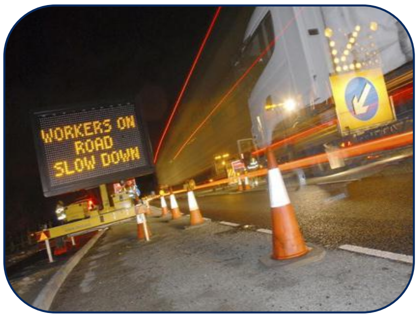
Transport Research Laboratory
Creating the future of transport



PUBLISHED PROJECT REPORT PPR729

Highways Agency skid resistance survey policy 2014: a review

A Dunford, P D Sanders, S Brittain, N Sidaway, R Smith

Prepared for:	Highways Agency, Pavements
Project Ref:	225(4/45/12): Effectiveness of skid policy in managing accident risk

Quality approved:

Alan Dunford
(Project Manager)

Martin Greene
(Technical Referee)

Disclaimer

Contents amendment record

This report has been amended and issued as follows:

Version	**Date**	**Description**	**Editor**	**Technical Referee**
0.1	27/11/14	First draft	AD	MG
0.11	16/12/14	Final draft for external review	AD	MG
1.0	05/06/15	Final version for issue	HV	MG

Contents

Executive summary

The Highways Agency currently manages the risk of wet skidding accidents on the Strategic Road Network (SRN) by measuring skid resistance in accordance with the provisions of HD28 (2004). The current policy manages the long term skid resistance on the SRN through specification of appropriate Polished Stone Value (PSV) materials in the surface course, as outlined in HD36 (2006). It is generally accepted that heavy traffic causes the greatest level of polishing of the road surface and an associated reduction in skid resistance. It is recognised that, for the majority of locations on the network, the greatest proportion of heavy vehicles is found in the nearside lane and so this is where the Highways Agency currently monitors skid resistance on an annual basis. However, HD28 does recognise that this may not always be the case and so allows for an alternative lane or more than one lane to be surveyed at locations where a greater proportion of heavy vehicles may use a lane other than the nearside lane, for example lengths where routes diverge.

Changes in the way the network is used in recent years, such as smart motorways, prompted a review of the current survey strategy to ensure that it remains fit for purpose and continues to deliver a safe network.

A review of relevant literature confirmed that the established principle of measuring skid resistance in the most heavily trafficked lane, i.e. the lane carrying the greatest number of heavy vehicles, is widely accepted and used. However, it was not possible to verify this principle using the measurements made routinely and stored in the Highways Agency Pavement management System (HAPMS). It is suggested that this is due to noise in the data: for the limited lengths where more than one lane was surveyed, the limited precision arising from the measurements having been made at different times and with different devices is of the same order as the difference in skid resistance between the lanes. Targeted measurements of skid resistance, carried out at locations where traffic levels are known to be different in two adjacent lanes, did confirm the principle.

Two issues were highlighted as a result of the targeted surveys. Firstly, skid resistance had not been measured in the most heavily trafficked lane at some of the sites, even though this is a requirement of the skid policy. Secondly, skid resistance was not always lowest in the most heavily trafficked lane where the surfacing is not the same in both lanes. The chances of either of these issues resulting in increased accident risk are considered to be very small: skid resistance on the parts of the network with more than one lane is typically well above the investigatory level. No immediate changes to the skid policy are recommended as a result of this work, but further investigation may be warranted, to discover:

- If there is any suggestion that skidding accidents have occurred on sections of the network, and specifically in outer lanes, that have not been monitored but could have been.
- Whether it is possible to adjust survey routes to ensure that the most heavily trafficked lane is monitored.
- The extent of additional surveys required if routine surveying included the most heavily trafficked, uniquely surfaced lane at every part of the network.
- The practicality and any risks associated with adopting an alternate lane survey strategy; i.e. measuring skid resistance in alternating lanes in alternate years, at

least on mainline sections. This could remove the need for the current requirement to determine which lane is the most heavily trafficked and could also deal with the presence of different surfacing materials in different lanes, and the potential for them to perform differently.

Reticence in recommending immediate changes to the skid policy result from the findings of a case study analysis that found that the majority of low risk sites on the network have skid resistance above investigatory level and have not required investigating for at least five years. This suggests that less, rather than more, emphasis should be placed on measuring skid resistance at these types of site. A relatively larger proportion of the high risk sites on the network are apparently underperforming in terms of skid resistance. Their performance is also somewhat less predictable, and skid resistance may be overestimated by aggregation of measurements over 50 m. It is recommended that:

- The full resolution of the data available in HAPMS (i.e. 10 m) should be used to determine whether high risk sites require further investigation, especially those falling into category Q.
- Routine measurement of skid resistance should concentrate on ensuring that valid measurements are made on high risk sites. It is understood that routine surveys have target coverage rates and it is recommended that these be adjusted, category by category, to make sure that high risk sites are adequately covered.

1 Introduction

The Highways Agency currently manages the risk of wet skidding accidents on the Strategic Road Network (SRN) by usually measuring skid resistance in the nearside wheel path of the nearside lane, according to the provisions of HD28 (2004). When aggregated to defined reporting lengths, sections of the network whose skid resistance fall below an investigatory level are subjected to detailed investigation to establish whether treatment to improve the skid resistance would be beneficial in terms of accident risk.

The current skid resistance policy manages the long term skid resistance on the SRN through specification of appropriate Polished Stone Value (PSV) materials in the surface course, as outlined in HD36 (2006). It is generally accepted that heavy vehicles cause the greatest level of polishing of the road surface and an associated reduction in skid resistance. It is recognised that, for the majority of locations on the network, the greatest proportion of heavy vehicles is found in the nearside lane and so this is where the Highways Agency currently monitors skid resistance on an annual basis. However, HD28 does recognise that this may not always be the case and so allows for an alternative lane or more than one lane to be surveyed at locations where a greater proportion of heavy vehicles may use a lane other than the nearside lane, for example lengths where routes diverge.

Changes in the way the network is used in recent years, such as smart motorways, prompted a review of the current survey strategy to ensure that it remains fit for purpose and continues to deliver a safe network.

This report firstly summarises a review of literature, in Chapter 2, which presents past research into the effect of traffic on the skid resistance of roads, which has been used to shape the current skid policy. In Chapter 3, a comparison is made between the skid resistance in multiple lanes of the SRN and the amount of traffic using those lanes. The aim of that process was to determine whether the strategy of measuring skid resistance only in the most heavily trafficked lane remains appropriate. Routine skid resistance measurements held in the Highways Agency Pavement Management System (HAPMS) were used initially but, due to noise in the data, additional targeted measurements of skid resistance were made in lane 1 and lane 2 at selected locations on the SRN. These additional measurements are reported and discussed in Chapter 4. Before recommendations and conclusions are made, an examination of other aspects of the skid policy is described in Chapter 5. This examination used a case study to consider the assignment of investigatory levels, the lengths of aggregated sections, and the potential for more targeted survey strategies.

2 Literature review

Research undertaken in the 1960s and 70s led to an understanding of the factors that influence the polishing of aggregates, and therefore the skid resistance of road surfacings. This research was used in the development of the UK skid resistance standard HD28 (2004) which is the basis for the current UK skid policy.

2.1 The effect of trafficking on skid resistance and friction

Skid resistance or friction properties are often categorised depending on the speed of measurement. The UK skid policy mandates direct measurement of skid resistance at low speed (using the sideway-force principle). High speed friction is not measured routinely, but the specification of appropriate levels of texture depth is used as a proxy for it. This is also typical across Europe and most of the body of past research concentrates on the effect of traffic (amongst other factors) on low speed skid resistance. However, measurement of friction at higher speeds is carried out routinely in other countries, particularly in the USA (Long, et al., 2014), so for completeness recent pertinent information is included at the end of this Section.

Initial research into the effect of traffic on road surface skid resistance was carried out by TRL and is reported in LR504 (Szatkowski & Hosking, 1972). Observations of traffic volume and skid resistance were made on a number of sites on the UK road network and the analyses were summarised using the following equations:

$$sfc = 0.033 - 0.664 \times 10^{-4} q_{cv} + 0.98 \times 10^{-2} PSV \quad (1)$$

$$sfc = 0.024 - 0.15 \times 10^{-4} q_{tv} + 1 \times 10^{-2} PSV \quad (2)$$

where:

q_{cv} is the traffic flow in commercial vehicles per day, q_{tv} is the traffic flow in total vehicles per day, and PSV is the Polished Stone Value of the aggregate, the ability of the aggregate to resist polishing.

The coefficient of the "q" traffic flow variable in each equation suggests that the degradation in skid resistance as a result of commercial vehicles is much greater than that of traffic as a whole. Note that the variable q_{tv} includes both commercial and non-commercial vehicles, so it is likely that the effect of non-commercial vehicles on skid resistance is even less pronounced. The effect of commercial vehicles was also deemed to be more defined than that of traffic as a whole because the correlation coefficient for Equation 1, 0.92, was higher than the correlation coefficient of Equation 2, 0.84.

The work reported in LR504 was based on observations made on roads with less than 4000 commercial vehicles per day (CVD). Work reported in TRL322 (Roe & Hartshorne, 1998), continued the earlier research with a view to making observations on roads with higher traffic flows. Skid resistance and traffic volume information was gathered for a number of sites and the results from were compared with those from LR504 (Figure 2.1).

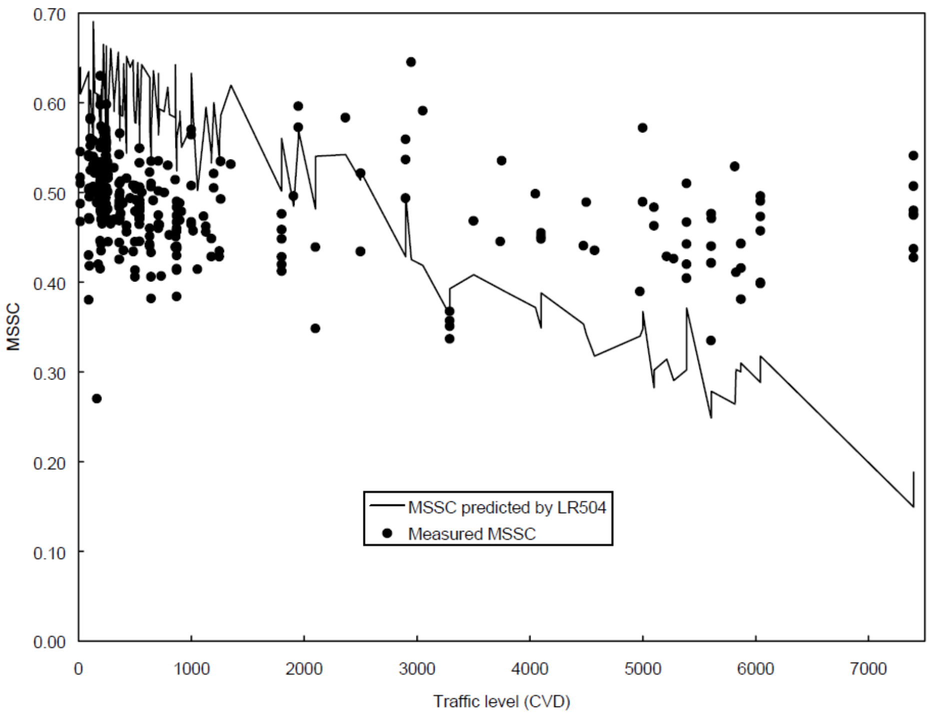


Figure 2.1 Comparison of skid resistance as predicted by LR 504 equations and observations, (Roe & Hartshorne, 1998)

Figure 2.1 shows that the LR504 prediction of skid resistance (Mean Summer SCRIM Coefficient – MSSC) is broadly comparable with the observations made as part of TRL322 at lower traffic levels. At higher traffic levels, however, the influence of traffic on skid resistance is less than that predicted by the LR504 model and the skid resistance level does not change as much as expected with increased traffic.

The results also showed that aggregate with the same PSV could produce different skid resistance with the same trafficking levels under different conditions. The data were categorised into bands according to skid resistance requirement, via the investigatory level (IL), and a relationship between MSSC, PSV and traffic level (commercial vehicles per day, CVD) was derived, with constants depending on these bands, as follows.

$$MSSC = [A \times PSV] - [B \times \ln(CVD)] + K \quad 3$$

Table 2.1 Constants for site category bands (Roe & Hartshorne, 1998)

Band	IL	A (x 10^{-3})	B (x 10^{-2})	K	No. of sections	R^2
I	0.35	6.18	2.25	0.252	2431	0.11
II	0.40	3.90	1.95	0.377	4073	0.13
III	0.45	2.94	1.70	0.407	1749	0.09
IV	0.50	5.81	1.46	0.193	82	0.11
V	0.55	4.73	0.98	0.231	43	0.08

The constants shown in Table 2.1 suggest that the influence of traffic volume (constant B) reduces with increasing skid resistance requirement (i.e. higher investigatory level). This may be because the polishing action of vehicles is harsher at these types of site, such as approaches to roundabouts and crossings, due to braking and manoeuvring, compared with sites where traffic is free flowing. At these more demanding sites, fewer vehicles are therefore required to achieve the same reduction in skid resistance.

More recently, work carried out in France (Kane, et al., 2012) used laboratory equipment to simulate the polishing effects of vehicle tyres on various aggregate specimens at different contact pressures. The Wehner-Schulze (W-S) machine was used to polish different aggregate samples, representing aggregates typically used in road construction, with two roller types: the standard W-S machine rollers with a contact pressure of 363 kPa and a shorter roller with a contact pressure of 527 kPa.

Friction measurements were made on each aggregate type, at different polishing states for tests with each of the two different roller types. The results were used to derive a model to predict aggregate skid resistance based on aggregate PSV and roller contact pressure:

$$\mu_g(N) = -a\log(N) + b \qquad 4$$

where μ_g is the friction measured after N passes of the polishing rollers and a and b are variables depending on the aggregate PSV and the contact pressure, P, respectively:

$$a = -0.0025PSV + 0.1787 \qquad 5$$

$$b = -0.0167P + 0.6445 \qquad 6$$

Considering the difference in contact pressures between the road and lorry or passenger-car tyres, the model was used to estimate the influence of these vehicles on road surface aggregates. The estimated effect on the friction of a 50 PSV aggregate is shown in Figure 2.2, which uses pressures of 0.3 Mpa and 1.1 Mpa for passenger-car and lorry contact pressures respectively.

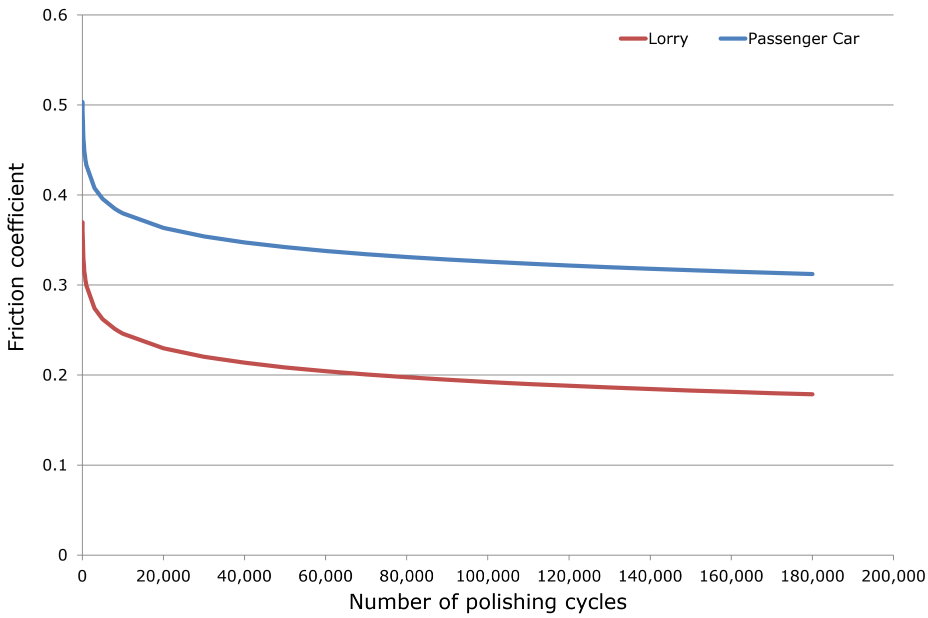


Figure 2.2 Friction reduction based on lorry and passenger-car trafficking

The work demonstrated that the effect on skid resistance of trafficking by vehicles with high tyre contact pressures is likely to be much greater than that of vehicles with low tyre contact pressures. Furthermore, Figure 2.2 suggests that a large increase in passenger-car traffic would not decrease skid resistance by as much as only a small number of lorries.

A study into the skid resistance behaviour of thin surface course systems (Roe & Dunford, 2012) showed that measurements of skid resistance made on highly trafficked sites were generally lower than those made on low trafficked sites, including a comparison between the traffic carried and skid resistance in lanes 1 and 2.

A review carried out in 2004 (WDM Ltd), using skid resistance measurements made in Highways Agency Area 8 (East Anglia), found that:

- Skid resistance in lane 2 was lower than in lane 1 at only 6% of sites and at most of these, values were well above the specified investigatory level
- At only three sites (of the 6,932 sites examined) was lane 2 below investigatory level when lane 1 was not
- There were 121 sites where skid resistance in both lane 1 and lane 2 was below investigatory level.

The study concluded that there was insufficient evidence to justify routine surveys of skid resistance in lanes other than lane 1. However, the study also recommended that, where skid resistance in lane 1 was found to be deficient, during site investigations the maintaining agent should consider the need to include lane 2 in any remedial works.

Research reported in the 1993 Transportation Research Record (Skerritt, 1993) collated information about the road network in New York state to build up a database containing the following information:

- Pavement friction (FN_{40}), the average locked-wheel friction at 40 mph (64 km/h)
- Lane Average Annual Daily Traffic (LAADT)
- Aggregate type
- Lane type (driving or passing)
- Pavement age.

When friction was compared to trafficking levels it was found that the pavement friction follows an inverse linear relationship to the natural log of the LAADT. The results reproduced in Table 2.2 show that, for various sites and surface types, the driving lane generally has a lower friction than the passing lane; this supports the theory that lorries, which are more prevalent in the driving lane, have a greater effect on friction than lighter vehicles.

Table 2.2 Friction measured in two lanes at various sites (Skerritt, 1993)

Site	Lane	LAADT	FN_{40}	Coarse aggregate
A	Driving Passing	2,800 2,500	52 52	Sandstone
B	Driving Passing	1,700 800	46 51	Siliceous Dolomite (22% AIR)
C	Driving Passing	10,800 6,500	42 47	Siliceous Dolomite (35% AIR)
D	Driving Passing	18,000 12,200	28 37	Blended Aggregate (18% Noncarbonate)
E	Driving Passing	4,100 2,000	29 42	Blended Aggregate (10% Noncarbonate)

A review of the effects of traffic and environment on the skid resistance of California's roads was carried out in 2010 (Oh, et al., 2010). Information about five freeways was collected between 1988 and 2008 including traffic volume, pavement type and high speed friction (FN_{40}). The results were used in a regression analysis to develop a skid resistance deterioration model, whose variables are described in Table 2.3:

$$Ln(FN_{40it}) = \beta_1 Ln(TRAFFIC_{it}) + \beta_2 Ln(LANE_{it}) + \beta_3 Ln(TEMP_{it}) + \beta_4 Ln(PRCP_{it}) + \beta_5 Ln(DP_{it}) + \beta_6 Ln(AGE_{it}) + \alpha_0 + u_{it} \quad 7$$

Table 2.3 Variables in Equation 7, California skid resistance model

Variable	Description	Coefficient (βx)	t-statistic
FN_{40it}	Locked wheel friction on section i at time t at 40 mile/h	N/A	N/A
$TRAFFIC_{it}$	Traffic condition on section i at time t	-0.059	-10.749
$LANE_{it}$	Dummy variable representing the lane where measurement was taken on section i at time t	-0.121	-14.292
$TEMP_{it}$	Temperature condition on section i preceding or at time t	-0.001	-1.712
$PRCP_{it}$	Amount of precipitation received at section i before time t	0.001	2.060
DP_{it}	The length of dry periods at section i preceding time t	-0.020	-4.180
AGE_{it}	Age of the pavement on section i at time t	-0.008	-1.978
α_0	constant	4.143	90.540
u_{it}	$= \varepsilon_{it} + (\alpha_i - \alpha_0)$ α_i is a random intercept term which varies across sections ε_{it} is a random term accounting for the unobserved characteristics of section i at time t	N/A	N/A

The researchers tested average daily traffic, truck volume and truck percent for use as the $TRAFFIC_{it}$ term and found average daily traffic to give the most significant results. This contradicts work carried out in Europe, which has typically found that heavy vehicle (truck) volume, rather than all traffic volume, has the largest effect on skid resistance.

2.2 Comparison of UK skid policy with other countries

In the UK the routine monitoring of skid resistance is carried out in the nearside wheel path of the most heavily trafficked lane, which is usually assumed to be lane 1. Because lane 1 is typically the most heavily trafficked lane, it should, according to the majority of previous research, provide the lowest skid resistance values. For comparison, the equivalent policies in place across Europe were identified by asking the partners of the European Commission 7th Framework project "ROSANNE" (ROlling resistance, Skid resistance ANd Noise Emission): "In your country, which lane of the road is surveyed during routine skid resistance monitoring, and what is the reason for surveying this lane in particular?" Information was also gathered from New Zealand skid resistance policy documents. Table 2.4 summarises the responses.

Table 2.4 Collation of responses to question about skid policy

Institution	Country	Lanes surveyed	Justification
NZTA	New Zealand	"By default the outer lane (furthest from centreline or median) only (excluding slow vehicle bays) is surveyed." - (New Zealand Transport Agency, 2013)	Not provided
IFSTTAR	France	Routinely, lane 1 is monitored. In some specific cases the outer lanes are surveyed where traffic is particularly heavy.	Lane 1 is mainly used by heavy vehicles that have the greatest contribution to aggregate polishing.
Vejdirektoratet	Denmark	Routine measurements of skid resistance are not conducted. Texture is measured and the values used to identify areas that are likely to possess poor friction characteristics. Areas that are identified as having possible poor friction characteristics have their skid resistance measured. In general it is the right lane (lane 1) that has the problems due to the heaviest traffic loads.	N/A
ZAG	Slovenia	The right lane (lane 1) is monitored.	Lane 1 has a much higher traffic volume than the overtaking lane.
BAST	Germany	Routine skid resistance measurements are made in Germany every 4 years: Motorways: all lanes are surveyed Dual carriageways: Lane 1 only is surveyed Single carriageways: Lane 1 is surveyed in one direction only	Lane 1 usually has the shortest service life because this is the most heavily trafficked. Construction on motorways is carried out on individual lanes, hence all lanes are measured. Construction on single carriageways is carried out on all lanes in both directions at the same time hence lane 1 is measured in one direction only.
AIT	Austria	Routine monitoring is carried out on motorways using a five year cycle: Year 1 – Lane 1 is measured Year 2 – Lane 2 and 3 are measured Year 3 – Slip roads are measured Year 4 and 5 – Measurements are only made on newly laid roads. On other roads only lane 1 is measured.	Not provided

By comparison, the UK policy of making skid resistance measurements in lane 1 only is broadly in line with the approaches taken in New Zealand, France and Slovenia. The Danish approach is interesting because it allows for the identification of high risk sites and uses targeted testing to assess those identified as high risk. In the UK, a similar scheme could be introduced using information from the traffic-speed condition surveys (TRACS), although the use of texture alone is unlikely to satisfactorily characterise the risk of low skid resistance. The Austrian approach was built up from a programme that originally tested lane 1 on motorways every five years, following a decision to collect information about the other, previously untested lanes. It is interesting to note that in Germany a programme of surveying once over several years is also used.

2.3 Summary

This review has shown that there has been a limited amount of research carried out into the effects of trafficking on skid resistance and friction. The work that has been identified is generally in agreement, and shows that:

- The effect of trafficking by heavy vehicles is much greater than that of lighter vehicles
- The effect of trafficking is more pronounced for low traffic volumes; an increase in traffic above 4000 CVD results in relatively small additional reduction in skid resistance
- The effect of trafficking can be exacerbated in areas where extra demand is placed on the surface, for example braking or turning
- The UK skid resistance policy of making measurements in lane 1 annually is supported by the findings of the literature review and is similar to, or more comprehensive than, the approaches adopted in some other European countries.

3 Assessment of skid resistance and traffic flow

This section assesses whether the principle of routinely monitoring only the most heavily trafficked lane is supported by current skid resistance data. If the principle is sound then it should be possible to demonstrate that skid resistance is always lower in the lane that carries the greatest volume of heavy traffic. Skid resistance and traffic flows on smart motorways are not explicitly considered due to the relatively small amount of data available for such sites. Results from the general analysis (and from the targeted surveys discussed in Chapter 4) should be relevant for smart motorways but it may be necessary to consider the impact of any findings specifically for these routes.

3.1 Skid resistance data

Skid resistance survey data collected on the HA network is stored in the Highways Agency Pavement Management System (HAPMS). Typically, only lane one is surveyed each year but, in some cases (particularly Design Build Finance and Operate contracts, DBFOs) additional lanes are surveyed. For the assessment of skid resistance and traffic flow, skid resistance data from the 2011, 2012 and 2013 surveys was collected where two or more lanes were measured in the same survey year. This data was then restricted to sites where the surface material and date laid were the same for the lanes being compared (according to the construction records in HAPMS).

3.2 Traffic data

MIDAS (Motorway Incident Detection and Automatic Signalling) vehicle detector data covers about 45% of the SRN in England, with over 9,600 sites in total. Of these, slightly fewer than 6,500 loops are currently enabled for traffic counting. Where provided, these vehicle detector sites (normally inductive loops or side firing radars) are typically positioned at 500 m intervals. The live data from these detector sites contains, for every minute:

- Detector location
- Date and time
- Count of vehicles by lane and vehicle length category
- Average speed of vehicles by lane
- Average headway between vehicles by lane
- Percent of time vehicles are occupying the loop (occupancy) by lane

In addition, data on whether the site has part time hard shoulder running was extracted from site data (a data source for information about the technology installed on the Highways Agency network).

Data was stored for the period 14th February – 23rd March 2014 from all enabled MIDAS sites. The dataset was then interrogated in order to return only detector sites that did not exhibit signs of being faulty and were not on a trunk road, slip road or in a hard shoulder running section. This was done on a day by day basis (so that one day of faulty data does not exclude the site in general) but not by lane (so one faulty lane will have excluded that day’s data from the dataset). Faulty data was defined as sites where (per lane per day):

- There was no data present

- There was no speed data present (as this also affects the flow categorisation by length)
- There was less than the desired count of flow data (less than 1,300 minutes out of 1,440 minutes present)
- There was a low count of speed data (less than 500 minutes out of 1,440 minutes present)
- The sum of flow in any lane was very low (less than 2,000 vehicles of any type per day)
- Data appeared to be sent for the wrong lane (known as crossed lanes).

This excluded from the dataset any sites with permanent or severe temporary faults, and should result in a reliable estimation, when data is averaged by day, of the traffic at any one location. Hard shoulder running sites were excluded from this analysis to avoid the potential confusion over the definition of "lane 1" that depends on whether the hard shoulder is open, although it is hoped that the results of this review have a direct impact on the skid policy for these sites in particular.

The flow of all vehicles and the flow of HGVs were calculated using the remaining data. The flow of all vehicles is simply the sum of values over each day, and the HGV flow is calculated using the MIDAS length categorisation data, where the number of HGVs is assumed to be the sum of category 4 vehicles (over 11.6 m) and half of category 3 vehicles (between 6.6 m and 11.6 m).

3.3 Comparison of skid resistance and traffic flow

In order to be able to identify trends between known skid resistance values and traffic data, HAPMS sections were linked to MIDAS detectors via Marker Post referencing.

HAPMS data includes a list of marker posts on each section and in most cases the marker posts are referenced as x/y, with x being the number of kilometres from the start of the road and y being the number of 100 m marker posts since the start of the kilometre. In some cases the marker posts were referenced slightly differently (e.g. with a "-" rather than a "/"). In some cases the marker post names did not appear to follow this system at all; these marker posts were excluded.

The remaining marker posts were converted to the geographic referencing system used by MIDAS, which assigns a four digit number to each marker post location. This is formed of a motorway identifier with the marker post number added on (with all punctuation removed). For example, marker post 23/7 on the M25 will have location 4237 (because the motorway identifier for the M25 is 4000) and 123/7 on the same road will have location 5237.

The difference between the maximum location and minimum location on each section was then calculated and compared to the length of the section as defined in HAPMS. Where these were significantly different (more than 200 m), the marker posts were manually assessed and removed where they obviously had errors such as transposition of digits (e.g. 23/7 changed to 32/7). A number of sections were completely removed where there were too few marker posts to decide which were correct or the values did not appear to match each other at all.

The maximum and minimum marker posts for each HAPMS section were then used to define the geographic limits of each section, and matched to all MIDAS sites within the section, allowing skid resistance and traffic to be compared.

For sites where skid resistance data is available for more than one lane, Figure 3.1 shows the average skid resistance measured in lane 1, lane 2 and lane 3 against the total flow of traffic measured at the equivalent locations. There is no obvious correlation between average skid resistance and traffic flow, although it is interesting to note that lanes 2 and 3 carry more traffic at some locations.

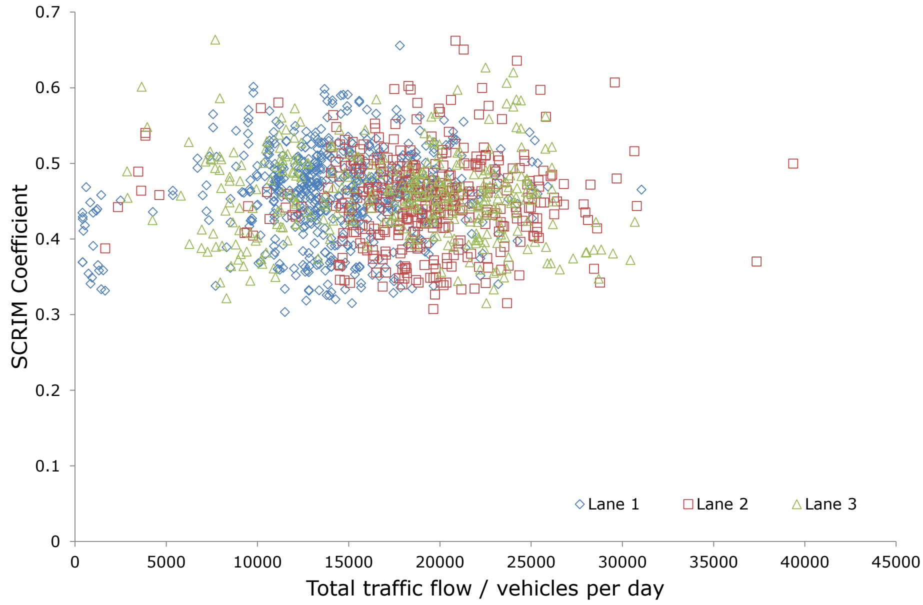


Figure 3.1 Average skid resistance against total traffic flow

Figure 3.2 shows the same information except that the traffic flow has been reduced to consider only HGVs (as defined above). There is still no obvious correlation between skid resistance and traffic flow; although there are some sites where lane 2 carries more HGVs than lane 1, in the majority of cases lane 1 carries the most traffic, as expected.

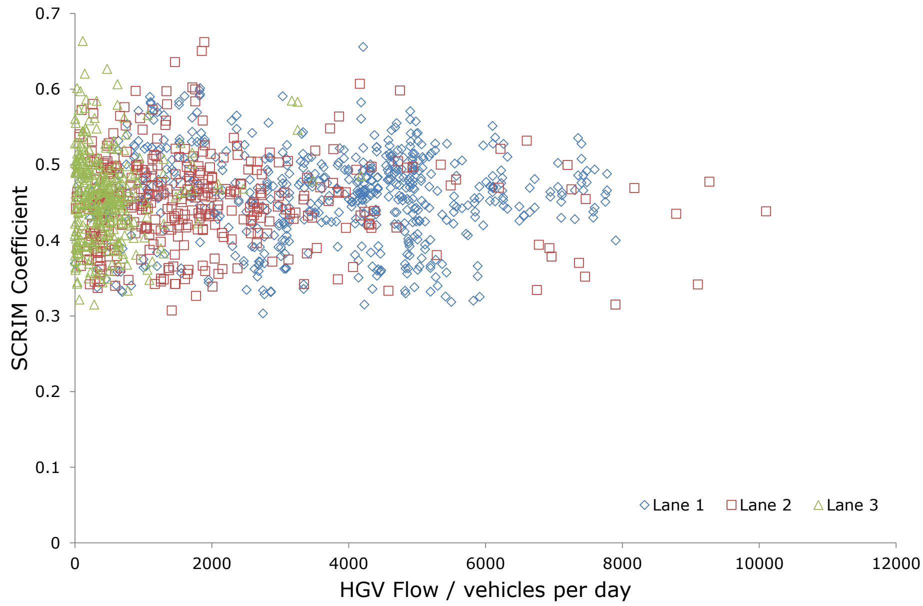


Figure 3.2 Average skid resistance against HGV flow

Considering only sites where skid resistance had been measured in lane 1 and lane 2, and where lane 1 and lane 2 were laid in the same year, it is possible to make a like-for-like comparison against traffic flow. Figure 3.3 shows the difference in skid resistance between the two lanes against the difference in HGV flow between the two lanes. If a site has lower skid resistance in lane 1, corresponding to higher HGV flow in lane 1 then a point will appear in the bottom right quadrant of the graph. Points in the top left quadrant of the graph represent sites where skid resistance in lane 2 is lower and HGV flow in lane 2 is higher. If the results of the analysis follow past research then the points should fall in these two quadrants and produce some sort of correlation between skid resistance difference and HGV flow difference with a negative slope. There does not appear to be any such correlation. This was also found to be the case for total vehicle flow.

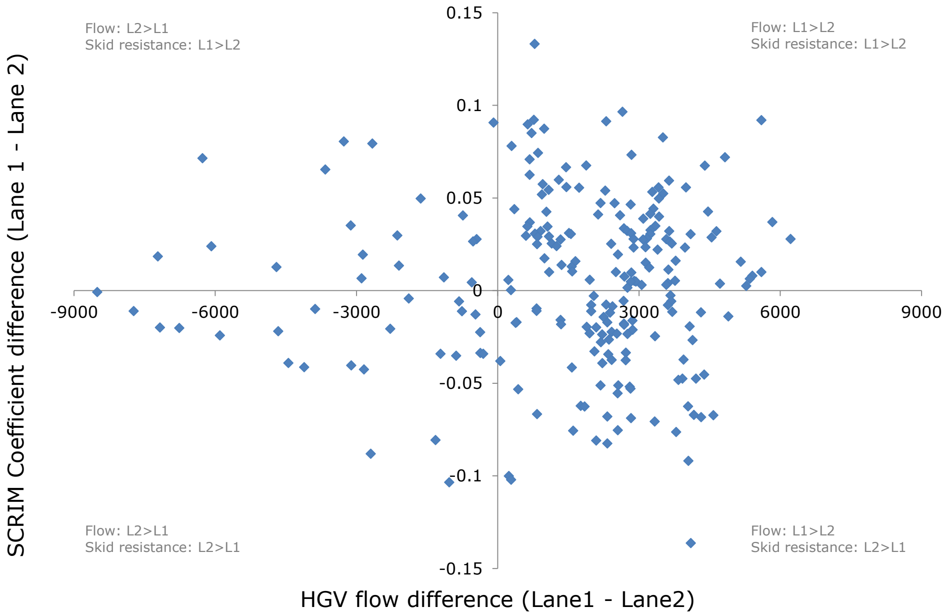


Figure 3.3 Skid resistance difference against HGV flow difference

Based on these results alone, it might be suggested that the policy of measuring skid resistance in the most heavily trafficked lane, assuming it to have the lowest skid resistance, is not sound. However, since the apparent lack of correlation between traffic flow and skid resistance has not been the general experience of researchers in the UK or Europe, the validity of the data was examined. The data had been trimmed to include only those sites where skid resistance had been measured in lane 1 and lane 2 and where lane 1 and lane 2 were probably surfaced at the same time. However, it was found that very few of the measurements of skid resistance in each lane at each site were made at the same time and many were made by different contractors (and therefore different SCRIMs). It is possible, therefore, that the difference in skid resistance observed between the two lanes could be attributed, at least in part, to variability in the measurement itself, which has a published reproducibility of 0.06 (CEN, 2009). Another significant factor in normal variability is the effect of prevailing weather conditions; although the data stored in HAPMS is corrected for seasonal effects, the correction is unlikely to have improved the variability between individual sites.

To overcome the variability in the data, targeted skid resistance measurements were made in lane 1 and lane 2 at a number of sites, where traffic volumes were known and these are described in the next chapter.

4 Targeted skid resistance surveys

Using the MIDAS database, a list of sites was generated so that skid resistance surveys could be made at locations where there was a difference in traffic flow in lane 1 and lane 2.

Initially, the sites were generated by reference to section lengths as defined in HAPMS. However, because HAPMS sections can be quite short, many only contained single traffic detecting loops and, due to the presence of faulty loops, the data produced was not very reliable. It was found that small faults in loops can skew the results because they do not correctly measure speed and vehicle category, which are critical for this analysis. Consequently, in addition to stricter criteria for fault checking, sites were selected based on junction to junction traffic counts instead. This means that measurements are based on values reported by several detector loops, and HGV flow can be estimated much more robustly.

4.1 Site selection

Average HGV flows for 652 motorway junction to junction links were listed and then variously categorised into:

- Links with the highest total HGV flow
- Links where lane 1 HGV flow is significantly greater than lane 2 HGV flow
- Links where lane 2 HGV flow is significantly greater than lane 1 HGV flow
- Links where lane 1 and lane 2 HGV flow is roughly equal.

It was noted that flows in lane 1 and 2 are higher than in other lanes but, given that the information covered all lanes present, there are sites where other lanes (normally lane 3) carry a significant number of HGVs.

From the categorised list, links where HGV flow in lane 2 is significantly greater than in lane 1 were considered to be the most interesting. These are sites where skid resistance in lane 1 is not necessarily the lowest, assuming the hypothesis suggested by previous research is correct (i.e. high HGV flow results in lower skid resistance).

Ten sites were selected based on relative traffic flows and their relative proximity - choosing sites that are close to one another increases the efficiency of the survey by maximising the data that can be gathered in the time available. These sites are listed at the top of Table 4.1 and are all on motorways around Manchester. The sites were supplemented by a further ten locations where lane 1 HGV traffic flow was higher than lane 2 HGV traffic flow, located on the route to or from the initial set (i.e. on the M6), which are not listed in the table.

In practice, only five of these sites were surveyed because roadworks and traffic congestion prevented the collection of more data within the time allocated for the surveys. Sites not surveyed are highlighted by grey shading. Consequently, a further set of sites was identified and surveyed, and these are listed at the bottom of Table 4.1, including some sites where lane 1 HGV traffic flow is higher than lane 2 HGV traffic flow (with text in italics).

Table 4.1 – Sites surveyed in both lanes where HGV traffic flow is different in lane 1 and lane 2

Site ID	Location	Lane 1 HGV flow	Lane 2 HGV flow
	M56 J6 – J5 Eastbound	356	3070
1	M60 J6 – J7 Clockwise	461	1950
2	M60 J13 – J15 Clockwise	1489	3971
	M61 J3 – J2 Southbound	463	1895
3	M62 Manchester Services – J18 Westbound	1164	3938
	M60 J15 – J13 Anti-clockwise	980	4459
	M60 J4 – J3 Anti-clockwise	275	2051
	M60 J3 – J2 Anti-clockwise	227	2072
4	M56 J4 – J5 Westbound	429	2729
5	M56 J5 – J6 Westbound	562	2679
6	M1 J11(m) - J10(d) SB	1973	6857
7	M25 J11(m) -J12(d) CW	2960	3195
8	M25 J12(m) - J13(d) CW	1483	3714
9	M25 J13(m) - J12(d) ACW	1308	2332
10	M25 J14(m) - J13(d) ACW	1994	3029
11	M4 J4b(m) - J5(d) WB	752	2584
A	*M4 J6(m) - J7(d) WB*	*2855*	*765*
B	*M4 J7(m) - J8/9(d) WB*	*3157*	*842*
C	*M4 J8/9(d) - J8/9(m) EB*	*2541*	*571*

In general, the locations where lane 2 HGV flow is higher than lane 1 HGV flow are ones where vehicles have reason to travel in outer lanes. For example, on the link between junction 4 and junction 5 of the M56, lane 1 diverges to Manchester airport at junction 5. Consequently, heavy vehicles not wanting to enter the airport move over to lane 2 well in advance of the junction and the point at which the lanes are relabelled.

4.2 Results

Average skid resistance over the length of each site is shown in Figure 4.1. Blue columns represent skid resistance in lane 1, red columns represent skid resistance in lane 2 and error bars indicate the range of skid resistance measured along the site. In general, skid resistance is lowest in the lane carrying the highest HGV traffic flow, i.e. lane 2 for sites 1 to 11 and lane 1 for sites A, B and C. There are two exceptions: skid resistance is lower in lane 1 at Site 2 and at Site 7 despite information suggesting that this lane carries fewer HGVs.

On closer inspection of the data available, it was found that, for some of Site 2 the surfacing material in lane 1 (thin surfacing laid in 2010) is different to the material in the adjacent lane 2 (hot rolled asphalt laid in 1990). The age of the material is not particularly significant: in either case an equilibrium skid resistance is likely to have been reached. However, the aggregate used and the type of asphalt are likely to have different polishing characteristics, responding to the action of traffic to different extents. Although the requirements of the site are likely to have been similar at the two dates, it is possible that the more recently laid material is of a lower specification (e.g. less polish resistant aggregate), although it is not possible to verify this.

At Site 7, the difference in traffic flow between the two lanes is very small, on average only 235 extra HGVs are found in lane 1 each day. The difference in skid resistance measured between the two lanes at this site can probably be attributed to variability in both skid resistance and traffic flow measurement.

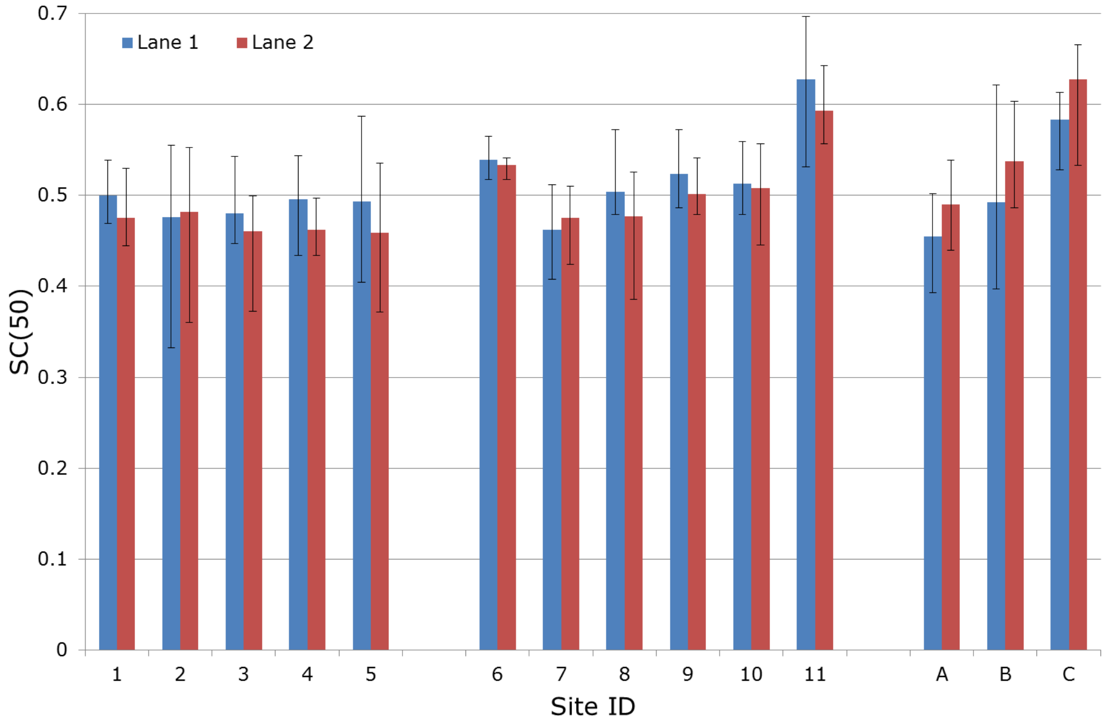


Figure 4.1 Average skid resistance in lane 1 and lane 2 of surveyed sites

The results can be emphasised by plotting the difference in skid resistance against the difference in HGV flow, comparing the two lanes, onto the graph shown in Figure 3.3. The resulting graph is shown in Figure 4.2, where the new points are red squares and the points originally calculated are shown in outline only. All but the two points representing sites 2 and 7, as discussed, fall into the top left and bottom right quadrants of the graph, as predicted by the theory.

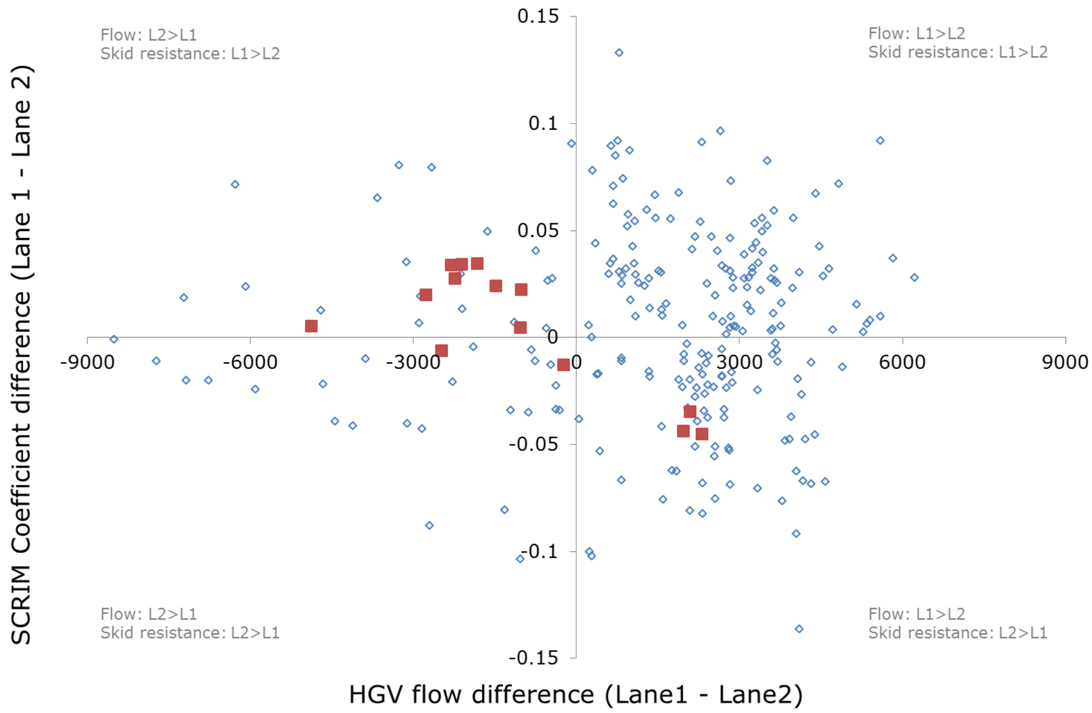


Figure 4.2 Skid resistance difference against HGV flow difference

4.3 Discussion

Targeted measurements of skid resistance at sites where the HGV flow was known to be different in two lanes has shown that the behaviour expected by researchers is generally evident. Although the number of sites was limited, the results do support the provision in the skid policy, that skid resistance should be measured in the most heavily trafficked lane, i.e. the lane with the greatest number of heavy vehicles. However, on the basis of the information reported herein, the subtlety in the policy that this is not always lane 1, is not always correctly implemented. Of the eleven sites surveyed, where HGV flow was known to be higher in lane 2 than in lane 1, skid resistance data was only available for lanes other than lane 1 for the sites on the M25. Skid resistance is routinely measured in outer lanes on the M25 for contractual reasons, and not because measurement regimes are targeted at sites that carry more traffic. As in the work summarised in Chapter 2, the risk of not measuring skid resistance in lane 2 is very low: even though skid resistance is lower in lane 2 at sites where lane 2 carries more traffic, it is much higher than the investigatory level (skid resistance values average around 0.45 compared with an investigatory level of 0.35).

One of the sites surveyed highlights a further complexity. On Site 2 it was argued that skid resistance in lane 2 was higher than in lane 1, despite lane 2 carrying more traffic, because the surfacing in lane 1 was newer, and possibly of a lower specification. The reason for resurfacing lane 1 more recently than lane 2 is not known. Unless it is common practice to resurface all lanes of a carriageway (as is apparently the case for single carriageway roads in Germany - Table 2.4) then there is a small risk that skid resistance deficiencies in outer lanes may go unnoticed. This would be mitigated somewhat if, when lane 1 is identified for resurfacing for reasons of poor skid resistance, a thorough investigation including measurement of skid resistance in outer lanes is carried out. However, even that strategy does not preclude skid resistance issues developing in outer lanes at a later date.

5 Evaluation of existing skid policy – unchanging sites and aggregation lengths

The findings of the work described in Chapters 3 and 4 suggest that the skid policy is sound, although elements of the measurement methodology policy could be highlighted or strengthened to address the small risks of missing incidents of low skid resistance. There is also a possibility that other aspects of the policy, including measurement and data handling strategies, could be amended or reinforced.

5.1 Case study introduction

The following sections summarise two analyses:

- The extent of unchanging sites. It has been suggested that skid resistance on almost 90% of the strategic road network is above the Investigatory Levels (ILs) set. If this is the case, and the same lengths have been over IL consistently for a considerable period of time, then resources may be better deployed measuring skid resistance on lengths that are more unreliable.
- The impact of reducing skid resistance averaging lengths. In the current skid policy, skid resistance is aggregated over lengths of 50 m or 100 m before values are compared against ILs, for most types of site. There may be a risk that individual 10 m lengths (the maximum resolution of the data available), which are slippery, are ignored.

For ease of data handling, Highways Agency's Area 9 network was used as a case study. Skid resistance data, as measured by SCRIM, in the years 2009 to 2013 was used, trimming the data to consider only those 10 m lengths of road for which there was a recorded value of skid resistance in each year. Table 5.1 shows the length of road in each site category, and indicates the aggregation length used before comparison against ILs. Note that there are no sites with category G2 (gradients over 10%) in Area 9.

Table 5.1 Area 9 total lengths by site category

Site category	Description	Aggregation length	Length (km)
A	Motorway		648
B	Dual carriageway non-event	100m	494
C	Single carriageway non-event		284
G1	Gradient 5-10% longer than 50m		17
K	Approaches to pedestrian crossings and other high risk situations		1.8
Q	Approaches to and across minor and major junctions, approaches to roundabouts	50m	43
S1	Bend radius <500m – dual carriageway		15
S2	Bend radius <500m – single carriageway		23
R	Roundabout	10m	18
	Total		1543

5.2 Extent of unchanging sites

In this analysis, firstly the proportion of the Strategic Road Network in Area 9 that was above or below IL in each of the years 2009 to 2013 was reviewed. Then the proportion of each site category that was above IL in 2013 that had also been above IL in each of the previous four years was summarised.

Table 5.2 shows the proportion of the Area 9 network above IL in each year of the analysis. There is a slight drop in average skid resistance in 2011 that corresponds to a change in the way speed correction of the data was handled.

Table 5.2 Percentage of network above IL

	2009	2010	2011	2012	2013	Overall
Above IL	93.3%	93.3%	90.1%	92.4%	91.8%	92.2%

Table 5.3 shows the proportion of lengths in each site category where skid resistance was at or below IL in each of the five years. Lengths categorised as Q or S2 have consistently required investigation more often than any other site categories, while category A and B lengths require proportionally less investigation. This is to be expected: high risk sites, where trafficking stress is higher, are likely to be more prone to loss of skid resistance and are therefore more likely to require investigation than low risk sites.

Table 5.3 Percentage of network at or below IL by site category and year

Year	Site category								
	A	B	C	G1	K	Q	S1	S2	R
2009	0.3%	2.1%	13.4%	28.1%	16.4%	44.6%	18.9%	55.6%	33.2%
2010	0.2%	3.2%	10.7%	29.6%	19.7%	46.7%	16.3%	56.4%	33.5%
2011	2.3%	6.4%	15.2%	40.3%	27.3%	50.6%	27.7%	56.3%	38.4%
2012	2.8%	5.1%	8.0%	27.9%	15.8%	36.5%	26.5%	39.7%	15.6%
2013	4.0%	4.9%	9.6%	25.2%	16.4%	33.9%	20.6%	35.3%	16.3%
Overall	1.9%	4.3%	11.4%	30.2%	19.1%	42.5%	22.0%	48.7%	27.4%

This information can be analysed to show the extent to which lengths of the network were generally above or below IL. Table 5.4 shows the proportion of each site category, for all years combined, falling within bands either side of the IL set. It is reassuring to note that, where skid resistance is below IL, it is most commonly only just below. However, at higher risk sites, skid resistance is less than IL by 0.05 or more for a significant proportion.

Table 5.4 Average deviation from IL for all measurements made 2009-2013

Skid resistance band		Site category								
		A	B	C	G1	K	Q	S1	S2	R
Above IL	0.40 to 0.50	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	0.30 to 0.40	0.5%	2.6%	0.1%	0.0%	0.1%	0.3%	0.8%	0.2%	0.2%
	0.20 to 0.30	16.4%	15.7%	2.4%	1.7%	2.5%	4.0%	4.3%	2.8%	4.5%
	0.10 to 0.20	50.9%	42.5%	26.3%	14.7%	29.1%	14.9%	21.4%	10.7%	26.3%
	0.00 to 0.10	30.3%	34.6%	59.8%	53.3%	49.2%	38.4%	51.4%	37.7%	41.6%
At or below IL	-0.05 to 0.00	1.7%	3.3%	9.0%	21.4%	8.3%	25.7%	15.8%	28.6%	15.4%
	-0.10 to -0.05	0.1%	0.8%	2.0%	8.3%	5.6%	12.8%	5.0%	15.0%	8.9%
	-0.20 to -0.10	0.0%	0.1%	0.3%	0.6%	5.1%	3.7%	1.2%	4.9%	3.0%
	-0.30 to -0.20	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.0%	0.1%	0.1%
	-0.40 to -0.30	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	-0.50 to -0.40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Year to year consistency varies by site category. At over 90% of A and B category sites, where skid resistance was above IL in 2013, skid resistance was also above IL for the previous four survey years. For site categories G1, Q, R, and S2, at least 50% of lengths had changed from being above IL to below IL (or vice versa) at some point in the same five year period. These observations are summarised in Figure 5.1, which shows the proportion of each site category with skid resistance above IL for 5, 4, 3, 2, 1, or 0 years.

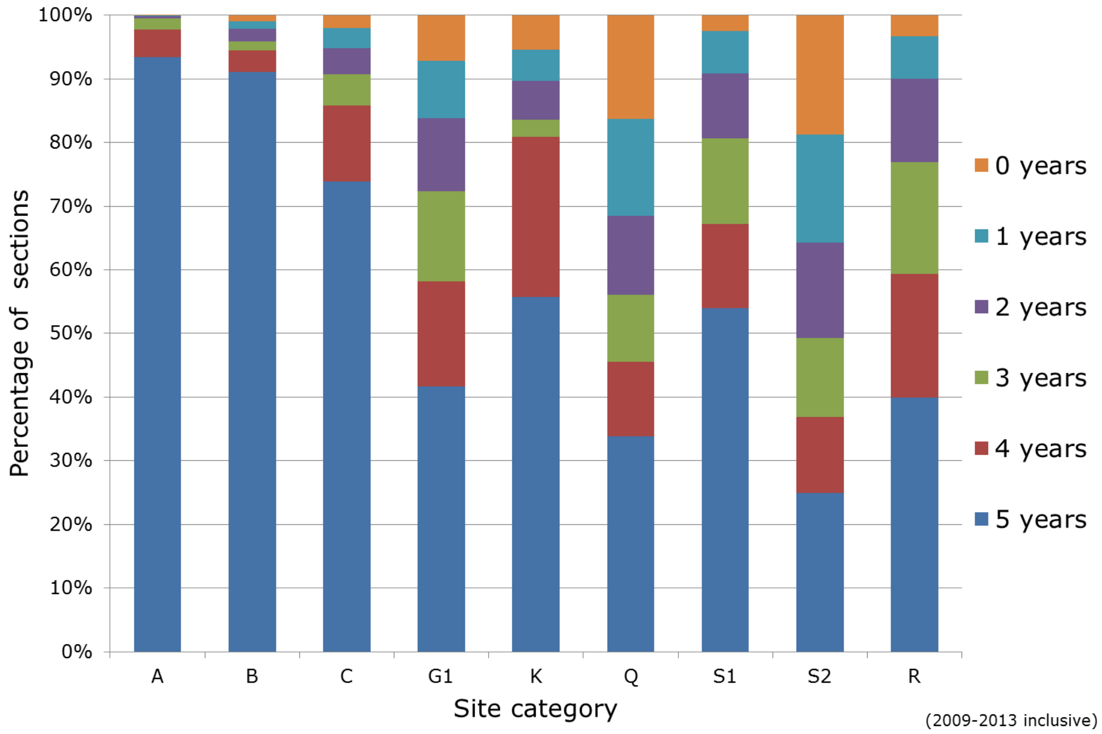


Figure 5.1 Number of years above IL between 2009-2013 for each site category

5.3 Reducing skid resistance averaging lengths

In this analysis, skid resistance measurements from Area 9, which are available at a resolution of 10 m, were aggregated according to the site category appropriate length (shown in Table 5.1) and compared to assigned investigatory levels. The same measurements were then compared to IL without aggregation to see if short, slippery lengths of road are being disregarded under the current skid policy.

Table 5.3 shows the percentage of the Area 9 network that was at or below IL during the five year survey period, when the data is aggregated to the lengths recommended in skid policy. The final row of that table is reproduced in Table 5.5 below, which also shows the proportion of the network that would be at or below IL if the 10 m data was used as measured, without aggregation. Table 5.6 shows that at least some of the additional lengths requiring investigation, based on 10m data, occur on network sections that did not have any lengths at or below IL based on the current averaging lengths.

Table 5.5 Percentage of network at or below IL based on current and 10m aggregation lengths

	Site category								
	A	B	C	G1	K	Q	S1	S2	R
At or below IL according to skid policy	1.9%	4.3%	11.4%	30.2%	19.1%	42.5%	22.0%	48.7%	27.4%
At or below IL using 10 m lengths	2.4%	4.7%	11.6%	31.9%	25.7%	52.6%	24.3%	54.1%	27.4%
Additional length requiring investigation (m)	2711	1572	562	272	120	4368	364	1232	0
Aggregation length (m)	100			50					10

Table 5.6 Number of unique network sections with lengths at or below IL

	Site category								
	A	B	C	G1	K	Q	S1	S2	R
At or below IL according to skid policy lengths	121	205	150	47	16	265	38	50	65
At or below IL using 10 m lengths	227	281	158	49	29	337	46	55	65
Additional sections at or below IL	160	76	8	2	13	72	8	5	0

5.4 Discussion

The two analyses presented above suggest that there may be scope to refine the skid policy. The majority of the Strategic Road Network has acceptable skid resistance and in many cases it is well above the assigned IL. Furthermore, based on the case study, the majority of the lengths of that network with the lowest accident risk, namely category A, non-event motorways, and category B, non-event dual carriageways, have not had skid resistance requiring investigation for at least five years. In contrast, there are relatively large proportions of high risk sites (categories G1, gradients, Q, approaches to junctions and roundabouts, and S2, bends on single carriageways) that currently require further investigation and have required investigation periodically during the same five years. A small change in data handling reveals that there are, potentially, short sections of the SRN that are not currently flagged for further investigation but may warrant it.

Having skid resistance below investigatory level does not necessarily mean that there is an unacceptably high risk of skidding accidents at a site. If, on further investigation it is found that there is no history of accidents, it may mean that the investigatory level is too high. However, it is an important feature of the skid policy that such sites are investigated and it is therefore important that the figures are available to inform that process. In other work (Sanders, et al., 2015) it has been found that some sites on the network are often not surveyed, largely owing to difficult geometry (e.g. small roundabouts) or traffic issues (e.g. red signals when traffic is heavy resulting in insufficient survey speed). There may therefore be scope to divert effort from measuring skid resistance on low risk sites in order to focus on measurements and investigation at high risk sites.

6 Summary and recommendations

A review of relevant literature confirmed that the established principle of measuring skid resistance in the most heavily trafficked lane, i.e. the lane carrying the greatest number of heavy vehicles, is widely accepted and used. However it was not possible to verify the principle using the measurements made routinely and stored in HAPMS. It is suggested that this is due to noise in the data: for the limited lengths where more than one lane was surveyed, the limited precision arising from the measurements having been made at different times and with different devices is of the same order as the difference in skid resistance between the lanes. Targeted measurements of skid resistance, carried out at locations where traffic levels are known to be different in two adjacent lanes, do did confirm the principle.

Two issues were highlighted as a result of the targeted surveys. Firstly, skid resistance had not been measured in the most heavily trafficked lane at some of the sites, even though this is a requirement of the skid policy. Secondly, skid resistance was not always lowest in the most heavily trafficked lane where the surfacing is not the same in both lanes. The chances of either of these issues resulting in increased accident risk are considered to be very small: skid resistance on the parts of the network with more than one lane is typically well above IL. No immediate changes to the skid policy are recommended as a result of this work, but further investigation may be warranted, to discover:

- If there is any suggestion that skidding accidents have occurred on sections of the network, and specifically in outer lanes, that have not been monitored but could have been.
- Whether it is possible to adjust survey routes to ensure that the most heavily trafficked lane is monitored
- The extent of additional surveys required if routine surveying included the most heavily trafficked, uniquely surfaced lane at every part of the network.
- The practicality and any risks associated with adopting an alternate lane survey strategy; i.e. measuring skid resistance in alternating lanes in alternate years, at least on mainline sections. This could remove the need for the current requirement to determine which lane is the most heavily trafficked and could also deal with the presence of different surfacing materials in different lanes, and the potential for them to perform differently.

Reticence in recommending immediate changes to the skid policy result from the findings of the case study analysis presented in Chapter 5. It was found that the majority of low risk sites on the network have skid resistance above investigatory level and have not required investigating for at least five years. This suggests that less, rather than more, emphasis should be placed on measuring skid resistance at these types of site. A relatively larger proportion of the high risk sites on the network are apparently underperforming in terms of skid resistance. Their performance is also somewhat less predictable, and skid resistance may be overestimated by aggregation of measurements over 50 m. It is recommended that:

- The full resolution of the data available in HAPMS (i.e. 10 m) should be used to determine whether high risk sites require further investigation, especially those falling into category Q.

- Routine measurement of skid resistance should concentrate on ensuring that valid measurements are made on high risk sites. It is understood that routine surveys have target coverage rates and it is recommended that these be adjusted, category by category, to make sure that high risk sites are adequately covered.

References

British Standards, 2006. *BS 7941-1. Methods for measuring the skid resistance of pavement surfaces - Sideway-force coefficient routine investigation machine,* London: BSi.

CEN, 2009. *DD CEN/TS 15901-6. Road and airfield surface characteristics. Part 6: Procedure for determining the skid resistance of a pavement surface by measurement of the sideway force coefficient (SFCS): SCRIM,* London: BSi.

Highways Agency, Transport Scotland, Welsh Assembly Government, Department for Regional Development Northern Ireland, 2004. *HD 28/04 - Skid resistance (DMRB 7.3.1),* London: The Stationery Office.

Highways Agency, Transport Scotland, Welsh Assembly Government, Department for Regional Development Northern Ireland, 2006. *Design Manual for Roads and Bridges.* London: The Stationery Office.

Kane, M., Zhao, D., De-Larrard, F. & Do, M. T., 2012. *Laboratory evaluation of aggregate polishing as a function of load and velocity. Application to the prediction of damages on skid resistance of road surfaces due to trucks and passenger cars,* s.l.: s.n.

Long, K., Wu, H., Zhang, Z. & Murphy, M., 2014. *FHWA/TX-13/0-6713-1. Quantitative Relationship between Crash Risks and Pavement Skid Resistance,* Austin: The University of Texas at Austin.

New Zealand Transport Agency, 2013. *NZTA T10 Specification 2013 - Specification for state highway skid resistance management,* s.l.: New Zealand Transport Agency.

Oh, S. M., Madanat, S. M., Ragland, D. R. & Chan, C. Y., 2010. *Evaluation of traffic and environment effects on skid resistance in California,* s.l.: Safe Transportation Research and Education Center.

Roe, P. G. & Dunford, A., 2012. *PPR564 The skid resistance behaviour of thin surface course systems - HA/MPA/RBA Collaborative programme 2008-11: Topic 1 final report,* Wokingham: TRL.

Roe, P. G. & Hartshorne, S. A., 1998. *TRL 322 The polished stone value of aggregates and in-service skidding resistance,* Wokingham: TRL.

Sanders, P. D., Brittain, S. & Premathilaka, A., 2015. *PPR737 Performance review of skid resistance measurement devices,* Wokingham: TRL.

Skerritt, W. H., 1993. Aggregate type and traffic volume as controling factors in bituminous pavement friction. *Transport Research Record,* pp. 22-29.

Szatkowski, W. S. & Hosking, J. R., 1972. *LR 504 The effect of traffic and aggregate on the skidding resistance of bitumionous surfacings,* Wokingham: TRRL.

WDM Ltd, 2004. *Comparison of lane 1 and lane 2 SC values in Area 8,* Bristol: WDM.