterpretation of a skid resistance value below a threshold level as implying that a dangerous situation existed, Gargett introduced the concept of and “investigatory level” (IL) of skid resistance. Skid resistance measured at or below the

IL would trigger a detailed examination of the site and an assessment of the need for remedial works.

This approach also recognised that at that time it was expected that the skid resistance levels on the network would be found to be lower than the proposed ILs in a significant proportion of cases; it would take a programme of improvements, carried out over a number of years, to remedy this. This work led to the definition of the 13 “site categories” and corresponding suggested ILs that were introduced in the standard for skid resistance in January 1988.

3. NETWORK ACCIDENT ANALYSIS

As part of the recent review of skid resistance policy, a database of pavement condition was constructed to support a new analysis of the link between site characteristics, skid resistance and accident risk.

The analysis drew data from a number of sources:

- A Highways Agency database containing pavement condition data from routine machine surveys, specifically measurements of skid resistance and texture depth, geometric parameters (gradient, crossfall and curvature), rut depth and longitudinal evenness. The site categories assigned to each part of the network under the existing skid resistance standard were also included. The data used in the analysis were the most recent data available during 2001 and were, therefore, as concurrent with the accident records as was practical.

- A network inventory database including carriageway and hard shoulder widths and details of junctions and other accesses.

- Junction locations and types obtained from Ordnance Survey maps.

- A Department for Transport database containing information on traffic flow and composition.

- A subset of the STATS19 data, used by police forces to record information about personal injury accidents, covering accidents on the trunk road network in the period between 1994 and 2000. Details such as incidence of skidding, number of vehicles, number and severity of casualties, road speed limit and road condition (wet, dry etc.) were extracted.

In the database, the network was divided into lengths of around 500m (motorways) or 200m (other roads) to which the other data were assigned. These lengths represented a compromise between needing a long length, to be reasonably confident of assigning accidents to the correct length, and preferring short lengths, so that the surface condition was reasonably homogeneous. Shorter lengths were created where necessary, e.g. around features such as junction approaches or bends. A summary of the data available for analysis is given in Table 1, broken down by the site categories defined in the 1988 policy.

Table 1 Summary of data available for analysis

Site category	Number of lengths with data	Median length (m)	Total length (km)	Data coverage (% of whole network)
Motorway	3979	500	1901	56
Dual c/way non-event*	8246	200	1648	59
Single c/way non-event*	9026	200	1711	67
Dual c/way minor junction	359	93	41	40
Single c/way minor junction	2096	70	202	73
Major junction	909	57	80	49
Gradient 5 to 10%	708	200	126	82
Gradient steeper than 10%	14	190	3	100
Bend <250m radius	453	120	62	46
Approach to roundabout	57	75	6	22
Approach to signals, crossings etc.	402	53	22	42
Bend <100m radius	534	50	31	59
Roundabout	286	196	52	42

* "Non-event" sites have no junctions, crossings, notable bends or gradients, but may have commercial or residential accesses

A combination of approaches was taken to analyse the data. Taking the site categories individually, values of mean and 95 percentile accident risk were calculated for different bands of skid resistance. Accident risk was defined here as the total number of accidents per 100 million vehicle km driven. Although improvements to skid resistance will particularly influence skidding accidents in wet conditions, it was decided to include all accidents in the analysis because of the difficulty with accurate reporting of the surface condition at the time of the accident, particularly if it is "damp" rather than obviously wet, and whether or not skidding occurred. However, the trends observed for all accident data were generally found to be stronger and more significant when examining only accidents where the surface was recorded as having been wet or where at least one vehicle skidded (Parry and Viner, 2005).

This approach allowed the overall effects of skid resistance to be analysed, but it was recognised that other factors, such as traffic flow, road condition and geometry also affect the accident risk and could introduce a bias to the analysis. To consider the effect of these factors on the accident rate, accident models were developed. In this approach, the number of accidents observed in each length in the database was considered as a function of the length, the traffic flow and a series of other explanatory variables, such as skid resistance. This form of model has been shown to be effective in other accident studies, for example Maher and Summersgill (1996). The modelling process and analysis of its results are described in more detail in Parry and Viner (2005).

4. RESULTS OF THE ACCIDENT ANALYSIS

The variation of the mean accident risk with skid resistance is shown in Figure 2 for "non-event" lengths of three classes of road and in Figure 3 and Figure 4 for the different junction categories.

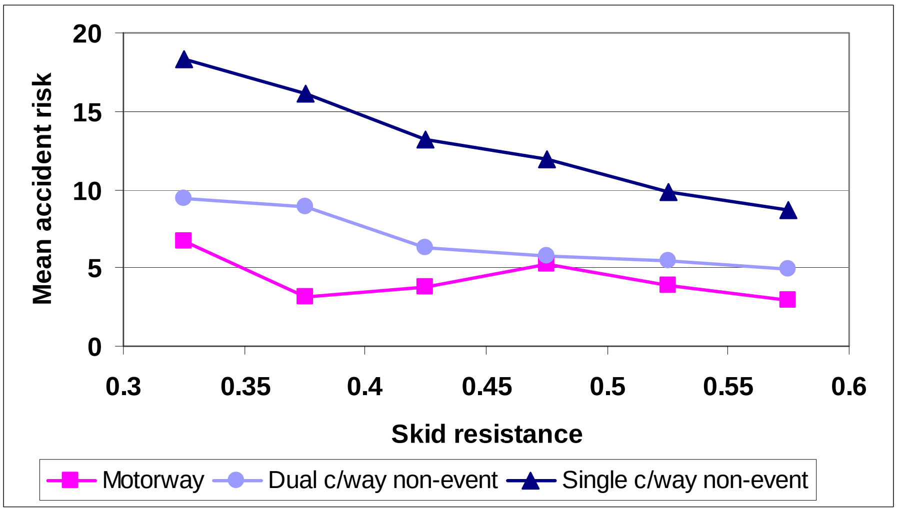

Figure 2 Mean accident risk by skid resistance

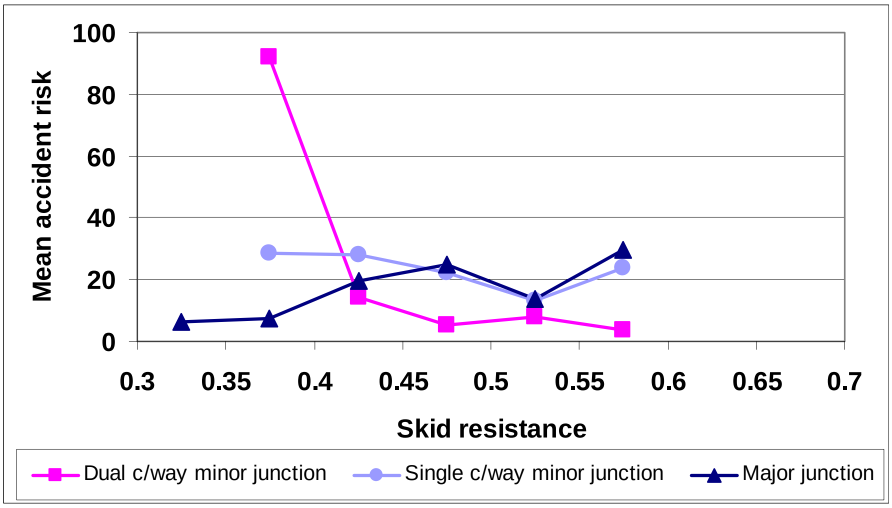

Figure 3 Mean accident risk by skid resistance for junctions (1)

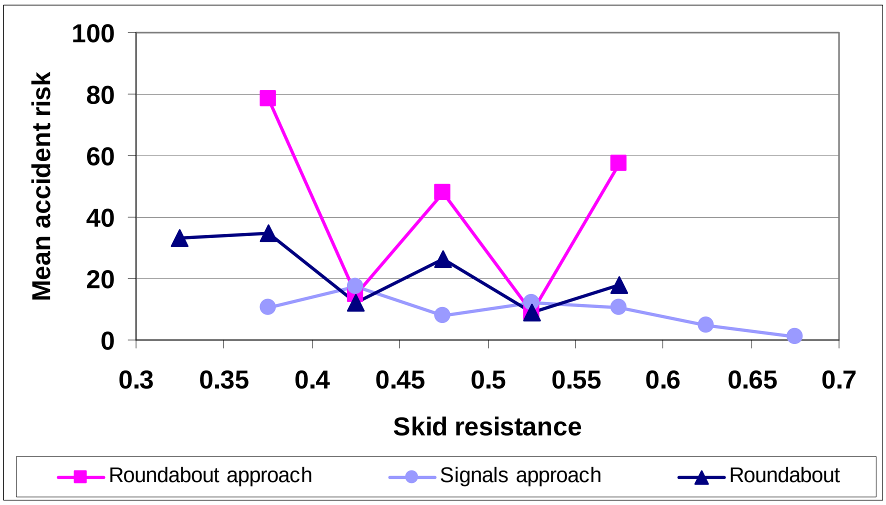

Figure 4 Mean accident risk by skid resistance for junctions (2)

The notable points from the analyses, in relation to the site categories and Investigatory Levels defined in the 1988 policy, are that:

- There is a clear distinction in accident risk observed between the three non-event categories, justifying them remaining separate.

- For motorways, the overall trend with skid resistance is very flat except within the lowest band of skid resistance. Although the number of cases within this band is rather small, it was felt to justify the Investigatory Level for this category remaining at 0.35[1]. Overall, the skid resistance was found not to be a significant explanatory variable in the accident models for motorways.

- For dual carriageways there is a statistically significant trend for accident risk to increase at locations with lower skid resistance. For single carriageway non-event sections, the trend is both stronger and more significant. The trend is even stronger when considering only wet or skidding accidents, which gives added confidence in the result. The mean accident risk for dual carriageways increases slightly below 0.4, suggesting the Investigatory Level could be increased to 0.4 for some sections. It was also observed that the accident rates in the vicinity of slip roads are higher than the other non-event sections (particularly for wet and wet skid accidents), also suggesting a selective increase of Investigatory Level to be necessary.

- The trend for single carriageway non-event sections shows a continuous increase in accident risk with decreasing skid resistance, and the models indicate a similar level of accident risk for single carriageway non-event sections at 0.40-0.45 as for dual carriageway non-event sections at 0.35 to 0.40.

- The accident risk for the various junction categories is generally higher than for the non-event sections but, otherwise, the results are somewhat variable. Single carriageway minor junctions exhibit the strongest and most significant trend with skid resistance of all the site categories. Conversely, the trend for major junctions is not significant. For dual carriageway minor junctions, the accident risk is rather low, except for the notable result at low skid resistance. Although this value is based on a rather small amount of data, it is indicative that some sites within the category exhibit higher accident risk.

- For roundabouts[2] and the approach to traffic signals, the mean accident rates and the trends with skid resistance fall approximately between the trends observed for minor junctions on dual and single carriageways. For roundabout

[1] In the UK, SCRIM results are normally reported as SCRIM Coefficient values, equal to the SCRIM Reading multiplied by 0.0078.

[2] HD28/88 required roundabouts and bends less than 100m radius to be tested at 20km/h, compared with 50km/h for most other site categories, but this distinction was removed in the revised standard for safety reasons. In Figure, the skid resistance values have been adjusted to compensate for the different test speed and allow a direct comparison between the categories.

approaches, the mean accident risk is clearly higher than for the other two categories, but the trend with skid resistance is rather ambiguous due to the small amount of data. Again, the clearest conclusion is that the different sites within the category exhibit significant differences in accident risk.

- In a number of cases, including single carriageway minor junctions and major junctions, the accident risk increases for the relatively small amount of cases where there is a particularly high level of skid resistance, indicating that improving the skid resistance does not always reduce the accident risk to the mean trend.

- As a result of the variability, a single junction category was recommended to allow an Investigatory Level appropriate to each junction layout to be chosen.

A similar analysis of the existing bend and gradient categories and models to ascertain the influence of curvature and gradient led to the conclusion that the bend category should be extended to include bends with a radius of curvature of up to 500m.

The accident risk for road lengths in the same site category and with similar skid resistance approximately follows a Poisson distribution, with typically more than half the lengths having no accidents, and a long tail of sites with higher accident risk. A comparison of the mean and 95 percentile accident risk for single carriageway non-event sections is shown in Figure 5, which indicates the wide range in accident risk within individual site categories, at all levels of skid resistance. This range is typical of all the categories and has implications for setting threshold levels and site investigation, as discussed in the following section.

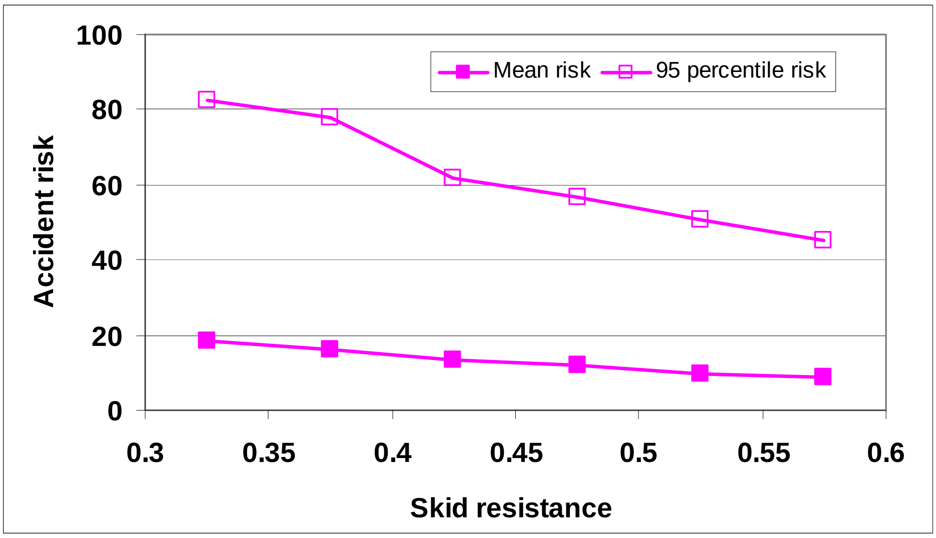

Figure 5 Mean and 95 percentile accident risk for single carriageway non-event lengths

5. INVESTIGATION VERSUS INTERVENTION THRESHOLDS

The background to the choice of threshold levels to trigger further investigation, as opposed to automatic intervention to improve the skid resistance, was discussed in section 2. By the late 1990s, after more than a decade of implementing a skid resistance policy, and with a much lower proportion of trunk roads with low skid resistance it was relevant to reconsider the use of "Intervention Levels" of skid resistance, representing the lowest acceptable level and making improvement mandatory.

The accident analysis demonstrated a wide variation in accident risk, at all levels of skid resistance within a site category, as shown in Figure 5. This variability implies that, at whatever level of skid resistance a threshold is drawn, it will be possible to find sites immediately above the skid resistance threshold with a high observed accident risk, which might justify treatment more than the low risk sites immediately below the threshold. For this reason, it is preferable to set an Investigatory Level at a relatively high level and to determine the sites that are more or less deserving of treatment through the process of site investigation. In particular, it would be preferable to set a higher Investigatory Level for the high risk sites within each site category, since there may be benefits of intervening at a higher level of skid resistance for some sites within the site category.

The 1988 standard for skid resistance incorporated the facility to vary the default Investigatory Level, but it had been found that engineers rarely made use of this facility in practice. It was therefore clear that better advice would need to be provided to allow engineers to identify the sites for which setting a higher Investigatory Level would be worthwhile.

However, this approach assumes that "high-risk" sites can be identified in practice and that the observed accident risk proves to be amenable to reduction through improving the skid resistance. Accidents result from a complex sequence of events that is impossible to fully predict and so part of the variability between sites in the same category will be as a result of these random influences. An analysis of accident patterns was carried out to determine whether the variability in accident risk appeared to be entirely random, or whether a component of appeared to be systematic.

In terms of the skid resistance standard, random variation implies that a site for which a high accident risk has been observed in the past has no greater or lesser chance of there being accidents in future than any other site. In this scenario, an intervention level might be preferred, so that all the sites within the category are maintained with skid resistance at a specified level. Conversely, if the variation is systematic, i.e. as a result of real differences between sites that influence accident causation, then the site investigation system can provide benefits by targeting treatment effectively at sites with the greatest potential for reducing accidents.

To investigate this, the accident data for each length in the database were summarised over two time periods: 1994 to 1997 and 1998 to 2000. The sites were then grouped according to whether or not accidents had been observed in each of these time periods. The leftmost two column in Figure 6 indicates that for all sites taken together, there were approximately 75% of lengths in the database where no accidents were observed in the period 1998-2000, with at least one accident recorded for the remaining 25% of lengths. However, when the sites are split using the criterion of whether or not any accidents were observed in the preceding period (1995-1997), it can be seen that a clear difference emerges. For sites where at least one accident occurred in the first period, a greater proportion was found to have had at least one accident recorded in the second period than for sites where no accidents had occurred in the first period.

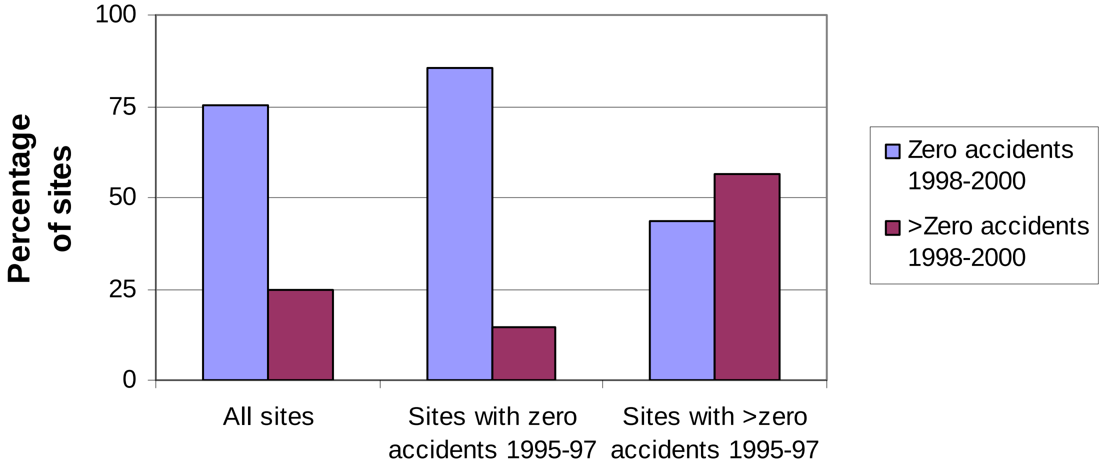

Figure 6 Random vs. systematic variability in accident risk

This indicates at least an element of systematic behaviour within the overall variability, which supports the case for retaining an Investigatory Level and basing the judgement on the need for treatment partly on the observed accident history. A further argument in favour of retaining the Investigatory Level is that fixing an Intervention Level, even as an underpinning level, would distort decisions about budget prioritisation that would otherwise be made based on a risk assessment. This is contrary to the ethos of a risk-based approach.

It should be noted that improving the skid resistance may not be the most appropriate solution to reducing accident risk in all cases. Figure 6 also indicates that some sites where no accidents were recorded in the first period did have accidents recorded in the second. This means it will also be important to determine whether there are identifiable risks at individual sites that might lead to accidents in future in spite of a current good accident record.

From these considerations, TRL recommended that the Investigatory Level should continue to be considered as a trigger for further investigation, as opposed to automatic intervention, and that a range of Investigatory Levels be specified for each site category to take into account the variability in accident risk observed. Furthermore, that to achieve this in practice, it would be necessary to strengthen the application of engineering judgement through improving the advice on setting Investigatory Levels and on site investigation contained in the standard.

6. NEW SITE CATEGORIES

The changes to the site categories and Investigatory Levels recommended as a result of the accident analysis are shown in Table 2.

Table 2 Old and new recommended site categories and Investigatory Levels from HD28/88 (and subsequently HD28/94) and HD28/04 for trunk roads in Great Britain

Site category and definition		Investigatory level (at 50km/h) HD28/88 (preceding)	Investigatory level (at 50km/h) HD28/04 (current)
A	Motorway	0.35	0.35
B	Dual carriageway non-event	0.35	0.35-0.40
C	Single carriageway non-event	0.40	0.40-0.45
Q	Dual Carriageway (all purpose) - minor junctions	0.40	0.45-0.55
	Single Carriageway minor junctions & approaches to and across major junctions (all limbs)	0.45	
	Approach to roundabout	0.55	
K	Approaches to pedestrian crossings and other high risk situations	0.45	0.50-0.55
R	Roundabout	0.45	0.45-0.50
G1	Gradient 5-10% longer than 50m	0.45	0.45-0.50
G2	Gradient >=10% longer than 50m	0.50	0.50-0.55
S1	Bend radius <500m – dual carriageway	0.45-0.50	0.45-0.50
S2	Bend radius <500m – single carriageway		0.50-0.55

Table notes: 1. Category R and some sites in new categories S1 and S2 were previously tested at 20km/h. 2. A reduction in Investigatory Level of 0.05 is permitted for categories A, B, C, G2 and S2 in low risk situations, such as low traffic levels or where the risks present are well mitigated and a low incidence of accidents has been observed. Exceptionally, a higher or lower Investigatory Level than indicated in the Table may be assigned if justified by the observed accident record and local risk assessment.

For most categories a range of Investigatory Levels is specified and it was recommended that the Investigatory Level set would normally be the lowest value in the band. Circumstances that would warrant setting a higher Investigatory Level include:

- Notable potential for conflict between road users, particularly at speed or where the outcome is likely to be severe.
- Road geometry departing substantially from current standards.
- Known incidence of queuing where the traffic speed is otherwise high.
- The presence of accesses onto the main carriageway, if they are busy, have poor advance visibility or create conflict between leaving or joining traffic.

- Low texture depth.

An attempt was made to estimate the financial costs and benefits that would accrue as a result of changing the skidding resistance standard for the English trunk road network in line with the recommendations of the report. The length of the network likely to be affected by the changes was estimated based on up to date records of the existing site categories, the current distribution of measured skid resistance and the percentage of the categories in the analysis database with geometry or accident risk that would imply a higher Investigatory Level would be selected. The cost estimates are based upon likely treatment lengths, the cost of resurfacing and traffic management and road user costs associated with delays at the works. Benefits are based upon the financial value assigned to accident reductions by the Department for Transport. Further details of this process are given in Parry and Viner (2005).

Depending on the assumptions made about the accident savings, it was found that the realisation period, i.e. the time at which the benefit associated with the accident saving would match the cost associated with treatment, varied from less than a year (best case) to 16 years (worst case). However for most site categories even the worst-case realisation period was within the normal lifetime of the surfacing, assumed to be around 10 to 12 years. Based on this albeit simple analysis, it appears that, in addition to assisting Highways Agency meet its targets for accident reduction, the costs of applying the recommended changes to the skidding resistance standard will be recovered in the financial value of the accident reductions that are estimated to result.

7. SUMMARY AND CONCLUSIONS

As a result of this work, recommendations were made for a rationalisation of the site categories and investigatory levels. A key finding was the extent of variability of the accident risk for individual sites within a site category, indicating that the effectiveness of the standard could be maximised by identifying and targeting maintenance treatment to improve skid resistance at sites where there is greatest potential to reduce the accident risk. It was recommended that this could be achieved through better procedures for setting investigatory levels and conducting site investigation.

These changes were implemented in the revision to the skid resistance policy for UK trunk roads that came into force in 2004. It is believed that the revision will result in more robust decision-making, leading to more effective prioritisation of maintenance budgets. Furthermore, it is expected that, although the revision to the site categories and investigatory levels would result in higher Investigatory Levels for some sites, and that a proportion of these would require maintenance to be brought forward under the new standard, the costs will be recovered through the reduced accident costs within the lifetime of the surfacings.

TRL are currently working with the Highways Agency to monitor the implementation of the new standard in England and to assess its effectiveness in delivering the desired outcomes detailed above. Research is also being undertaken to determine whether there are areas of the policy which could be further improved.

8. ACKNOWLEDGEMENTS

The work in this paper was carried out in the Infrastructure division of TRL Limited as part of projects carried out for the Highways Agency.

9. REFERENCES

Bird G and W J O Scott (1936). Measurement of the non-skid properties of road surfaces. Department of Scientific and Industrial Research and Ministry of Transport Road Research, Bulletin No. 1 HMSO, London.

Giles C G (1957). The skidding resistance of roads and the requirements of modern traffic. Proceedings of the Institution of Civil Engineers, 1957, Vol 6 (Feb) pp216-42, ICE, London.

Highways Agency, Scottish Executive, Welsh Assembly Government and the Department for Regional Development, Northern Ireland. Design Manual for Roads and Bridges, Volume 7. The Stationery Office, London.
HD28 (1988 and 2004). Skid Resistance. DMRB 7.3.1.
HD36 (1999). Surfacing materials for new and maintenance construction. DMRB 7.5.1

Hosking J R and G C Woodford (1976). Measurement of skidding resistance: Part I. Guide to the use of SCRIM. Department of the Environment, TRRL Report LR 737, TRRL, Crowthorne.

Maher M J and I Summersgill (1996). A comprehensive methodology for the fitting of predictive accident models. Accident Analysis and Prevention, Vol 28, No 3, pp281-296.

Parry A R and H E Viner (2005). Accidents and the skidding resistance standard for strategic roads in England. TRL Research Report TRL622, TRL Limited, Wokingham, Berkshire.

Roe P G, A R Parry and H E Viner (1998). High and low-speed skidding resistance: the influence of texture depth. TRL Report TRL367, TRL Limited, Wokingham, Berkshire.

Roe P G and R Sinhal (2005). Recent developments to the SCRIM measurement technique in the UK. International Conference on Surface Friction of Roads and Runways, Christchurch, New Zealand, May 2005.

Rogers M P and T Gargett (1991). A skidding resistance standard for the national road network. Highways and Transportation, Vol 38, No 4, pp10-16.

Salt G F and W S Szatkowski (1973). A guide to levels of skidding resistance for roads. TRRL Report LR510. Department for the Environment, Transport and Road Research Laboratory, Crowthorne, Berkshire.

Paper reference PA/INF/4520/05