Accidents and the skidding resistance standard for strategic roads in England

Prepared for Safety Standards and Research, Highways Agency

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Executive Summary

In 1988 the Department of Transport introduced a standard for the skidding resistance of the UK strategic road network, in HD28 of the Design Manual for Roads and Bridges. That standard was based upon an analysis of the relationship between accidents and skidding resistance on 1,000km of road and derived relationships for 13 site categories, based upon geometry and the presence of junctions. As a result of the analysis, each site category was assigned a recommended skidding resistance, the Investigatory Level, at or below which a site investigation is triggered to determine if accident risk would be reduced by improving the skidding resistance at that site.

There have been some important developments since the standard was introduced in 1988. A new generation of road surfaces has been developed, the strategic road network has changed to some extent in terms of length and geometry, traffic levels have grown, vehicle and tyre technology have improved and research into skidding resistance has progressed. As a result, it was recognised that the standard might need to be revised. Highways Agency, therefore, decided to review the standard and to commission a new accident analysis of the strategic road network in England. This report describes the accident analysis that was undertaken, the results and the recommended revisions to the site categories and corresponding Investigatory Levels and an assessment of the potential benefits and costs in terms of accident savings and costs of surface treatments.

A network level analysis of the influence of skidding resistance on accident risk was made using existing databases of information on; road condition and geometry; traffic statistics; an inventory of certain accesses and junctions and; injury accident records. Information from the databases was assigned to a common location referencing system using a geographical information system and aggregated into sections, upon which the analysis was made. Junctions were identified from electronic map tiles and assigned to the relevant section. The analysis included 29,250 accident records.

A number of approaches have been taken to the accident analysis. The first approach was to plot accident risk against skidding resistance for the site categories in the existing standard. Secondly, accident risks were analysed using statistical models of the type found to represent trends in other accident analyses, for instance of the influence of road geometry on accident risk. Thirdly, where the influence on accident risk of curvature, gradient and being in the vicinity of junctions was significant, the results were used to reassess the definition of site categories; where new site categories were recommended, the accident analysis was repeated.

The results have led to recommendations for some new site categories and Investigatory Levels. For most site categories, a range of Investigatory Levels has been recommended. This is regarded as critical because of the range of accident risk observed for different sites within the same category. It is recommended that the normal Investigatory Level will be the lowest value and that the advice in the skidding resistance standard, describing the circumstances that will justify it being increased, should be strengthened.

An attempt has been 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 this report. 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. 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.

1 Introduction

In 1988 the Department of Transport introduced a standard for the skidding resistance of the UK strategic road network, in HD28 of the Design Manual for Roads and Bridges. That standard was based upon an analysis of the relationship between the risk of accidents and skidding resistance, as described by Rogers and Gargett (1991). The accident data were derived from records of fatal and injury accidents on wet roads contained in STATS19 accident records (the blank form can be seen in an Annex to Road Casualties Great Britain 2002: Annual Report, Department for Transport *et al.* (2003)). The skidding resistance was measured with the sideway-force coefficient routine investigation machine (SCRIM), British Standards Institute (1999), Hosking and Woodford (1976). The analysis was made on 1,000km of road and derived relationships between the SCRIM value and the risk of wet-skidding accidents for 13 site categories, based upon geometry and the presence of junctions.

As a result of the analysis, each site category was assigned a recommended skidding resistance, the Investigatory Level (IL), at or below which a site investigation is triggered to determine if accident risk would be reduced by improving the skidding resistance at that site. The default ILs in the standard were intended for guidance only because the accident risk at individual sites may vary considerably from the network average. Where the result of a site investigation is to recommend resurfacing, maintenance of the site is given priority. Alternatively, other safety measures may be recommended, such as improving markings or signing. Site investigation could also result in a change in the IL. Where no action is recommended the site would be investigated again after the next SCRIM measurement if the skidding resistance remained below the IL.

The latest version of the standard with ILs based upon this original analysis was published in 1994 and is referred to as HD28/94 (Highways Agency *et al.,* Design Manual for Roads and Bridges). Similar standards have subsequently been introduced in other countries, including Australia, RTA/VicRoads (1995) and New Zealand, Donbavand (1989). Other studies have also found relationships between accident rates and skidding resistance, Gothié (2001), Gáspár (2000).

There have been some important developments since the standard was introduced in 1988. A new generation of road surfaces has been developed, the strategic road network has changed to some extent in terms of length and geometry, traffic levels have grown, vehicle and tyre technology have improved and research into skidding resistance has progressed. As a result, it was recognised that the standard might need to be revised. Highways Agency, which is responsible for the operation of the strategic road network in England, therefore decided to review the standard and to commission a new accident analysis. This report describes the accident analysis that was undertaken, the results and the recommended revisions to the site categories and corresponding ILs and an assessment of the potential benefits and costs in terms of accident savings and financial costs of surface treatments.

2 Accident analysis

A network level analysis of the influence of skidding resistance on accident risk was made using existing databases of information on road condition and geometry, traffic statistics, an inventory including the presence of certain accesses and junctions and injury accident records. Information from the databases was assigned to a common location referencing system using a geographical information system (GIS) and aggregated into sections, upon which the analysis was made.

2.1 Data sources and aggregation

The data used in the accident analysis were from the following sources:

- *State of the Network (SON).* A Highways Agency database containing pavement condition data from routine machine surveys, particularly skidding resistance level measured by SCRIM, texture depth, geometric measurements, rut depth and longitudinal profile variances. Site categories, defined in the HD28/94 skidding resistance standard, are also included. The version of SON used in this analysis was current during 2001 and contains data collected recently before then. The data are, therefore, as concurrent with the accident records as is practical, see below. Since 2001, data collection procedures and storage systems have been updated.

  (It is important to note that the SCRIM data recorded in SON are not the measured SCRIM readings but have been multiplied by a factor of 0.0078 in order to be consistent with previously recorded levels (more details are available in HD28).)
- *Routine Maintenance Management System (RMMS).* A network inventory including carriageway and hard shoulder widths and details of junctions and other accesses.
- *Integrated Transport Economics and Appraisal (ITEA).* A Department for Transport database containing information on traffic flow and composition.
- *STATS19.* A database of STATS19 records, containing information about personal injury accidents, such as incidence of skidding, number of vehicles, number and severity of casualties, road speed limit and road condition (wet, dry etc.). The grid-referenced position of the accident is also recorded, Department for Transport *et al.* (2003).

The definition of the strategic road network changes as new roads are built and others pass to and from the control of local highway authorities. The Department for Transport 'Trunk Road Definition for 1999' was used for this work and any accident locations which are not on the strategic road network, according to this definition, were not included in the accident analysis.

The data sources use different location referencing systems. They have been combined on a common location system defined by section and chainage, Highways Agency (2003). SON and RMMS already use this location system. Other data sources, referenced by grid co-ordinates, were linked to section and chainage using the GIS platform

MapInfo®. Traffic flow measurements were assigned to sections using the nearest ITEA census point. Accident locations from STATS19 were snapped to the nearest section and chainage, subject to validation (see Section 2.1.2).

Before the analysis, software aggregation functions were used to combine the data into sub-sections of predetermined lengths, within the site categories in the existing standard HD28/94. The preferred lengths were chosen as 500m for motorways and 200m for other roads. These lengths represent a compromise between being sufficiently long to provide confidence in correctly assigning accidents to individual sub-sections yet being short enough to be in reasonably consistent condition. Road condition data for SCRIM, texture depth, rut depth, cross-fall, gradient and radius of curvature were aggregated in this way, using the average values for all surveys available in the database. Longer or shorter aggregated lengths were created where necessary, for example at the ends of sections or where the site category changed around features such as junction approaches or bends.

A summary of the road length available for analysis, for which all the data sources are complete, is given in Table 1, broken down by the site categories defined in HD28/94.

Table 1 Summary of data available for analysis

Site category	*Number of lengths with data*	*Median section 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	453	120	62	46
Approach to roundabout	57	75	6	22
Approach to signals, crossings etc.	402	53	22	42
Bend <100m	534	50	31	59
Roundabout	286	196	52	42

2.1.1 Junctions

The data sources described do not contain detail about the types of junctions present or their location. However, the presence of a junction is an important factor in accident risk, Walmsley and Summersgill (1998) and so junctions were identified individually in order to provide detail of their type and location.

Junctions were identified on electronic OS 1:50,000 map tiles. Using MapInfo® GIS, the strategic road network was overlaid onto the maps. A program was written to allow information about junctions to be identified and collected. This allowed an operator to relate each junction to relevant network sections that were located at or near the location of the junction. As a result, data could be aggregated over a length referenced to the junction.

Junctions were classified as Minor (with a non-trunk road), Major (with a trunk road, not roundabout or grade separated), Roundabout, Slip On (slip road joining main carriageway), Slip Off (slip road leaving main carriageway), Level Crossing or Other (junctions or marked accesses which do not readily fit with the above categories e.g. lay-bys).

When a junction was identified, the operator would select the sections on the network that it was adjacent to (the system provided a list of nearby sections to assist in this task). The position and junction classification was recorded, along with the orientation. This allowed further information to be derived, such as, if the junction was a left or right turn, depending on direction of travel. Finally, the number of other roads that comprised the junction was recorded along with road type (i.e. number of trunk and non-trunk roads). Once the data had been recorded, they were processed to translate the junction grid references into the location reference system and assign it to a reference section and distance along it.

2.1.2 Accident records

In all, 122,046 accident records for accidents between 1994 and 2000 inclusive have been identified from the database of STATS19 records as being on the strategic road network. Occasionally, map reading or transcription errors occur when accident details are recorded in STATS19; therefore accident co-ordinates may not be precise and require validation.

To do this, the GIS was used to define a 300m diameter circle around each accident's recorded position. If a road section intersected the circle then the accident was snapped to that section at a chainage corresponding to the closest approach, providing that the road name listed in the STATS19 record matched the road name assigned to the section and the direction of travel was consistent with the type of carriageway, i.e. an accident would not be snapped to the wrong side of a dual carriageway. The direction of travel was determined on a majority basis from the directions recorded for all the vehicles involved in each accident.

This resulted in 94%, or 114,457 accident records, being successfully assigned. Of these, 29,250 occurred on sections for which all the data sources were complete and unambiguous; these accidents were included in the subsequent analysis. By following these procedures each accident was assigned to a location reference section and distance along it, such that it can be cross-referenced to data held in SON and RMMS.

2.2 Form of the analysis

Accidents occur for a multitude of reasons and risk is influenced by a large number of factors. This can lead to unclear conclusions from analysis of accident risk. A number of approaches have been taken to the accident analysis in order to overcome this. Where the results of one approach indicate a trend without being conclusive, a similar trend produced by another method can give more confidence in drawing conclusions. Results are given in Section 3.

The first approach to the analysis was to plot accident risk, expressed as the number of accidents per 10^8 vehicle kilometres, against skidding resistance for the individual site categories in HD28/94. All-accident risk; wet-accident risk and wet-skid-accident risk were plotted, along with the percentage wet-accidents compared to all-accidents and the percentage wet-skid-accidents compared to wet-accidents.

As well as the mean accident risks, the 95^{th} percentile values were also plotted. This value is important within the context of site investigation. If the trend of the 95^{th} percentile with skidding resistance is different to that of the mean then the appropriate IL for higher risk sites may be different to that for average sites.

Secondly, accident risks were analysed using models of the type found to represent trends in other accident analyses, Maher and Summersgill (1996), of the form:

$$R = kQ^{\alpha}L^{\beta}\exp\left(a_1x_1, a_2x_2 \ldots a_nx_n\right) \quad (1)$$

Where R is the number of accidents, Q is traffic flow, L is length, x_1-x_n are factors including skidding resistance, texture depth etc. and, k, α and a_1-a_n are constants determined in the modelling process. The value of β was set to 1 because the sub-section lengths were nearly constant and so the effect of length could not be modelled. Generalised linear modelling (GLM) allowed the strength of any trend in accident risk with skidding resistance to be quantified, along with its statistical significance. The variables traffic flow, SCRIM skid resistance, texture depth, friction at 50 km/h and at 100 km/h (estimated from SCRIM and texture depth, Roe *et al.* (1998)), curvature and gradient were tested individually for significance. Significant variables were then combined in the model of the type above. Any variables that were found not to be significant in the combined model were dropped, starting with the least significant, until a final model was reached and the contribution of skidding resistance could be assessed for each site category.

The influence of other variables such as rural or urban environment and proximity to junctions can also be modelled in this way. The results that follow in Section 3, below, are for rural roads, defined as those having a speed limit above 40mph.

Thirdly, where the influence on accident risk of curvature, gradient and being in the vicinity of junctions and accesses was significant, the results were used to reassess the definition of site categories. Where site categories in HD28/94 include more than one carriageway type, the carriageway types were analysed separately. Where new site categories could be recommended as a result, the accident analysis was repeated for these new categories.

3 Results and recommended Investigatory Levels

3.1 Non-event sections

'Non-event' sections are motorways, dual carriageways and single carriageways with no junctions or crossings or notable bends or gradients, although they may have other accesses, for example commercial or residential properties. Figure 1 shows the relationship observed between mean all-accident risk and SCRIM skid resistance for non-event lengths on motorways and dual and single carriageway all purpose trunk roads in England, according to the HD28/94 site categorisation recorded. In HD28/94, these categories have ILs of 0.35, 0.35 and 0.40, respectively.

There is a distinction between these three categories that justifies them remaining separate. The mean levels of all-accident risk are different and for single carriageways about twice the level for other roads. More details about the significance of skidding resistance in relation to accident risk are given in the following sections. Subsequently, an analysis of the influence of curvature and gradients led to the recommendation that these site categories be changed (Section 3.4) and so the GLM analyses of non-event sections of dual carriageways and single carriageways was made taking this into account. For motorways, GLM revealed that the influence of skidding resistance was not significant and so the analysis was not repeated.

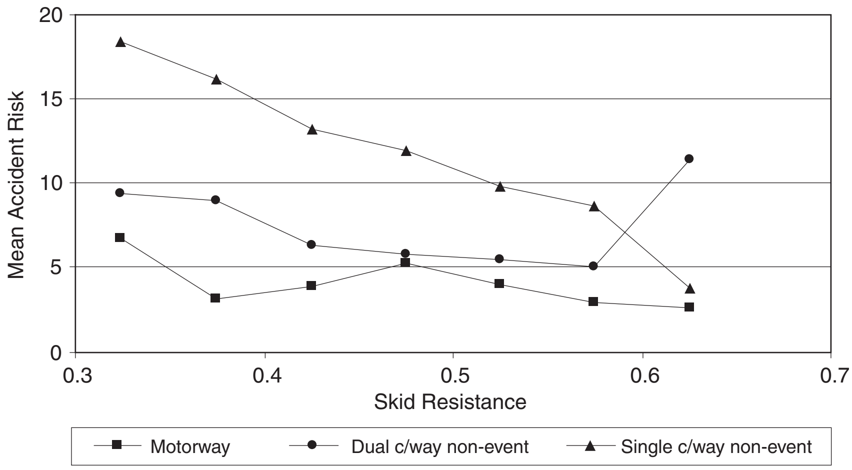

Figure 1 Mean all-accident risk by skid resistance for non-event lengths

3.1.1 Motorways

Figure 2 shows the all-accident risk plotted against skidding resistance for motorways, also shown in Figure 1, along with the wet-accident risk and the wet-skid-accident risk. The three plots are similar, and show no trend in risk with skidding resistance, except in the 0.30-0.35 band where it is seen to increase. However, Figure 3 shows that the number of cases, N, in this band, which is below the current IL of 0.35, is relatively small and the result must, therefore, be treated with caution. As stated above, GLM of the all-accident risk reveals the level of skidding resistance is not significant in explaining the risk.

Figure 3 also shows that the percentage of accidents in the wet (%W) and the percentage of wet accidents that were reported to have involved skidding (%WS) do not increase as clearly below 0.35 skidding resistance as the accident risk. This supports the premise that the role of skidding resistance is unclear at this level because if it was, then the trend might be expected to be more marked in accidents in the wet or where skidding was recorded.

Figure 4 shows that the 95th-percentile (95%) all-accident risk also increases in the 0.30-0.35 skidding resistance band. This is also seen for 95th-percentile wet-accident risk and wet-skid-accident risk.

The conclusion is that, at least for some sites, the accident risk may increase below 0.35 skidding resistance and the IL should remain at its current level of 0.35. For many sites, however, this increase in accident risk will not exist and this emphasises the role of site investigation in prioritising sites below IL for treatment.

An analysis of motorway lengths 400m either side of slip roads showed higher accident risk compared with non-event sections but showed no increase in risk associated with skidding resistance and the same default IL applies.

For this category, there is a relationship between traffic level and skidding resistance, with higher traffic levels being associated with lower skidding resistance. Traffic level will therefore be an important factor in maintenance prioritisation.

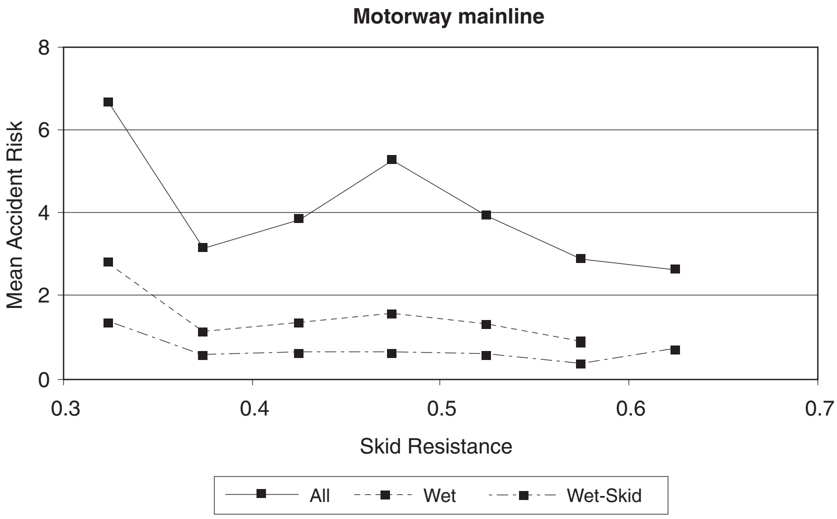

Figure 2 Mean accident risk by skid resistance for motorways

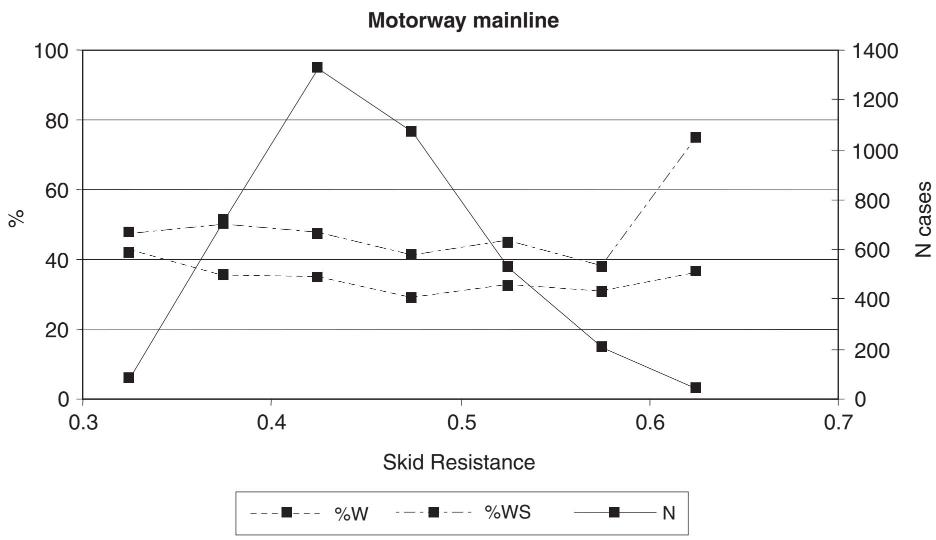

Figure 3 Accident ratios and numbers by skid resistance for motorways

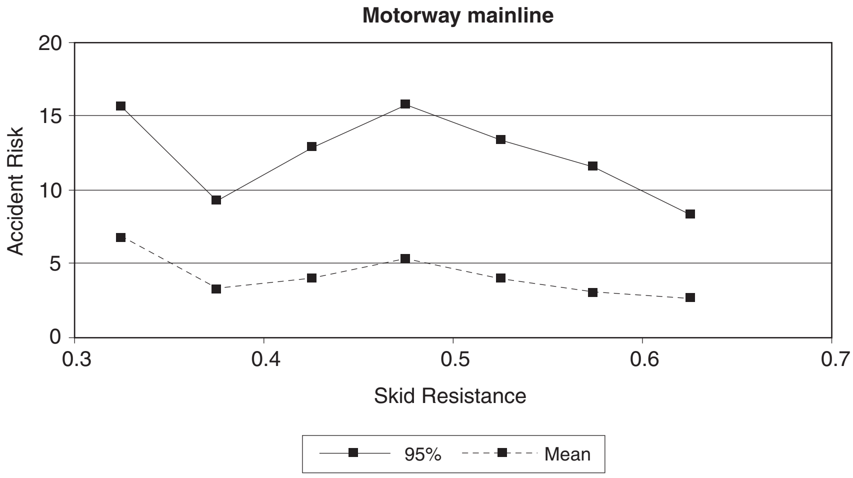

Figure 4 Mean and 95th percentile all-accident risk for motorways

3.1.2 Dual carriageways

The all-accident risk on rural dual carriageways, defined by the site categories based on HD28/94, shows a slow but steady increase as skidding resistance falls with an upturn below 0.4. This may also be shown in the wet and wet-skid risk but this trend is not as clear, Figure 5. The anomalous increase in all-accident and wet-accident risk at the highest level of skidding resistance may be due to special treatment of high risk sites with high friction surfacings as part of local safety schemes. No attempt has been made to confirm this assumption but in subsequent GLM modelling these data have been ignored.

There is a small number of sites below 0.35, Figure 6, which also shows that the %WS increases below 0.4 but this is not apparent in %W.

The accident risk was modelled using GLM, on dual carriageway sites not including those sections which fall in the new categories recommended for bends and gradients, following. Unlike for motorways, for dual carriageways the model shows that skidding resistance is a statistically significant variable in explaining accident risk. When the model is re-run only for wet- or wet-skid-accident risk, then the trend is stronger and this gives extra confidence in the trends seen in Figures 5 and 6.

Accident risk is slightly higher than for motorways and increases more strongly below 0.4. However, accident risk is still low at this level (compared to other site categories, following) and so it is important to try to identify those sites at which it will increase below 0.4. For this reason, two possible ILs of 0.35 and 0.40 are recommended. In setting the IL the site engineer will be required to decide if the site warrants the higher level. This approach, recommending a range of ILs and putting more emphasis on local risk assessment is continued throughout this analysis.

An analysis of accident rates in the vicinity of slip roads reveals that accident risk is higher than for non-event sections, particularly for wet- and wet-skid-accidents and that the level of skidding resistance is significant in the GLM model on the approach to off-slips and downstream of on-slips. The length of these sites could extend to 400m or more. For this reason the upper IL may be

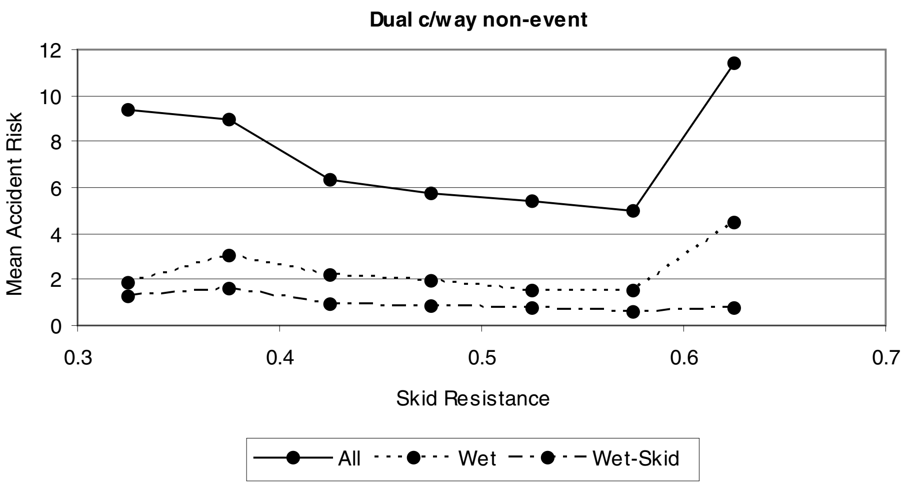

Figure 5 Mean accident risk by skid resistance for dual carriageways

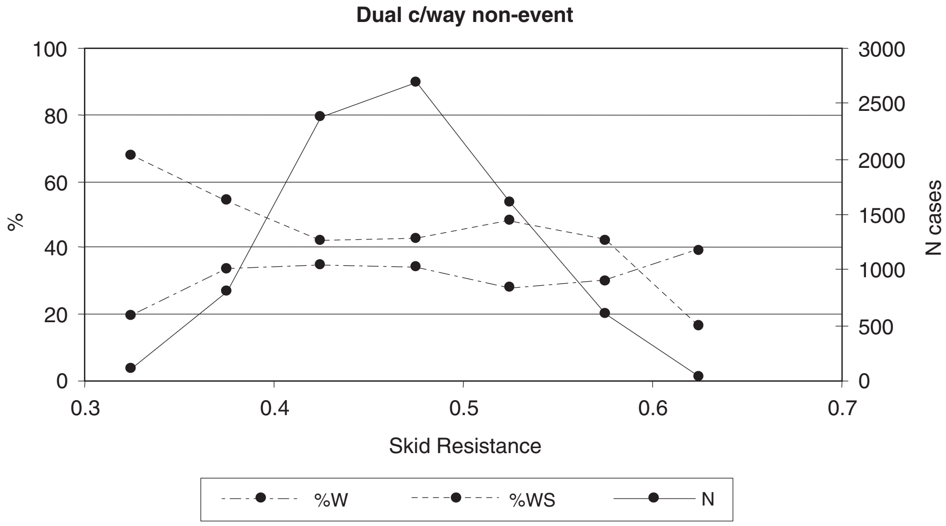

Figure 6 Accident ratios and numbers by skid resistance for dual carriageways

recommended on the mainline near slip roads where local knowledge indicates that they may be associated with increased risks. Other junctions are dealt with in a separate section, following.

3.1.3 Single carriageways

Non-event, rural single carriageway all-accident, wet- and wet-skid-accident risk, using the HD28/94 categorisation, are shown in Figure 7 and all increase with fall in skidding resistance. There appears to be an upturn in %W and %WS below a skidding resistance of about 0.45, Figure 8.

These findings are supported by the GLM analyses of accident risk (not including those sections which fall in the new categories recommended for bends and gradients, following) which show a significant influence of skidding resistance on accident risk and a significantly stronger trend associated with wet and wet-skid accidents.

For single carriageways, the accident risk increases continuously with skidding resistance and so it is difficult to decide where to place the IL simply from inspection of the graphs. The GLM models show that the accident risk for duals at the recommended ILs above (0.35 to 0.40), is approximately the same as that for singles at an IL of 0.40 to 0.45. This has been adopted as the recommended IL range. Once more, allocation of IL will depend upon a risk rating exercise. Factors such as previous accident history and radius of curvature will be significant.

3.2 Junctions

The junction site categories in HD28/94 are dual carriageway minor junction, single carriageway minor junction and major junction (both single and dual). (Approaches to traffic signals and roundabouts and roundabouts themselves form separate site categories.) Corresponding plots for these junction categories are shown in Figure 9. For dual carriageway minor junctions the accident risk is relatively low, similar to levels for non-event sections, except for the striking increase at both high and low skid resistance. As for non-event dual carriageways the accident risk at the highest skidding resistance may be due

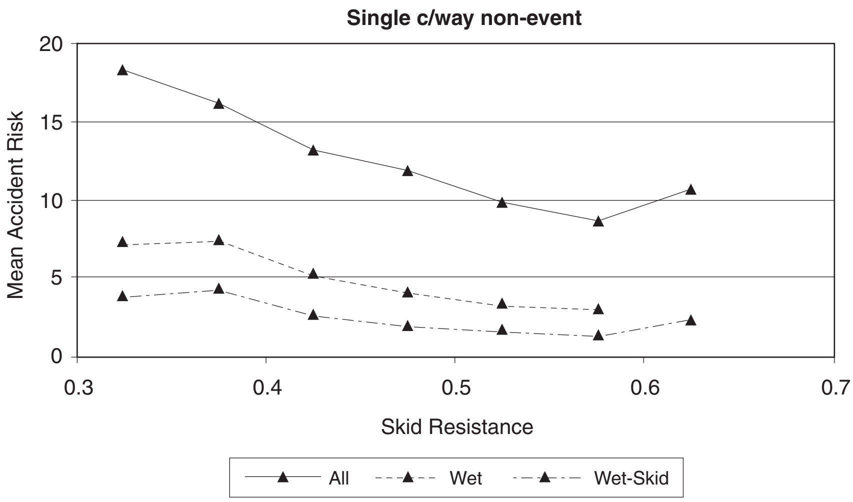

Figure 7 Mean accident risk by skid resistance for single carriageways

to the use of high-friction surfacings at sites with high accident risks. The high value for the band 0.35 to 0.40 is driven by a relatively small number of sites where a very high accident risk was recorded, demonstrating the range in accident risk for different sites within a single site category. The site with the highest accident risk had a risk more than 20 times higher than the average.

For single carriageway minor junctions the mean accident risk is higher than for non-event sections and there is a marked trend with skid resistance. In the GLM accident models this trend was found to be very significant. For major junctions the accident risk is also generally higher than for non-event sections but the trend with skid resistance was not found to be significant in the accident models (small numbers of sites at low skidding resistance mean that these sites do not have a determining influence on the modelled trend).

For single carriageway minor junctions, having both a higher level of accidents and a significant impact of skidding resistance, a higher IL than non-event sections, that is above 0.4 to 0.45, could be justified. There is some justification for this to apply to major junctions as well because of the similar accident risks at these levels of skidding resistance, however the lack of a significant impact of skidding resistance on accident risk means this is not as well justified. For dual carriageway minor junctions the relatively low level of accidents and the absence of a significant impact of skidding resistance do not necessarily support a higher IL than for non-event sections (0.35 to 0.40). However, as discussed above, this category is associated with a large scatter in accident risk and this strengthens the case for early investigation at sites were accident risk may be influenced by skidding resistance, as determined by accident rates or site investigation. Furthermore, it might be expected that accidents at junctions have similar causal factors and should be treated in a similar way.

To resolve this unclear evidence for junctions as a whole, a single new category is recommended including these three types of junction with a wide IL range of 0.45 to 0.55. This range includes a lower level of IL similar to that for non-event sections and a higher level more

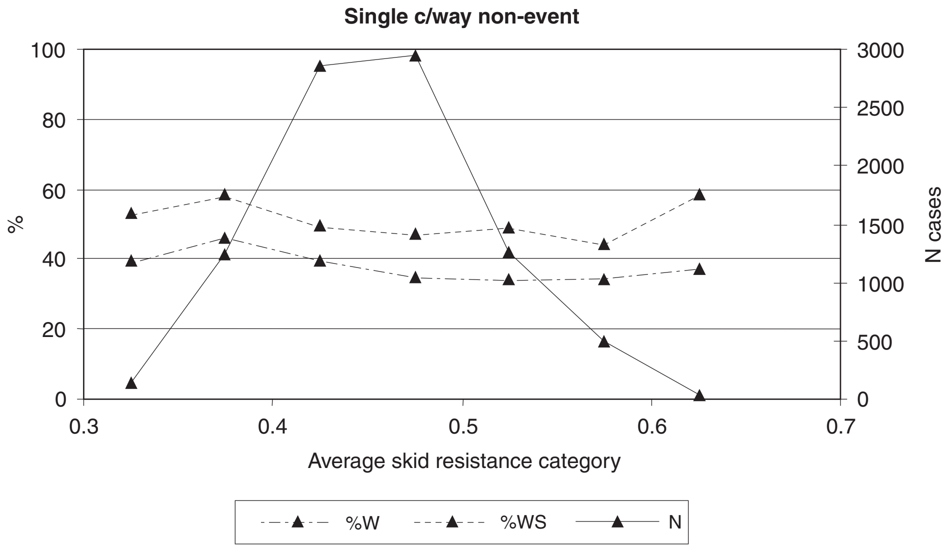

Figure 8 Accident ratios and numbers by skid resistance for single carriageways

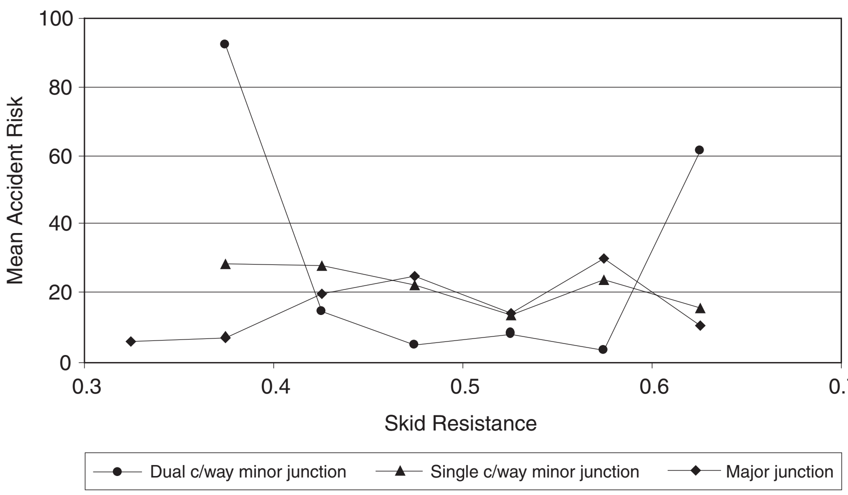

Figure 9 Mean all-accident risk by skid resistance for junctions

appropriate to sites where there is evidence from previous accident records or local risk assessment that a higher accident risk, associated with reduced skidding resistance, exists or may be expected to exist. This recommendation places a strong emphasis on the role of the engineer in assigning the appropriate IL on a site-by-site basis.

The junction categories currently defined in HD28/94 typically stretch to 50m either side of the junction centre point. By identifying the junctions on a GIS, as described in Section 2, then accidents on the mainline surrounding the junction can be identified. The accident models show that skidding resistance has a significant effect on accident rate up to at least 400m either side of minor junctions for single carriageways. This is also true for at least 100m on the approach and 400m after dual carriageway minor junctions. As stated above, the evidence is inconclusive for major junctions. It is recommended that when using their judgement in setting IL, engineers should consider setting the IL over a section up to at least 400m either side of all junctions.

3.3 Roundabouts, approaches to roundabouts, pedestrian crossings and similar

There are only a small number of sites in the 'approaches to roundabouts' category within the database. For these, the level of skidding resistance has a weak influence and is only marginally significant in predicting accident risk, Figure 10, although the level of average risk was generally greater than for the junctions, above. For these reasons, it is recommended that approaches to roundabouts are placed in the same IL band as for the junctions.

Figure 10 also shows the mean all-accident risk for sites in the HD28/94 category of 'Approaches to traffic signals, pedestrian crossings, railway level crossings or similar'. Here, there is a significant although relatively weak trend of increasing accident risk with reduced skidding resistance. The level of risk is similar to that for junctions. For these reasons a similar IL range to that for junctions, above, may be appropriate. The IL in HD28/94 stands at 0.55. It is recommended that the IL range for these approaches be 0.50 to 0.55 in order not to allow for a large reduction with the associated potential increase in accident risk, particularly because it may be expected that accidents at these sites could involve more vulnerable users (pedestrians and cyclists etc.) than for other categories. Nevertheless, the skidding resistance standard does allow for the setting of IL outside the recommended default ranges so that, where the results of site investigation and accident analysis support this, a lower IL can be set.

For roundabouts, while there are a good number of sites in this category, many of the other variables are not complete. This has meant that the GLM process of modelling a number of variables has not been possible in the same way as for other categories. The accident rate is similar to that for the other junctions and approaches and, when considered as a single variable, the level of skidding resistance is significant in a linear regression. The requirement in HD28/94 is for roundabouts to be measured at a test speed of 20km/h, as opposed to the standard speed of 50km/h but this distinction was removed in the updated standard. The data in Figure 10 have been corrected for speed to produce equivalent measurements to those expected at the standard speed. It is recommended that roundabouts be assigned a range of IL of 0.45 to 0.50 similar to that for junctions.

3.4 Geometry

3.4.1 Bends

The site categories in HD28/94 for bends are for those sites with radius of curvature <250m and <100m. The data show that for both categories there is a general trend for accident risk to increase with fall in skidding resistance. However, GLM showed no statistical significance of skidding resistance in a multi-variable model for <250m. For <100m there were few data to model.

It was decided to make a more general review of the impact of curvature on accident risk. For this, all sections below 2000m radius of curvature were modelled for motorways, dual carriageways and single carriageways. For motorways, the radius of curvature was found to be significant in accident risk but the level of skidding

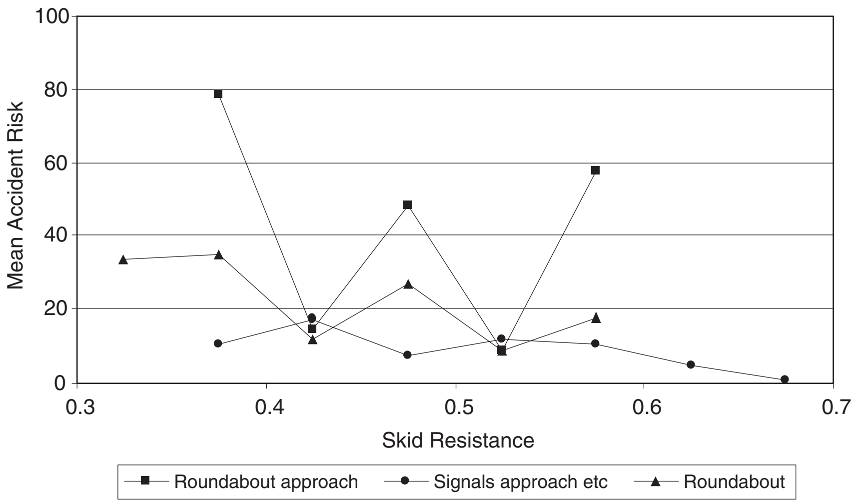

Figure 10 Mean all-accident risk by skid resistance for approaches and roundabouts

resistance was not (as for all motorway sites). For both dual carriageways and single carriageways, both radius of curvature and skidding resistance were found to have a significant impact on accident risk. Figure 11 and Figure 12 show the results of the model expressed as accident rates at a given traffic level, for dual and single carriageways respectively. The traffic levels were chosen to represent moderate levels and were 25,000 annual average daily traffic flow (AADT) and 12,000 AADT respectively.

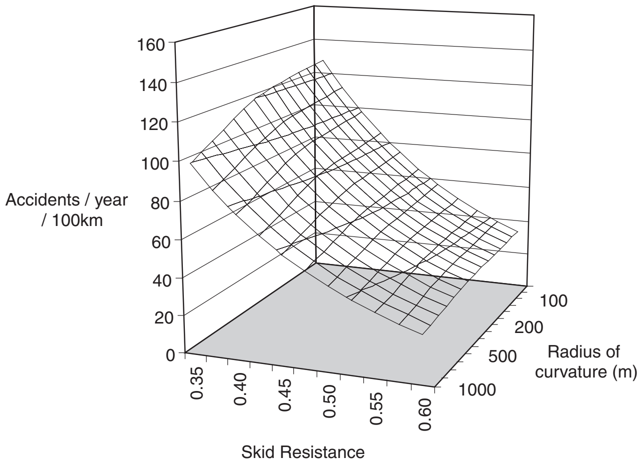

Figure 11 Mean predicted all-accident rate by skid resistance and radius of curvature for dual carriageways with moderate traffic flow

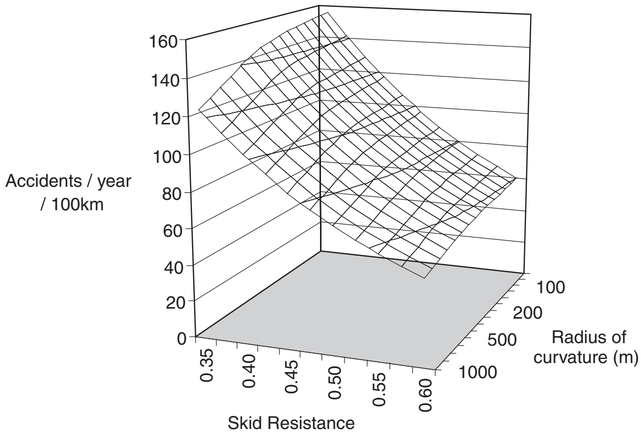

Figure 12 Mean predicted all-accident rate by skid resistance and radius of curvature for single carriageways with moderate traffic flow

The general conclusion of this analysis was that, compared to the accident rate on ‘straight’ roads (with radius of curvature between 1000 and 2000m), the skidding resistance of roads with radius of curvature between 500m and 100m would need to be increased by up to two IL bands (0.1) in order not to have an increased accident risk. For single carriageway roads with sharp bends of the order of 100m radius of curvature, this level might need to be increased even further, but these sites are few in number so the general conclusions may not apply and they are so uncommon on trunk roads that they should be considered as special cases.

It is recommended that the IL for dual carriageways with radius of curvature below 500m should be 0.45 to 0.50 and for single carriageways with radius of curvature below 500m the IL should be 0.50 to 0.55.

3.4.2 Gradients

The gradient categories in HD28/94 are for sections with gradient 5-10% and >10%, although there are few data for the latter. For the 5-10% category, there is a clear trend to increased risk at lower skidding resistance, Figure 13. The level of accident risk on non-event dual and single carriageways, at the recommended ILs, corresponds to the level for this site category at a skidding resistance of approximately 0.45 to 0.50 and this range is recommended, therefore, as the IL for gradients 5-10%.

Higher risk may be expected at steeper gradients and so an IL range of 0.50 to 0.55 is recommended for gradients >10%, although the data available are too sparse to fully justify this and the small number of very steep gradients on the trunk road network are probably best considered on a case by case basis.

3.5 Other factors

3.5.1 Accesses

Accesses, identified in the RMMS database, are generally on single carriageways, with too few to analyse reliably on duals. Compared to non-event single carriageways, the accident model shows a similar trend for sections that contain an access, but at a higher level of accident risk. The 95% accident risks are also higher than for non-event sections. It is recommended during site investigation and when setting IL that the presence of accesses is considered as a potential factor in estimating accident risk.

3.5.2 Texture depth

Accident models showed texture depth to be a significant variable in a number of categories although, notably, not for motorways. As a result, it is recommended that texture depth be considered during site investigation and when setting IL and that the combination of low skid resistance and low texture depth should receive greater priority for maintenance than low skid resistance alone.

Figure 14 shows the combined effects of skid resistance and texture depth in the accident model for single carriageway non-event lengths at moderate traffic flow. It is clear that the highest accident rate arises from a combination of low skid resistance and low texture depth and that the trend with skid resistance is more pronounced at low texture depth.

In general, for this site category, the increase in accidents when comparing a site with a moderate texture depth of 0.8mm to one with a higher texture of 1.3mm SMTD (the root-mean-square measure of texture depth, Cooper (1974)) is similar to the increase for reducing the skid resistance by 0.05. A similar effect was observed for non-event dual carriageways.

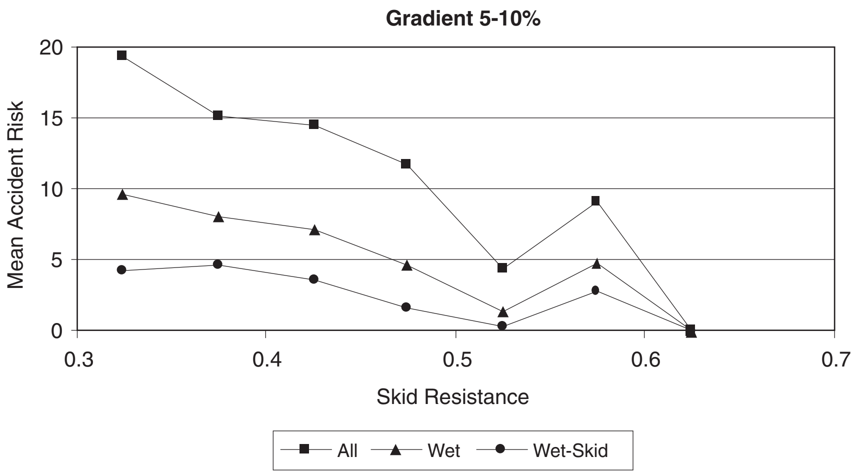

Figure 13 Mean accident risk by skid resistance for gradients 5-10%

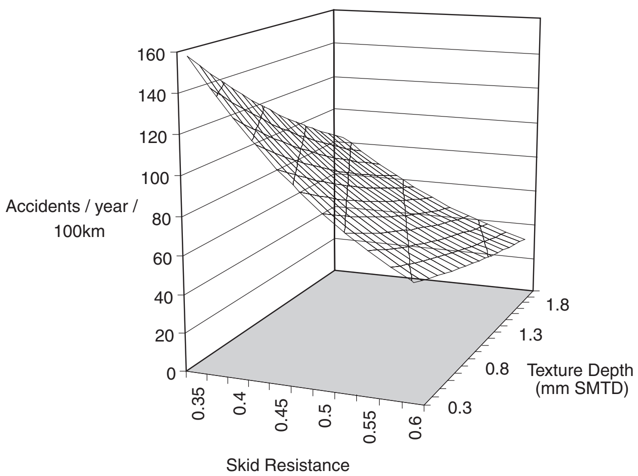

Figure 14 Mean predicted all-accident rate by skid resistance and texture depth for single carriageways

3.5.3 Urban roads

The results and analysis above are based upon data from rural roads identified as those with a speed limit above 40mph (which comprise the majority of the trunk road network). For urban roads the relationships described generally do not hold. In particular, in the accident models the influence of traffic level is often inverse (i.e. accident risk increases as traffic flow falls). While there are a number of plausible reasons for this (such as the influence of traffic flow on speed), the small number of sites combined with this anomalous behaviour means that it has not been possible to derive independent recommendations on ILs for urban roads. Instead, it is recommended that the ILs suggested here are taken only as the first stage in more detailed consideration of all relevant risk factors when setting urban ILs.

3.6 Summary of recommended site categories and Investigatory Levels

The results of the accident analysis reviewed above have led to recommendations for some new site categories and ILs. These are summarised in Table 2. For most site categories, a range of default ILs has been recommended. This is regarded as critical because of the range of accident risk observed for different sites within the same category. It is recommended that the normal IL will be the lowest value and that the advice in HD28 on the circumstances that will justify it being increased should be strengthened.

The existing non-event categories have been retained, but with the option to give a higher IL for dual and single carriageways. The higher level would be considered, for example, for sections with radius of curvature less than about 1000m or lower texture depths.

Junctions, with the exception of roundabouts and approaches to pedestrian crossings etc., have been combined into a single category with a range of ILs between 0.45 and 0.55. This allows an IL to be chosen appropriate to each junction layout and acknowledges the need to raise the IL for sites with greater potential for conflict between road users, particularly where the outcome is likely to have severe consequences. It is anticipated that this would result in some single carriageway minor junctions being assigned a higher IL than at present (0.45), reflecting the strong trend with skid resistance found in the accident analysis. It is recommended that major junctions would continue to be assigned an IL of 0.45, the lowest in the band, unless the site characteristics justify an increase, which reflects the lack of a strong trend for skid resistance for this category overall. For approaches to roundabouts and traffic signals, currently assigned a default IL of 0.55, it is recommended that the IL should be reduced over time for sites that do not exhibit a notable accident pattern or where there are other factors likely to lead to higher accident risk. (Individual sites with high accident rates will still be identified and may be treated as part of safety schemes separate to the skidding resistance standard.)

Roundabouts should remain a separate site category, because skid resistance data is reported differently (at 10m intervals rather than 50m intervals), with a range of ILs between 0.45 and 0.50. This is consistent with HD28/94, given a change in test speed to the general level of 50km/h. Approaches to pedestrian crossings etc. have been retained in a separate ‘high risk’ category, with IL of 0.50 or 0.55, reflecting the vulnerability of pedestrians.

Table 2 Recommended site categories and Investigatory Levels for the strategic road network in England

	Investigatory level at 50km/h							
Site category and definition	*0.30*	*0.35*	*0.40*	*0.45*	*0.50*	*0.55*	*0.60*	*0.65*
A Motorway		■						
B Dual carriageway non-event		■	■					
C Single carriageway non-event			■	■				
Q Approaches to and across minor and major junctions, approaches to roundabouts				■	■	■		
K Approaches to pedestrian crossings and other high risk situations					■	■		
R Roundabout				■	■			
G1 Gradient 5-10% longer than 50m				■	■			
G2 Gradient >=10% longer than 50m					■	■		
S1 Bend radius <500m – dual carriageway				■	■			
S2 Bend radius <500m – single carriageway					■	■		

For bends, it is recommended that the site category be extended to include radius of curvature up to 500m and separate ILs are recommended for dual and single carriageways consistent with different levels of accident risk.

4 Financial costs and benefits

In this section an attempt has been 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 made above.

The cost estimates are based upon likely additional treatment lengths, the cost of resurfacing and road user costs associated with the works. Benefits are based upon the financial value assigned to accident reductions.

4.1 Costs

The cost of treating that length of the network likely to require resurfacing, as a result of implementing the recommendations made in this report, has been estimated using a four stage process:

1 The length of the network likely to be assigned a higher IL was estimated as described in Section 4.1.1.

2 The proportion of sites with higher IL requiring site investigation was then estimated as in Section 4.1.2.

3 The proportion of sites investigated that are recommended for treatment was estimated as described in Section 4.1.3.

4 The unit treatment costs, traffic management and road user delay costs for these schemes were estimated as described in Section 4.1.4.

The results are described later and summarised in Table 3 and Table 4.

4.1.1 Length of network assigned higher IL

For motorways the recommendation is to make no change to the default IL and so no account is taken of this class of highway in the analysis of costs and benefits. For non-event sections on dual carriageways, the assumption was made that the higher IL would be applied to sections including possible risk factors, other than those which place them in other categories (i.e. junctions, approaches, bends and gradients). The selected factors were texture depth and the presence of slip roads joining or leaving the mainline section. These factors were chosen because the accident analysis has identified them as being significant in terms of accident risk. A texture depth of less than 0.8mm was chosen as the cut-off point for higher risk because previous work has shown this level of texture to be associated with both increased accident risk and increased fall in skidding resistance with speed, Roe *et al.* (1991), Roe *et al.* (1998). The texture criterion was also used to define those sections on single carriageways assigned higher risk. In practice, many other factors will be taken into account in making this decision on a site by site basis but for this network analysis there is a limited number of factors available for consideration.

For junctions the recommended default IL range is 0.45 to 0.55. The accident analysis shows that the evidence for junctions is not entirely clear and so for this analysis some simple assumptions have been made. It is assumed that all dual carriageway minor junctions would be placed in the new minimum default IL of 0.45, compared to the current IL of 0.40, because increased accident risk is only apparent below this level (see Figure 9). It is assumed that 50% of single carriageway minor junctions would be placed in the higher IL category of 0.50 (compared to the current IL of 0.45). Major junctions would remain unchanged with a default IL of 0.45, reflecting the weak trend between skidding resistance and accident rates and so no costs or benefits would accrue from the recommendations. For

Table 3 Assumed treatment lengths

Site category and definition	Recommended IL range	Network length (Lane 1 km)	% higher IL	% investigated	% treated	Length treated (km)
A Motorway	0.35	5169	0			0.0
B Dual carriageway	0.35-0.40	3977	25	10	15	14.9
C Single carriageway	0.40-0.45	1589	35	30	15	25.0
Q Junctions	0.45-0.50					
Dual minor		150	100	30	7	3.1
Single minor		280	50	30	7	3.1
Major		298	0			0.0
Roundabout approach		46	50	30	30	-2.1
Approaches (other)		34	0			0.0
K Approaches (high risk)	0.50-0.55	No data				
R Roundabouts	0.45-0.50	113	0			0.0
G1 Gradient 5-10%	0.45-0.50	171	45	30	31	7.1
G2 Gradient >10%	0.50-0.55	9	45	30	31	0.40
S1 Bend <500m dual	0.45-0.50	702	100	40	10	28.1
S2 Bend <500m single						
250-500m radius	0.50-0.55	681	100	65	25	110.7
100-250m radius	0.50-0.55	125	100	65	25	10.9

Table 4 Treatment costs

Site category and definition	Length treated (km)	Material cost (£)	Scheme length (km)	TM and delay cost (£)	Total cost (£)
B Dual carriageway	14.9	268,456	0.5	126,354	394,810
C Single carriageway	25.0	450,473	0.3	1,332,785	1,783,258
Q Junctions					
Dual minor	3.1	154,629	0.2	32,240	186,869
Single minor	3.1	160,523	0.1	261,455	421,978
G1 Gradient 5-10%	7.1	294,870	0.2	291,342	586,212
S1 Bend <500m dual	28.1	1,660,160	0.5	157,551	1,817,711
S2 Bend <500m single					
250-500m radius	110.7	5,255,261	0.5	2,986,069	8,241,330
100-250m radius	10.9	518,234	0.2	215,402	733,636

approaches to roundabouts the current IL is 0.55 and it is assumed that 50% of these will be assigned to a new IL of 0.50. Approaches to pedestrian crossings and other high risk situations form only a short length of the trunk road network and have been ignored for the purposes of this analysis. The change in recommended IL for roundabouts only reflects a change in test speed and so there will be no change in required skidding resistance and they have not been included in this analysis.

For bends the new site categories include sections, previously assigned as non-event, with a radius of curvature between 250 and 500m. All off these sections are assumed to be assigned the lower IL of 0.45 for dual carriageways and 0.50 for single carriageways. For dual carriageways the length of the network below 250m radius of curvature is so small as to be negligible for a network analysis. For single carriageways it is assumed that all the sites below 250m radius are assigned the higher IL in the recommended band of 0.55.

For sites with gradients, those with texture below 0.8mm or with radius of curvature between 500 and 1,000m were assumed to be in the higher IL.

The proportion of the network likely to be assigned a higher IL estimated above, was calculated based on the data set used for the accident analysis. However, the strategic road network has changed as a result of control of some roads being passed to other highway authorities since that dataset was current. To obtain a better estimate of the costs and benefits of implementing these recommendations, the latest available information about the length of the network in each site category was used to determine the length of the network likely to be assigned to higher IL. This is the reason for the difference in lengths reported in Table 1 and Table 3.

4.1.2 Proportion of sites requiring investigation

Of the lengths of the network identified above as falling into a higher recommended IL band, those with a skidding resistance below that IL will require investigation. This additional length requiring investigation will be the sites above the current IL and below the new recommended IL, i.e. the sites that would not have triggered investigation with the IL assigned under the previous system, but that do trigger investigation at the higher IL under the recommended system.

By analysing the distribution of skidding resistance, these lengths have been identified and are reported in Table 3 (*% investigated*) as the proportion of the whole length of the network within that category. No costs have been assigned to the extra site investigation required. The number of different forms of contract for maintaining the HA network and the likely changes in the nature of these contracts in the future, means that it is very difficult to make assumptions about these costs.

4.1.3 Proportion of sites requiring treatment

Once more, this is a judgement that, in practice, will be decided on a site by site basis by considering a number of factors. For this analysis it was assumed that only those sites with an accident risk above the mean will receive treatment.

4.1.4 Treatment costs

The length of the network assumed to require treatment as a result of the recommended ILs, above that required by the existing standard, was determined by combining the factors described above. The results are given in Table 3.

Estimated treatment costs are given in Table 4. For non-event sections, an assumption has been made that only lane one of the sections identified as requiring treatment will be resurfaced. This is clearly correct for single carriageways and is usual practice for dual carriageways where outside lanes generally carry less heavy traffic and therefore are assumed to retain a higher level of skidding resistance. Treatment to two lanes has been assumed for dual carriageway junctions and bend and gradient sections.

By assuming standard lane widths for single and dual carriageway lanes the treatment area can be calculated. For material costs, the default values currently used in Highways Agency whole-life cost analysis are used of £5/m^2 and £15/m^2 for thin surfacings (TS) and high friction surfacings (HFS), respectively.

Although HFS is often used in safety schemes, for maintenance purposes natural aggregates can generally meet the requirements except where the highest levels of polished stone value (PSV) are required, at junctions, gradients and bends (Highways Agency *et al.*, Design Manual for Roads and Bridges, HD36). By assuming a typical traffic distribution the likely PSV requirements can be estimated and the likely proportion of TS and HFS required was determined and reflected in the costs.

In addition to material costs, road works have costs associated with traffic management and road user costs due to delays and other impacts. In order to estimate these, assumptions need to be made about the likely lengths of the individual schemes that would form the overall network lengths. This will lead to assumptions about the number of schemes. Traffic management costs are clearly related to the number of schemes and are not greatly influenced by scheme length. Road user costs depend on both the number of schemes and the scheme lengths. Delay costs have been calculated using QUADRO software (Highways Agency *et al.*, Design Manual for Roads and Bridges, Volume 14).

The traffic management and road user delay costs determined by QUADRO, based on a series of assumptions about typical traffic flows and speeds, proportion of heavy vehicles and maximum queue lengths, are summarised in Table 4. The same traffic flows were assumed in determining these costs as for parts of the accident modelling, see Section 3.4, being 12,000 AADT and 25,000 AADT for single and dual carriageways, respectively. Table 4 does not include site categories for which there is no change, treatment lengths are very small or there are insufficient data.

4.2 Benefits

The benefits of introducing the recommended revisions to the skidding standard are those associated with accident reductions. Accident savings were estimated based upon, firstly, linear regression relationships fitted to the accident data plotted against skidding resistance in Section 3, and secondly, the results of the GLM models described by equation 1. The same traffic flows were assumed as in calculating costs, above. Both a low estimate of accident savings based upon the mean and a high estimate based upon the 95th-percentile were generated for both relationships for each site category in Table 4. The low estimate might be achieved even if there was limited success in identifying for treatment those sites with higher than average accident risk. The high estimate would represent a situation where a high degree of success had been achieved.

For each site category the accident saving was calculated based upon changing the skidding resistance of the treated lengths, Table 3, from the old IL to the recommended new IL. This represents the minimum equilibrium level of skidding resistance that should be achieved by the surface treatment after any initial period of different behaviour associated with new surfaces had elapsed. This assumption for skidding resistance will generate a conservative estimate of accident saving.

The Department for Transport provides figures for use in quantifying the financial benefits of accident reduction, Department for Transport (2003). For non-built up roads, the financial cost of all injury accidents, including a sum for the likely rate of damage-only accidents saved, is £111,790 for 2002, to be multiplied by 1.0466 to reach a value for June 2003 of £116,999. This is the value placed on accidents saved, in this analysis.

Table 5 summarises the estimated accident savings for the categories in Table 4 (single carriageway bends have been combined into a single category). The table includes the number of accidents that would need to be saved (at the financial valuation above) to match the treatment costs in Table 4 (the equivalent value accident reduction), the four estimates of annual accident reduction and the corresponding shortest and longest period over which the equivalent value accident reduction would be realised.

Assuming that the lifetime of a new surfacing is at least ten to twelve years, it can be seen from Table 5 that the realisation period, based even on the worst case estimate of accident reduction, is generally within the lifetime of the treatment. Based on this albeit simple analysis it appears, therefore, that in addition to assisting Highways Agency meet its targets for accident reduction, the costs of applying the changes to the skidding resistance standard recommended in this report will be recovered in the financial value of the accident reductions that are estimated to result.

5 Summary

A network level analysis of the influence of skidding resistance on accident risk has been made in order to recommend any changes required to the skidding resistance standard for the English strategic road network. The analysis was made using existing databases on; road condition and geometry; traffic statistics; an inventory including the presence of certain accesses and junctions and; injury accident records. Data were assigned to a common location referencing system using a geographical information system and aggregated into sections, upon which the analysis was made.

Firstly, accident risk was compared to skidding resistance for the site categories in the existing standard, HD28/94. Secondly, the influence of skidding resistance and other factors, such as texture depth, geometry etc., on accident rates was analysed using generalised linear modelling. Thirdly, where the influence on accident risk of curvature, gradient and being in the vicinity of junctions was significant, the results were used to redefine the site categories in the standard. The accident analysis was then repeated for these new categories.

New Investigatory Levels for skidding resistance have been recommended as a result of these analyses. For most site categories, a range of Investigatory Levels has been recommended because of the range of accident risk observed for different sites within the same category. This range of risk emphasises the need for the reaction to low skidding resistance to be based upon investigation rather than automatic intervention. It is recommended that generally the normal Investigatory Level will be the lowest value and that the advice in the skidding resistance standard, describing the circumstances that will justify it being increased, should be strengthened. The standard should also include more thorough advice on the requirements of site investigation.

The findings of this report are based upon rural trunk roads in England. Roads either in urban areas, under the control of other highway authorities or in other parts of the UK will not necessarily show the same behaviour and the recommendations of this report should only be interpreted with caution in relation to these other roads.

An attempt has been 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 this report. 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. 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.

Table 5 Estimated accident reductions and periods of return

		Estimated annual accident reduction				Realisation period (years)	
Site category and definition	*Equivalent value accident reduction*	*Linear (mean)*	*Linear (95%)*	*GLM (mean)*	*GLM (95%)*	*Best case*	*Worst case*
B Dual carriageway	3.4	1.8	4.8	0.9	4.3	0.7	3.8
C Single carriageway	15.2	2.0	4.3	4.5	22.3	0.7	7.6
Q Junctions							
Dual minor	1.6	0.1	0.7	0.6	2.8	0.6	16.0
Single minor	3.6	1.1	5.3	2.4	12.2	0.3	3.3
G1 Gradient 5-10%	5.0	0.9	2.7	1.2	5.9	0.8	5.6
S1 Bend <500m dual	15.5	3.6	45.3	13.7	68.6	0.2	4.3
S2 Bend <500m single	76.7	7.0	88.2	43.2	215.9	0.4	11.0

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Abstract

The skidding resistance standard for trunk roads in England is contained in HD28 in the Design Manual for Roads and Bridges. It requires an Investigatory Level of skidding resistance to be assigned for each part of the network, based on the site category (carriageway type and geometry etc.) plus other local factors. If the measured skidding resistance falls to, or below, this level a site investigation is triggered to determine if resurfacing the road would reduce accident risk. This report describes the analysis of accident risks that was undertaken as part of an update to the standard made in August 2004.

The accident analysis was made in three parts. Firstly, accident risk was compared to skidding resistance for the site categories in the previous version of the standard. Secondly, generalised linear modelling was used to test the significance of skidding resistance and other factors, such as texture depth and road geometry, on accident rates. Finally, new site categories and Investigatory Levels were recommended.

The range of accident risk at sites within the same category is large and as a result a range of possible Investigatory Levels has been recommended. It was also recommended that the advice in the standard on setting Investigatory Levels and subsequent site investigation is strengthened.

A simple estimate of the financial costs and benefits of applying the recommendations was also made. It appears that in adopting the recommendations of this report, Highways Agency will both reduce accident risk on trunk roads in England and that the costs of resurfacing that result will be recovered in the financial value of accidents saved.

Related publications

TRL367 *High and low speed skidding resistance: the influence of texture depth* by P G Roe, A R Parry and H E Viner. 1998 (price £25, code E)

TRL334 *The relationship between road layout and accidents on modern rural trunk roads* by D A Walmsley and I Summersgill. 1998 (price £35, code J)

RR296 *The relation between the surface texture of roads and accidents* by P G Roe, D C Webster and G West. 1991 (price £20, code B)

RR76 *Relationship between skidding resistance and accident frequency. Estimates based on seasonal variation* by J R Hosking. 1986 (price £20, code B)

LR737 *Measurement of skidding resistance: Part 1. Guide to the use of SCRIM* by J R Hosking and G C Woodford. 1976 (price £20, code AA)

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