Tyres, road surfaces and reducing accidents: a review

A report on research carried out for the AA Foundation for Road Safety Research and the County Surveyors' Society

County Surveyors' Society

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John C Bullas

May 2004

(This review was completed prior to the re-issue of the Highways Agency skidding standard in August 2004)

County Surveyors' Society

AA Foundation for Road Safety Research

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The AA Foundation for Road Safety Research

Objectives

i To carry out, or procure, research into all factors affecting the safe use of public roads.

ii To promote and encourage the safe use of public roads by all classes of users through the circulation of advice, information and knowledge gained from research.

iii To conceive, develop and implement programmes and courses of action designed to improve road safety; these to include the carrying out of projects or programmes intended to educate children or others in the safe use of public roads.

Research strategy

The basis for future strategy is a broad programme of new work, and the commitment to follow through on the findings of earlier research. The Foundation's priority must be to move greater effort into influencing road user behaviour and the application of findings from completed research. It has been agreed that future planning by the Foundation should concentrate on:

i clear strategies on how to influence road-user behaviour to reduce risk, and thereby accidents and casualties, through education and training, enforcement or deterrence; and

ii interactions between agencies concerned with highways, the road environment and land-use, health, enforcement and education, in order to target resources to greatest effect.

Research findings must be systematically pursued, and it is essential to include the issues of:

i public acceptance of, and support for, road safety interventions;

ii the interface between road-users and new technology - their adaptation to its use for information, enforcement and deterrence; and

iii interactions between modes of transport on the roads - pedestrians, cyclists, car drivers etc - and the necessary changes in infrastructure for safety purposes.

It is recognised that these are difficult areas, but unquestionably they offer potential for productive research. By moving into them, and identifying work that is usefully complementary to studies that may be underway in other organisations, the Foundation can continue to make a powerful contribution to road safety, with an agenda that has relevance far beyond the year 2000.

The County Surveyors' Society

Objectives

Founded in November 1885, the County Surveyors' Society represents local authority chief officers with responsibility for Strategic Planning, Transportation, the Environment, Waste Management and Economic Development. The Society's membership is drawn down from all four nations of the United Kingdom.

The objectives of the Society are:

- To promote the acquisition and exchange of knowledge and experience within the fields of members' responsibility;
- To consult and co-operate with kindred bodies concerned with these subjects;
- To serve and advise the local authorities in England and Wales and the Department of the Environment (NI) Roads Service in all matters pertaining to their duties;
- To maintain such contact with appropriate departments of government and national and international bodies as may be necessary for the proper pursuit of the said objectives and
- To consult and co-operate with similar bodies and organisations concerned with these functions.

The Society delivers its objectives through a structure of Committees and Special Activity Groups, which mirror members' fields of responsibility, with overall leadership provided by a Presidential Committee. The 2003-04 President is Bob Wilkins, Director of Transport and Environment, East Sussex County Council.

Funding for Research Projects

In order to pursue highway and transport related research activities the Society has over many years had a Research Board funded through contributions from individual member authorities. Research projects and priorities are established through an annual bidding process and with input from external agencies or partners in many cases. Outcomes of research have been the subject of Technical Reports which have, over the years, provided local highway authorities and national bodies with guidance based on case histories and more meaningful specifications. All these have contributed to a better and safer service for the Road User.

This project has been undertaken in response to a very strong bid from the Traffic and Safety Committee.

Synopsis

The AA Foundation for Road Safety and the County Surveyors' Society funded jointly this investigation into surface characteristics and road safety and the project was carried out by a Research Officer based in the offices of the Hampshire County Council.

The reasons for carrying out the project at this time were concerned with the targets set by the Department for Transport for accidents in 2010, which included a reduction in the number of people killed and seriously injured of 40 per cent compared with the mid-1990s levels. In addition, there were separate targets for child casualties of 50 per cent reduction in killed and seriously injured. It was recognised that these targets would be difficult to achieve, taking into account the improvements in road safety achieved between the mid-1980s and the year 2000. Nevertheless, the targets serve to focus everyone's efforts on improving road safety and this project was developed from a discussion of these new targets. The objectives of the study were:

To investigate whether any relationship exists between the surface characteristics of the road surface and the accidents that occur, and, in particular, to investigate influencing factors, including:

Wet/dry conditions;

The role of splash and spray on skidding and as an impairment to visibility;

Lighting provision for accidents after dark;

The presence of porous surfaces and their effect on skid resistance and speed;

The presence or absence of road markings at the road margins;

To report on the position regarding relevant research on the role and efficacy of the tyre/road interaction.

To advise Decision Makers on appropriate levels of maintenance, Suppliers on the selection of materials and, generally, the direction the development of surface characteristics should take in order to improve safety.

The method used was to review the information available on the various aspects and to draw it together into three chapters on surfacings, tyres and accident databases, carrying out additional research as appropriate to each area.

There are detailed conclusions in the individual chapters of this report and some strategies have been proposed that could be developed to deal with some of the more important aspects.

In taking this step, it has been recognised that many of the factors contributing to accidents are not within the control of the vehicle, tyre or highway engineer. Therefore, the engineer has to pursue a course that will, as far as possible, remove these factors from the conflict situation, thereby reducing the risk of an accident occurring. It is proposed that this could be done by:

Prioritising the development of the SMART tyre technology whereby drivers are informed, by displays in the vehicle, of the condition of their tyres. In the interim, policies should be developed that provide greater assurance that the condition of tyres on the national car fleet comply with national Standards and with manufacturers' recommendations.

The new generation of road surfaces do not appear to have their designed frictional properties until they have been trafficked for a considerable, as yet undefined, period. Thus, there is a need to develop ways of advising the motorist of this situation and of accelerating the development of the designed frictional properties of the surfacing.

The STATS19 database is being extended to include records of Contributory Factors to accidents as well as the information on location etc that has been routinely collected. All organisations should support the collection of this additional information because it will greatly assist the engineer in designing measures to minimise the risk of accidents occurring.

The MOLASSES database has provided very useful information on the performance of accident alleviation schemes. However, in recent years, there has been a marked reduction in the number of schemes that have been input into the database. This should be reinvigorated because this type of scheme has an important contribution to make to the 2010 accident reduction targets and because a more comprehensive database will provide useful information for engineers, designing safety schemes, on the performance of measures that they are considering introducing.

Various ways of enhancing the properties of the tyre/road interface have been outlined in this report. However, there is general concern about the ability of the motorist to exploit to the maximum the safety factors that the engineer introduces thereby mitigating the benefits to some extent.

Executive Summary

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The detailed conclusions in the individual chapters of this report are set out below:

Tyres

Worn tyres are common, reducing braking capability and increasing accident likelihood, especially on wet roads:

- Tyre Industry surveys show that 1 in 10 cars have one or more tyres with a tread depth at or below the legal (1.6mm) limit. Research more than 30 years ago showed broadly similar results.

- Worn tyres may contribute towards 9 per cent of accidents in wet conditions compared with only 2 per cent of accidents in the dry.

- On wet roads, the risk of certain types of accident has been seen to treble when the tread depth is less than 1.5mm and increase seven-fold when the tread depth is less than 0.5mm.

- Below 1mm tread depth, the braking force coefficient may be only about one-third of that when tyres comply with the legal limit.

- Those more at fault in high speed accidents were six times more likely to have worn tyres than those innocently involved.

- *Greater efforts are required to establish a better understanding of the problems of worn tyres and to ensure vehicles have adequate tread.*

- *Generally, stopping distances in the wet are likely to be at least doubled.*

- *When there is a water film on the road of more than 2mm, even when tyres have 2mm tread depths, the available friction can be comparable to that of a smooth tyre.*

Front-rear tyre tread imbalance is an issue that apparently is not well understood by motorists:

- Handling may be affected when the tyre tread depth is substantially greater on the front tyres than on the rear tyres.

- Many consumers appear unaware of the issue of front-rear tread imbalance.

- *The tyre retailing and fitting industry should increase its efforts to draw attention to the issue and its contribution to accidents should be researched.*

Under-inflated tyres are common and this leads to excessive wear and to an increase in fuel consumption; also, it may cause vehicle-handling problems:

- Tyre Industry surveys have shown that as few as 5 per cent of tyres are correctly inflated and that 75per cent are under-inflated.

- Tyre life decreases by up to 10 per cent for every 10 per cent under-inflation.

- *Tyre manufacturers should be encouraged to develop technologies that will maintain pressure consistently and that will provide affordable and accurate on-board monitoring of tyre pressures.*

Structural defects of tyres play little part in accidents:

- Tyre quality and performance have improved in recent years and will continue to do so with the development of SMART tyre technology.

- Studies in other countries have shown that structural defects of tyres cause only 3 or 4 per cent of accidents and in most cases this could be attributed to the result of extended running at low pressure or physical damage.

- *Researchers should concentrate their efforts on the role of tyre characteristics in accidents rather than the structural failure of tyres.*

Drivers of vehicles with worn tyres may have other characteristics associated with increased accident risk:

- There is evidence that motorists driving vehicles with worn tyres are more likely to be the party at fault in accidents.

- *There is a need for a better understanding of the association between driver behaviour, tyre condition and accident risk.*

Many tyre pressure gauges are inaccurate:

- Surveys of the accuracy of air pressure gauges at garages have found 1 in 5 to be defective and almost half to be inaccurate (ie. outside reasonable tolerances).

- *Garages and local authority trading standards departments should do more to ensure that gauges are either accurate or are withdrawn from service.*

Surfaces

Surfacing materials do not always deliver appropriate levels of both macro- and micro-texture throughout their service lives:

- Accident rates increase markedly at low levels of macro-texture.

- *There is a need for a standard for macro-texture on in-service roads.*

The Skidding Standard.

The Skidding Standard has provided a soundly-based structure for the effective allocation of resources to maintain the frictional properties of the Highway Network:

- The Standard has been in operation on trunk roads and motorways since 1988.

- A Code of Practice, similar to the Standard, has been established by local authorities for their highways.

- *There is a need to establish the contribution that the Skidding Standard has made to accident reduction since 1988 and to ensure it continues to meet the needs of the roads of the 21st century*.

The National Road Maintenance Condition Survey (NRMCS).

The new skid resistance indicator in the NRMCS provides a single benchmark statistic for the overall skid resistance condition of the highway road network. However, this single statistic does not reflect the distribution of skidding resistance deficiency, or its consequential effects on accidents, across the network:

- On low risk sites, making up a substantial proportion of the network, there is a small increase (5-10 per cent) in the risk of a wet skidding accident occurring.

- On high stress sites, which make up 10 per cent of the total network, there is a much larger increase (about 50 per cent) in the risk of a wet skidding accident occurring.

- *A more detailed NRMCS skidding resistance statistic, possibly associated with the risk rating of the site, is needed in order to represent the national situation.*

Negative texture "new generation" surfaces.

New generation surfaces (often "low noise") have lower early-life, dry-skidding-resistance than that which they were designed to deliver over the long-term:

- Early on, these surfaces can be as slippery in the dry as in the wet.

- Most local authorities do not have the means to measure or monitor dry skidding resistance.

- *Technologies should be developed, and local authorities equipped with the means, to quantify the risk that these surfaces may pose to the driver and develop strategies to alert them to it.*

- *The industry should develop processes for improving the early-life characteristics of new surfacings.*

Retexturing.

The mechanical treatment of a sound road surface to restore skidding resistance and texture depth can provide an effective short- to medium-term solution to micro- and macro- texture deficiencies, which may need treatment more immediately than can be achieved by conventional resurfacing techniques:

- Retexturing may cost only 10 per cent of that of resurfacing.

- Retexturing is environmentally friendly.

- Retexturing does not require any new materials such as scarce premium aggregates.

- Retexturing may only be a short-term solution on highly trafficked or stressed sites.

- *Retexturing should be considered where restoration of aggregate properties is needed to return the road to an acceptable condition.*

High friction surfacing (HFS).

High friction surfacings are extremely effective in reducing accidents at high-risk sites:

- On bends, HFS can reduce accidents by half.

- HFS can now be specified through a British Board of Agrement (BBA) Highway Authorities Product Approval Scheme, (BBA/HAPAS), which assures appropriate performance at high-stress locations.

- HFS is not a panacea for all high-stress locations; account should be taken of the probable durability of the various types at the specific location so that the treatment is cost effective.

- *Engineers should be selective in the use of HFS, ensuring that it is the most appropriate treatment. Information should be collected on the performance of materials so that the assurance provided by the BBA/HAPAS approval system is enhanced.*

Spray

Spray suppression devices and negative-textured surfaces have improved the wet-road driving experience in the UK:

- Many vehicles, including those from other countries, those under 12 tonnes, bulk tankers and tippers, may be partly or wholly exempt from the UK legislation.

- The development of more effective types of spray suppression is restricted by the present material-based specification for spray suppression equipment.

- *The EC needs to develop a performance-based specification for spray suppression devices and the UK government should review current exemptions in order to improve further driving conditions in the wet.*

Road markings and Intelligent Roadstuds (IRS).

The installation or upgrading of carriageway markings can significantly reduce accidents:

- Studies have shown that a 20 per cent reduction in accidents for local area safety schemes can be achieved.

- There is conflicting evidence on the accident reduction achieved by the use of edge-markings.

- The use of IRS may represent the logical next-step in road markings because they transmit dynamic information to the road user in a way similar to that of traffic information systems.

- *More research is needed on the long-term functionality and durability of road markings and their role in accident reduction.*

Highway Lighting

The installation or upgrading of lighting has generally proved effective in reducing accidents:

- New lighting schemes have reduced accidents by up to 25 per cent when used in local area safety schemes.

- However, some studies suggest lighting may have a detrimental effect on accidents when used on isolated rural junctions.

- *A more detailed review is needed of the effect of lighting on accidents at isolated rural junctions*.

Worn surfaces and worn tyres

- Worn surfaces, combined with worn tyres, greatly increase accident risk – factors affecting accident risk include the road surface texture, shape and geometry, combined with the speed of travel, the properties of the rubber, temperature and deformation of the tyre, the contact geometry and the road-type interface, the extent to which water can drain from the contact patch and the presence of any local contaminants such as oil or detritus.

Accident databases

STATS19 database:

- STATS19 is a valuable and continuously-improving database of information on personal injury road accidents in the UK.

- STATS19 provides data, recorded after the event, about the general layout of the accident location, the time and weather, and the vehicles and drivers involved.

- STATS19 lacks detailed information on the nature of the tyre/road interface.

- The inclusion of Contributory Factors in the STATS 19 data will provide an additional source of information on accident causation.

- *Studies of the Contributory Factors data included within STATS19 should be encouraged because they may give a better picture of the circumstances leading to an accident.*

Data-mining and accident data:

- Data-mining relies on the “domain expert” to guide the data-miner towards new and relevant, rather than obvious and known patterns in the dataset.

- Data-mining may be effective on a STATS19 database containing contributory factors.

- *The application of data-mining to local authority accident data may complement existing established analytical techniques.*

MOLASSES

MOLASSES is a database that contains information about local road safety schemes installed by local authorities in the United Kingdom.

The acronym MOLASSES stands for "Monitoring Of Local Authority Safety SchemES". The database was started in 1991:

- The MOLASSES database is a valuable central resource, detailing over 4500 local area safety schemes installed since the late 1970s.

- There has been a significant decline in submissions of new schemes from local authorities to the MOLASSES database since the mid 1990s.

- The overly complex database structure makes analysis difficult.

- *MOLASSES should be revised and made available on-line for the benefit of those investing time and resources in the providing data.*

Chapter 1 Introduction

The UK accident record in perspective, and the 2000 target.

Britain has had remarkable success in reducing road casualties and this has occurred while there has been vast growth in traffic since the beginning of the last century. In 1930 there were only 2.3 million motor vehicles in Great Britain, but over 7,000 people were killed in road crashes. Today, there are over 27 million vehicles but at about 3,500, half the number of road deaths.

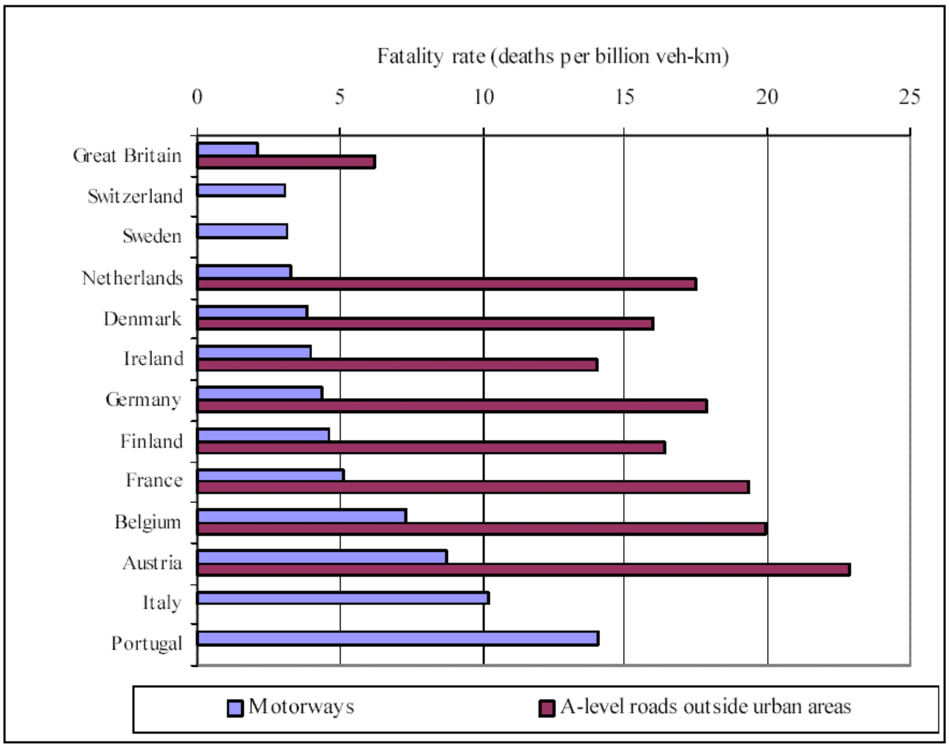


Figure 1.1 Road deaths per billion-vehicle km (Lynam et al. (2003))

These figures can be seen in comparison with those for other countries in Figure 1.1, which indicates the road fatalities per billion-vehicle km for a number of countries.

In 1987, a target was set in Britain to reduce road casualties by one-third by the year 2000 compared with the average for 1981–85. This target was largely achieved; to the extent that road deaths fell by 39% and serious injuries by 45% and the road network in the UK is one of the safest in the world. However, there has not been such a steep decline in the number of crashes, nor in the number of slight injuries, although improvements in vehicle design have helped to reduce the severity of injuries to car occupants.

The new targets for 2010

However, building on past successes, it was considered that road casualties could be reduced still further. Therefore, a new 10-year target and a new road safety strategy was launched in the year 2000, focussing on achieving further substantial improvements in road safety over the next 10 year period and setting new targets.

("Tomorrows Roads: safer for everyone", Department of the Environment, 2000).

The following new targets were set to be achieved by 2010 (compared with the average for 1994–98):

a 40% reduction in the number of people killed or seriously injured in road crashes;

a 50% reduction in the number of children killed or seriously injured; and

a 10% reduction in the slight casualty rate, expressed as the number of people slightly injured per 100 million vehicle kilometres.

Child pedestrian casualties

Although the overall record of the UK for child safety is relatively good, the child pedestrian record is poor compared with some European countries. The Government were, and still are, particularly concerned about child safety and there is a special focus in the new strategy on reducing the number of children who are killed or injured in road accidents.

The new targets are challenging. Reductions in the last period were helped by marked changes in attitudes to drink driving and legislation on seat belts. But with sustained effort, it is considered that the new targets are achievable by 2010. Reducing road casualties in this way will also contribute to the targets for overall accident reduction set by the "*Saving Lives: Our Healthier Nation" White* Paper and the equivalent Scottish White Paper "*Towards a Healthier Scotland"*.

The targets are serving to focus everyone's efforts on achieving a further substantial improvement in road safety over this next 10 years, and the concept of this project was shaped from a discussion of these targets. (AA Foundation (2001))

The objectives of this study were:

To investigate whether any relationship exists between the surface characteristics of the road surface and the accidents that occur, and in particular to investigate influencing factors, including:

- wet/dry conditions;
- the role of splash and spray on skidding and as an impairment to visibility;
- lighting provision for accidents after dark;

- the presence of porous surfaces, skid resistance and their effect on speed;

- the presence or absence of white lines at road margins;

- to report on the position regarding relevant research on the role and efficacy of the tyre in the tyre/road interaction;

- to advise Decision Makers on appropriate levels of maintenance, Suppliers on the selection of materials and, generally, the direction that developments of surface characteristics should take in order to improve safety.

A wealth of knowledge has been accumulated over the last century to enable the Road Engineer to create, monitor and maintain the properties of the road surface in order to provide a safer environment for the road user. Much of this information was used to formulate the UK Skidding Standards in which the engineer became responsible for the frictional properties of the road surface, which gave road safety added prominence.

The "Skidding Standard"

Although it is not mentioned in the calendar of events affecting road safety and traffic that forms part of the annual publication: "Road Accident Great Britain" (Department for Transport, 2002), HD 28/94 Amendment Number 1 Skidding Resistance (Design Manual for Roads and Bridges, Highways Agency (2003)) details the method of routinely determining the wet skidding resistance of sections of trunk roads and relating them to the investigatory levels below which the probability of wet skidding accidents may increase significantly (Rogers & Gargett, 1991).

Figure 1.2 Slippery Road Signs may be erected to identify a section of road where the wet skid resistance is at or below the appropriate investigatory level: Department for Transport (2002)

The sophistication of the Skidding Standard is in the concept of investigatory levels, which is different from intervention levels. The engineer investigates sites with levels at or below investigatory levels and reassesses the risk of accidents occurring and the appropriate investigatory level before deciding on the maintenance treatment to restore the skid resistance.

The role of “The Skidding Standard” in reducing accidents is currently under review by the Highways Agency together with the role of surface texture as a factor in accident reduction.

When a driver passes a slippery road sign they should consider this as evidence of ongoing investigation and, at the same time, they should be aware there may also be a small, but not insignificant, increase in the probability of a wet skidding related accident on that stretch.

Many gigabytes of data are generated annually by the many surface condition surveys carried out by local and central government; the application of this data and its effective dissemination are discussed.

Recent innovative materials are providing quieter surfaces that can be laid with less disruption to traffic. Issues of reduced skidding resistance when these materials are new and their behaviour when they require de-icing are being investigated.

However, the road surface is only half of the interface controlling the movement of the vehicles, the tyre is the other part.

Tyre safety

Modern tyres stop better in the wet and offer improved handling. Now tyre technology is moving towards the concept of the “smart tyre” where the tyre's behaviour is monitored and integrated with that of the suspension and traction systems. Also run-flat tyres and tyre pressure monitoring and low-pressure warning systems are helping the driver to keep on the road.

A relatively recent report, "Macrotexture and Road Safety" (the MARS project, Parry (1998)), provides a valuable insight into the behaviour of tyres on both conventional and latest generation surfaces and suggests that tyre properties should be tested on surfaces representative of "the real network". One positive outcome of the report is that at least one tyre developer was investing in equipment to investigate tread compound dynamic properties to enhance wet and dry friction and minimise energy losses.

With the increasing need to reduce environmental noise pollution, the reduction of tyre noise is high on the agenda. As the tyre generates noise in response to energy transfer, it is thought by some to be of paramount importance that any regulations limiting tyre noise incorporate controls on associated minimum levels of “grip”.

Vehicles with low tread depth have been proven not to handle as well in the wet. Legislation was first introduced in 1967, and unified over the EC in 1992 at higher levels to enforce minimum levels of tread depth.

The relationship between tyre tread depth and road holding is well understood and recent work carried out in the USA, together with UK tyre survey data, suggests that additional controls relating to tyre fitment could potentially improve safety further.

Unfortunately, the relationship between tread depth and accident risk is complex , and is exacerbated by some drivers not considering the condition of their tyres.

Challenges facing the road safety engineer

In evaluating crashes and designing measures that will reduce the number and/or severity of crashes, the Road Safety Engineer needs two key resources:

- Records of Personal Injury Accidents (PIAs); and

- Data from road surface condition surveys.

Data from road surface condition surveys are relatively straightforward to interpret, being carried out under controlled conditions and with well-defined criteria against which to assess performance.

With PIAs, however, the many unknowns involved make interpretation difficult and in many cases a resolution can only be achieved through the analysis of trends.

The road user is probably the most prevalent and certainly the most variable in accident causation but, when looking at the road/tyre interface, both the road surface and tyres can be subject to major variations also.

It is noteworthy that the lifespan of the average road surface is potentially an order of magnitude greater than that of the average tyre and the surface characteristics tend to be consistent throughout a site and subject to relatively minor changes over time.

With tyres, however, condition will change from car to car and may even be inconsistent from axle to axle. An investigation into the road/tyre interaction needs to consider all these variables.

The use of novel surfacings, road markings and other techniques to improve the safety and comfort of the road user are studied through routine monitoring by highway authorities and targeted research is carried out by bodies such as the Highways Agency, the County Surveyors' Society and the AA Foundation.

Highway authorities invest millions of pounds in maintaining and monitoring the road network. With an increased reliance on integrated data from many sources and the use of Geographical Information Systems (GIS) to interpret and analyse it, precision and accuracy are paramount.

Systems must be in place to audit all surveys both when in-house and when provided by third parties to ensure each survey is accurate and the layering of such data is precise.

All locational data must be verified when used for all but the most general statistical analysis to avoid misinterpretation, mis-association and, potentially, misdirected, and therefore wasted, resources.

Details of road safety and maintenance schemes implemented (and their accident records) need to be recorded in a standard format in order to be of greatest value to those attempting to address similar problems within the same authority or elsewhere in the UK.

Schemes to record data centrally need to provide, and be perceived as offering, local value, otherwise in these days of scarce resources, they will fail. In the UK, the long-term commitment to recording road accidents, and their consequences, has provided an extensive database that can be used to derive trends and to evaluate the effects of changes in vehicle and highway legislation and practice.

The aim of this report

This report aims to highlight the current areas of achievement and of concern, how best value might be achieved and where some existing technologies and resources may be improved.

Many of the subject areas in this report are inter-related through the tyre-road interface.

Firstly, the tyre and its interaction with the road surface is considered, and is followed by an overview of the factors that play the greatest role in maintaining safe surface characteristics. Then the various sources of data relating to accidents in the UK are reviewed together with areas where the quality and exploitation of these resources may be improved. Conclusions are drawn at the end of each chapter and, finally, some overall conclusions are set out at the end of the report.

It is hoped that the information contained in this report will be of interest to specialists, providing them with a broader perspective of road safety issues, as well as to road users.

Chapter 2 Tyres

2.1 Introduction

Tyre development has continued unabated since the first pneumatic tyres were used on bicycles in 1889. The tyre complements the properties of skid resistance and water dispersion provided by the road surface so that effective contact can be established between vehicle and road.

In contrast to the characteristics of the road (which fall under the control of the highway engineers), drivers can easily and directly influence the handing characteristics of their vehicles by their choice of tyre and their degree of attention to tyre tread depth and to tyre pressure.

2.2 Recent history of tyres

Both the tyre and the cars they are used on have changed. As can be seen from Table 2.1, tyres have had to accommodate increasingly arduous workloads over time.

Table 2.1 Some characteristics of typical motor cars: Dunlop Tyres (2000)

Average Family Car	**1920s**	**1930s**	**1960s**	**1980s**	**1990s**
Brake horsepower	20	25	40	55	90
Vehicle Weight (kgs)		450	920	830	1000
Power to Weight Ratio (bhp/tonne)		56	43	66	90
Top speed (mph)		55	70	85	100+
0-60mph (secs)			36	16	10

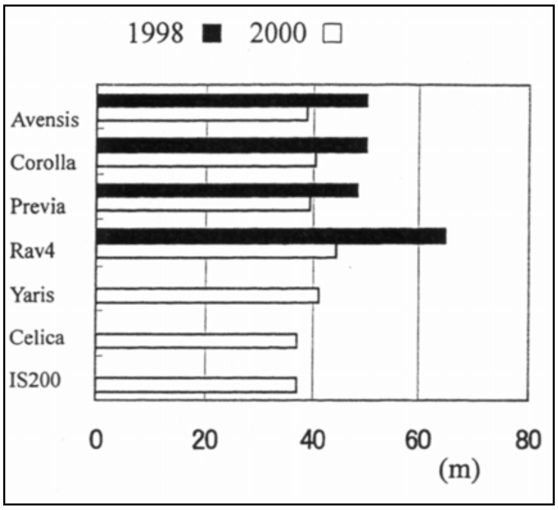


Figure 2.1 Improvements in dry stopping distances: Isomura(2002)

Figure 2.1 illustrates how the stopping distances for some Toyota vehicles (as an example) have reduced in just 2 years. The improved performance of tyres has contributed significantly to these benefits.

A light vehicle must transmit all the energy it needs to move through tyre-road contact areas that add up to about the size of an A4 sheet of paper (Gothie, Parry and Roe (2001)).

Modern tyres are carefully matched to the vehicle to handle the stresses imposed upon them by higher speeds, more efficient braking systems, faster acceleration, higher power to weight ratios and the heavier drive trains of diesel cars with greater levels of torque.

Power steering and front-wheel-drive further focus the requirements of traction delivery and road-holding.

The improvement in tyre performance has been achieved by improvements in tyre construction, improvements in tyre tread design and by improvements in tyre compounds.

Improved tyre longevity

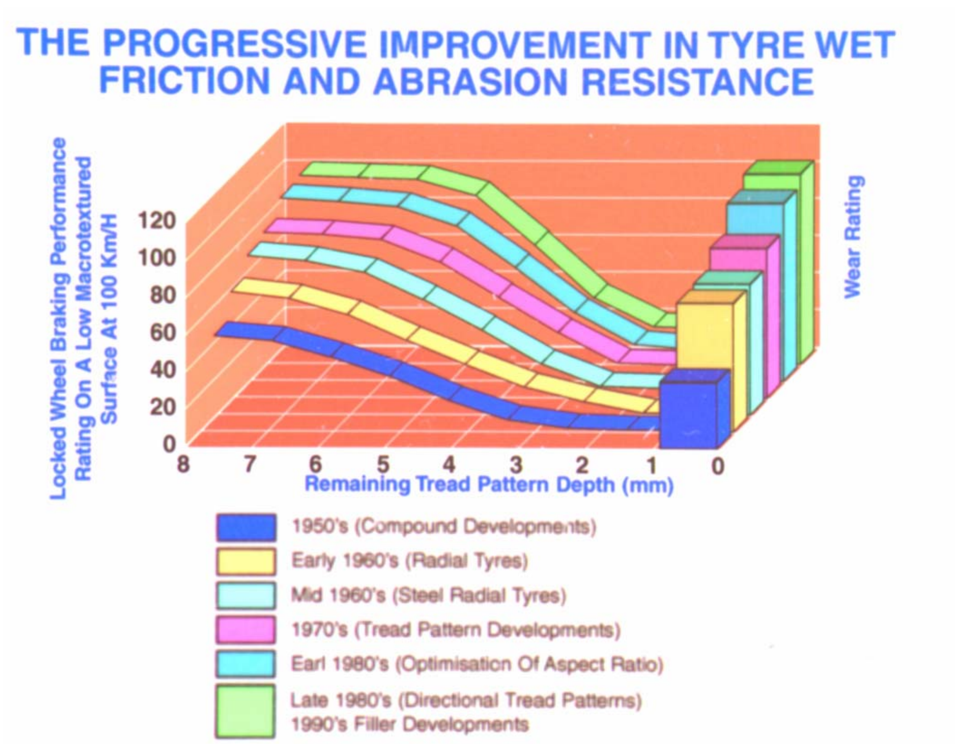


Figure 2.2 Improvements from the 1950s to the 1980s in general tyre braking performance and wear resistance: Williams (1992).

Figure 2.2 illustrates the almost three-fold increase in the wear resistance of a typical tyre between the mid 1950s and the 1980s, and the way in which the level of wet road holding has been improved as the tyre wears.

Research and development in the tyre industry has continued unabated and now accounts for approximately 3 to 4 per cent of the turnover revenue of the major companies (Just-Auto.com (2001)). However, the potential for future benefits from changes to compound and tread pattern are predicted to result in only a five per cent improvement in current performance characteristics.

2.3 Future developments

Some examples of the types of development envisaged are available in the publications of individual companies.

Figure 2.3 Continental Tyres SWT system: Continental Tyres literature (2002)

The "smart tyre" concept is one in which the performance of existing tyres can be optimised by integrating their characteristics into an adaptive suspension/braking/chassis system, measuring the deformations of the tyre profile and tread contact area and using this information to optimise the characteristics of the other systems.

Figure 2.3 illustrates one typical system developed by Continental Tyres. Their "Sidewall Torsion Sensor" (SWT), due to go into volume production in 2003 involves inserting a magnetised ferrite powder into the tyre sidewall. Two magneto-resistance sensors in the wheel housing pick up sinusoidal signals and their amplitudes serve as a measure for longitudinal and lateral forces.

The latest developments in "smart tyre" technology are moving towards the direct measurement (and feedback to the vehicle's suspension, braking and power train) of the actual forces at the tyre road interface.

One area of development is in the monitoring of tyre pressure either by using the ABS braking sensors (to detect a relatively sudden pressure loss in excess of 15 per cent in individual tyres on an axle) or, more accurately (±1.5 per cent), by direct measurement of tyre pressure, such as that used by the Smartire System illustrated in Figure 2.4. Systems that are not reliant on an internal power source offer the greatest serviceability. Retrofitting these systems to existing vehicles may be possible.

Figure 2.4 Smartire pressure sensor and receiver: Smartire literature (2002)

Extended mobility ("run flat") tyre technology now enables the driver to maintain control over the vehicle when a tyre is deflated and to proceed to a safe place instead of changing a wheel at the side of a busy road.

Extended mobility tyres are increasingly available as an optional extra on new models with the general drive toward the elimination of the spare wheel, which is often reduced to a limited speed "space saver" tyre or replaced by an aerosol can of tyre sealant.

Extended mobility tyres

Some extended mobility systems enable the driver to reach their destination a hundred kilometres or more away, with only an insignificant (but designed in) change of handling characteristics, and substantial advantages for the driver not having to change a wheel.

Retrofitting some extended mobility systems to existing vehicles may be possible.

2.4 The consumers' choice

In the customer-facing world, the consumer is increasingly empowered with information to assist them with their purchase.

Some examples are:

- Domestic appliances are classified in terms of energy efficiency and effectiveness.
- New cars are ranked in terms of crashworthiness within a vehicle class.
- Food labelling breaks the ingredients down by calories, salt content etc.

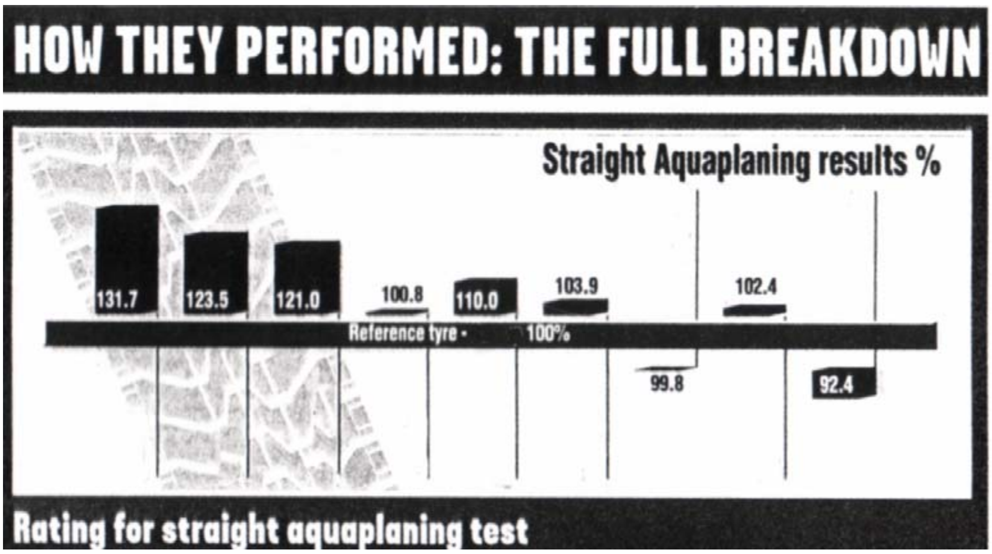
However, if drivers try to apply a similar reasoned decision-making process to the purchase of new tyres they will be disappointed.

The European driver is not empowered with the same ability to judge the relative tyre performance as he is able to assess the relative energy efficiency of a new refrigerator or the safety of a new car.

The UTQG system in the USA

In the USA, the Uniform Tyre Quality Grading (UTQG) system introduced in the 1980s, which sought to grade all tyres in terms of their performance in various standard tests, has been made almost redundant because of the additional performance warranties and after-sales benefits offered by US tyre outlets.

Figure 2.5 A typical automotive press tyre performance summary: Auto Express (1999)



The automotive press carry out tests to give a limited perspective on the relative levels of performance expected, these tests usually compare the top 10 tyre brands. Common practice is to use one brand/design as a reference "100" with tests commonly resulting in a fairly narrow range of performance. Figure 2.5 illustrates a typical (anonymous) automotive press tyre performance summary for one particular tyre size and application. It should be observed that these tests are carried out on new tyres, their performance when part worn may be different.

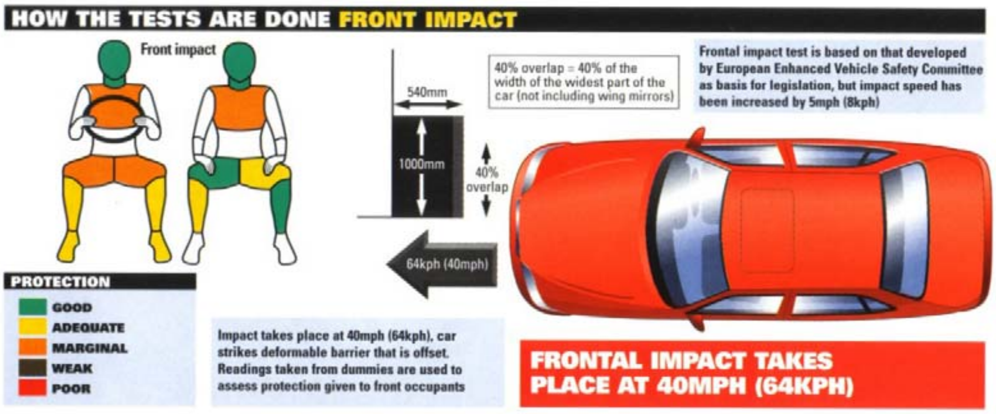


Figure 2.6 Detail of EuroNCAP test parameters: EuroNCAP literature (2002)

The potential purchaser of a new car or washing machine has a wealth of resources to assist them in their choice: crash test performance and pedestrian safety data for the EuroNCAP tests for their car purchase (Figure 2.6 details one aspect of the EuroNCAP procedure) and energy efficiency for many functions of electrical appliances under consideration

Existing tyre sales literature

The tyre industry does not publish the results of tests against named competitors, as the test procedures and conditions, and the actual tyres used for the test, may be questioned, and litigation might result if the findings could not be substantiated. Figure 2.7 illustrates a typical comparison of the last year's production with the tyre it replaced.

To provide the equivalent system of benchmarking for the performance of tyres, in the same way as the energy efficiency of domestic appliances has been tackled, would require a significant investment.

Such a benchmarking scheme might appeal to fleet managers with an interest in reducing fuel costs or those requiring a reduced level of road noise because, at present, they have little on which to base their choices.

Benchmarking of tyre performance by environmental criteria (manufacturing processes, lowest environmental impact, low noise, low rolling resistance, good durability) has been included within the brief of the "Nordic Green Swan" ecolabel, introduced by the Nordic Council of Ministers. Kumho Tyres (who provided the technical literature shown) have recently been awarded this label in Norway.

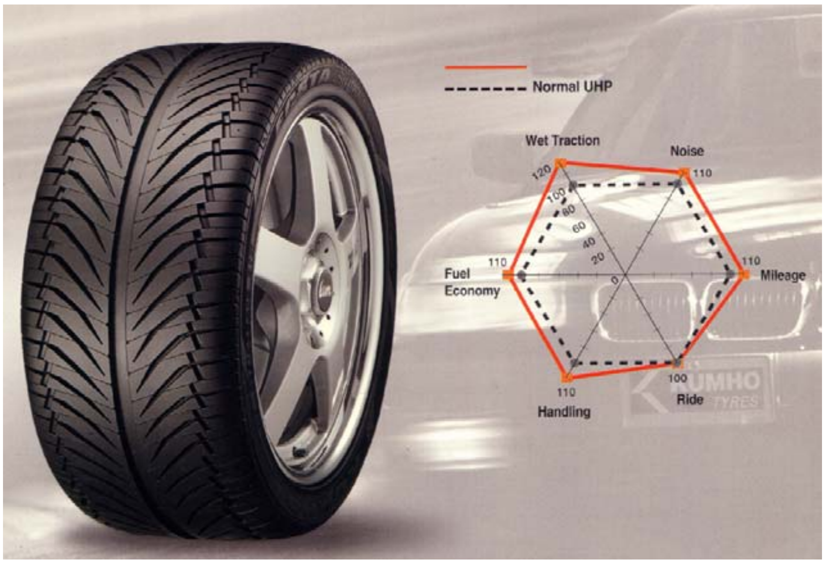


Figure 2.7 Sales literature detailing performance improvement on a year versus year basis: Kumho Tyres' sales literature (2002)

A need for minimum safety requirements

Work carried out by TRL (Nelson *et al.* (1993)) identified a need to establish minimum safety requirements for tyres irrespective of the introduction of noise limits (see Section 2.6).

2.5 Tyre pressure: effects on wear and handling

The 'OE' or 'original equipment' tyre is matched to meet the manufacturers' requirements of fuel economy, braking, cornering and ride comfort. Every owner's manual provides data on recommended tyre pressures and type for optimum performance.

The sidewall markings on tyres provides information concerning their operating limits and specification, as illustrated in Figure 2.8.

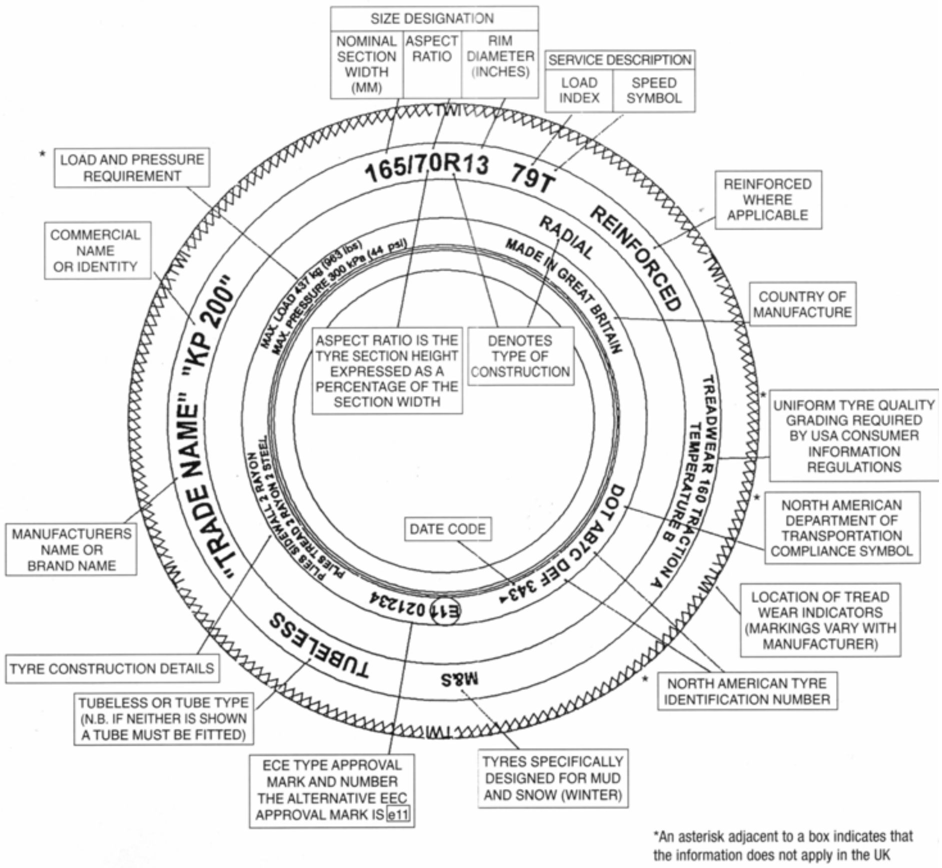


Figure 2.8 Typical markings on a tyre and their meanings: Tyre Industry Council (2003)

All tyres are designed to operate within a range of speed, load and temperature, the coding found on the side of the tyre provides the necessary detail. However, the correct tyre pressures for the vehicle are not marked on the sidewall.

During the design of the vehicle, the manufacturer will have worked in conjunction with their suspension and handling teams and with the tyre supplier to establish not only the correct tyre but also the correct tyre pressure to provide the best performance to balance fuel economy, handling and load carrying capability.

To drive with tyre pressures above or below that recommended not only costs the driver in terms of quality of ride and fuel economy but may also damage the tyres and shorten their lives.

Tyre pressure and wear

Over- or under-inflated tyres traditionally manifested classic wear patterns. Figure 2.9 illustrates the typical appearance of such tyres. Modern steel-braced radial tyres are far less likely to show these characteristics and, in the case of wide low-profile tyres, hard acceleration with correctly pressurised tyres may result in what appears to be evidence of running at too high a tyre pressure (McCarthy (2003)).

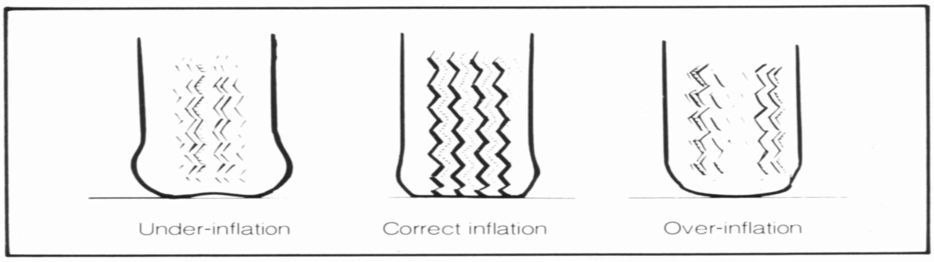


Figure 2.9 The typical appearance of over- or under-inflated tyres in terms of classic wear pattern: Tyre Industry Council (2003)

Under inflation is, by far, the most common and serious problem.

Under inflated tyres

Low pressure causes the tyre to collapse slightly, and more vehicle weight is carried on the tyre sidewalls than on the centre of the tread. Consequently, tread wear will be greater towards the sides than in the centre.

Reducing inflation pressure increases a tyre's rolling resistance and reduces fuel economy. Also, an under inflated tyre flexes more, which leads to increased and uneven tread wear. As a rule of thumb, tyre life decreases 10 per cent for every 10 per cent it is under inflated. Under inflation also makes a tyre run hot. Increased flexing of the sidewall increases the temperature of the tyre, which in turn increases the risk of a tyre failure and blow-out. Also, an under-inflated tyre can cause other problems as well. The amount of air in each tyre affects weight distribution between the wheels. An under-inflated tyre does not carry its full share of the load. This, in turn, affects chassis loading, traction, steering, alignment and braking. It may also cause a noticeable steering pull when driving or braking.

An under-inflated tyre can also lose traction more easily than one which is properly inflated, which can cause skidding during braking or hard cornering, or wheel spin when accelerating.

Modern tyres with advanced compounds are quite capable of maintaining their pressure for long periods. However, slow leaks from small punctures and corrosion of wheel rims, leaky valves, etc may result in loss of pressure so that when motorists check the oil they should also check the pressures, and do this weekly.

Handling: deflated tyres

Studies reported to the Society of Automotive Engineers (SAE) (Robinette, Deering and Fay (1997)) on the effect of deflated ("flat") tyres on vehicle handling concluded that the drag caused by a deflated tyre at 45 mile/h "could be readily controlled by a fairly minor response from the test driver". This work highlighted that the drivers of 4x4s were potentially the least likely to be aware of deflated tyres as these tyres had the least difference in rolling resistance compared with those correctly inflated. Therefore, there may be greater potential for long term damage from running under inflated because of a lack of driver awareness. However, the increase in the probability of tyre deflation at high speeds, as a result of damage caused by extended running at the wrong pressures, is of greatest concern.

Tyre pressure and ABS brakes

Work published in 2002 by the SAE, (Marshek, Cuderman and Johnson (2002)) observed for the vehicles tested:

"ABS braking performance is reduced at low and high tyre inflation pressures with optimum performance near the tyre inflation pressure recommended by the vehicle manufacturer"

However, the magnitude of the effect of tyre pressure on ABS braking was only slight. It should be noted that a vehicle's ABS system is optimised for the tyre supplied with the new vehicle and with high levels of tread depth. The optimum performance of the ABS system may not be delivered when alternative tyres are used and/or if tread wear is significant.

The effect of temperature on tyre pressure

The recommended inflation pressures are for cold tyres. This means tyres that have not been driven on for several hours (ideally overnight). It also means tyres that are at a normal outside temperature of about 20°C. The definition of a cold tyre is when its temperature is equal to the ambient temperature. If someone drives to the garage to check their tyres then the tyres will not be cold. In this case, Michelin advise the motorist to inflate the tyre by an additional one to two psi and then check the tyre the following morning when it is cold, and this will give them the actual pressure (Cordle (2003)).

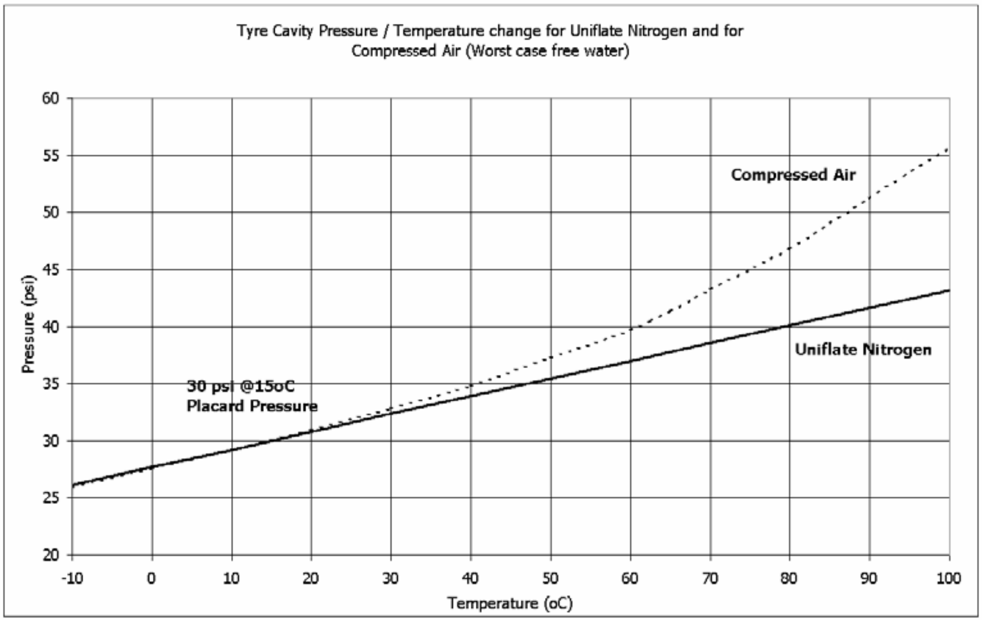
Temperature has to be taken into account in the accurate inflation of tyres. For every 5°C change in ambient temperature, tyre pressure will change by about 0.03 Bar (0.5 psi). The European Tyre and Rim Technical Organisation (ETRTO (2001)) also suggested hot pressures can be up to 20 per cent higher than cold and that under no circumstances should hot tyres be pressurised to the specified cold pressures given by the car manufacturers.

In equatorial and tropical regions with higher ambient temperatures, when the tyres need to be maintained at appropriate pressures to reduce excessive temperature build up, a 15 per cent under-inflation is (unknowingly) being set into the tyres when uncompensated manufacturers cold pressure figures are maintained (Tooke (2002)).

A tyre that contains air at 2.2 Bar (32 psi) at 20°c will have a little over 2.4 Bar (35 psi) at 38°c - even if the vehicle has not been driven. Conversely, when seasons change and temperatures drop, tyres lose pressure. The same tyre that held 2.2 Bar (32 psi) at 20°c will have about 1.9 Bar (28 psi) at 0°c and when temperatures are in the subzero range, the loss in tyre pressure will be even greater.

Figure 2.10 shows a plot of tyre pressure versus internal air temperature, which illustrates the danger of deflating a hot tyre showing 33 psi down to the vehicle manufacturers "placard" pressure of 26 psi; the cold pressure may then be 20 psi and not 26 psi. This is further exacerbated by the fact that lower initial pressures show a greater degree of internal heat build up with running time (Tooke (2002)). Temperature compensation needs to be integrated into tyre pressure monitoring devices to provide the driver with appropriate advice.

Figure 2.10 Increase in tyre pressure with temperature change: Compressed air versus inert gas. (Uniflate)



For the typical driver, maintaining pressures of tyres in the cold state is difficult because of the impracticality of carrying out 'home' checks. Therefore an easily accessible and accurate inflation and checking system combined with a more workable system to advise on correct tyre pressures needs to be in place to reduce the 72 per cent of tyres that are under inflated (from tyre pressure surveys discussed later). Tyre pressure monitoring devices such as that produced by Smartire can (if of sufficient accuracy) provide a means of alerting the owner to the need for intervention.

Tyre pressure loss, which is not attributable to structural damage to the tyre or to the wheel, results from the migration through the tyre wall of water vapour and oxygen. Using nitrogen to fill the tyres reduces the diffusion and has the added benefit of lower fluctuations in tyre pressure with temperature.

Owners of vehicles fitted with tyre pressure monitoring systems that lack temperature correction, or indeed those lacking any pressure monitoring, may obtain better tyre pressure control from using more inert alternatives to compressed air. Nitrogen has been used to inflate Formula 1 tyres for nearly ten years and may offer a reduced level of pressure increase with rise in temperature (as shown in Figure 2.10) and maintain the correct pressure longer with additional benefits of reduced corrosion and potentially extended tyre life.

2.6 Tyre noise and safety

With an increasing need to reduce environmental noise pollution, limits will soon be in place on the maximum level of noise that a tyre can generate.

EC Directive 2001/43/EC, which amends the base tyre Directive 92/23/EEC, introduced limits for tyre noise emissions with the following implementation dates:

Approval of newly introduced tyres - 4 August 2003.

Approval of newly introduced vehicles with respect to tyres - 4 February 2004.

Refusal to register new vehicles unless tyres comply - 4 February 2005.

All new tyres sold, including replacements, must comply - 1 October 2009 except for the wider car tyres for which dates of 1 October 2010 (C1d, 185 - 215 section width) and 1 October 2011 (C1e, > 215 section width) apply.

The Directive contains a commitment to adopt an amendment to Directive 92/23/EEC to include grip tests by 4 August 2003 and to carry out a study by 4 August 2004 into the effects of the noise limits established by this Directive. The results of the study would be used to establish the validity of further reductions in limit values in line with those indicated in Annex V, Section 4.2.1, Columns B and C and of further provisions regarding safety, environmental and rolling resistance issues.

Research linking noise to tyre safety

The issue of tyre grip tests is an integral part of ensuring that tyres are both quiet and safe. Research by TRL (Nelson *et al.* (1993)) identified a significant relationship between tyre noise and safety performance, i.e. a decrease in tyre noise was associated with a reduction in tyre safety performance and vice versa, for the tyre sample studied. One example provided was that a reduction in tyre noise of 4 dB(A) (within the range studied) was associated with an increase in braking distance from 90-60 km/h of 7 per cent for car tyres. For guidance, a 10 dB(A) reduction would normally be judged as a halving in the loudness of the noise, a 3 dB(A) reduction is broadly equivalent to halving the acoustic energy of the sound. Clearly a reduction of 4 dB(A) represents a significant reduction in noise. The TRL work also identified a need to establish minimum safety requirements for tyres irrespective of the introduction of noise limits.

However, findings of work carried out in Sweden (Sandberg (2001) and Sandberg and Ejsmont (2000)) does offer new evidence suggesting there is no significant conflict between the requirements for high friction and low tyre/road noise. A significant relationship has been found between tyre properties and noise with lower aspect ratio tyres invariably generating more noise.

Nevertheless, the introduction of "grip tests" will provide assurance that new tyres will continue to provide properties appropriate to the safe movement of vehicles.

2.7 Tyre design and handling

Aspect ratio

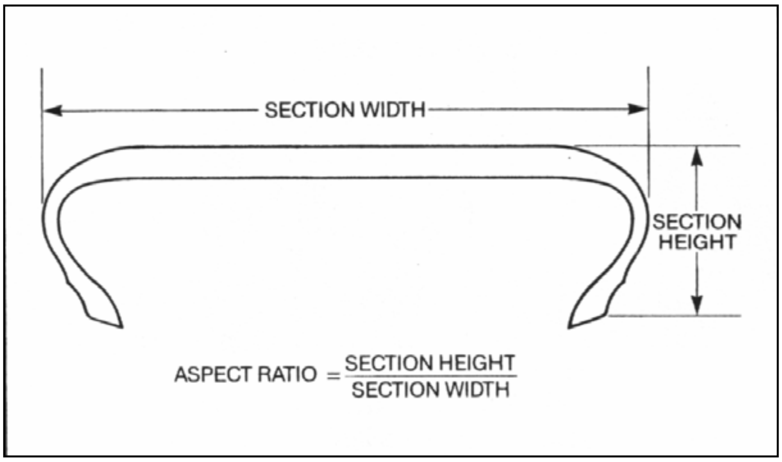


Figure 2.11 Aspect ratio: Warchol and Schneider (1984)

There are many fundamental properties of any tyre that can be changed by the technologist using the facilities of factory and test track, for example, aspect ratio as illustrated in Figure 2.11. However, the motorist may choose tyres of a different aspect ratio from standard fitment.

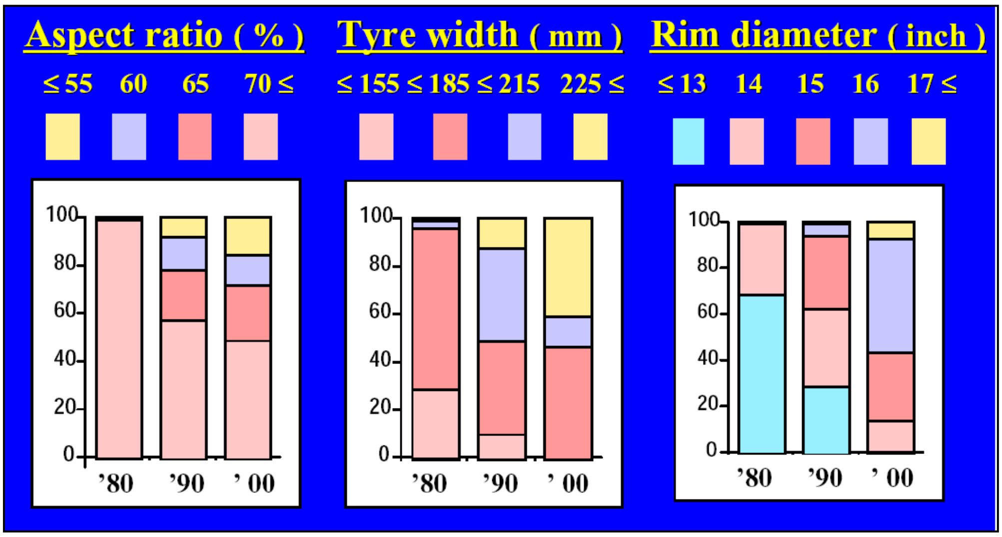


Figure 2.12 The change in the period 1980 –2000 of the aspect ratio, tyre width and rim diameter from Toyota Tyre Usage: Isomura (2002)

Isomura (2002) summarised how the aspect ratio, tyre width and rim diameter has changed for Toyota cars over the last 20 years, this shown in Figure 2.12.

So termed "Low Profile Tyres" are now expected as standard on new vehicles and the effect of reducing aspect ratio is generally perceived as beneficial but motorists are not aware of the effect that a change from 70 to 50 profile tyres will have on vehicle handling.

Changing aspect ratio affects the two properties of self-aligning torque and cornering coefficient. Cornering coefficient measures the response of the steering to the turn of the steering wheel. A change from an aspect ratio of 70 to 50 for tyres of the same type may produce an increase in steering response, which may not be expected.

It is noteworthy that there are no great improvements in cornering coefficient below a 60 profile tyre. However the self-aligning torque decreases as the aspect ratio is reduced and does not level out, this torque is the force felt when turning the wheel.

Tread width

Work carried out by TRL (Gothie, Parry and Roe (2001)) as part of the VERT Project included a study of the capabilities of tyres of various aspect ratios in comparison to standard test tyres used worldwide. The investigation included a study of the relationship between braking force, tread depth and aspect ratio.

Their comments focussed primarily on the effect of water depth on tyre friction at speeds below 50 km/h for all levels of surface texture. One very interesting conclusion was:

"There is a suggestion that wide tyres may perform less well than more common sizes if they have worn tread". Though true for straight line braking, this may not be the case for cornering manoeuvres (Williams, 2003).

It is important that drivers are aware of any reduction in tyre performance as a result of changing the aspect ratio.

2.8 Tread depth

Tread depth and the law

The significant effect that low tread depth can have on braking and handling has been understood for many years.

1968- 1 mm minimum tread depth

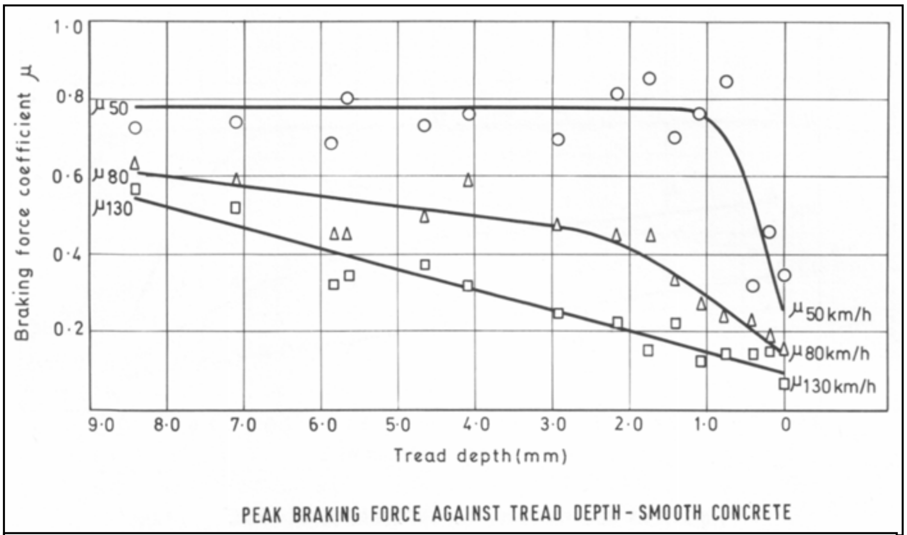


Figure 2.13 Change in wet braking force with speed and tread depth on smooth concrete (low texture): Staughton and Williams (1970)

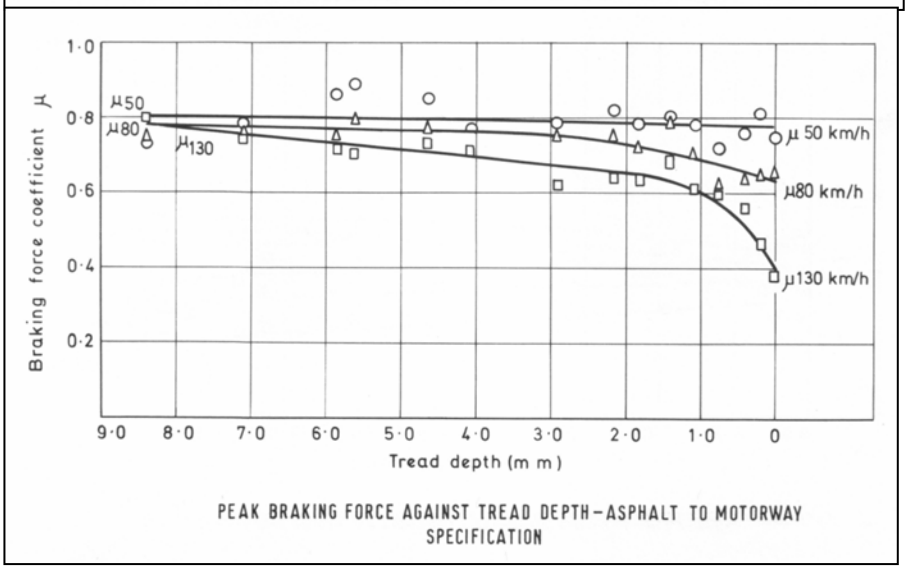


Figure 2.14 Change in wet braking force with speed and tread depth on asphalt (high texture): Staughton and Williams (1970)

Published TRL work (Staughton and Williams (1970)) indicated a sudden loss in tyre traction below 1 mm tread (As shown in Figures 2.13 and 2.14), this knowledge combined with a need to prevent exposure of tyre steel bracing (that could lead to corrosion and explosive tyre failure), led to the introduction of a 1 mm minimum tread depth requirement.

Minimum tread depth for tyres became a legal requirement on 1st April 1968, and was set for most vehicles at 1 mm. Although there have been slight revisions in the wording, in essence, the current requirements for HGVs have not changed since then.

The tyre regulations in the US

In 1969 a minimum tread depth of 2/32" (1.6 mm) was adopted in the USA for commercial vehicles. However, despite the fact the Federal Highways Administration received submissions from 257 parties during the rule-making process (Morrison (2002)), no record of the reasoning for the decision to use 2/32" is likely to be established because, until the late 1970s, US Regulatory agencies often gave only meagre explanations of their reasoning for adopting rules (Medalen (2003)).

38 FR 23950, Sept. 5, 1973, as amended, provided the US Federal Regulation for inspection of vehicles in use which includes the tread depth of tyres for vehicles under 10,000 lb gross vehicle weight, as given in 49 CFR 470.9 the tread on each tire shall be not less than 2/32 of an inch deep (1.6 mm), again no evidence supporting the decision is available.

The latest UK tread depth requirements

Work carried out by TRL (Williams *et al*. (1981)) had established the importance of tread depth on grip especially in cases where the road had low levels of surface texture and an increased reliance on the tyre tread to disperse the water film.

There were further developments in legislation. Luxembourg introduced a 1.6 mm tread depth requirement by the mid 1970s. However, there is no record of the research behind this decision.

The new standard for car tyre tread depth in the EC was agreed at the Council of Transport Ministers in June 1989 under European directive 89/459/EEC (EC (1989)), and came into force in the UK on 1st January 1992.

It is now included as an amendment in 'The Road Vehicles Construction and Use Regulations 1986', and is stated as: 'the grooves of the tread pattern shall be of a depth of at least 1.6 mm throughout a continuous band comprising the central three-quarters of the breadth of tread and round the entire outer circumference of the tyre'.

Commercial vehicle minimum legal tyre tread depths are also covered in the Road Vehicles Construction and Use Regulations 1986. A common tyre tread wear indicator requirement of 1.6 mm for both the US and EC markets now exists.

Tread depth and aquaplaning

Though often feared by the driver, aquaplaning (hydroplaning in the US) is not a common occurrence, it requires a combination of tyre tread depth, road-surface texture depth and vehicle speed to introduce a significant degree of penetration of a wedge of water between the tyre and the road surface.

The loss of traction experienced in the wet is a phenomenon that many consider to be aquaplaning. However, true aquaplaning is defined as when the tyre is rotating at only one-tenth of the vehicles forward speed. Significant loss of tyre/road friction occurs with tread wear at highway speeds on wet roads well before aquaplaning occurs and is probably a more significant safety issue than aquaplaning, which is a relatively rare event (Blythe and Day (2002)).

Research has shown that the aquaplaning speed does decrease as tread depth decreases with all other things being equal (Gallaway *et al*. (1979)). However, the greater exposure to reduced handling /braking performance with low tread, long before aquaplaning occurs, should be of greater concern.

Tread depth and vehicle stability

Tyre research has challenged the general belief that having tyres with a lot of tread depth is always a good thing. Although generally true, the inappropriate placement of additional tread may result in problems. Test track work has shown that having greater tread depth on the front tyres than on the rear tyres above a certain level can halve the cornering forces a car can cope with before loss-of-control occurs. Conversely, excess tread depth on the rear is not identified as a problem by Blythe and Day.

Currently many owners of front-wheel-drive vehicles assume that when presented with the dilemma of having four nearly worn tyres (and being able to afford only two) they fit them to the front axle. It would seem to be the obvious action as the front wheels are where "everything is happening" in terms of steering and drive. However, this is not the case and research carried out in the USA has highlighted the potentially dangerous scenario that may arise from this action.

Work by Williams and Evans and Blythe and Day (Williams and Evans (1983), Blythe and Day (2002)), identified the potential danger that two new tyres on the front and two worn ones on the back could create. Blythe and Day reported that normal lane change manoeuvres can lead to loss of control on a wet road if sufficient difference in tread depth exists from front to rear, with the better-treaded tyres on the front axle of a passenger car. Blythe and Day observed that the effect holds true regardless of the drive train configuration.

The National Tyre Distributors Association have issued guidelines (as shown in Figure 2.15) and several tyre company websites, for example, Pirelli and Dunlop include this important observation in their FAQs (Frequently Asked Questions).The results of an independent analysis of tyre survey data, described later, suggests that a minimum of 4 per cent of cars on the road may have tyres fitted contrary to this advice.

> **NEW TYRES TO THE REAR**
>
> A regular question over the NTDA 'technical help line' is ...When fitting two new tyres, are they best fitted to the front or to the rear? It was always thought that new tyres should go on the front wheels, but in recent years this thinking has changed.
>
> NTDA advice is, whenever two new tyres are being fitted, ***fit them to the rears***.

Figure 2.15 Typical Leaflet offering advice to tyre fitters: NTDA (2002)

Insufficient tread depth and accident risk

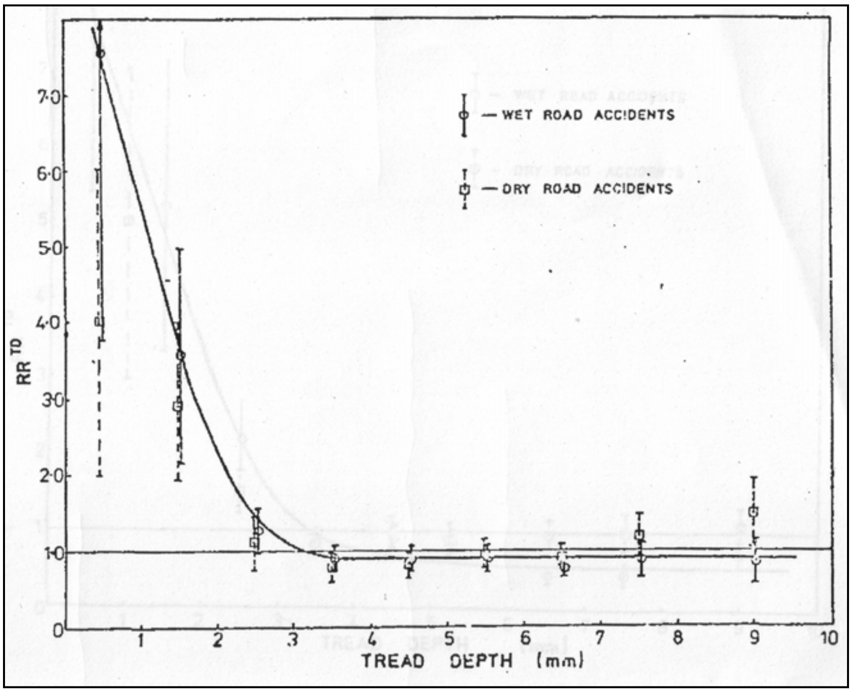
However, the critical factor is the relationship between tread depth and the risk of accidents.

Many studies from the 1970s have shown how tyre "grip" is greatly reduced as tread depth decreases, but there is a general lack of research in the UK linking accident risk directly to insufficient tread depth. Work carried out by TRL (TRRL (1979)) identified 221 instances of "illegal tread or combinations" in 2042 accidents. However, this was identified as a main contributory factor in only 2.9 per cent of the accidents studied. In comparison, all mechanical defects (including tyres) were contributory in around 8.5 per cent of 2042 accidents studied by TRL.

Work carried out in Australia (Fox, Good and Joubert (1979)) showed a very strong link between tyre tread depth and the chances of being involved in an accident with a utility pole, though this may not be direct causal link between tyre tread depth and accident risk as 61% of the casualties were male and in their late teens or early twenties. The risk increases exponentially when tread depth dropped below three millimetres. (See Figure 2.16)

A study of relationships between tyre tread depth and the likelihood of accident involvement in the US in the 1970s (Highway Safety Foundation (1972)) aimed to determine the relationships between car tyre tread depth and the likelihood of involvement in a traffic accident. The study was undertaken to validate and refine the findings of an earlier project (Highway Safety Foundation (1971)), which demonstrated an inverse relationship between tyre tread depth and accident involvement. A major task of the study was to determine objectively the relative contributions of low tread depth, *per se,* and the behaviour of drivers operating with low tread depths, to the abnormal accident experience at lower tread depths.

Figure 2.16
The relationship between front tyre tread depth and relative accident risk for collisions with utility poles in Australia: Fox, Good and Joubert (1979)



In the earlier work, the possible contributory effects of the behaviour of drivers who operate with low tread depth tyres were recognized. The reports recommendation of a 4/32 inch (3.2 mm) legal minimum tread depth was based upon assigning only 50 per cent of the projected accident reduction as a benefit. The remaining 50 per cent was not expected to materialize based upon the unchanged behaviour of the driver. However, the fifty-fifty split was subjective and was challenged.

Tyre tread depth measurements were collected for a sample of vehicles involved in traffic accidents at the time of moving traffic violation. A second sample was acquired from vehicles involved in moving traffic violations where there was no accident. Using the propensity for a moving traffic violation as an indicator of driver behaviour, relative involvements for both samples were computed by comparison with the distribution of tyre tread depths found in the population at large. This analysis produced a more objective determination of the proportion of abnormal accident occurrence at lower tread depths than could be assigned to the lower tread depth, *per se*.

Again, this proportion was found to be inversely related to tyre tread depth. Using these proportions, an analysis was performed to determine the legal minimum tyre tread depth below which motorists were apt to incur more costs in abnormal accident involvement than could be saved by postponing the purchase of new tyres. Again, the desired legal minimum tread depth was found to be 4/32 inch (3.2 mm). It was recommended that the individual States enact legal minimum tread depths of 4/32 inch. Also, that the federally required tyre "wear indicator", now constructed in the tyre at 2/32 inch (1.6 mm) remaining tread depth, be moved to the 4/32 inch dimension. The large number of tyres found to be illegal according to these criteria demonstrated the need for more effective enforcement.

More recent work on 1991-1996 insurance statistics by the Finnish Motor Insurers Centre (Hanttula (1998)) identified that in wet conditions, worn tyres were a risk factor in 9 per cent of accidents compared with only 1.8 per cent in the dry. In the same report, research (Lundell (1994)) examining a number of two car accidents identified that, for speeds in excess of 70 km/h on "slippery roads", the percentage of "first party" cars (those causing the accidents) with worn-out tyres (0-3 mm) was six times that of the "opposite cars" (those innocently involved).

2.9 The consequence of the structural failure of tyres

The case where the failure of the mechanical structure of the tyre leads to an accident has been documented by a number of investigators and has been found to be relatively small. For example:

- Mechanical tyre defects caused 3.8 per cent of 35782 accidents studied in Germany in 2001 by the Federal Statistics Office (Statistisches Bundesamt, Gruppe VC-Verkehr (2001)).

- 3 per cent of accidents in a study in Pretoria (van Schoor, Niekirk and Grobelaar (2001)) were caused by mechanical failures including tyres.

Thus the evidence is that tyres seldom fail due to structural problems, *per se,* but lack of routine tyre pressure maintenance can lead to failure resulting from overheating under-pressure tyres.

2.10 Tyre condition and pressure surveys

Tyre pressure surveys

Roadside surveys by the Tyre Industry Council in the UK have highlighted how little attention is given to tyre pressure.

In a UK survey of over 1000 tyres, only 5 per cent were correctly inflated and 72 per cent were under inflated. Figure 2.17 illustrates the distribution of 1072 cold tyre pressures measured by the Tyre Industry Council for one survey in 2002. Figure 2.18 reproduces the same information with respect to over-, under- or correct inflation.

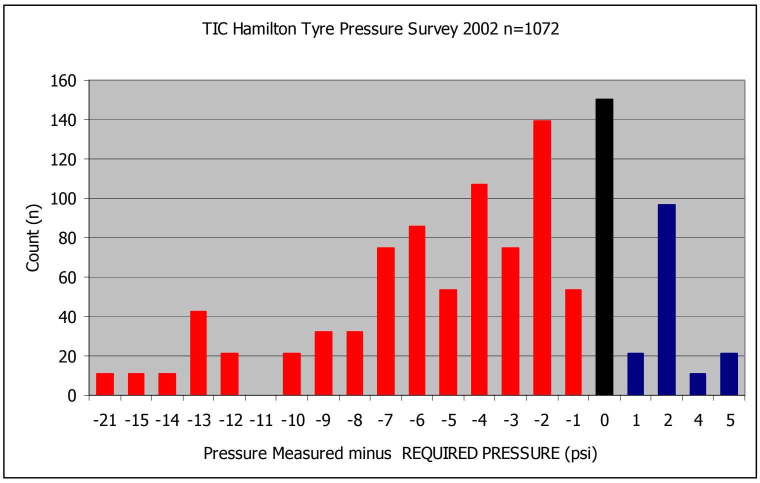


Figure 2.17 Cold tyre pressures measured at the 2002 Hamilton TIC survey

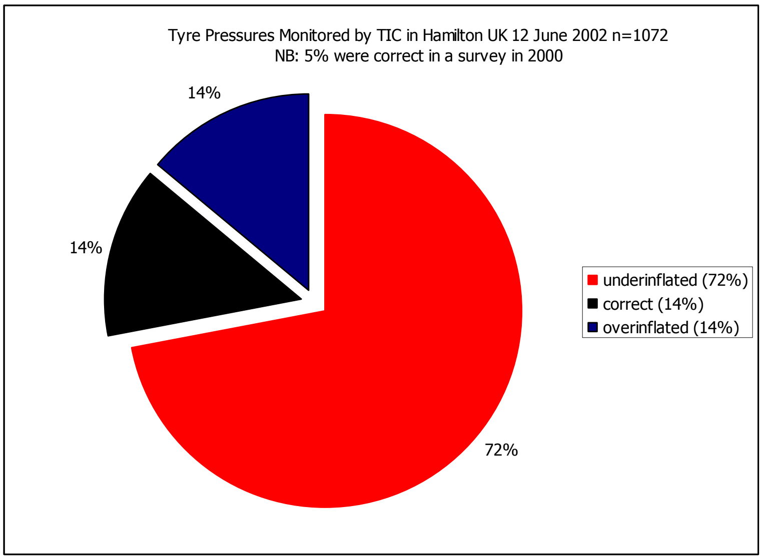


Figure 2.18 Classified cold tyre pressures for the 2002 Hamilton TIC survey

It must be said that the removal of tyre valve caps and the struggle with garage airlines is not a task many relish, but if both the cost implications of the reduced service life of the tyres and the effect of under inflation on handling were more widely publicised, more attention might be paid to maintaining tyres at the correct pressure.

However, there are issues with the accuracy of the tyre inflation devices provided by petrol stations and other road side services.

Pressure measuring device surveys

Local authorities are sometimes unable to allocate resources to the task of ensuring the 28 psi displayed on the gauge is accurate. Also the mishandling of the gauges by the users is another problem. Enforcement action by local authorities against inaccurate tyre pressure gauges on garage forecourts is limited to the obliteration of EC marks on those (few) instruments which have been subjected to EC type approval. The testing of all other instruments would be on an advisory basis only. The safety of such instruments will be controlled in future by amendments to the General Product Safety Regulations which will be changed to include the safety of products provided as part of a service.

Gauges sold for DIY use by motorists are controlled only in respect of safety and description. For example, if advertising or packaging of a gauge carried a clear statement as to its accuracy that was false, action might be possible under the Trade Descriptions Act.

The certification of gauges could be run on similar lines to the certification/calibration scheme for exhaust gas analysers in garage repair workshops. This would have the advantage of being privately funded, whereas a Trading Standards scheme would be unlikely to obtain funding.

Several surveys of garage tyre pressure gauge accuracy have been carried out in the UK, typical of these was a survey by Coventry City Council in 2001. The survey considered 80 per cent of the 139 gauges tested as accurate, the worst gauge read 6 psi too low, with one over-reading by 6 psi.

Table 2.2
2002 NOP survey of pressure gauge accuracy for Smartire in the UK

Garage	per cent accurate
BP	64
Esso	43
Fina	50
Independents	71
Jet	33
Murco	33
Save	0
Shell	5
Texaco	76
Total	64
Average per cent	***44***

A more recent survey of 200 London Garages carried out by NOP in 2002 for Smartire showed an overall accuracy of 44 per cent (accuracy being defined as ± 2 psi), as represented in Table 2.2.

The misuse of gauges and the damage sustained can result in garages withdrawing the service rather than providing an inaccurate one, which could, in the worst possible case, result in a subsequent tyre related accident.

Tyre condition surveys

An indication of the condition of tyres on vehicles in use is obtained from two sources: MOT failures (as vehicles are inspected annually when they are more than 3 years old), and roadside surveys of tyre condition.

The published figures for a 2 per cent sample of MOT tests for 2001/2002 are set out in Table 2.3.

Table 2.3
Results from a 2 per cent survey of MOT test failures for cars and other passenger vehicles: Vehicle Inspectorate (2002)

CLASS		RESULT	NUMBER OF VEHICLES	NO. UNSATISFACTORY AS % OF TOTAL TESTED	NO. UNSATISFACTORY AS % OF TOTAL UNSATISFACTORY
CLASS 3 & 4					
		Tested	22,768,809	-	-
CARS AND OTHER		Unsatisfactory	7,280,972	31.98%	-
PASSENGER VEHICLES		Failure Items			
(up to 12 passenger seats)		Lights	3,666,324	16.10%	50.35%
		Steering	3,169,272	13.92%	43.53%
		Brakes	2,812,009	12.35%	38.62%
		Tyres	1,830,945	8.04%	25.15%
		Reg. Plates & VIN	270,177	1.19%	3.71%
		Drivers View	1,213,309	5.33%	16.66%
		Petrol Emission	584,533	3.11%	8.03%
	**	CAT Emissions	10,296,709	2.64%	-
	**	Diesel Emission	3,955,547	5.50%	2.99%
		Other	2,755,747	12.10%	37.85%

Assuming that most vehicles arrive at the MOT Station under their own power rather than on transporters, approximately 8 per cent of vehicles 3 years or older in age have one or more defective tyres (attributed to insufficient tread or other damage). This equates to roughly 1.5 million (8 per cent of "MOTable" cars) to 2.1 million vehicles (8 per cent of the "car" population) on the road at any one time with one or more defective tyres (data from DVLA 2002).

Tyre surveys by the Tyre Industry Council (TIC (2002)) and the National Tyre Distributors Association (NTDA (2001)) indicate that about 10-15 per cent of vehicles (NTDA, Tyre Check 2001, TIC Wiltshire Survey 2000) have one or more tyres at or below the 1.6 mm legal limit, supporting the MOT findings.

Surprisingly, the results of two surveys in 1969/70 (Lowne (1972)) concluded that about 9 per cent of cars have at least one tyre with a tread depth below the legal limit of 1 mm, indicating that nothing much seems to have changed in terms of the motorists' attitude towards tyre legislation.

The TIC kindly provided this project with data from 12 Roadside surveys carried out during 2001-2002 that recorded the tyre tread depths from 6538 Cars.

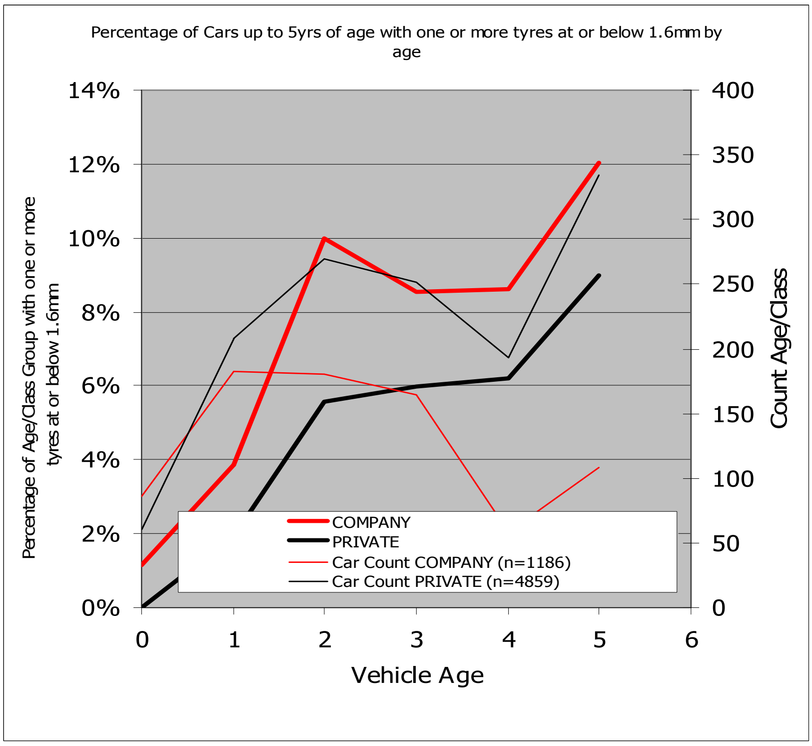
Table 2.4 Distribution of vehicles with one or more tyre at or below 1.6 mm as a percentage of the survey. TIC Survey Data

	Number of tyres at or below 1.6 mm on vehicle					
Ownership	Nil	1	2	3	4	Cars by ownership
Company Cars	89.7 per cent	7.2 per cent	2.8 per cent	0.3 per cent	0.1 per cent	19.6 per cent
Private Cars	88.5 per cent	7.8 per cent	3.4 per cent	0.3 per cent	0.0 per cent	80.4 per cent
Grand Total	88.7 per cent	7.7 per cent	3.3 per cent	0.3 per cent	0.0 per cent	

Around 4 per cent of tyres surveyed were at or below the 1.6 mm minimum for the UK.

An overall summary of the number vehicles with one, two or more tyres at or below 1.6 mm is represented in Table 2.4. Approximately 11 per cent of the fleet have one or more tyre at or below the 1.6 mm legal minimum , which broadly supports the MOT Test figures.

Figure 2.19 Percentage of cars of each class by age with one or more illegal tyres: vehicles 0 – 5 years old: TIC data



Less than 1 per cent of vehicles surveyed were found to have an average tread depth over their four tyres of 1.6 mm or less, company cars generally having a greater average tread depth.

New vehicles and percentage of illegal tyres

The lack of an MOT test in the first 3 years of a cars life may have resulted in the relatively high occurrence of tyres at or below 1.6 mm at 2 years for company cars, a level not seen again until the unexpectedly high percentage at 4-5 years old. Figure 2.19 illustrates this trend.

Surprisingly, for both populations, there is a rise after the MOT comes into operation.

2.11 Observations

The effect of tyre pressure on tyre life and handling

As a lack of attention to tyre pressure seldom results in a serious incident, the significant effect that extended running at low pressures can have on the service life of tyres and increased fuel consumption is generally ignored. The handling effects again generally manifest themselves as retrograde rather than life-threatening changes in the vehicle's manoeuvrability. The driver is not assisted in achieving the correct pressures by the relatively poor accuracy of forecourt pressure gauges, and the general difficulty of the checking process. However, the developments in tyre technology should make the driver more aware of fluctuations in tyre pressures.

The effect of tread depth on accident risk

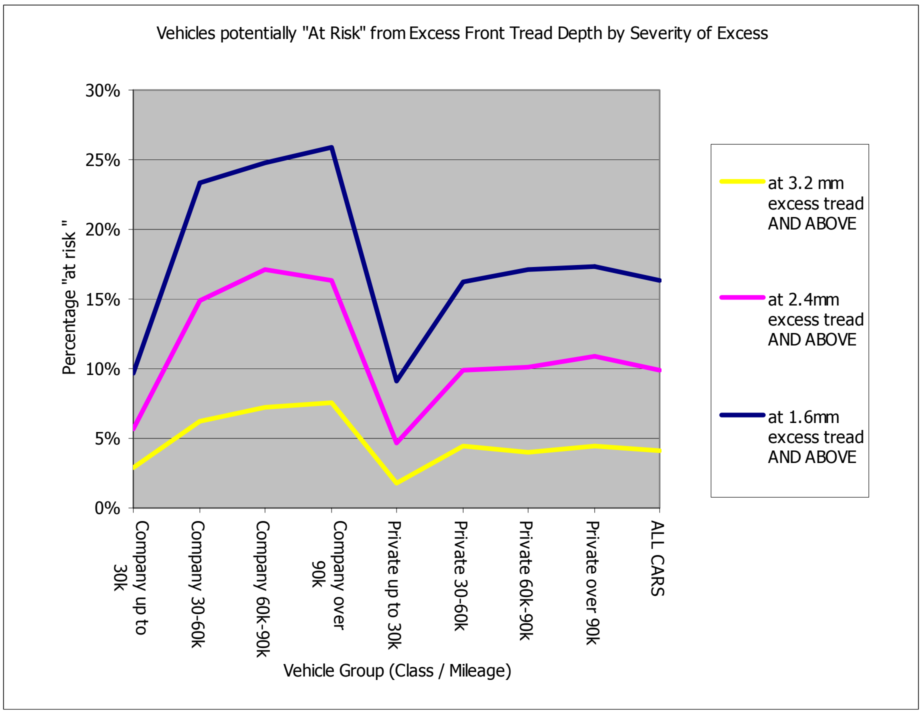
There is a need to investigate the association between low tyre tread depth and accident risk, especially as survey data suggests that around 10 per cent of the cars on our roads may have one or more tyre at or below the legal minimum.

The effect of excess front tread depth on handling

Excess front tread depth has been proven to cause significant instability in cars. The co-author of the SAE paper (Blythe and Day, (2002)) has confirmed that, from the lowest water depth cases (only 0.05 inches) and for vehicles with an average excess of front tread depth over rear of at least 4/32 inches (approx 3.2 mm), there may be potential for handling instability at highway speeds around 60 mph or above.

The vehicles used in the USA tests (for both the physical tests and the simulations) were of a relatively longer wheelbase than many typical UK cars, and vehicles with shorter wheelbases may be considered to be even more susceptible to over-steer in which case a smaller excess of front tread depth over rear of 3/32 (approx 2.4 mm) is considered to be of potential concern.

Figure 2.20 Analysis of the TIC tread depth survey data to establish the percentage of vehicles by class and mileage versus excess of front tread depth over rear



As part of this project, the TIC database was examined for evidence of tread depth imbalance. The findings, shown in Figure 2.20, suggest that approximately 4 per cent to 17 per cent of the cars surveyed are potentially "at risk" by virtue of the lesser tread depth on the rear tyres compared to that on the front tyres.

Figure 2.20 identifies the percentage of vehicles falling within the "over 3.2 mm", "over 2.4 mm" and "over 1.6 mm" excess front tread depth groups. For example, around 25 per cent of company cars with a recorded mileage in excess of 90,000 miles have 1.6 mm (or more) excess front tread, whereas only 2 per cent of private cars with a recorded mileage of up to 30,000 miles have 3.2 mm (or more) excess front tread.

Therefore, based on the findings from the USA, 4 per cent of vehicles from the TIC survey may be considered potentially vulnerable (with more than 3.2 mm excess front tread), and possibly up to 10 per cent, taking the SAE authors comments on wheelbase into consideration, with company cars being more exposed than private cars.

The frequency of the "risk" condition is about 50 per cent greater for company cars than that for private cars.

The effect of worn tyres on the friction available at the road/tyre interface is discussed further in Chapter 4.

2.12 Conclusions

Worn tyres are common, reducing braking capability and increasing accident likelihood, especially on wet roads:

- Tyre Industry surveys show that 1 in 10 cars have one or more tyres with a tread depth at or below the legal (1.6mm) limit. Research more than 30 years ago showed broadly similar results.

- Worn tyres may contribute towards 9 per cent of accidents in wet conditions compared with only 2 per cent of accidents in the dry.

- On wet roads, the risk of certain types of accident has been seen to treble when the tread depth is less than 1.5mm and increase seven-fold when the tread depth is less than 0.5mm.

- Below 1mm tread depth, the braking force coefficient may be only about one-third of that when tyres comply with the legal limit.

- Those more at fault in high speed accidents were six times more likely to have worn tyres than those innocently involved.

- *Greater efforts are required to establish a better understanding of the problems of worn tyres and to ensure that vehicles have adequate tread.*

Front-rear tyre tread imbalance is an issue that apparently is not well understood by motorists:

- Handling may be affected when the tyre tread depth is substantially greater on the front tyres than on the rear tyres.

- Many consumers appear unaware of the issue of front-rear tread imbalance.

- *The tyre retailing and fitting industry should increase its efforts to draw attention to the issue and its contribution to accidents should be researched.*

Under-inflation of tyres is common and this leads to excessive wear, increases in fuel consumption and potential vehicle-handling problems:

- Tyre Industry surveys have shown that as few as 5 per cent of tyres are correctly inflated and that 75 per cent are under-inflated.

- Tyre life decreases by up to 10 per cent for every 10 per cent under-inflation.

- *Tyre manufacturers should be encouraged to develop technology that will maintain pressure consistently and that will provide affordable and accurate on-board monitoring of tyre pressures.*

Structural defects of tyres play little part in accidents:

- Tyre quality and performance have improved in recent years and will continue to do so with the development of SMART tyre technology.

- Studies in other countries have shown that structural defects of tyres causes only 3 or 4 per cent of accidents and in most cases this could be attributed to the result of extended running at low pressure or physical damage.

- *Researchers should concentrate their efforts on the role of tyre characteristics in accidents rather than the structural failure of tyres.*

Drivers of vehicles with worn tyres may have other characteristics associated with increased accident risk:

- There is evidence that motorists driving vehicles with worn tyres are more likely to be the party at fault in accidents.

- *There is a need for a better understanding of the association between driver behaviour, tyre condition and accident risk.*

Many tyre pressure gauges are inaccurate:

- Surveys of the accuracy of air pressure gauges at garages have found 1 in 5 to be defective and almost half to be inaccurate (i.e. outside reasonable tolerances).

- *Garages and local authority trading standards departments should do more to ensure that gauges are either accurate or are withdrawn from service.*

Chapter 3 Surface characteristics

3.1 Introduction

The characteristics of the road surface have been studied for many years; they are generally well understood and routinely monitored to ensure that they are maintained.

Surface characteristics work in tandem with the tyre to deliver grip when it is needed most. The interaction of the road surface and tyre, and the way surface characteristics can “assist” the tyre are discussed here together with other aids to safer motoring.

When roads are dry and free from contaminant materials, the friction between the tyre and the road is, almost without exception, high (typically with a co-efficient of friction in excess of 0.7-0.8). Wet roads have significantly lower levels of friction (co-efficients of friction as low as 0.4 can be commonplace) and skidding/loss-of-control can occur when the forces generated in acceleration, braking or cornering exceed the level of grip available.

Decision Makers need an understanding of the complex interplay of location, traffic level, surface texture and the mechanical properties of the surfacing aggregates in order to implement the systems now in place to deliver safer roads, and to deliver accident remedial schemes that are effective in the long term.

Modern surfacing techniques have reduced delays to the road user by minimising road closures. The more open structure of these new generation surfacings can reduces traffic noise and spray, but there are concerns about the early life skid resistance of these materials.

The road surface can play a limited role in the reduction of surface spray, a far greater contribution can be made by vehicle mounted spray suppression equipment that is subject to the spray suppression legislation in the UK.

Road markings can provide an effective means of reducing accidents but they need to be maintained in good condition to remain effective. High friction surfaces are another effective accident reduction measure.

However, these strategies may lead to an increase in speeds in areas of potentially high accident risk. This is an important consideration in all areas of highway maintenance where the motorist may exploit improvements by driving faster, thus offsetting the improvement in safety.

3.2 Fundamental properties of the road surface

To provide a surface with appropriate properties the Decision Maker needs to understand the interrelationship between a number of fundamental (and measurable) characteristics of the road surface and specify accordingly. The most relevant property with respect to this project is that of skid resistance.

The prevention or effective reduction of accidents involving skidding implies that the nature of skidding accidents is understood: Hosking (1992) provides a concise overview of skidding.

What is skidding?

Skidding occurs when the coefficient of friction between the tyre and the road is inadequate to maintain full adhesion:

- When roads are dry and free from contaminant materials, the friction between tyre and road is, almost without exception, high. This means that the available friction permits full use to be made of the braking and cornering performance of the vehicle. At the other extreme, ice or snow covered roads have low friction and the accelerations and decelerations used in driving gently can generate forces in excess of those available between the tyre and the road and skidding occurs.

- The wet road condition presents a much more complicated situation; the effect of water on the road greatly influences the design of both the road surface and the tyre. Wet road friction varies with many factors, including the characteristics of the surfacing and of the tyre, the degree of wetness of the road, the presence of any surface contamination (such as mud or diesel fuel), and the vehicle operating conditions, contributing.

Past studies have addressed the wet skid resistance of roads and much guidance is already available. However, this report identifies areas where accepted guidance perhaps needs to be revisited and, for example, with "new generation" surfacing that may necessitate a change in the road engineers' philosophy.

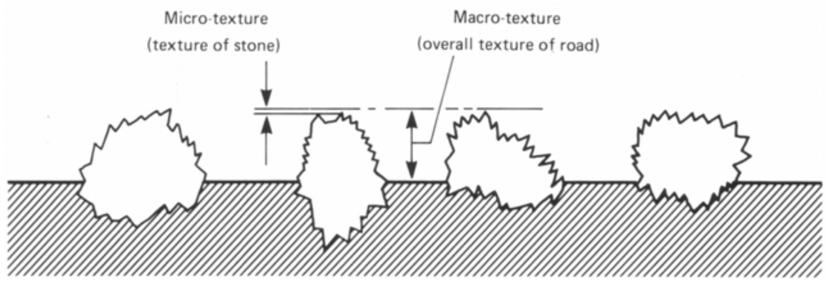
The three important characteristics of the road surface that relate to wet road skid resistance under most conditions are:

- Good macro-texture of the surface, which is needed to maintain skidding resistance at higher vehicle speeds and to enable low resilience tyres to improve braking performance.

  Macro-texture is the texture created by the combination of aggregate particles on the road surface and the voids between them.

- Adequate micro-texture of the surface.

Figure 3.1 Illustrates the difference between macro- and micro-Texture: Hosking (1992)



Micro-texture is the property of the individual aggregate particle, which, when combined with the free draining properties provided by the macro-texture in the wet, results in the effective skid resistance of the surfacing:

- Adequate drainage of water from the road surface.

Figure 3.1 illustrates the difference between micro- and macro-texture.

The in-service micro- and macro- texture properties of the road surface are a function of the physical properties of the aggregates used in the road construction, the design of the surface and the characteristics of both the road layout and the traffic levels using it. It must be understood that this dynamic interplay results in surface characteristics that may vary significantly with the seasons and with changes in traffic levels.

Skidding resistance: variation with aggregate properties

Even under the same conditions, the rate at which individual aggregates polish and/or wear will vary. Moreover, the relationship between these two properties is not consistent and, in order to achieve the appropriate level of in service skid resistance, the specifier must fully appreciate how his chosen aggregate will perform over time.

It is possible to rank resistance to polishing through a test which applies a standard cycle of roughening / polishing then measures the resulting skid resistance – the Polished Stone Value (PSV) test.

Similarly it is possible to rank resistance to abrasion through a test which applies a standard cycle of abrasion and measures the aggregate loss which occurs – the Aggregate Abrasion Value (AAV) test.

The results of PSV and AAV testing give specifiers a valuable pointer to the likely performance of an aggregate in-service. However, the skid resistance measured as part of the PSV test and the in-service skid resistance are not the same thing.

It may only be assumed that, with all other things being equal, an aggregate with a higher PSV should deliver a relatively higher level of skid resistance. Similarly it may only be assumed that an aggregate with a lower AAV will wear relatively more slowly.

However, the in-service skid resistance of a road surface is dependent on many factors other than the properties of the aggregate, such as the nature of the surfacing used (and the way this presents the aggregate to traffic), the season of the year, the layout of the road and the intensity of traffic using it.

Skidding resistance: seasonal variation

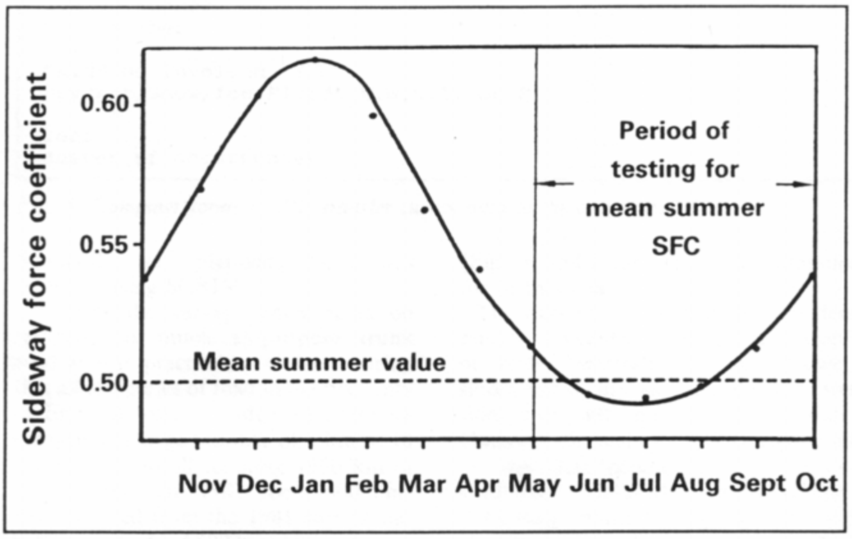


Figure 3.2 Mean summer scrim co-efficient - a normalised measure of skidding resistance: Rogers and Gargett (1991)

In the UK, there is a significant seasonal variation in skidding resistance, (as shown in Figure 3.2) with minimum values occurring during summer and early autumn. During the summer, dry polishing of the road's micro-texture occurs due to the action of traffic, and skid resistance values fall. Later in the year, when the road is wet for prolonged periods, wet polishing with gritty materials tends to restore the micro-texture and skid-resistance values rise.

Early life skid-resistance and accidents

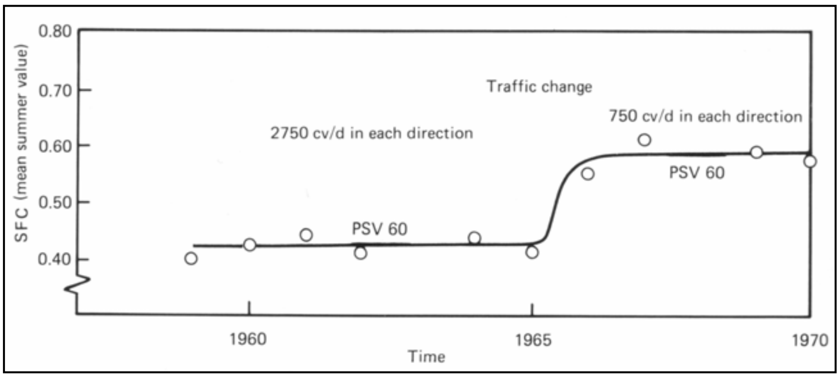
As an added complication, specifiers need to be aware that the skidding resistance of any new surfacing may fluctuate considerably before it settles down to an "equilibrium" state. In general terms, surfaces deliver higher levels of skid resistance when new than they do in the longer term. This is particularly the case with treatments like surface dressing which can yield extremely high skid resistance values in the first instance (akin to high-friction treatments), yet settle down to a much lower value over time, as the aggregate polishes/wears and becomes embedded into the surface.

However, the behaviour of some surfaces with thick bituminous coatings can depart from this general rule, potentially yielding very low values of skid resistance in the short term, before the coatings wears away. This is particularly the case with new generation "negative-textured" surfaces which are discussed in detail later in this report.

Skidding resistance: variation with traffic levels

The level of skid resistance on the road is a function of the level of traffic and of the severity of braking manoeuvres being carried out on any given length.

Figure 3.3. The effect of a reduction in traffic intensity on skidding resistance: Hosking (1992)



The polishing effect of traffic is the controlling factor in determining the skidding resistance and the increase in the level of skid resistance shown in Figure 3.3 above resulted solely from a reduction in traffic levels from 2750 commercials per day (cv/d) to 750 (cv/d). Conversely, an increase in traffic level or braking stress is likely to be reflected in a marked decrease in skidding resistance and Decision Makers need to make appropriate allowances when implementing changes in traffic flow or road user behaviour.

Higher PSV aggregates are needed, for example, at higher-stressed approaches to junctions to provide adequate levels of skid resistance, which are provided by lower PSV aggregates elsewhere on so called "non event" sections.

PSV and AAV specification

The retention of macro-texture by a surface is also partly a function of one of the fundamental properties of the aggregate, resistance to abrasion.

Skidding resistance: variation with traffic stress

An aggregate with a low resistance to mechanical abrasion from the action of traffic (as determined by the Aggregate Abrasion Value (or AAV) test) invariably delivers a high level of polishing resistance as it wears away before it polishes. Thus to supplement the specification of minimum PSV (resistance to polishing), similar documentation provides requirements for maximum AAV levels based on traffic intensity.

The combination of the specification of aggregates that exceed a minimum PSV requirement and a maximum AAV requirement aims to deliver an aggregate that when used for the surface course of a road will deliver sufficient skidding resistance, assisted by a free-draining surface via adequate macro-texture, for the life of the layer.

The guidance as to appropriate levels of PSV to be used are based on a generalised model of the relationship between PSV, traffic intensity and the level of in-service skidding resistance required.

Issues with the performance of low AAV aggregates

There have been a number of instances where the use of some aggregates with very low AAVs (AAV<5, high resistance to abrasion) but with acceptable PSVs have produced levels of skid resistance well below those expected of aggregates with a similar PSV but with higher AAVs (with less resistance to abrasion). There may be a fundamental difference in the balance between traffic level, abrasion and polishing observed two or three decades ago and today and further research is required to ensure that appropriate use is made of high PSV aggregates.

Excluding aggregate sources on grounds of excessive resistance to abrasion would reduce the number of available sources in certain areas by 30-60 per cent and is difficult to justify, particularly in terms of sustainable development, unless backed by wider research findings.

The specification of aggregate properties

The lack of correspondence between laboratory assessments of aggregate properties and their "real life" behaviour has been addressed in guidance documents enabling the engineer to establish suitable aggregate properties for a road, based on the location and predicted or measured traffic levels.

As described earlier, the in-service level of micro-texture (skidding resistance) on the road is primarily a function of traffic intensity and the severity of the manoeuvres carried out on it.

Research into this inter-relationship and wet skidding accidents has resulted in the introduction of the "Skidding Standard" which aims to give networks a uniform risk of a skidding accident occurring. This Standard is described later. This Standard provides the road engineer with a value for the minimum PSV required for an aggregate to be used in the trafficked surface of a road (based on predicted traffic levels and the nature of the site *i.e.* whether a dual carriageway, sharp bend or steep gradient).

Long terms benefits of specification

As roads where both the levels of AAV and PSV have been specified appropriately represent an increasing percentage of the road network, the effect of higher levels of texture depth and skidding resistance will be reflected in the accident record regardless of whether actual measurements of the macro- or micro- texture exist.

Measuring skidding resistance network wide

The earliest device developed for measuring skid resistance (and still in limited use today) is the Portable Skid Resistance Tester (HMSO (1969) also known as "The Pendulum") but this is unsuitable for network survey use.

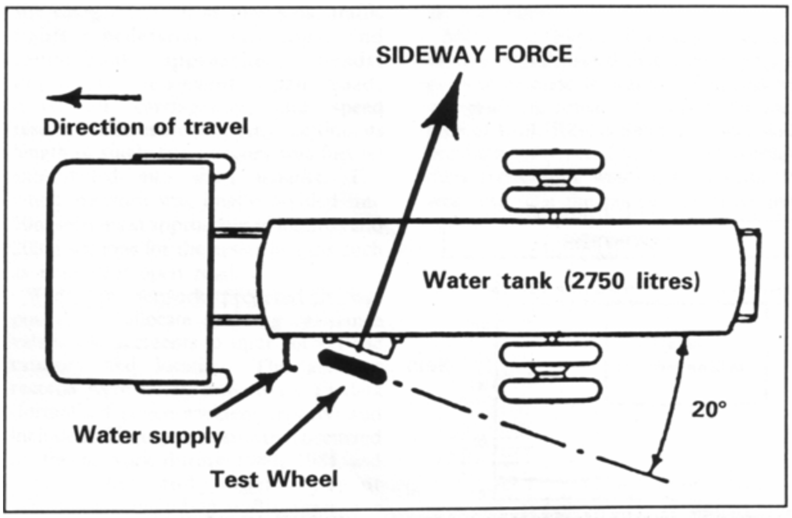


Figure 3.4 Illustrates the principles of SCRIM: Rogers and Gargett (1991)

The HGV-based SCRIM (Sideway force Co-efficient Routine Investigation Machine, illustrated in Figure 3.4) is presently the main device used for measuring the skid-resistance of complete networks.

Measurement of in-service skid-resistance over time identified a seasonal fluctuation in the measured output SFC (sideways-force coefficient), as already illustrated in Figure 3.4. This has resulted in the network skid-resistance being expressed as the MSSC (Mean Summer Scrim Co-efficient: an average of 3 readings over a summer season).

3.3 "The Skidding Standard"

Research in the early to mid eighties identified that a significant increase in wet-skidding accident risk could occur when the skid resistance values dropped below a certain "threshold level". Figure 3.5 illustrates this data for one particular category of site.

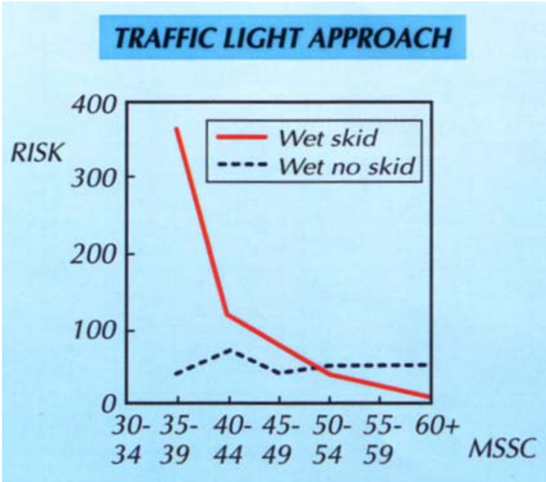


Figure 3.5 The distribution of accident risk with MSSC for traffic light approaches: Highways Agency (2002) after Rogers and Gargett, (1991)

Arising out of this work, the "Skidding Standard" (HD 28/94) was implemented nationwide for Motorways and Trunk Roads in January 1988. It formalised the relationship between aggregate properties (including PSV), traffic levels and SFC and established levels of in-service skidding resistance that ensured a uniform risk of a wet skidding accident occurring over the whole network.

The adoption and application of the Skidding Standard by local authorities

Local authorities have adopted the Skidding Standard as a blueprint for their own local policies though the local authority associations "Code of Good Practice". The implementation of these policies relies on regular skid-resistance surveys and action when a length of road is found to be at or below what is now termed the "investigatory level". There is an associated need to review accident data apart from the skidding resistance measurements to establish if it is appropriate to modify the "investigatory level" at any specific site.

Interim Advice Note 50/03 "Investigation Of Sites Identified From Skid Resistance Measurements", issued by the Highways Agency in April 2003, provides detailed information about the procedure for investigating sites identified from skid resistance measurements which should be read in conjunction with HD28/94 "Skidding resistance" when developing maintenance schemes identified from skid resistance measurements.

Expected risk and driver behaviour.

Most importantly for the driver, the "Skidding Standard" does not aim to eliminate the risk of a wet skidding accident over a network, as this would be economically impossible to implement, nevertheless, it does aim to create a network of equal low risk over its whole length.

Also, the driver must also consider that the implementation of the Skidding Standard relies on every site having an established risk rating, which takes into account the typical manoeuvres (severity of braking and cornering etc) characteristic of that layout.

Higher risk sites such as sharp bends and junction approaches with hard braking and hard cornering are assigned higher investigatory levels of skidding resistance.

However, should a driver choose (or be caused) to carry out a manoeuvre on a section of road more akin to a section of a higher risk rating (*e.g.* making an emergency stop on a motorway carriageway), there may be insufficient skid resistance to prevent a skid.

The need for accuracy in the application of the Skidding Standard

In order for both the engineer and the motorist to derive maximum benefit from the "Skidding Standard" it is essential that skid resistance data is accurately referenced for the particular network.

Every section of road is classified according to risk, with higher risk sites requiring a higher investigatory level of skid resistance. Systems must be in place to audit surveys provided by in-house resources and by third parties to ensure layering of data is precise, so that the right measurement of MSSC is assigned to a correctly applied site category.

Implementation of a skidding policy by local authorities on their networks is likely to be more complex than those of the Trunk Roads both in the variety of investigatory levels used and the greater number of individual sections. Effective GIS based visualisation of the data can help to confirm that, for example, road sections identified as junction approaches are actually located on the approach to junctions. There is an over-riding need for accuracy and quality control at all stages of the data collection process.

Figure 3.6a illustrates an error in the investigatory levels for a skidding resistance survey, a roundabout approach (light blue) appears *outbound* from the roundabout marking the northern limit of the link, and junction approach misalignments have also occurred.

Figure 3.6a Typical errors in investigatory level assignments identified during local authority vetting: (data licensed from Ordnance Survey ©. Crown Copyright, 2003)"

Equally, cluster analysis of accident records relies on accurate locational referencing and description to ensure a correct interpretation of the circumstances. Accurate accident data is as much an essential part of the Skidding Standard as the skid resistance data itself. The reliance on the accuracy of STATS19 accident data is dealt with elsewhere.

Review of Skidding Standards

TRL is reviewing the performance of the Skidding Standard for the Highways Agency and is using the STATS19 data on accidents together with the information on the skid resistance of the network. An example of the preliminary data being obtained is give below where the relative risk of accidents with changes in skid resistance is being investigated for various road configurations (Viner 2003). This information will enable assessments to be made of the appropriate level of skid resistance required for various locations.

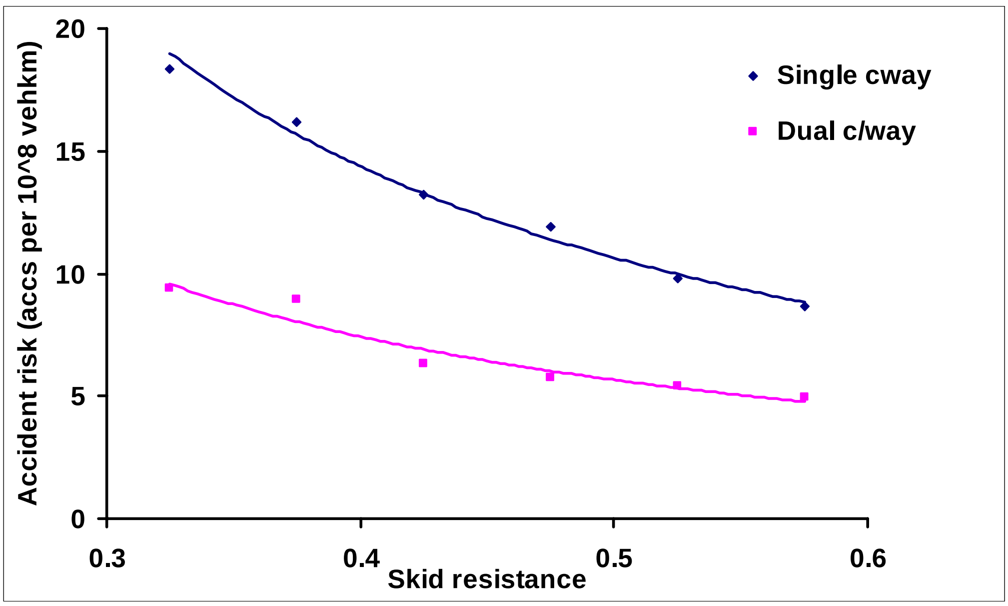
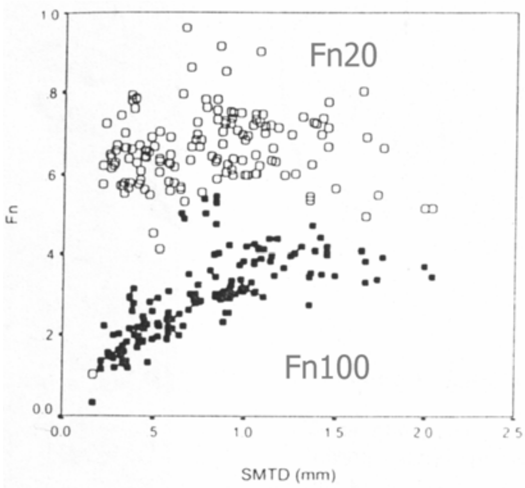


Figure 3.6b Relationship between overall accident risk and skid resistance for different types of site

3.4 A "Texture Standard?"

Figure 3.7
The relationship between speed, texture depth and tread depth, Fn20 & Fn100 Friction Number at 20km/h and 100km/h for a smooth tyre
(Viner, Roe, Parry and Sinhal, 2000)



The Skidding Standard is geared around wet-skid-resistance measurements taken at relatively low speed. However, the level of wet skid resistance delivered at high speeds will depend to a great extent on the surface texture.

Work by TRL, Dunlop and others has identified the positive contribution texture depth makes to maintaining wet skid resistance at high speed and recent work has highlighted the role of tyre tread depth in the same relationship.

Figure 3.7 shows how the skid resistance (given as the Friction Number: Fn) noticeably decreases with the macro-texture depth (SMTD: sensor measured texture depth) at a test speed of 100 km/h (Fn100) whereas the skid resistance remains relatively constant with macro-texture when tested at 20 km/h (Fn20).

Macrotexture and accident risk

The use of high-speed texture measurement enabled a study to be carried out to establish an association between macro-texture depth and accident risk (Roe, Webster and West (1991)).

Roe, Webster and West (1991), identified a relationship between texture depth and accident risk not dissimilar in appearance to that observed by Rogers and Gargett between skid resistance and accident risk that resulted in the Skidding Standard described earlier. This relationship is illustrated in Figure 3.8.

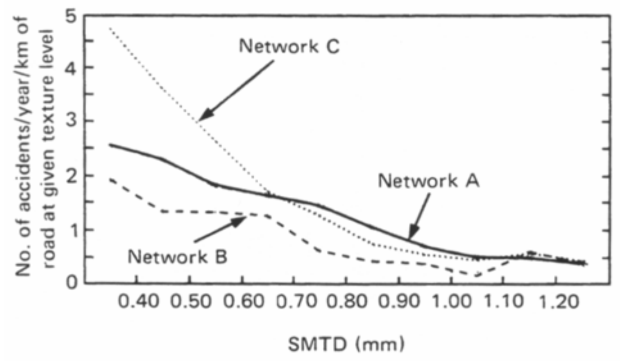


Figure 3.8 The varying relationship between texture level and accident rate: Roe, Webster and West (1991)

This research linking texture depth to accident risk supports the use of the 1.5mm minimum texture depth requirement for new construction of high speed roads in the UK.

In service macrotexture requirements

A CSS survey (CSS (1994)) indicated that 50 per cent of respondents had a texture depth requirement for new construction other than for high-speed roads.

There is not a standard for in-service macro-texture (the equivalent of a Skidding Standard) in the UK.

The routine use of in-service texture depth as a decision-making tool is yet to be adopted, however, some Authorities are beginning to collect network texture depth data.

For example, Cumbria County Council has been undertaking HRM (High-speed Road Monitor) and MRM (Multifunction Road Monitor) surveys on its Principal Road Network (PRN) for approximately 10 years. The Council's skidding resistance policy contains an Investigatory Level of 0.7mm SMTD (taken from Roe, Webster and West (1991)). Texture depth is used as part of the assessment of maintenance needs on their PRN. Currently they are examining improving the links between accident records and the Pavement Management System to help prioritise maintenance work. To date, there has been no specific work done to relate texture depth and accidents although their accident investigators do look at the SCRIM and texture data for sites that are identified as accident clusters. With better coordinated data in the future they may be able to look at this on a network-wide basis.

3.5 The Skidding Standard and the NRMCS

The background to the NRMCS

The condition of trunk roads and principal roads is reported in the annual National Road Maintenance Condition Survey (NRMCS).

The skid resistance condition of the network is expressed in the NRMCS as the percentage of the network "at or below investigatory level".

Table 3.1 Percentage of principal roads survey at or below investigatory level Average 1999-2001 for principal routes: Department for Transport (2003)

Type of authority	Lane 1 length of network km	Lane 1 length surveyed km	Lane 1 length surveyed Per cent	Percentage of Lane 1 length surveyed at or below investigatory level [2] Per cent
England				
Counties	33,328	16,839	*51*	*17*
Unitary authorities	6,672	2,243	*34*	*19*
Metropolitan authorities	6,848	2,459	*36*	*28*
London boroughs	2,835	2,102	*74*	*35*
All authorities [3]	**49,683**	**23,643**	***48***	***20***
Wales				
All authorities	5,220	2,321	*44*	*18*

1 Figures are provided by local highway authorities.
2 In deriving results for each type of authority, percentages for individual responding authorities have been weighted by their road length.
3 In deriving the percentage at or below investigatory level, results for each type of authority have been weighted by the total network length of each authority type.

The latest available results for England and Wales from the NRMCS Skidding Resistance Survey 2002 are shown in Table 3.1.

The percentage needing further investigation is lowest for motorways (2 per cent in 2002, detailed elsewhere in the NRMCS report) and highest for principal roads, almost 30 per cent of principal roads in Metropolitan Authorities and 35 per cent in London Boroughs need further investigation to determine if remedial treatment in relation to skidding resistance is required.

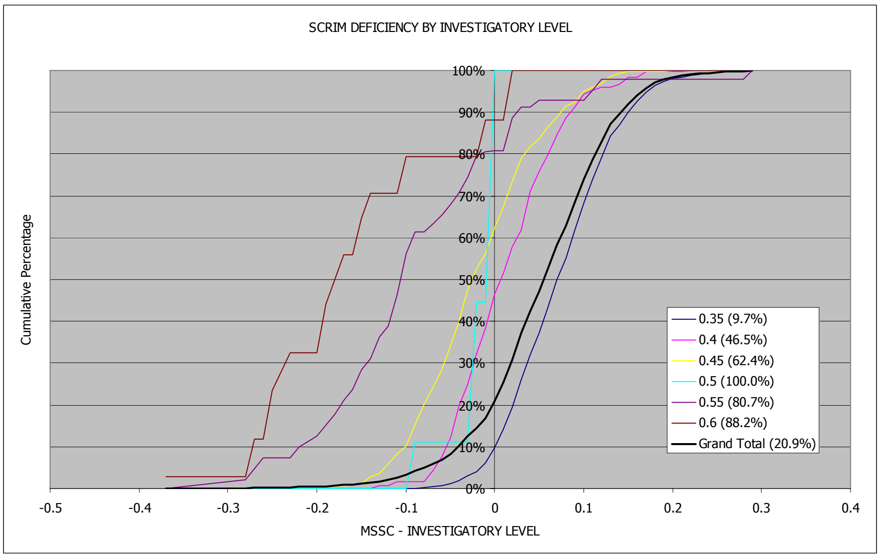
Detail behind the NRMCS results

What may not be widely understood is that these NRMCS summary values are derived from a far more complex dataset comparing specific investigatory levels with skid resistance measurements for sites with a wide range of accident risk.

The percentage of sections at or below investigatory level are commonly not the same for each site category and, generally, the higher the accident risk rating, the higher the percentage of sites that are below the appropriate investigatory level.

In order to gain a more meaningful picture, this more complex data was collected for this project from a number of Authorities considered to be representative of the county/unitary/metropolitan non-trunk road networks as a whole.

Figure 3.9 Iillustrates a typical distribution of SCRIM DEFICIENCY (MSSC minus Investigatory Level) by Investigatory Level



As can be seen from Figure 3.9 (representative of the data collected from 15 authorities), the single NRMCS statistic of approximately 20 per cent for one Authority is an oversimplified combination of many individual results with 10, 20, 40, 80 and even 100 per cent of MSSCs at or below the relevant investigatory levels.

Further, when comparison is made between road classes, the distribution of sections at or below investigatory level can also be seen to vary. The percentage of sections at or below investigatory level tends to increases for the more minor routes. This may be as a result of the more minor routes having a greater number of higher risk sites, a lower specification for materials, or a reflection of a poorer state of maintenance, or a combination of all three.

Summarising, for the low risk sites, which make up a substantial proportion of the network, there is a 5-10 per cent increase in the risk of a wet-skidding accident occurring whereas on the high risk sites, about 10 per cent of the network, there is a much larger increase in the risk of about 50 per cent.

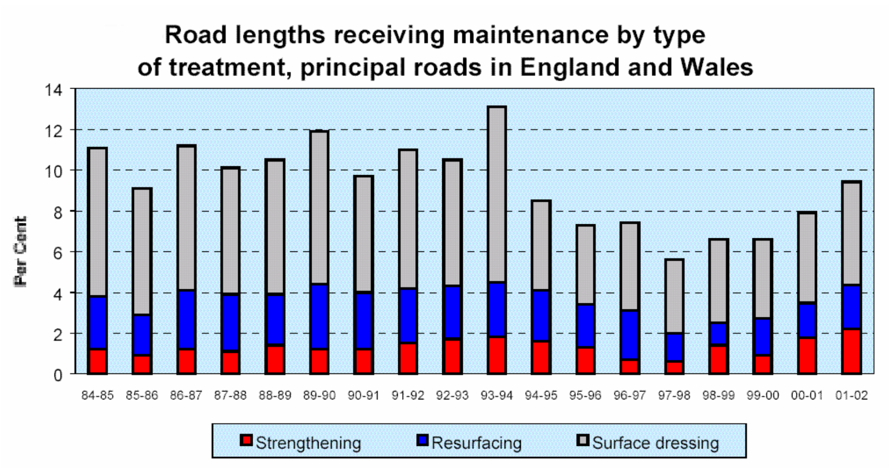
The intercept of the SCRIM deficiency curve (the basic unit of the NRMCS survey) varies together with the slope of the SCRIM Deficiency curve (as shown by Figure 3.9). A single curve for the whole network is derived from many discrete sub-sets of data. The more shallow the slope of the curve for the same intercept the greater the maximum SCRIM deficiency and, potentially, the greater the safety/maintenance issue, assuming that a higher deficiency could be associated with a higher accident risk.

Authorities with a network with a greater proportion of the higher investigatory level sections, for example, Metropolitan Authorities, which generally appear to be more difficult to maintain, will therefore have a higher number of sections at or below investigatory level, but this should not necessarily be taken as evidence of a poorer maintenance regime.

Declining maintenance budgets and a greater need for prioritisation

Maintenance expenditure on non-principal roads is detailed in the NRMCS and Figure 3.10 below shows the decline in real terms of this expenditure for the period 1991- 2002 and the difference in the percentage of the principal network receiving maintenance compared to that of the non-principal network.

This is reflected in the NRMCS visual survey results that showed the largest increases in the defects index - corresponding to deterioration - occurring in the latter half of the decade.



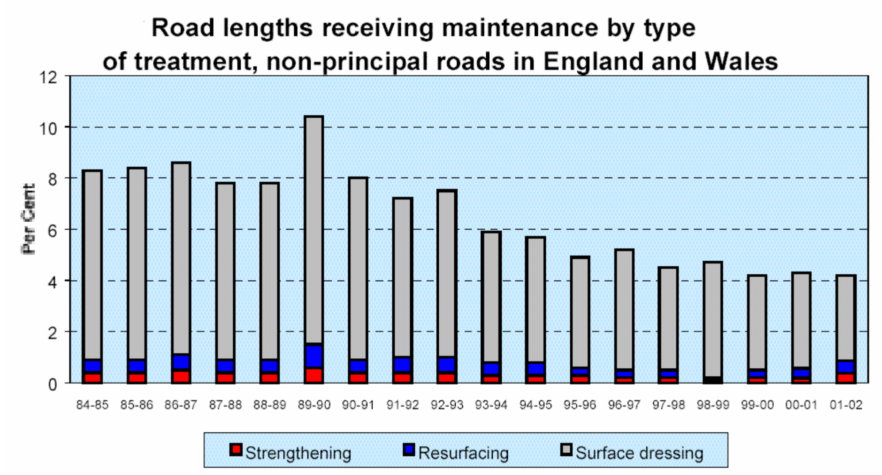


Figure 3.10 Percentage of road lengths receiving maintenance by type of treatment, from 2002 NRMCS: Department for Transport (2003)

In July 2000 the Government set out its transport strategy in "Transport 2010 – The 10 Year Plan", this included the target to halt the deterioration in the condition of local roads, *i.e.* non-trunk roads, in England by 2004. In 2002, the defects index for English local roads fell from 110.5 to 107.6. It is suggested that this reflects a real improvement in road conditions. (Department for Transport (2003).

It remains to be seen what impact the increased level of funding will have on skid resistance values.

The true condition of the skid resistance of the highway network is far more complex than would be suggested by the single skidding resistance indicator currently included in the NRMCS.

3.6 "New generation" surfaces

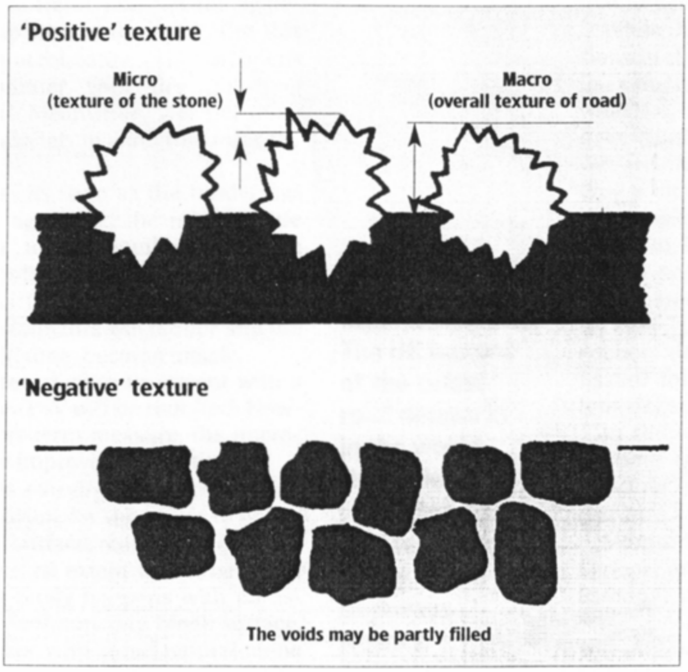


Figure 3.11 Illustration of conventional versus "negative" texture Depth: After Walsh (2000)

The classic associations between aggregate properties and texture depth have all been established from measurements on a range of surfacing types with one common feature, namely, "positive" texture depth.

The latest developments in surfacing which have brought with them benefits in construction techniques reducing delay and road closures, have another common feature: "negative" texture depth. Figure 3.11 illustrates the nature of these two types of texture depth. Negative texture is similar to the surface of a sponge whereas positive texture is akin to sandpaper.

Early life skid resistance: dry skidding?

The first negatively textured surface, porous asphalt (PA) has not been widely used in the UK due to problems with durability and winter maintenance. However, the latest generation of proprietary materials provide a compromise between porous asphalt and conventional surfaces.

The structural integrity of negatively textured surfaces is reliant on relatively thick films of high specification binding agents coating the aggregate particles to ensure that the aggregate lattice remains cohesive. The thickness of these films may be more than twice that of those found on the aggregates in more conventional materials such as Hot Rolled Asphalt (HRA) and coated macadam.

The physical properties needed for a modern bituminous coating to maintain long-term structural integrity conflict with the need to produce a rapid exposure of the aggregate micro-texture to generate the desired skid resistance.

A CSS publication in 1994, "The Achievement of Skidding Characteristics for Road Pavements"(CSS (1994)), recognised that bitumen coated materials, whilst having more than adequate frictional requirements when measured by one of the limited slip devices (SCRIM, Griptester etc) can be very slippery when subjected to a loaded locked wheel and suggested that surfaces exhibiting negative texture seemed much more prone to these problems. It was suggested this might be overcome by the temporary installation of 'slippery road' signs at potential accident spots.

Issues of the lower levels of skid-resistance provided by coated materials on first opening to traffic are not new and are not confined to negatively textured materials, but the enhanced properties of the binders in these surfaces may extend the period during which tyres are in contact with a bitumen film rather than the aggregate micro-texture.

The measurement of dry skidding resistance

In the UK, the highway engineer has never really considered the dry skid resistance of road surfaces as an issue, all routine measurements concentrate on wet skid resistance using SCRIM, Griptester or "pendulum" readings.

However there is evidence in the literature (from France and The Netherlands primarily), that the excess binder film may provide a lubricating film (akin to that of surface water) when the tyre is passing over it.

This effectively exposes the driver to the scenario where, with a sudden application of brakes, the dry road behaves as though it is wet. The driver has no advance warning of potential skidding, as when driving in the wet, and is suddenly precipitated into a more unexpected situation than skidding in the wet.

In the UK, there are no standardised devices for measuring dry skid resistance on the highway. Trials by TRL for the Institute of Traffic Accident Investigators (Viner, Roe and Lambourne (2001)) confirmed that SCRIM and Griptester could not measure this property effectively.

UK Police use the SKIDMAN device for accident investigation but it is not designed as a survey tool. The Highways Agency's Pavement Friction Tester, a Dynatest 1295 device, (Figure 3.12 shows a similar device) is the only wet- and dry-skidding survey device currently in the UK.

Figure 3.12 Dynatest 1295 Pavement Friction Tester (Dynatest)

Evidence, particularly from The Netherlands, suggests that the monitoring of porous asphalt (the longest established "negatively textured" material) using locked-wheel dry-skid testing may be required to provide the engineer with a guide as to when signs warning of extended dry stopping distances on new construction should be removed (Jutteo and Siskens (1997)).

More recent work, also from The Netherlands (Bennis TA and Leusink J (2000)), has gone on to show that dry friction testing can be carried out effectively in live traffic using a towed locked wheel device as an alternative to skid car tests that required road closures and night working.

A programme of measuring dry skid resistance, would need to address the following issues:

- The minimum level of dry skidding resistance below which warning signs should be erected and the link between low dry-skid resistance and increased accident risk.
- Whether all negatively textured surfaces are of equal concern, and whether conventional materials such as HRA and coated macadam which may be binder rich on first opening should be similarly investigated.
- What might be the road users' perception of a warning sign that effectively said "slippery when dry" and was associated with a length of new rather than visibly worn-out road?
- How would a section found to have insufficient dry skid resistance but sufficient wet skid-resistance be dealt with?

Recent observations on early life dry skid resistance

A summary of a presentation made by P G Roe (Principal Scientist and Research Fellow Transport Research Laboratory) at the Society of Chemical Industry (SCI (2002)) provides a valuable overview of the research carried out by the CSS and the Highways Agency in the UK to investigate the "early life skid resistance phenomena"

Newly laid asphalt surfaces exhibiting different skid resistance properties compared with roads that have been in service for some time has generally been attributed to the presence of a bitumen film on the surface of the aggregate particles that would normally be expected to provide the micro-texture, which governs low speed skid resistance.

As well as the possibility of reduced wet skid resistance resulting from smooth bitumen masking the aggregate micro-texture, there has been concern over the possibility of lower than usual dry friction on new surfaces. This was first raised by a Police accident investigator in the aftermath of a tragic incident on the M4 in 1988 that occurred shortly after the road had been resurfaced using hot rolled asphalt with pre coated chippings (HRA). He found lower than expected friction in his skid tests (which were not standard road assessment tests) and he suggested that bitumen on the chippings was "melting", thus reducing friction.

More recently, Police accident investigators are increasingly commenting on lower than usual dry friction in their routine stopping distance skid tests. This has coincided with more widespread use of types of surfacing materials that tend to have a thicker layer of binder on the surface than was normally found on the conventional surfacings like HRA or dense bitumen macadam.

Although there have been occasional localised studies, systematic research into this topic has been limited. The CSS has recently carried out some work on wet skid resistance. Work on dry friction, however, has not been possible until recently because suitable equipment was not available in the UK. However, future work may utilise the Highways Agency's Pavement Friction Tester already described.

TRL is using this equipment to study both wet and dry friction on new surfacings. A short study was made for Derbyshire County Council in 2001 (Derbyshire County Council (2001)) and a longer programme of work for the Highways Agency, as part of its review of the Trunk Road Skidding Standards, is ongoing. The work for HA has the objective of determining the scope of the phenomena, including magnitude and likely duration.

To date, measurements have been confined to roads surfaced with a "generic" Stone Mastic Asphalt (SMA) material, continuing to monitor the sites initially studied in Derbyshire and also monitoring another principal road from when it was first opened to traffic in March 2002. This is probably effectively a "worst case" study, in that the roads concerned are comparatively lightly trafficked and the surfacings used on them have a higher proportion of bitumen on the surface compared with many Trunk Roads. It is intended to extend the work to include Trunk Road examples in due course.

Although it is too soon to draw definitive conclusions, some points emerging relating to the surfaces studied are:

WET friction

Wet friction on these surfaces is high at low speeds, but it tends to yield values typical of lower textured or more polished aggregate surfaces at higher speeds.

DRY friction

Dry friction on these surfaces shows a speed effect, it is higher than wet friction at highest speeds, but still much lower than the dry friction levels expected on conventional surfaces at all speeds. It is higher than wet investigatory levels at the lowest speed, but can be similar to the investigatory level at high risk sites. It is similar to wet friction levels at intermediate speeds.

The dry effects at higher speeds do appear to be associated with "melting" bitumen.

Peter Roe's concluding remarks

These effects can be observed from new for at least six months on lightly trafficked roads but after about a year, the measurements appear more "normal".

The concern over the level of early life skid resistance of new surfaces, with particular reference to SMA, has produced a number of local responses, many use combinations of either the "exclamation mark" sign or the "slippery road" sign with text such as "new surfacing" to alert road users (for example Figure 3.13).

Figure 3.13 'slippery road' sign to diagram 557 with supplementary plates as used by Cornwall County Council (Cornwall County Council)

Cornwall County Council

Cornwall County Council has concluded: "Whilst skidding is a complex subject and there is no definitive guidance on behaviour and performance of early life skidding resistance of thin and SMA surfacings, the County Council need to demonstrate that they are applying a reasoned approach to assessing and treating sites in a consistent manner".

Their document (Cornwall County Council (2001)) represents their first stage in developing such a procedure on the county road network and: "uses our skidding standards and reliable methods of testing on which to make a judgement."

Derbyshire County Council

Derbyshire County Council employed TRL to investigate two accidents on SMA surfaces (both accidents were at night and in the wet) following concerns expressed by the Police.

Following this investigation, SMA will continue to be used in the County subject to a risk assessment being carried out at each site with reference to accident data and all new sites resurfaced would feature "new surfacing" warning signs until they are 'weathered' or worn in. The Police continue to assist with skid tests on older sites.

The TRL findings (Derbyshire Council (2001)) concluded that, though not relevant to the nature of the accidents in question, there was potential for a thick binder film on aggregates forming a new surface such as SMA (and potentially on similar proprietary "thin surfacing") to generate levels of sliding friction on a dry road less than a driver may expect and this could be as low as that experienced in the wet. This risk is likely to disappear as the bitumen is worn away by traffic, but the time taken for this to happen is yet to be quantified as it is likely to be a function of the traffic intensity and vehicle types for any particular length.

Highways Agency guidance on signing new asphalt surfaces

Interim Advice Note 49/03 part of Volume 7: Section 5: Surfacing And Surfacing Materials, "Use Of Warning Signs For New Asphalt Road Surfaces" (Highways Agency (2003)) offers, as an interim measure, a strategy to mitigate any additional risk to road users as a result of the lower skid resistance in this early life period, for trunk roads.

The Note recognizes that newly laid asphalt surfacings can exhibit lower skid resistance than the same surfacings after a period of trafficking, and suggests that the binder film, which initially coats the aggregate particles, could cause this. The Note goes on to observe that measurements on a limited number of surfacings have shown that the skid resistance can be affected in both wet and dry conditions and this potentially gives rise to additional accident risk to road users.

The Note does, however, state that this characteristic of new surfaces is not fully understood, particularly in relation to the duration of the effect, and the influence of different types of asphalt surfacing materials, and is the subject of ongoing research.

The Note continues to explain that the Highways Agency has no skid resistance policy for dry conditions, because the skid resistance is generally high in this case. However, current research shows that locked-wheel friction on newly laid asphalt surfaces in dry conditions is lower than normal, although similar to or higher than that in wet conditions. Stopping distances under emergency braking conditions will, therefore, be increased in comparison to those on a dry road, but to no greater extent than on wet or damp road surfaces. Under normal braking conditions, dry friction should be adequate.

Exposure to risk

What must be borne in mind is that the risk exposure to the individual road users remains the same whether the duration of a period of low early life skidding resistance is one week, one month or one year, until the action of traffic removes the binder film on the aggregate (Peter Roe previously raised this issue in the presentation described).

Accidents caused by low early life skidding resistance would be less likely to be routinely detected on sites with high traffic levels as the period over which low skid resistance is an issue may be shorter.

Skidding Resistance and HAPAS approval of negative textured surfacings

The new generation of "thin surfacings" are regulated in the UK by the British Board of Agrèment's HAPAS (Highways Authority Product Approval Scheme), which provides an independent approval process for the manufacture and provision (via approved contractors) of a number of proprietary materials. The HAPAS scheme does not extend to non-proprietary generic SMA (Stone Mastic Asphalt). Currently the BBA/HAPAS scheme for thin surfacing systems does not address issues of early-life skid resistance.

Behavioural adaptation to lower noise/spray surface types

No literature appears to document any studies of driver behaviour when driving on the new generation of thin surfacings in the UK. However, much exists relating to porous asphalt (PA) in continental Europe. Thin surfacings with their relatively reduced drainage potential and less ability to absorb road noise (when compared to PA) may not produce such a marked effect.

One TRL study (Frith (2000)) showed a statistically significant effect of rainfall on road speed for part of the M25. A comparison of the relationship between negative- and positive-textured surfaces and their effects on road speed would partly address this issue for the UK.

Table 3.2
Speed reductions expected during adverse weather and ambient lighting conditions observed: Frith(2000)

Average speed in daylight without adverse weather (dry flow 500 veh /hr/lane visibility over 500metres)		74 mph
Change in Speed	Per mm of rainfall /hr Per 100 lux decrease in light level Per 100 metre decrease in visibility from 500 metres	6 mph reduction 0.4 mph reduction 0.07 mph reduction*
* Provisional result based on only 2 days with low visibility in earlier work		

Work by van der Zwan *et al*. (1997) and Swart (1997) in the Netherlands observed that one of the main objectives in introducing porous asphalt (PA), i.e. improving road safety, is not attained. They added that it was clear that the application of porous asphalt had not resulted in any "spectacular" improvement in road safety.

One explanation advanced was that of the perception of safety limits. The psychology of the road user is such that each improvement may be compensated for, to a lesser or greater degree, by a change in driving behaviour. This equally applies to improvements to the vehicle, improvements to road configurations and also to improvements in the type of road surface. They are quoted as saying that it had been found that drivers tended to drive faster on porous asphalt, probably because of the lower noise generated. But the absence of splash and spray also gave the driver the impression of driving on a dry road in rain, so that the speed and distance between vehicles were not adjusted to the conditions. For porous asphalt, this could mean, as suggested by the comprehensive Dutch study, that the positive advantages for this type of surfacing are negated by the road users' behaviour.

Cifre (1997) reported that a quantitative increase has been detected in skidding as a cause of accidents on PA surfaces in the Balearic Islands, the reasons given included the increase in the speed of traffic, which is considered to be a consequence of the greater sense of security arising from the more freely draining surfacing.

Work in France by Bonnot (1997) observed an overall increase (17 per cent) in total accidents (a 23 per cent increase in accidents in the dry, a 31 per cent reduction in the wet).

3.7 Improving in-service skid resistance through "retexturing"

One potential method of exposing aggregate in negative textured surfaces and indeed improving skid resistance on existing sound (but polished) surfaces is retexturing.

Retexturing is defined as the mechanical reworking of a sound road surface to restore skidding resistance (micro-texture), texture depth (macro-texture) or both.

The application of mechanical processes using cutting, hammering or grinding or by the application of high pressure water or heat has been widely used to temporarily restore a combination of micro- and macro-texture to sections falling below the investigatory level or otherwise having substandard texture or skidding resistance.

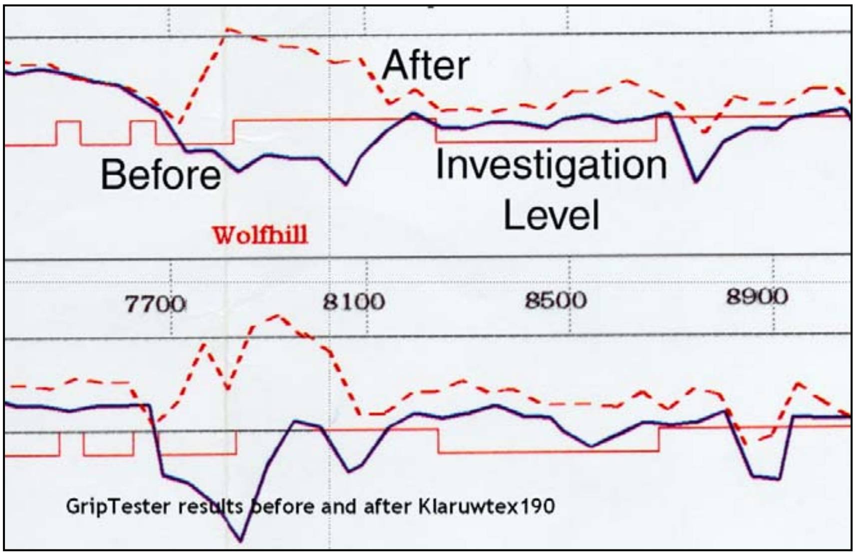
The various processes either remove the relatively softer surrounding binder material in the case of "fatted up" surfaces where texture depth is lost through embedment of the aggregate in the road surface, remove the binder film where an excess exists that is obscuring the micro-texture, or attempt to restore the micro-texture by the exposure of new aggregate faces. Restoration of micro-texture by this last means must not reduce the macro-texture below reasonable levels in the act of exposing new faces on the particles.

A study of the various retexturing processes and their early life performance was reported by TRL (Roe and Hartshorne (1998a, 1998b)).

Retexturing processes are also included in the Highways Agency DBRM in Vol.7 Sec.5 Ch11 (Highways Agency (2003)).

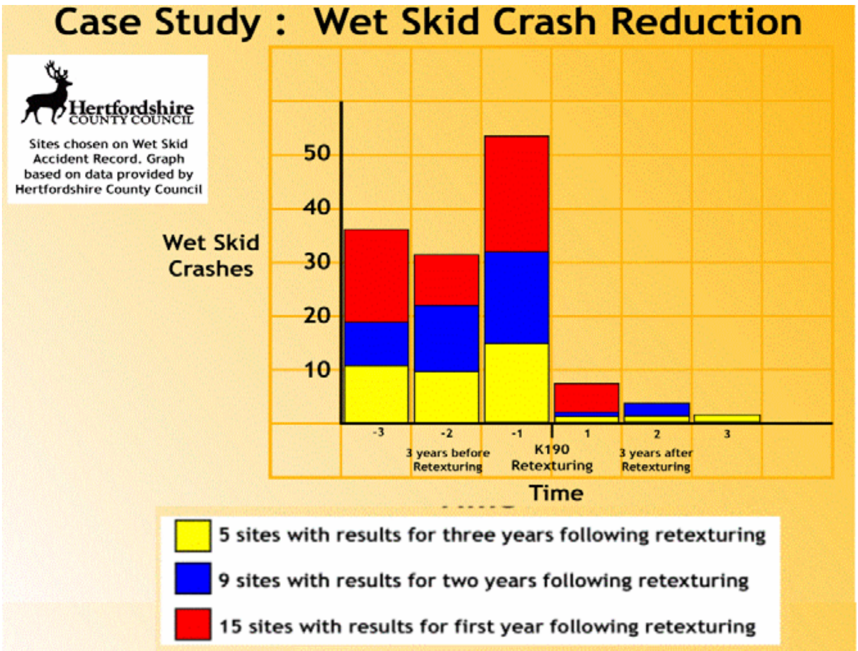
The effect on micro-texture observed after retexturing is shown in Figure 3.14 (note: investigation level refers to an investigatory level of skid resistance). However evidence of the effect of retexturing processes on accident reduction (by effectively raising the skid resistance of the road and/or increasing the macro-texture) is not as readily available.

Figure 3.14 Skidding resistance before (blue line) and after (red dashed line) retexturing: Klaruw



If the study by Hertfordshire of the effect of retexturing on wet-skid accident reduction (see Figure 3.15) can be reproduced elsewhere, and augmented to include the micro- and macro- texture state of the sections during the before and after periods, the true effect and whole life cost of these low cost retexturing processes may be better understood.

Figure 3.15 Wet skid accidents before and after retexturing: Klaruw



3.8 High Friction Surfacing

Of all the surfacing strategies available to the highway engineer, high friction surfacings (also known as "Shellgrip", "anti-skid" or "HFS") are considered to have the greatest effect on reducing accidents. They can offer the highest levels of skidding resistance of any surfacing type and can be laid on many existing surfaces to produce an immediate increase in friction. HFS is routinely required on the highest risk rated sites to meet the skid resistance requirement of the Skidding Standard.

Two main types of high friction surfacing are used:

Types of high friction surfacing

Cold applied materials: a high specification epoxy, bitumen-epoxy or polyurethane binder applied cold or hot sprayed combined with a layer of fine (1-3 mm) high PSV low AAV artificial aggregate (almost exclusively calcined bauxite). "Blinding" the wet resin film surface with aggregate creates the surface texture; the excess is subsequently swept up.

Hot applied materials: commonly a layer of rosin ester thermoplastic material with an entrained high-specification aggregate (again almost exclusively calcined bauxite), applied at over 150ºc as a plastic slurry. The surface texture is generated by the action of the screeding device dispensing the hot material. The finished surface may show evidence of screed lines between the individually screeded lengths. The surface texture may be more variable with these materials.

High friction surfacing is thin (approximately 3-5mm) and is laid over existing surfaces, this in itself can pose problems if the underlying road is sub-standard or contaminated because the HFS can delaminate under such circumstances.

HFS history

High friction surfacing was first used in the UK in the 1960s with the then GLC (Greater London Council) being the first Authority to exploit its properties of very high skidding resistance. TRL identified the source of the aggregate for the system and contributed to the product's development.

HFS and accident reduction

Work by the London Accident Analysis Unit in the 1970s (LAAU (1978)) quoted about a 65 per cent reduction in wet road accidents and an overall accident reduction of about 30 per cent for 33 accident blackspot sites, 19 junctions, 11 pedestrian crossings, 2 bends and one roundabout.

Studies by the GLC in the 1980s on the effect on accident reduction of HFS (LAAU (1989)) showed about a 60 per cent reduction in wet accidents for 12 junction sites, overall accidents reduced by about 15 per cent.

HFS accident data from MOLASSES

Accident data from MOLASSES for sites using only HFS suggests an average reduction in total accidents of nearly 30 per cent. Table 3.3 illustrates this.

Table 3.3 Average accident reduction for local area safety schemes using only high friction surfacing (data MOLASSES)

YEAR	Number of Sites	Average percentage change in accidents for period
1983	1	33%
1985	1	-34%
1986	2	-58%
1987	7	-34%
1988	3	-48%
1989	4	-63%
1990	3	-47%
1991	2	-55%
1992	1	-24%
1993	4	-37%
1994	11	30%
1995	2	55%
1996	6	-27%
1997	11	-51%
1998	2	-42%
1999	5	-62%
2000	1	-100.0%
Grand Total	66	-29%

Nevertheless, the conspicuity of HFS may lead to certain drivers exploiting its potential when they are aware of the fact it offers the ultimate in skid resistance. This is a constant concern for those with responsibility for highway safety.

This concern is a result of experiences at some sites where accidents have increased after treatment. HFS must be used appropriately; on roundabouts it can result in HGVs overturning rather than skidding, and problems may be experienced where the HFS starts or ends other than on straight sections.

HFS application and performance

Concerns over controlling the correct specification and quality of a number of highway materials (without naming individual products) in the nineties prompted the introduction of the British Board of Agrèment's HAPAS (Highway Authorities Product Approval Scheme) procedure to provide a certified and accredited source of materials and installers.

HAPAS certification for HFS

HFS was included in this scheme and engineers now have access to a list of approved installers of a range of HFS materials backed by a performance guarantee.

Table 3.4 HAPAS application guide by type classification: BBA/HAPAS (2003)

Table 2 Area[1] of application by type classification

Site category (as defined in HD28/94)	Site definition	Maximum traffic levels (number of commercial vehicles per lane per day) Type 1	2	3
F	Approaches to and across major junctions (all limbs)	3500	1000	250
G1	Gradient — from 5% to 10%, longer than 50 m			
H1	Bend — not subject to 40 mph or lower speed limit, radius from 100 m to 250 m			
L	Roundabout			
G2	Gradient — >10%, longer than 50 m	2500	750	175
H2	Bend — not subject to 40 mph or lower speed limit, radius <100 m			
J/K	Approach to hazard, such as roundabout, traffic signals, pedestrian crossing, railway level crossing	2500	500	100

(1) Suitable areas for use of systems classified in accordance with Table 1 of the Guidelines Document to give an expected service life of 5 to 10 years.

HAPAS for HFS introduced certification gradings of Type 1, 2 and 3 (see Table 3.4):

- Type 1 materials are capable of withstanding the highest stresses of traffic and site location, they are predominantly of the cold applied type.
- Type 2 and 3 materials meet less rigorous requirements; Type 3 materials are predominantly of the hot applied type.

The use of this grading into types has enabled lower cost materials to be specified where appropriate. However, there are upper limits on the suitable traffic levels (Maximum 3500 commercial vehicles per lane per day) within the grading system, and it must be recognized that at extreme traffic levels the thin, albeit relatively high specification, layer may wear at an accelerated rate.

The HAPAS scheme enables the engineer to have greater confidence in the level of control over the manufacture and installation of HFS, a premium product that is commonly installed on sites with significant safety issues.

3.9 The MARS Project (Macrotexture And Road Safety)

The MARS project is one of the few studies carried out jointly by road and tyre specialists. It was orientated towards tyres that are designed to exploit the properties of the road network rather than the test track, and towards roads that are designed to provide improvements in areas previously considered a function of the characteristic of the tyre rather than the surface it was travelling over.

The key objectives of this research project were to determine whether a method could be developed to predict the safety performance of a road surface from knowledge of the form and pattern of the surface texture. Factors affecting road noise and rolling resistance were also evaluated. These results would be used to improve the surface characteristics of surfacing materials.

The research was carried out by TRL under a LINK project largely funded by Science and Technology Policy Div. DETR with contributions from CSS, Dunlop, Associated Asphalt, Lafarge and Jean Lefebvre UK.

A summary of the MARS report may be found on the Internet:

http://www.cssnet.org.uk/members/committees/transport/activities/MARS%20summary%20report%20arial.pdf

The project included:

The numerical modelling of surfacings, the measurement of the dynamic properties of tyre tread polymers and interpretation in terms of the measured contact stresses, trials of surfacings, and the assessment of the potential to design a new surfacing with adequate friction and low noise and rolling resistance, based upon the results of the project

MARS and the effect of surface characteristics on tyre compounds

One of the aims of the study was to determine the effect of surfaces on tyre development.

Tread compound developments have generally been validated by measuring friction and rolling resistance on proving grounds using test surfaces with low levels of texture. However, actual road surfaces in the UK have wider distributions of stress, and higher peak stresses, which create high strain rates in the tyre tread, these require different formulations for optimal grip. As more use is made of thin surfacing and high friction surfacing, MARS suggested it might be possible to match tyre tread compounds to perform better on these surface types.

MARS and skidding resistance and texture

A fall in SCRIM readings with change in speed was found to be related to the percentage actual contact area between the surfaces and the SCRIM tyre, as predicted from the profile measurements. The rate of fall with speed was lower for smaller contact areas *e.g.* HFS and thin surfacing. The contact area may have had this influence because it was related to the drainage properties of the surface and/or the tyre contact pressures.

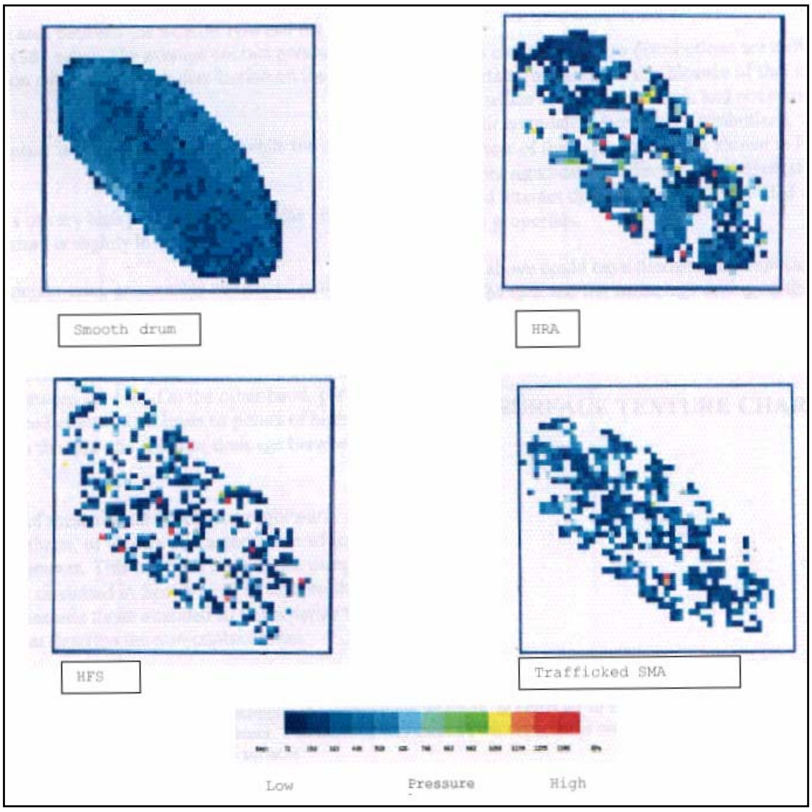


Figure 3.16 Pressure level maps for four different surface types: CSS (2002) from Parry (1998)

New surfacing materials have been developed which are significantly quieter than conventional ones. They have a voided structure, which reduces rolling resistance (hence fuel consumption), and have a surface geometry that maintains high speed and low speed skid resistance.

The outcome of the MARS project

High point stresses in the tyre contact area were introduced for HFS (high friction surfacing) and thin surfacings and this could have an impact on tyre compound design. The data obtained from this project may be used to optimise tyre performance.

Although material made using 6mm aggregates had a lower texture depth, the drop off of skid resistance with speed was no different to those for the 10mm or 14mm materials. This suggested that texture depth is less relevant for porous materials and that the drainage of surface water is the more important factor.

There is some suggestion that (at least for the special thin surfacings tested) the PSV of these types of surface may be reduced compared to standard designs based on HRA (hot rolled asphalt).

Further work resulting from the MARS project

As a result of this work Dunlop proposed to adjust the surface on their tyre proving track to represent more closely those used on the highway network and commenced a programme of tyre compound optimisation for improved performance. New surfacing materials based on this research are now on the market.

3.10 Spray

Spray generated by vehicles travelling on wet roads has been recognised as a hazard when road speeds exceed approximately 40 mile/h.

Local authority perception

The issue of spray was considered “important” on motorways and trunk roads by 35 out of 36 highway authority respondees to a CSS survey (CSS (1994)), 21 of the 35 considered it also an issue on local roads and 15 of them had used lengths of porous asphalt (a spray reducing surface) to reduce surface spray.

Spray results from the turbulence created by vehicles entraining and dispersing water droplets. About 10 per cent of the water dispersed by the tyre treads is being released in a form likely to generate spray.

Putting this 10 per cent in context, the volume of water displaced by a single 295 section-width truck tyre driving through water 3mm deep at 80 km/h is nearly 2 litres per second (Cordle (2003)). However, this may be reduced through continued development work by tyre manufacturers.

Driver perception

The issue of spray from lorry tyres has always been high on drivers' agenda. One overlooked aspect is that a driver who may be blinded by spray may be hidden in the same cloud of spray from the view of the driver of the vehicle they are passing (The effect is illustrated in Figure 3.17). This concern is supported by the results of driver perception surveys on road dangers.

Figure 3.17
The effect of spray on the rear view of HGV drivers and how visibility can be improved via spray suppression (Clear Pass)

A survey carried out by TRL (Baughan, Hedges and Field (1983)), before the UK had spray suppression legislation, placed "spray from lorry tyres in wet weather" as a problem that had bothered 82 per cent car drivers and motorcyclists at some time. 31 per cent of car drivers and motorcyclists citied spray as their worst or second worst problem. The increased concentration needed to drive in spray may also lead to fatigue later in a journey.

Research into the effect of spray

On a more objective level, research carried out in the Netherlands (Padmos and Varkevisser (1977)) studied the effect of spray on the drivers' abilities to distinguish detail and contrast

One of the important findings of the work was:

".. the most critical effect of spraying rain water for road safety is the rendering invisible of objects with low to average contrast, such as, for example, road markings."

The work also observed the positive contribution so called "negative texture" surfaces can have on visibility, apart from reducing spray:

".. the road marking on a road surface of a very open structure, when it rains, (is) probably better visible, owing to the fact that these road surfaces are darker under the given lighting conditions."

The measurement of spray

Research work carried out by TRL to quantify the level of spray generated by the tyre road interaction led to the development of a device (Nicholls and Daines (1992)) to measure spray by detecting back scatter from a near infrared light source. The device is insensitive to ambient light and the effect of spray on the detectors lenses. This device could be used as part of the development of spray suppressing equipment or new spray reducing road surfaces.

This technology could be used to measure the reduction in spray achieved by spray suppression devices thereby quantifying the benefits of fitting them.

Surface characteristics and spray

Until recently, the positive "texture depth" of conventional road surfaces provided free draining of water across the surface. More recent developments in surfacing have led to materials with so-called "negative texture" which drains vertically and then horizontally through the interconnected macro-texture.

The spray reduction properties of negative textured surfaces will vary, with materials like porous asphalt almost certainly exceeding those of more modern negative textured materials. However, the difference in spray between sections of conventional rolled asphalt and the more recent thin surfacings can still be easily discerned by the driver.

Figure 3.18 Composite picture showing The difference in the level of spray generated in the laboratory between a conventional smooth spray flap material (right) and spray suppressing media (left) (clear pass)

Spray suppression devices

As novel vehicle-mounted products were developed in the 1980s to reduce spray created by goods vehicles there was no legislation in the UK making them mandatory.

Spray reduction legislation: current practice in the UK

A combination of lobbying by manufacturers, representation by researchers and objective evidence of the efficacy of certain methods led to the introduction of BS AU 200 in 1984 that specified both the design of spray suppression devices and how they were to be tested.

BS AU 200 (British Standards Institution (1984)) was incorporated into The Motor Vehicle Construction and Use Regulations in 1984. The Regulations made the fitting of spray suppression mandatory for most vehicles in excess of 12 tonnes in weight. Bulk solids tankers and tippers were made exempt from this requirement on the grounds that the arduous nature of their use may lead to the devices becoming clogged or damaged.

The development of a European Standard for spray suppression followed in 1991 (EC (1991)), however, the only fundamental differences between BS AU 200 and Council Directive 91/226/EEC are that the amount of spray entrained by the spray suppressing media under test conditions increased from 65 per cent to 70 per cent and the extent of the spray suppressing wheel arch liner extends further.

In the UK, new trailers are fitted with devices to BS AU200 whereas tractor units and rigid trucks are fitted to the EC Directive.

When EC wide vehicle homologation is introduced all vehicles covered by the existing Directive will then have to comply with 91/226/EEC.

However, manufacturers of the spray suppressing material may well already supply only materials that meet the EC Directive in order to simplify the supply chain.

Maintenance of spray suppression equipment

If a UK vehicle has defective spray suppression this matter will be addressed at the next MOT test, if not before, through failure to comply with The Motor Vehicle Construction and Use Regulations.

Fitted spray suppression equipment required by law is tested as part of the UK MOT test and is routinely checked at the roadside during Vehicle Inspectorate Spot Checks. Defective spray suppression equipment features in the top ten prohibition defects for both motor vehicles (2.7 per cent) and trailers (3.2 per cent) for data from 2001/02; to put this into perspective, brake systems and components were responsible for 11.3 per cent and 18.1 per cent respectively of all prohibition notices issued.

European adoption of 91/226/EEC

In addition to the UK's partial recognition of the Directive, the extent of adoption in other countries is summarised below:

- *Denmark:* No legislation.
- *Holland:* No legislation. A decision was made to concentrate on porous road surfaces.
- *Spain:* Legislated. Most if not all new vehicles are fitted with spray suppression flaps.
- *Portugal:* Legislated.
- *Germany:* No legislation. Germany has proposed amendments to the EC Directive and even a new Directive. In both cases the Spray Suppression test for flaps is of a higher standard of accuracy. However, the standards and dimensions for fitment of containment (wings etc.) and flaps on vehicles are lower and may reduce the effectiveness of the spray suppression on the road.
- *Australia:* It is necessary for all axles of "B" double vehicles (combinations consisting of a tractor unit towing 2 trailers) to be fitted with a form of spray suppression which meets or exceeds the requirements prescribed in British Standard AU200 Part 1+2 – spray reducing devices for heavy goods vehicles or equivalent.

Legislation in the US

It is noteworthy that there is a lack of nationwide legislation in the US regarding spray suppression because the requirement for the measurement of the efficacy of such devices in real conditions (rather than the laboratory) is fraught with problems and has not been carried out. The US decision to base judgement on the performance of spray suppression on real rather than laboratory conditions has resulted in the statement that:

"The technologies that purport to reduce splash and spray cannot be shown to translate into real world visibility improvements for drivers" (NHTSA (2000)).

It is of concern that, despite the evidence from the laboratory work carried out, the implementation of the EC directive and the visual evidence, that the inability to produce standardised test results representing the variable road environment has inhibited the implementation of spray suppression in the US.

Spray and accident risk

The contribution of spray to accidents is difficult to assess but a TRL study in 1994 (Savill, 2003) asked Police Officers to judge the contribution of spray to the wet-weather injury accidents they were reporting on. It was estimated that spray plays a part in between

131 and 552 injury accidents each year on motorways and A(M) roads in Britain at an annual cost of between £7 and £29 million.

The lack of evidence linking spray to accidents was used in the decision of the US not to proceed with spray suppression research.

However, accident reporting systems generally lack the resolution, either from the constraints of a limited choice of contributory factors or from the problems of recording circumstances "after the event", to record the role spray may (or may not) have had on the cause of the accident.

The only method by which the role of spray in accidents can be established is if the recording process has the ability to both identify and record this occurrence.

What must also be considered is the effect of spray on speeds. Drivers may become accustomed to the reduced level of spray and increase their speeds. However, the reduced level of spray does not imply that the wet skidding resistance has improved thereby reducing stopping distances.

UK legislation

The forthcoming introduction of the EC Spray Reduction Directive is unlikely to make a significant difference to levels of spray from vehicles that already meet BS AU 200.

The issue of the percentage of vehicles falling within the scope of legislation but exempt from requirements could not be established as this would require analysis of licensing information. However, a new research project funded by the Department for Transport (Project Number: S0131/VE: "Integrated safety guards and spray suppression for HGVs") will:

- review the various exemptions from fitting side/rear guards and spray suppression in the current directives/regulations;

- examine current Construction & Use regulations, EC directives and UNECE regulations for front/rear under-run and side guards, recognise any conflicts that may exist between the requirements and identify the benefits of vehicles being fitted with integrated side/front/rear guards;

- identify the safety and cost saving benefits in vehicles being fitted with 'smooth' side guards as opposed to the two rails that are currently normally fitted;

- investigate and propose remedial solutions to the side guard height problem with UK & continental truck/trailer compatibility;

- develop a test method that would effectively measure the performance of a aerodynamic spray suppression system, and allow a comparison to the types that are currently fitted to HGVs;

- analyse and determine the cost benefit for combining integrated side guards with an aerodynamic spray suppression system for HGVs; and

- consider the impact that any regulatory proposals that might emerge from this research will have on business and society.

Therefore, the results of this project should address many of the issues raised in this report.

3.11 Road markings

Road markings (now specified in CEN Standards as "horizontal signs") are widely used in the UK to delineate lanes, mark give-way and stop lines, and for hatched areas.

In this section, only road markings used to delineate lanes and carriageway edges will be considered.

The practice of the 1970s and 1980s to replace lines on a four year cycle (25 per cent per year) has been made untenable by the continued increases in traffic levels.

Lines are specified to comply with relevant standards (including skid-resistance) based on road type or application, however, the service life of a line is not normally specified. Lines commonly last for only a small percentage of the service life of the surfacing and their condition needs to be monitored to maintain their efficacy. The installation and subsequent replacement of lines make up a substantial part of the whole life cost of a road, particularly since the life of current road marking materials can be relatively short.

Most road marking contracts make reference to what is known as the functional life of a marking, which relates to the period in which a new marking will fulfil all of its specified performance criteria. The normal functional life period for a marking would be two years.

Edge lining and centre markings

Lines are made conspicuous by their contrast with the surrounding road surface. Contrast will vary depending on conditions (*e.g.* light/dark/wet). Certain types of line (typically used on edge lining), which have a higher profile and surface texture designed to generate vibration and noise in the passenger compartment, may also have greater conspicuity, particularly in the wet, as their surfaces may project above any standing water on the road. Conversely, contrast can be reduced when a white line is placed on a lighter Portland cement concrete road surface.

Certain proprietary markings such as Rainline primarily use higher surface relief to enhance wet weather visibility rather than to provide a vibrational cue to alert drivers that they are moving outside of the lane.

When high friction surfacing is laid, lines are commonly masked and later re-exposed to save re-laying them. Recessed lines are not only less conspicuous to the driver but can also lie under pools of water thereby reducing retro-reflectivity and contrast. These issues are made worse when the lines are recessed in light coloured high friction materials further reducing contrast.

Night time retro-reflectivity (reflected brightness as measured in milliCandellas: mCd) may be enhanced through the surface application of glass beads (ballotini) enabling lines to be seen in the dark when illuminated by headlights, although this requirement is not called up universally.

Performance surveys

The durability of road markings is a common concern. In addition to a very few local authority surveys of the condition of road markings, the Road Safety Marking Association (RSMA) has recently commissioned an ECODYN survey of several routes to measure the condition of white lines. The RSMA kindly provided the raw data from this survey for analysis as part of this study.

The ECODYN device was developed in France by Prismo in the early 1980s as a high-speed survey tool for measuring white line condition and was first used in the UK in 1984. Now ECODYN is used routinely on trunk roads and its output has been integrated into the Highways Agency PMS (Pavement Management System). ECODYN can also provide post installation measurements for contract lining where confirmation of as-laid performance is needed.

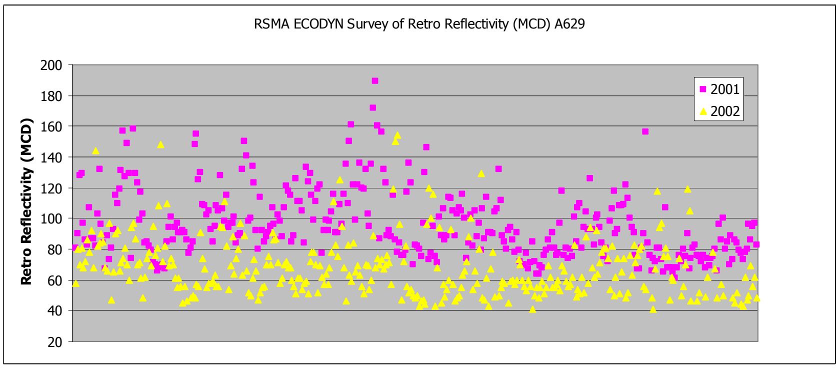
The more common visual surveys of line condition identify a line with less than 70 per cent of its original "footprint" as due for replacement, whereas the Highways Agency's Specification proposes replacement at a level of retro-reflectivity at or below 80mCd.

2002 was the first year where ECODYN data for two consecutive years could be compared to attempt to quantify the changes over a 12-month period.

Unfortunately a lack of locational referencing within the individual road lengths prevented a precise correlation between each year's data.

Figure 3.19 is a simple graphical representation of the changes in retro-reflectivity (reflected brightness measured in MilliCandellas (mCd), data for 100m section averages) over the 12-month period for one of the routes surveyed. This illustrates the apparent deterioration in the condition of the lines over the year between surveys.

Figure 3.19 Illustrates two typical plot of retro-reflectivity for route in the RSMA ECODYN 2001/2002 Survey



What must be observed is the potential for the retro-reflectivity to drop from an initial maximum high as the beads applied to the surface are lost, then to increase to a longer term equilibrium established shortly afterwards (with the onset of the exposure of new glass beads within the mass of the line as it slowly wears away).

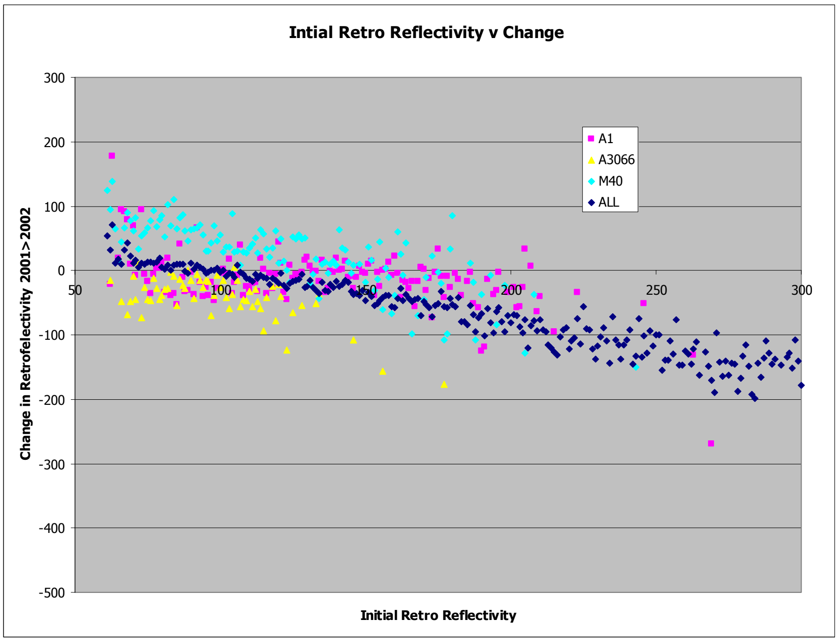
Retro-reflectivity is the most common parameter used to describe the performance of lines. However, the ECODYN survey also records day and night contrast, but this information is not used in any analysis as no specification for contrast exists in the UK or in the EU; also, there are issues with the precision of the present measurement method. Visual/video surveys are most commonly used to measure the percentage of the line remaining in place without considering their performance in the dark.

Observations on the RSMA data

There appears to have been little published research on the rate of deterioration of the line with time and unfortunately without knowing the age of the lines, only the last year's reading can be compared with the loss in retro-reflectivity that occurs in the following 12 months.

Taking on board the potential problems with precisely linking the 2001 reading of a section to that made in 2002, Figure 3.20 is the plot of 2001 retro-reflectivity against change in retro-reflectivity over the 12 months intervening provides a useful indicator of the general condition of the lining on a route and may point to evidence of the replacement strategy employed.

Figure 3.20 Change in retro-reflectivity (2001 to 2002) versus initial retro-reflectivity for 2001: RSMA ECODYN SURVEY



This plot appears to identify where lines have been replaced (new lining shows as an increase in retro-reflectivity between 2001 and 2002) This indicates replacement is generally taking place when retro-reflectivity is well below the proposed Highway Agency investigatory level of 100mCd and the minimum level suggested by the industry.

What can also be seen is the difference in the distribution of data for routes considered one of the best (the M40) and one of the worst (A3066) by the RSMA. Figure 3.20 suggests the M40 shows evidence of widespread replacement of lining at 150 mCd and below whereas the length of the A3066 tested shows little or no evidence of any line replacement even where the retro-reflectivity is well below the proposed Highway Agency investigatory level of 100mCd and the minimum level suggested by the industry.

Figure 3.20 does also suggests that there is a noticeable reduction in early life retro-reflectivity likely to be caused by loss of the surface applied ballotini.

Tests may have to be carried out in a controlled environment to establish the parameters for using these values on a regular basis in the UK.

Table 3.5 summarises the RSMA ECODYN survey results with deterioration on all but two of the 29 routes. There is cause for concern that so many sections fall below 80 mCd in this relatively short period, with those on trunk roads requiring replacement.

Table 3.5 Summary of the RSMA ECODYN survey

Route	Change in Percentage of Sections below 80mCd 2001-2002
B1403	91%
A629	54%
A352	52%
A59	50%
A356	46%
A45	45%
A303	43%
A161	42%
A3066	37%
B3181	35%
A56	32%
A7	30%
A709	28%
A66	28%
A671	27%
A1	26%
Average	**21%**
M69	21%
M62	16%
A68	15%
A361	14%
M6	11%
A75	8%
A6088	7%
M1	6%
A359	5%
A46	5%
A373	4%
A358	-4%
M40	-17%

There has been little research carried out to quantify the effect of road markings on accidents. Safety schemes commonly combine lining with many other features such as signing and surfacing changes making the contribution of the lining alone to improving safety difficult to measure.

The effect of road markings on accidents

Research carried out in the early 1980s (Road Marking Industry Group (1981)) suggested a reduction of 5 per cent to 66 per cent in night-time accidents could be achieved by the use of edge lining or reflectorised edge lining. The greatest improvements were in reducing single vehicle 'loss of control' accidents, head on collisions and accidents away from junctions.

However TRL research (Willis, Scott and Barnes (1984)) showed no evidence of reductions in accident frequencies at edge-lined sites, an increase in night time speeds was also observed for some sites though few night time measurements were made.

A study of the MOLASSES database by the RSMA (RSMA/ARTSM (2001)) reported a 32 per cent reduction in the total accidents for 48 schemes where lines only were used, however the individual accident changes for each site were not stated.

Hampshire used edge marker line on a scheme on the A287 where no other measures were used, 10 accidents during a three-year before period reduced to 5 in three years after.

A study of schemes using only road markings in the TRL MOLASSES database revealed an average accident reduction of 19 per cent for the 94 sites during 1983 to 1997.

More recently, the use of high performance road markings has been investigated by Hertfordshire and the study shows mixed results, as can be seen from Table 3.6. These sites used lining as the only improvement unlike other schemes where many other strategies were combined making the precise contribution of the lines difficult to quantify as the evidence was conflicting.

Table 3.6 Accident changes on several Hertfordshire sites where lining alone has been used as an accident reduction measure

Before Accidents (3 Years)	After Accidents (3 years)	Cost (Accident Change)
10	20	Cost £7420 (+100 per cent but Accidents in the dark dropped from 8 to 5)
21	6	Cost £2,947
5	1	£856 (-80 per cent)
7	5	£1,630 (-28 per cent)
5	10	£3,893 (+100 per cent,

Easier to see, easier to speed?

One authority has reported an increase in accidents on at least one location. Comments from drivers using the section in question suggested they perceived the lines to be better in wet conditions, which was reported to inspire more confidence, and hence increased speeds.

There may be a need to examine the effect on road user behaviour of improving the visibility on a route. Both the surfacing and the infrastructure (curvature, signing, skid resistance) need to be appropriate for a potential increase in road speed that might result from the better delineation.

3.12 Road studs

The conventional self-illuminating road stud, known to millions as the "catseye" (the term is in fact a registered trade mark of Reflecting Roadstuds Limited), refracts and reflects the light from vehicle headlights to provide additional guidance to the night-time driver.

Originally patented in the 1930s by Percy Shaw and still manufactured by Reflecting Roadstuds Limited, generic embedded cast iron housings that protect the "catseyes" in rubber inserts that clean them are still in production and make up about 75 per cent of all installations. Surface mounted reflectors are significantly cheaper to install and can provide superior levels of reflection but are more prone to damage or loss.

The relative ease of installation, the efficiency of alternative surface mounted devices, and subsequent maintenance issues need to be taken into account when making a choice.

"Intelligent" road studs: IRS

A recent development is that of the self-illuminating or so-called "intelligent" road stud (IRS). By means of a solar cell and LED array, the stud delivers illumination independent of vehicle lighting striking it. The LED assembly is automatically activated at night or in response to other circumstances.

Astucia invented and patented the technology in the 1980s and were the first to install IRS devices complying with UK regulations in the mid 1990s at a site in Wakefield in West Yorkshire.
.
The "intelligence" of IRS systems is their ability to detect conditions such as low ambient temperature, surface water or low visibility. "Intelligent" studs can even provide illuminated trails behind vehicles that pass them or indeed provide, through an array of the devices, a warning to a vehicle when following too closely.

Potential exists for not only the studs to communicate with each other to provide strobe lighting but also to receive instructions (to illuminate en mass for lane marking purposes) and to send information to traffic control centres, by detecting stationary vehicles on the hard shoulder.

Owing to the hostile environment the studs are placed in, issues of durability, structural integrity and additional cost have to be offset against the benefits of the new technology. IRS devices are likely to be as resistant as any other surface mounted devices to damage from metal tyred vehicles such as vintage traction engines and agricultural implements.

The latest designs used in other countries and awaiting UK approval have a far lower profile and thus offer further improved resistance to the effect of extremes of traffic loading. They are also of an encapsulated design giving superior resistance to the encroachment of moisture.

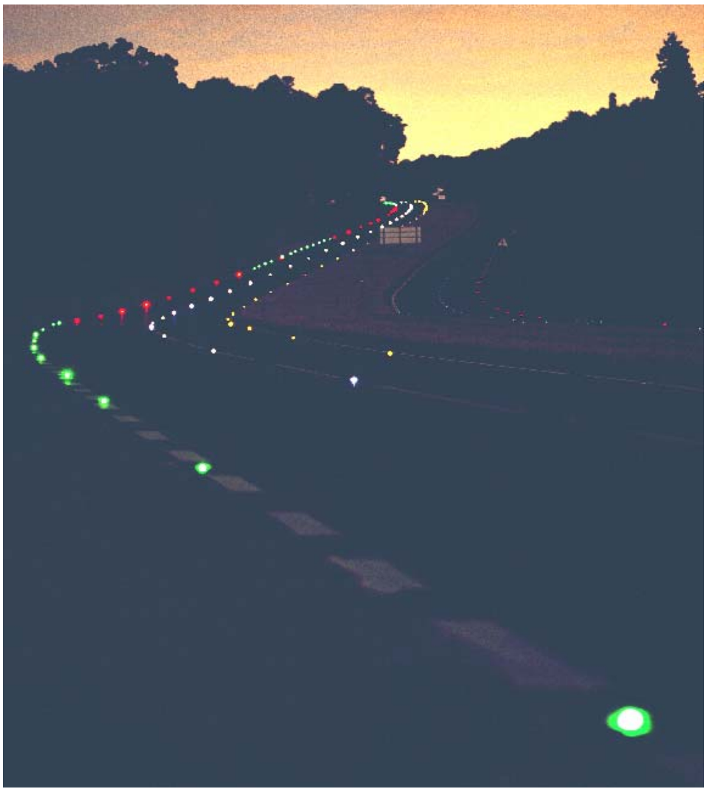
IRS and road safety

An investigation in the late 1990s in The Netherlands (Provincie Noord Holland (1999)), using only IRS studied the use of brakes at night. It was observed that braking in response to oncoming traffic on a bend was reduced by 75 per cent. Without oncoming traffic, the use of brakes was reduced by 40 per cent. Positioning on the road with respect to oncoming traffic was also improved.

In the UK a number of trial sites may be used to assess the efficacy of these devices:

Milton Keynes Council's site between Calverton and Stony Stratford was recorded as having significantly reduced accidents.

Figure 3.21 Dorking A24 site (Astucia)



Norfolk County Council's site at Haddiscoe (with approximately 95 per cent of accidents being loss of control) resurfaced the road to improve skidding resistance and used IRS (solar powered road studs on the centreline only) to improve driver guidance in dark/low visibility conditions. In the 3 years prior to the scheme there were 22 recorded accidents (2 fatal, 6 serious, 14 slight) 40 per cent occurred in dark and 65 per cent on wet road (a high number appeared to be during damp misty conditions). In 2 years and 2 months after the scheme there were 5 recorded accidents (all slight), all of which were in daylight with 1 in the wet.

The true measure of IRS?

A more comprehensive measure of the performance of IRS may be established shortly from the accident data from a new Surrey County Council site on the A24 between Leatherhead and Horsham, which has over 1000 IRS in four colours to delineate centre line, offside and nearside edges, entrances, exits and lay-bys.

There had been concerns about safety on this stretch of road for a long time and until major improvements could be agreed and implemented, the Council welcomed any measures that added to the safety of this stretch of road.

3.13 Lighting

Street lighting and vehicle lighting are two areas with their individual histories of development and improvement. This report will comment on the effect of street lighting on accident reduction and the influence of road surface characteristics on artificial lighting and natural light.

The negative effects of street lighting both, as a source of light pollution and its role on decision making at rural junctions are new areas of concern for the lighting engineer.

Studies continue into the complex behaviour of the eye at reduced lighting levels and recent work (Murray *et al.* (1998)) has established the existence of a critical luminance level below which movement is not readily detected. The same work indicated that the detection of small low-contrast objects resulted in substantial increases in stopping distances when compared to those for larger high-contrast objects.

Artificial lighting and accident reduction

Lighting may be introduced as both a safety measure to reduce accidents by an improvement in visibility for road users, including pedestrians, and also to reduce crime and increase the confidence of pedestrians who make journeys at night.

Research by TRL (Scott (1980)) identified a strong link between average road luminance and the dark:day accident ratio.

The Highways Agency publication TA 49/86 -"Appraisal of new and replacement lighting on trunk roads and trunk road motorways" sets out the ways of calculating the cost benefit of providing lighting or replacing old lighting systems. Although the Institute of Lighting Engineers considers this document out of date, the principles still apply and the Highways Agency and its agents generally use it for this purpose.

The principles set out in this document relate solely to reduction in accidents and are therefore limited to trafficked routes and do not take account of crime reduction and environmental impact.

The process of identifying a night time accident problem leading to the introduction of lighting will vary from authority to authority, however, there does not appear to be any obligation to carry out an accident study after the introduction of the scheme in order to establish its efficacy.

Lighting on rural roundabouts may be reduced?

Work in the mid-1990s suggested that for at-grade rural roundabouts (which normally require some lighting provision) the level of illumination could be reduced without a significant effect on accident numbers (Jacoby and Pollard (1995)).

Adoption of a 10 lux minimum level for the illumination standard was suggested as a means of reducing the amount of adaptation required by the eyes of a driver emerging from an unlit stretch of road whilst not jeopardising safety. The report observed a need to consider the local accident record and issues such as lines-of-sight when deciding on the level of illumination to be used. Fewer lighting columns result in clearer definition of the roundabout for the driver, less light pollution and fewer targets for impact.

Lighting and accident risk studies

Box (1989) conducted a 4-year before-and-after study of lighting improvements: lighting was installed on one side of a 2.8 km length of 18m wide roadway. Overall, night-time accidents were reduced from 31 per cent of all accidents to 23 per cent in the after period. The night time accident rate dropped by 36 per cent in the "after" period and there was a 14 per cent reduction in the overall accident rate.

Richards (1981) examined the effects of reduced lighting as an energy-saving measure. In this study, 72 miles of southbound carriageway had the lighting turned off whilst the northbound lane remained illuminated. The night accidents on the unlit side increased by 47 per cent while accidents on the lighted side and all daytime accidents decreased.

The possible negative contribution of street lighting at rural junctions

It has been suggested from TRL work that it may be safe to decrease lighting at junctions on minor roads because, at the greatest extent of lighting tested (180m),drivers accepted potentially less-safe gaps when turning right. (Fletcher (2000)).

CIE report on road lighting as an accident countermeasure

A Commission Internationale De L'Eclairage (CIE) report (CIE (1993)) studied 62 lighting schemes in 15 countries, and found that 85 per cent showed some safety benefit from lighting, of which about 1/3rd were statistically significant, with the reduction in accidents varying from 13 to 75 per cent.

The report concluded that the installation of lighting cannot be expected to result in a reduction in accidents if there is a major non-visual problem at any particular site and that the level of lighting at which there is no further decrease in accidents may be several times greater than national standards.

UK data from the MOLASSES database suggests that new lighting alone offers an average 27 per cent reduction in accidents (43 sites) and improved lighting an average 23 per cent reduction (25 sites).

Lighting and road surface characteristics: surface colour

Research in the 1960s identified the significant role that the reflectance of the surface has on the level of light reflection. TRL produced guidance for sourcing white- and light-coloured aggregates to this end in the 1960s (Road Research Laboratory (1966)), with a darker bituminous road surface providing less reflected illumination with the same lighting than a lighter Portland cement concrete road surface. Extrapolating this finding to the modern negatively textured surfaces with their open texture (which can reduce glare), it would be expected that they may require higher levels of illumination.

The measurement of the ability of the road surface to reflect light is already included in the calculations for designing new lighting schemes, however, the effect on existing lighting schemes of new "negatively textured" surfaces, which may not only be darker for longer but absorb more light into their more open textures, should be taken into consideration.

It should be noted that the use of lighter road surfaces can potentially reduce the efficacy of road markings by reducing contrast, this is particularly relevant to light coloured "buff" high-friction surfacing.

3.14 Observations

Fundamental properties of the road surface

When engineers and decision makers fully understand the dynamic nature of skidding-resistance, better use can be made of network-wide skidding resistance surveys, and specifications can be used to best effect.

Problems associated with aggregates delivering lower than expected levels of in-service skidding resistance need to be investigated carefully to ensure the materials used on site correspond to those specified before looking elsewhere.

The abrasion loss and polishing of aggregate was thought to be predominantly due to the action of goods vehicle traffic, but advances in braking systems, increase in performance and kerb weight of non-goods vehicles and the increase in traffic levels may require a review of our present understanding.

The effect of worn surfacings on the friction available at the tyre/road interface is discussed further in Chapter 4.

The Skidding Standard

After fifteen years, the Skidding Standard has proved its worth in contributing towards the accident reductions achieved in meeting the Department for Transport's target to reduce accidents by one-third by the year 2000 compared to the mid 1980s. Nevertheless, there may now be a need to review the Standard in the light of recent advances in surfacing technology and progressive change in the characteristics of the networks and the performance and secondary safety of the vehicles that use them. Parry and Viner (2003) describe a recent review of the existing policy.

Any data used pursuant to the implementation of a local Skidding Standard needs to be rigorously vetted to minimise the risk of erroneous safety critical decisions being made.

A Texture Standard

Engineers may look to in-service texture depth studies to provide the next component of improvement in their continuing drive to meet both local road safety initiatives and deliver the targets of the Department for Transport's new Ten Year Plan.

The Skidding Standard and the NRMCS

Ideally the NRMCS indicator should be reconfigured to compare skid resistance with the investigatory level for each site category on each road class. It is suggested that the indicator would be best served by presenting the mean skid resistance deficiency (MSSC minus investigatory level) across each site category, irrespective of road class. This approach would highlight deficiencies at high-risk sites where a lack of the required skid resistance may have a potentially greater influence on the risk of accidents occurring.

"New generation" surfacings

There is a general concern over the early life skid-resistance of the "new generation" of thin surfacings, whether generic or proprietary materials.

Although the HAPAS approval scheme gives the engineer a rapid route for the specification of "new generation" materials it does not generally provide any additional confidence in the areas of concern regarding early life skid resistance. In-service skid resistance testing using SCRIM is optional in the certification process and is rarely carried out, however, it cannot address issues of dry skid resistance.

A better understanding of both the wet- and dry- skidding resistance characteristics of these new surfaces and the way these change with time in relation to traffic intensity is needed to enable a standard procedure for identifying, monitoring and signing those which may constitute an increased risk to the motorist.

Retexturing

It is recognized that these processes may not restore the surface characteristics for as long as, or to the same level of, a new surface, but at, say, 10 per cent of the cost of some alternative options, the improvement in microtexture may be at least sufficient to "tide over" a site that needs immediate treatment until the following season.

It is noteworthy that the environmental and sustainability effects of retexturing rather than resurfacing are often overlooked, especially where high PSV aggregates are a scarce resource.

High Friction Surfacing: HFS

As a thin but high strength layer, HFS must be used wisely with the understanding they may not survive for long when installed on very high traffic and/or high stress sites outside the BBA/HAPAS requirements for the material type.

Rates of return and accident savings commonly quoted as achievable using HFS may need to be revisited in the light of improvements in the skidding resistance of the network as a whole since the 1970s, and with the general reduction in accidents in the last twenty years.

However, despite a limited number of shortcomings HFS has been shown by new analysis of the MOLASSES database as part of this project, to provide the engineer with one of the highest levels of accident reduction combined with an acceptable first year rate of return.

The MARS project

The MARS project has set the benchmark for future joint ventures between highway specialists and tyre technologists.

Spray

Increasingly, the use of negatively textured surfaces will reduce the amount of surface water available for entrainment by vehicles.

More work is needed to establish the accident risk from spray; to achieve this, the factor would need to be incorporated as a recordable factor in the STATS19 personal injury accident database. The role of poor visibility from spray contributing to general driver fatigue rather than immediate risk may be worthy of investigation.

The use of the TRL spray measurement device to quantify both the vehicle-generated and surface generated components of spray would greatly assist new developments. The use of TRL device, or a variant thereof, may enable the efficacy of spray suppression devices that would presently fail the existing product based assessment to be established.

Road markings

The network-wide routine measurement of retro-reflectivity may now occupy the position that monitoring skidding resistance had twenty years ago. As the drive to reduce road casualties gets higher on the agenda, saving some casualties as the result an effective testing and replacement strategy for markings may increase in priority.

The performance of markings may be simply maintained by a prioritised network-wide annual application of a thin veneer of lining and beads (just before the dark winter nights set in) to refresh the existing lining. Network-wide surveys are needed to identify routes where this cannot be achieved because of excessive erosion where total replacement of the line is required rather than a thin overlay.

The use of new road markings in safety schemes, as shown by an analysis of the MOLASSES data can provide a very cost effective accident reduction strategy. Work to determine the effect of edge marking on accident reduction has been inconclusive.

I.R.S.

The more sophisticated road stud is a promising development for certain accident prone locations. When it has been used for a longer period, it will be possible to compare the cost/benefit with other treatments.

As with markings, the improved guidance and driver confidence derived from the use of IRS devices must be supported by a road with a layout and surface characteristics capable of accommodating any resultant increase in speed.

Lighting

Generally lighting has been shown to reduce accidents.

Nevertheless, there is a need to carry out more routine before and after accident studies for lighting schemes. This information will not only provide a better measure of the efficacy of lighting in reducing accidents in the UK but will also identify other locations (in addition to those identified by Fletcher(2000)) where lighting may potentially increase accidents or lead to "less safe" driver decisions.

The inclusion of light, including sunlight and artificial light, in the contributory factors recorded at the scene of an accident should provide more information on their influence on accidents. In time, this should lead to some assessment of the desirable surface properties of a road.

The benefits to be gained from the illumination provided by additional lighting columns need to be balanced against the significant risk these additional columns may pose, if unprotected, to impact by vehicles. Also, there is concern about light pollution, but this can be reduced by redesigning the lighting units.

3.15 Conclusions

Surfacing materials do not always deliver appropriate levels of both macro- and micro-texture throughout their service lives:

- Accident rates increase markedly at low levels of macro-texture.
- *There is a need for a standard for macro-texture on in-service roads.*

The Skidding Standard.

The Skidding Standard has provided a soundly-based structure for the effective allocation of resources to maintain the frictional properties of the Highway Network:

- The Standard has been in operation on trunk roads and motorways since 1988.
- A Code of Practice, similar to the Standard, has been established by local authorities for their highways.
- *There is a need to establish the contribution that the Skidding Standard has made to accident reduction since 1988 and to ensure it continues to meet the needs of the roads of the 21st century*.

The National Road Maintenance Condition Survey (NRMCS).

The new skid resistance indicator in the NRMCS provides a single benchmark statistic for the overall skid resistance condition of the highway road network. However, this single statistic does not reflect the distribution of skidding resistance deficiency, or its consequential effects on accidents, across the network:

- On low risk sites, making up a substantial proportion of the network, there is a small increase (5-10 per cent) in the risk of a wet skidding accident occurring.
- On high stress sites, which make only 10 per cent of the total network, there is a much larger increase in the risk of a wet skidding accident occurring.
- *A more detailed NRMCS skidding resistance statistic, possibly associated with the risk rating of the site, is needed in order to represent the national situation.*

Negative texture "new generation" surfaces.

New generation surfaces (often "low noise") have lower early-life, dry-skidding-resistance than that which they were designed to deliver over the long-term:

- Early on, these surfaces can be as slippery in the dry as in the wet.

- Most local authorities do not have the means to measure or monitor dry skidding resistance.

- *Technologies should be developed, and local authorities equipped with the means, to quantify the risk that these surfaces may pose to the driver and develop strategies to alert them of it.*

- *The industry should develop processes for improving the early-life characteristics of new surfacings.*

Retexturing.

The mechanical treatment of a sound road surface to restore skidding resistance and texture depth can provide an effective short- to medium-term solution to micro- and macro- texture deficiencies, which may need treatment more immediately than can be achieved by conventional resurfacing techniques:

- Retexturing may cost only 10 per cent of that of resurfacing.

- Retexturing is environmentally friendly.

- Retexturing does not require any new materials such as scarce premium aggregates.

- Retexturing may only be a short-term solution on highly trafficked or stressed sites.

- *Retexturing should be considered where restoration of aggregate properties is needed to return the road to an acceptable condition.*

High friction surfacing (HFS).

High friction surfacings are extremely effective in reducing accidents at high- risk sites:

- On bends, HFS can reduce accidents by half.

- HFS can now be specified through a BBA/HAPAS scheme, which assures appropriate performance at high-stress locations.

- HFS is not a panacea for all high-stress locations; account should be taken of the probable durability of the various types at the specific location so that the treatment is cost effective.

- *Engineers should be selective in the use of HFS, ensuring that it is the most appropriate treatment. Information should be collected on the performance of materials so that the assurance provided by the BBA/HAPAS approval system is enhanced.*

Spray

Spray suppression devices and negative textured surfaces have improved the wet road driving experience in the UK:

- Many vehicles, including those from other countries, those under 12 tonnes, bulk tankers and tippers, may be partly or wholly exempt from the UK legislation.

- The development of more effective types of spray suppression is restricted by the present material-based specification for spray suppression equipment.

- *The EC needs to develop a performance-based specification for spray suppression devices and the UK government should review current exemptions in order to improve further driving conditions in the wet.*

Road markings and Intelligent Roadstuds (IRS)

The installation or upgrading of carriageway markings can significantly reduce accidents:

- Studies have shown that a 20 per cent reduction in accidents for local area safety schemes can be achieved.

- There is conflicting evidence on the accident reduction achieved by the use of edge-markings.

- The use of Intelligent Road Studs (IRS) may represent the logical next-step in road markings because they transmit dynamic information to the road user in a way similar to that of roadside intelligent traffic systems.

- *More research is needed on the long-term functionality and durability of road markings and their role in accident reduction.*

Highway lighting.

The installation or upgrading of lighting has generally proved effective in reducing accidents:

- New lighting schemes have reduced accidents by up to 25 per cent when used in local area safety schemes.

- However, some studies suggest lighting may have a detrimental effect on accidents when used on isolated rural junctions.

- *A more detailed review is needed of the effect of lighting on accidents at isolated rural junctions.*

Chapter 4 Friction and the Tyre-Road interface - the effects of worn tyres and worn roads

4.1 Backgound

At the tyre-road interface, many mechanisms influence the control of the vehicle and the safe negotiation of particular situations will depend on the relative importance of them.

The mechanisms involved in rubber sliding friction are adhesion and hysteresis; adhesion is controlled by the interaction of the sliding faces at the molecular level and hysteretic energy losses occur in the rubber as the result of deformation as the tyre slides over the surface, with the level of energy loss being determined by the shape and frequency of the surface asperities as well as the properties of the tyre rubber. Adhesion dominates when intimate contact can be made between dry rubber and a dry road surface.

The geometry of the road surface has a greater influence on friction when intimate contact between the tyre and the road surface is lost due to the presence of a water film. At low sliding speeds, the finer scale surface geometry determines the degree to which the water film can be penetrated and adhesion re-established. This is assisted by the larger-scale surface roughness, which enables the water to be drained from the contact area. As sliding speed or water-film thickness increases, adhesion is lost and the large scale surface geometry controls the level of friction due to hysteretic losses in the rubber. The visco-elastic properties of the rubber can be optimised by using various polymers and fillers and are dependent on temperature and deformation frequency.

The interaction of these mechanisms will be manifest in the stress distribution at the tyre-road interface, which is determined by the road surface texture shape and geometry as well as the condition of the tyre. The available friction will be affected by the contact geometry at the tyre-road interface and the extent to which water can drain from the contact patch, as well as the presence of any local contaminants such as oil or other detritus on the road surface.

4.2 Practical implications

The ordinary motorist needs sufficient friction between the tyre and the road to generate forces that will react against the brakes, or against the side forces when cornering, that allow the car to complete a particular manoeuvre. From a general perspective, the coefficient of friction between the tyre and the road is usually high in dry conditions, but when the road is wet the available friction will be much less and also decreases as speed increases.

The tyre, too, influences the available friction, with different compounds giving different levels of grip. Tyre manufacturers use different compounds and tread patterns in order to maximise available friction depending upon the circumstances in which a tyre is expected to be used, and these are usually a compromise between wear and performance. In some countries with markedly different weather and temperature conditions at different seasons of the year, drivers may have two sets of tyres with different compounds or tread patterns for use in winter or summer.

The highest friction levels on any particular road are likely to be achieved when tyres are new. When the road is dry, the new tyre polymer can grip the surface and when it is wet, not only is the new polymer better able to grip the relatively dry part of the contact patch, the full tread depth is available to assist in the bulk removal of water and offset any shortcomings in the road surface texture.

However, as the tyre wears and ages, it is likely that available friction will be reduced. The tyre tread compounds will gradually harden, reducing the maximum grip that can be achieved, but the greatest influence is in the reduced tread depth as the tyre wears. The reduction in tread depth and hardening of the rubber reduce the size and flexibility of the tread blocks and hence the ability of the tyre to wrap over the surface irregularities and make intimate contact with the road.

Reduced tread depth on worn tyres has an adverse effect on friction at higher speeds in wet conditions because there is less scope for removal of bulk water and for hysteretic losses to occur. This is a particular potential problem when the surface is not just wet, but also has a film of water above the surface of the aggregate particles, as can occur in heavy rain. Research has shown that, for tread depths of 2 mm (above the legal minimum) and water film thicknesses over 2 mm, the available friction can be comparable to that with a smooth tyre.

In the UK, road surfacings are constructed with 'designed' frictional properties, taking into account the intensity of the traffic and the manoeuvres that drivers are likely to undertake at the specific location. However, the frictional properties vary seasonally with greater 'polishing' of the microtexture occurring during the drier summer period and with greater 'abrasion' leading to increased friction in the winter period. Also, the removal of water from the tyre/road interface, which is dependent on the surface asperities that are gradually reduced by trafficking particularly when very high temperatures are experienced. Therefore, worn surfacings will have reduced frictional properties but these properties are monitored on the principal road network and remedial work undertaken when the risk of accidents occurring has been considered to be increased.

The Highway Code gives typical stopping distances for dry conditions and these assume a typical average coefficient of friction of about 0.65 for the "braking" part of the process. While this is a reasonable "typical" value, the actual value in a specific situation can vary depending upon the extent to which the road surface has been polished by traffic and on the nature and condition of a particular vehicle's tyres. When the road is wet, the situation becomes much more complex, with substantial differences between peak and sliding friction and with variation in friction with speed. For these reasons, the Code makes a general comment that stopping distances in wet conditions are likely to be at least doubled. This implies that average friction may be reduced by fifty per cent or more, and standardised measurements of skid resistance demonstrate that this can frequently be the case.

Thus, it is not possible to give generalised values for parameters such as stopping distances because in any particular situation they depend upon the interaction of so many different factors.

Chapter 5 Road accident databases

5.1 Introduction

The dictionary definition of an accident is "an event without apparent cause; an unexpected event; an unintentional act".

The single largest database of personal injury road accidents in the UK is the STATS19 database maintained by the Department for Transport (DfT).

Ways of enhancing the information available in STATS19 are being considered in order to provide more details of the cause of accidents, which will provide an indication of the contribution that road surface characteristics make to road safety.

Insurance databases, the untapped data store

A large number of accidents not resulting in personal injury may feature in insurance claims for material damage, however, unlike other countries such as Sweden (where the insurers Folksam produce a biannual report of vehicle safety), the vast wealth of UK information relating to damage-only claims remains inaccessible. If this information could be used to identify clusters of non-injury claims that do not feature elsewhere, "accidents waiting to happen" i.e. those yet to result in injury, may be able to be identified.

5.2 The STATS19 database

The Central Government personal injury accident database STATS19 is a partnership between central government, local authorities and Police and exists primarily for the generation of national road accident statistics. However, it is used extensively by local authority practitioners for detailed analyses to identify accident "black spots" (commonly termed "clusters") in order to enhance road safety. Detailed examination of the STATS19 database was also considered appropriate for this project .

The analysis of the causes of accidents relies in the first instance on the accurate recording of accident location and the attendant circumstances.

Concerns: locational accuracy

A major concern for local authorities is the accuracy of the accident location information within the STATS19 record. Local authorities are playing a major role in checking their accuracy. Work forming part of the SolEuNet joint venture, described elsewhere, has shown that the quality of this locational data has improved markedly at a macro level over the 20 year period studied. Despite local authorities playing a major role in checking the accuracy, its suitability for applications such as cluster analysis is still of concern if it is not appropriately vetted using GIS to ensure that the locations recorded closely correspond to where the accidents actually took place.

It is important that local authorities do not expect or assume that a system developed to provide Central Government with broad accident statistics will contain information of sufficient resolution for a more detailed accident investigation and prevention programme without additional vetting.

STATS19: data vetting

It is possible for the text description of an accident to be used to verify the tabulated STATS19 data and about half of the Police forces do this either as an in-house role or with the assistance of the local authority prior to the data being sent to DfT. Several local authorities check the STATS19 records that are sent by the Police Force to the DfT.

Figure 4.1 shows the vetting procedure built into one accident-clustering package to ensure that the location of the accident corresponds to the STATS19 text description.

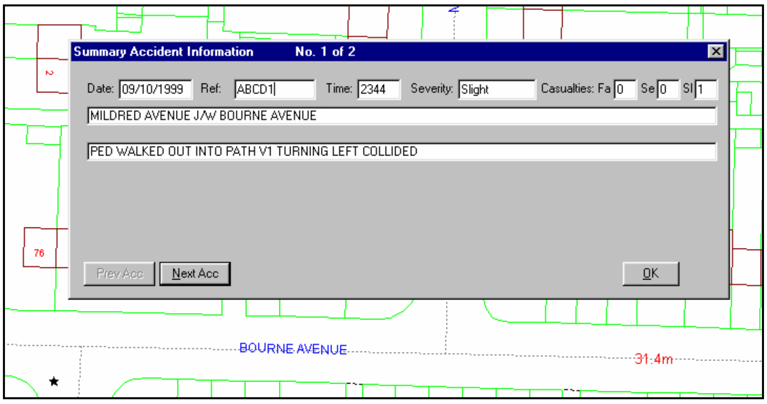


Figure 4.1 STATS19 data vetting: Buchanan Computing, data licensed from Ordnance Survey ©. Crown Copyright 2003. Licence Number 100027293

These procedures are not applied nationally; therefore, the locational accuracy of a significant proportion of the information in the STATS19 database may be inaccurate.

Limitations of STATS19

Although many local authorities aspire to improve the accuracy, delivering data with the accuracy required to enable STATS19 to be used as part of a detailed local authority accident prevention programme may be placing too great a burden on the Police officers involved in the collection process. Police Forces cannot be expected to record data with better resolution than Central Government require without additional resources from the end-users benefiting from it *i.e.* the local authorities. Onus ultimately has to be on the local authority partner to contribute most to the cost of enhancements.

Limitations of STATS19 in respect of this work

Taking these observations on accuracy into account, the STATS19 database was, by virtue of its sheer size, assessed to be a viable data source for investigating areas such as skidding and surface characteristics within the scope of this project . However, the in-house analysis of the dataset and the SolEuNet analysis (described later) identified that the "Skidding/Overturned" field is a very subjective record, which is prepared after the event. If skidding did occur, it is not recorded whether it resulted from a lack of skidding resistance of the road surface, or as a result of excessive speed or other driver error. Also:

- The influence of spray in precipitating or contributing to an accident is not recorded.
- No details of surfacing type or condition (micro- or macro-texture texture values) are recorded.
- Local speed limit is recorded without an indication of estimated vehicle speed(s).
- It should be noted that plans are in place to include contributory factors in STATS19 in 2005.

5.3 New data analysis tools

The STATS19 database for the period 1979 to 1999 contains approximately four million accident records linked to seven million casualty records linked to nine million vehicle records; it was considered appropriate to apply innovative data-mining techniques in the analysis of this extensive database.

Analysis of the STATS19 Database (combined with accident causation data) using Inductive Logic Programming (Progol) was carried out in 1997 (Williams *et al.* (1997)), however no significant factors were discovered from the analysis.

Data mining is an interdisciplinary activity involving many fields: databases, machine learning, pattern recognition, statistics, visualization, etc. It can be actively applied in many areas including: marketing, fraud detection, financial services, inventory control, fault diagnosis, network management, scheduling, medical diagnosis and prognosis, etc.

This project was fortunate to be given free access to the resources of SolEuNet (Mladenić (2001)), funded by the European Commission as part of the Information Societies Technology (IST) Programme.

Through Bristol University, SolEuNet kindly offered, in return for the experience of working with such a large database, to assist this project by applying the experience of the project partners to exploring the STATS19 database.

The SolEuNet partners included The University of Bristol, Katholieke Universiteit, Jozef Stefan Institute, University of Economics Prague, University of Oxford, University of Porto, and Robert Gordon University.

A significant number of outputs were produced by the partners, which identified that any analysis of the STATS19 database to establish relationships between surface characteristics and accidents would require links to other databases to be effective (Flach *et al.* (2003), Kavšek, Lavrač and Bullas (2002), Ljubič, Todorovski, Lavrač & Bullas (2002), and Todorovski *et al.* (2003)).

However, as the technique may have wider applications, the output from several of the SolEuNet partners was passed to the local authorities whose areas were studied.

Feedback from these local authorities provides an assessment of the value of using data-mining in this way. There were the usual concerns about this type of analysis, namely, separating the things of interest from the statistical artefacts, for example, when more accidents occur at one location in the first half of the year than in the second half without any apparent reason for it. Nevertheless, some situations were highlighted on the networks that engineers are currently investigating and this confirmation of their need to act was well received. In general, any technique that can provide the engineer with a means of prioritising their remedial work is welcomed, particularly when those with local knowledge can direct it.

Data-mining and STATS19

The analysis of the STATS19 Database performed so far by the SolEuNet consortium holds considerable promise for the application of these technologies to other databases currently analyzed with long-established processing tools.

The feedback from the local authorities confirmed that they already knew many of the patterns found in the accident record; this bodes well for a more locally structured analysis using the data-mining tools. Indeed the visualisation tools that were also used (Ljubič, Todorovski, Lavrač & Bullas (2002)), may be of value on a local level where expert knowledge can drive the direction of the investigation.

Future data-mining: accident characteristics and contributory factors

Analysis of the contributory factors now collected in tandem with the long-established STATS19 data may be an area where data-mining techniques may be usefully applied.

Contributory factors provide a more detailed insight into the causation of accidents. Indeed, the linking of databases recording skid resistance to those holding accident records would provide an ideal future application for the data-mining technology.

5.4 In-house STATS19 analysis: the possible effect of glare on accident risk

One of the objectives of this project was to investigate the influence of spray on accidents, however, as the role of spray is not recorded in STATS19, it was decided, with the assistance of Peter Ljubič from the SolEuNet team, to look for evidence of the role of glare on accident risk using the STATS19 data that was available.

STATS19 does not include any record of whether accidents are caused by the driver being dazzled. However, since the time of the accident and the direction in which the vehicle was travelling are known, a study was made of the distribution of vehicle direction against the time of day.

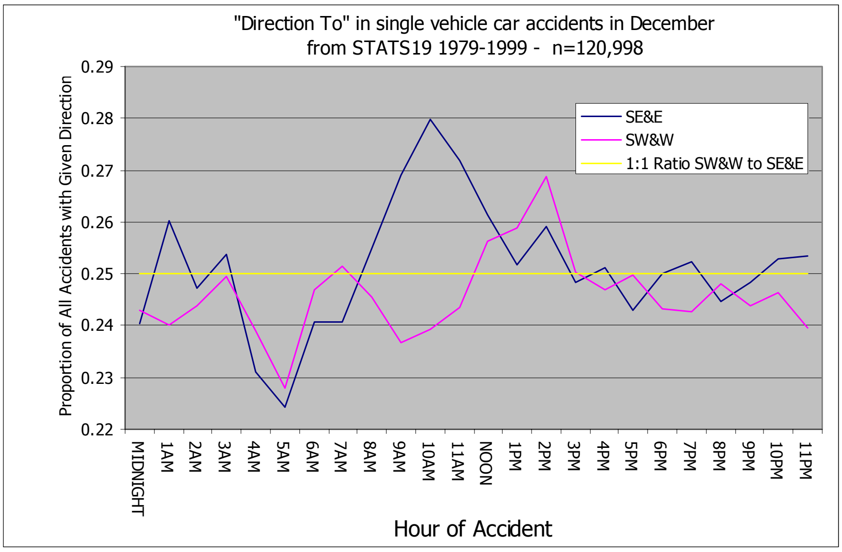
As it is not possible to establish the direction of the vehicle precipitating a multiple vehicle accident, the analysis of multiple vehicle accidents was considered unlikely to yield little about any influence of the sun; therefore, single vehicle car accidents were used as source data.

Also, as journeys to work do not vary markedly with the seasons, the absolute numbers of accidents per hour during rush hours are relatively consistent over the year . Therefore, the analysis looked at the whole database because it may be assumed there is no predominant direction of travel at any time .

Based on the above assumptions, the proportion of cars in single vehicle personal injury accidents travelling west and south west (sunset direction) and those travelling east and south east (sunrise direction) were compared with the recorded hour of the accident for December.

Figure 4.2 shows the proportion of accidents with cars driving to the East and Southeast appears to increase around sunrise time in December. A similar pattern was established for June with the shift to the East and Southeast earlier in the day reflecting an earlier sunrise. The graph is centred at the point where both West and Southwest and East and Southeast trajectories each make up 25% of "all directions" (as each group makes up two of the eight possible values for the "direction towards" STATS19 field).

Figure 4.2 Proportion of single vehicle car accidents by time and "to" direction (South east and south west versus all directions): December.



This initial study suggests there may be a small but measurable effect of glare on accident risk. Further work, combining the new contributory factors data with the STATS19 information used in this project, together with a more precise measure of the orientation of the sun with time and accident location, would confirm this effect.

Contributory Factor 46, "View - Glare from the Sun", featured in 0.9% (55) of a sample of 2795 accidents studied (Broughton *et al.*, 1998) including 0.3% (7) of these of these where it was given as a definite factor.

5.5 Developments in accident databases

Factors that precipitated or contributed to an accident now form a separate Department for Transport database. More than half of Police Forces already record Contributory Factors so that this information can be used by local authorities in their analysis. The first summary of this new data will form part of the annual "Road Accidents Great Britain" report in 2003. The data may subsequently be made available for research use and the integration of this new data with the existing STATS19 database would add greatly to its overall value.

The DfT Fatal Accident Database & the On-The-Spot (OTS) Project

1992 saw the successful setting up of agreements with all Police Forces in England and Wales to supply fatal accident reports, which were no longer needed for legal processes, to TRL. They would be stored and catalogued and the data from them made available to researchers investigating all aspects of road and vehicle safety.

The files provide a unique source of information for use in such research, containing a wealth of detail at relatively low cost, compared to the other two sources of data available for accident research. These other sources are:

i The STATS19 database, already described, which provides a very large sample size but the level of detail is limited.

ii Special in-depth investigations with a far greater level of detail such as those conducted by TRL with the cooperation of several Police Forces and hospitals. However, these are very expensive, and so have to be limited in both geographical area and in the type of vehicles investigated. Usually they concentrate on priority groups such as car occupants.

Police fatal accident files represent a halfway house between these two extremes, being far more detailed than STATS19 but far cheaper than the special in-depth studies.

A fuller account of the project can be found in Minton's publications.

TRL is also part of a two centre study of accidents via the 'On-The-Spot' (OTS) project when qualified accident investigators attend accidents and their reports augment past OTS studies.

The OTS project

The OTS process includes the collection of tyre condition data which could be a valuable addition to tyre condition information from national surveys and Police accident investigations.

The latest OTS project has yet to report and, as the data is not in the public domain, it could not be released for consideration in this project. The number of accidents studied will, however, be relatively small but the database should provide a valuable tool for refining the data interpretation process.

5.6 The MOLASSES database

The background to MOLASSES

MOLASSES is a database that contains information about local road safety schemes installed by local authorities in the United Kingdom.

The acronym MOLASSES stands for "Monitoring Of Local Authority Safety SchemES". The database was started in 1991.

The MOLASSES project was initiated by one of the sponsors of this project, the County Surveyors' Society's Accident Reduction Working Group (ARWG) in 1991. MOLASSES is now a joint project between TRL and the Department for Transport.

Using MOLASSES to measure effectiveness of schemes

For road engineers to make use of the data in order to assess the likely impact of their own remedial strategies, they need to be able to pinpoint schemes very similar to that proposed. MOLASSES potentially provides engineers with the tools to draw such comparisons. Unfortunately there are two main shortcomings:

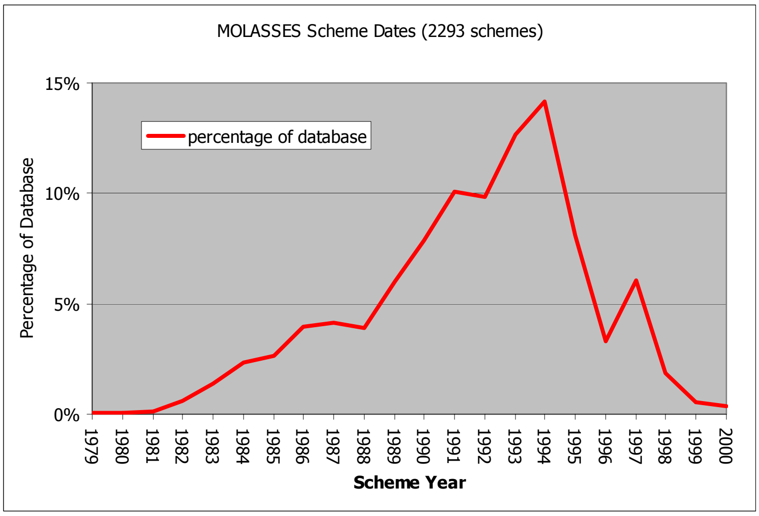
The MOLASSES database may require improved resolution, multiple "treatments" such as high-friction surfacing on a bend, a chicane and traffic calming may all be consolidated into a single entry in the MOLASSES database as an "area-wide " scheme. These schemes have been excluded from the latest analysis for that reason.

After an initial good response to the setting up of MOLASSES, the submission of data for more recent schemes has declined.

The practicalities of MOLASSES

A survey of 27 councils, carried out jointly between the CSS and the AA Foundation in 2002 (EuroRAP (2002)), showed that many accident prevention engineers are held back by a skills shortage and a lack of funding in the right areas, although nearly half of those questioned put the cost of measures per life saved at less than £50,000. The Department for Transport are likely to spend more than £10 Million in the next year on accident prevention engineering. As can be seen in Figure 4.3, the submissions began to tail off after 1994. Reduced spending on schemes may have been the reason but it cannot explain a reduction in submissions to this low level.

Figure 4.3 Distribution of MOLASSES schemes by year of completion



At present, the database records 4949 schemes, 4620 (94%) have a recorded year of completion, 2845 (57%) have valid accident data, and 4181 (84%) have a recorded scheme cost.

For the purpose of this analysis, the dataset was reduced from the 4949 schemes in the complete database to the 2293 schemes with a single scheme location of mini roundabout, roundabout, bend, priority junction or link, which is a length of road between two junctions .

The EuroRAP organisation recently commented (EuroRAP (2002)) on the general lack of investment by local authorities in low cost safety schemes. The MOLASSES Database records 1544 of such schemes, and the majority (64%) of these schemes cost less than £10k.

How to improve MOLASSES

The problems associated with canvassing interest in sending information for the MOLASSES database are two-fold:

1) Complex data submission procedures:

The earlier database relied on those contributing entering multiple values separated by commas and errors resulted in inconsistencies in the data.

The latest Microsoft Access version of the database is an improvement in this respect but it is still not particularly user friendly.

2) Lack of perceived value in terms of what those contributing could gain from their time spent in adding details to MOLASSES:

Following a meeting with TRL, the feedback regarding this project's attempts to utilize the MOLASSES database is to be taken on board.

The latest database constrains and simplifies the data entry process thus limiting the potential for variations in the data format encountered with the first version of the database. However the use of over 250 data fields in the new database makes the summarising and analysis of its contents virtually impossible without major re-tabulation and modification.

Analysis of the MOLASSES database

The MOLASSES database was seen as the only viable source of data for examining the characteristics of safety schemes utilising strategies within the scope of the project.

Section 3.6 details the analysis carried out on a modified version of the new MOLASSES database produced for this project.

5.7 Analysis of the MOLASSES database

The shortcomings of MOLASSES

The 2002 version of the database was kindly provided by TRL for this analysis.

The lack of resolution in the existing MOLASSES database makes comparing the performance of schemes with more than a single type of strategy, either with time or between locations inadvisable.

For the purpose of this analysis, the dataset was reduced from the 4949 schemes in the complete database to the 2293 schemes with a single scheme location of mini roundabout, roundabout, bend, priority junction or link, which is a length of road between two junctions.

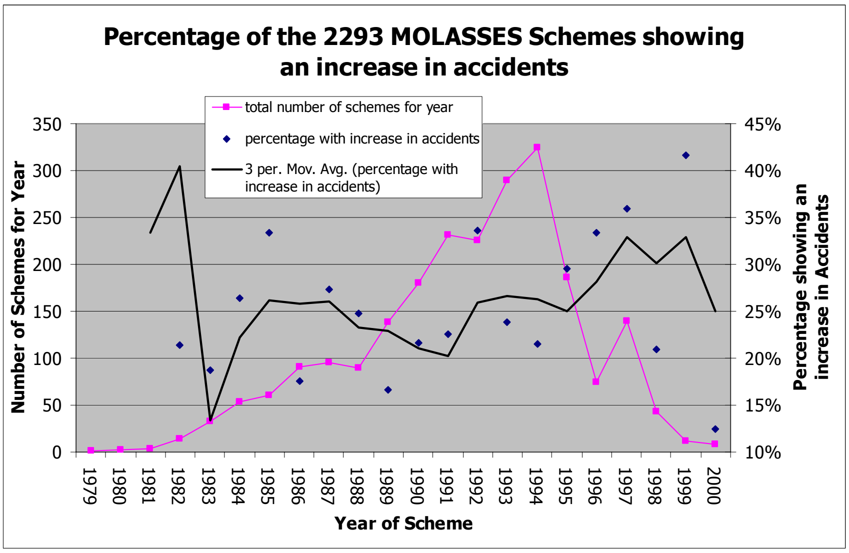


Figure 4.4 MOLASSES schemes: distribution of schemes showing an increase in accidents (n=2293)

The percentage of single location (non-area) schemes showing an increase in accidents per year after implementation has grown from around 20-25 per cent in the 1980s to approximately 25-30% in the 1990s, see Figure 4.4.

There may be scope for detailed analysis to identify the common features of schemes that result in an increase in accidents, however, without a measure of the change in accident levels for the surrounding network the change cannot be viewed in context.

First Year Rates of Return (FYRR) and accident reduction

First Year Rate of Return (FYRR) compares accident reduction to scheme cost as a measure of cost effectiveness.

First year rate of return is commonly defined as:

(Cost of a Personal Injury accident X Number of accidents saved per year X 100) / Cost of the scheme.

Prioritise for the best FYRRs or the greatest saving in accidents, not both.

However, a scheme, designed to reduce accidents from two to nil can only ever achieve a maximum accident reduction from two to nil, regardless of the expenditure on the scheme. Compare this to first year rate of return (FYRR) which is a function of accident reduction and scheme cost. Therefore, for MOLASSES schemes with a single strategy, a comparison was made between FYRR and accident saving.

As can be seen from Table 4.1 the highest rates of returns will not necessarily be achieved at the same time as the greatest reduction in accidents.

Table 4.1 FYRR ranking versus accident reduction ranking.

Location	Single Strategy	Average Change in Accidents	Average FYRR	Accident Reduction Rank (1 Greatest)	FYRR Ranking (1 Greatest)
Bend	antiskid	-54.6%	1050%	1	8
Link Calming	surfacing	-42.8%	1010%	2	9
Bend	signing	-32.7%	5533%	3	4
Roundabout	antiskid	-30.8%	1697%	4	6
Link General	new lighting	-26.7%	997%	5	10
Link General	improved lighting	-23.5%	2231%	6	5
Priority Junction	antiskid	-23.3%	500%	7	12
ALL	ALL	-21.7%	6973%	8	2
Priority Junction	markings	-19.9%	48525%	9	1
Link General	markings	-18.5%	5720%	10	3
MINI roundabout	antiskid	-11.3%	1198%	11	7
Link General	surfacing	-5.4%	968%	12	11
Link General	antiskid	-1.0%	161%	13	13

The content of the MOLASSES database includes identification of the strategies used for each scheme and, by identifying those that fell within the scope of this project, a measure of the efficacy of each together with the general effect of additional strategies on accident reduction could be carried out.

Analysis of data for MOLASSES schemes relevant to this work

Table 4.2 shows the average reduction in accidents between the location categories for single strategy sites where the treatment fell within the area of study of this project.

MOLASSES: Accident reduction achieved by relevant strategies

Anti-skid/high-friction surfacing as a single strategy shows an average accident reduction of 29 per cent (66 sites): 55 per cent on bends (18 sites), 31 per cent on roundabouts (15 sites) and 23 per cent on junctions (18 sites).

Road markings (of all types) as a single strategy showed an average 19 per cent reduction in accidents (18 per cent for 56 link sites, 20 per cent for 38 junction sites), for the 173 sites where markings were combined with another unlisted strategy the accident reduction increased by 3 per cent suggesting that road markings have a major role in accident reduction in their own right.

Surfacing treatments (excluding anti-skid) alone reduced accidents by an average of 8 per cent (43 per cent for 9 calming schemes, 5 per cent for 142 link schemes), when combined with another strategy the accident reduction increased to 40 per cent (17 link sites), for the nine link sites where surfacing was combined with road markings and a third strategy an average 48 per cent accident reduction was seen.

New lighting schemes showed an average reduction of 27 per cent (43 sites); the five sites where new lighting was combined with another strategy showed a lower average accident reduction of 6 per cent.

Table 4.2 Average accident reduction and count of the 526 relevant single strategy schemes identified from MOLASSES

Average of Percentage Change in Accidents (526 Schemes)	Strategy						
Location	Antiskid	Improved lighting	Markings	New lighting	Signing	Surfacing	Grand Total
Bend	-55%				-33%		-35%
Link calm						-43%	-43%
Link general	-1%	-23%	-18%	-27%		-5%	-13%
Mini Roundabout	-11%						-11%
Priority Junction	-23%		-20%				-21%
Roundabout	-31%						-31%
Grand Total	-29%	-23%	-19%	-27%	-32.7%	-8%	-22%

Number of schemes							
Bend	18				147		165
Link calm						9	9
Link general	11	25	56	43		142	277
Mini Roundabout	4						4
Priority Junction	18		38				56
Roundabout	15						15
Grand Total	66	25	94	43	147	151	526

Improved lighting alone yielded an average 24 per cent accident reduction over 25 link sites.

Antiskid/high-friction surfacing appears to be the most effective single treatment when used on bends. Signing alone on bends provides approximately half the accident reduction. Road markings appear to deliver a consistent 18-20 per cent reduction in accidents.

MOLASSES: accident reduction achieved by the use of multiple strategies

Table 4.3 shows a simple comparison of the total count of all the recorded MOLASSES treatment strategies (described in Section 5 of Appendix X, DfT (2003)) versus accident reduction for each of the 2293 schemes studied. In general, the more strategies, the greater the accident reduction, however, bends and junctions appear to benefit less from the use of more strategies. This may be where the prime strategy, such as antiskid surfacing, offers an initially high level of accident reduction.

Table 4.3
A simple comparison of the total number of strategies versus accident reduction for each scheme location.

Average change in Accidents	Number of Strategies recorded in MOLASSES database (2293 schemes)					
	1	2	3	4	5	Grand Total
BEND	-40%	-48%	-49%			42%
Link calming	-45%	-42%	-55%			-44%
Link general	-15%	-23%	-39%	-53%	-100%	-17%
Mini Roundabout	-27%	-53%	-100.0%			-30%
Pedestrian	-12%	-5%	-58%			-13%
Priority Junction	-32%	-31%	-29%	0%		-31%
Roundabout	-25%	-14%	8%			-22%
Grand Total	-26%	-30%	-37%	-35%	-100%	-27%

The need for the effective use of single and multiple strategies

By studying the changes in accident reduction for, say, antiskid surfacing, as more strategies are combined, the effect of these strategies on further accident reduction may be assessed.

The relative merits of the same single strategy between site types may also be studied, where sufficient sites exist in the database to provide a representative sample.

Issues arising from the analysis of the MOLASSES database

With a well-tabulated and robust database, it may be possible to predict the effect of a number of strategies for new schemes and to consider the likely contribution (and therefore the cost effectiveness through use of the FYRR) of additional strategies over the main treatment.

Likewise it may be possible to identify and amend/improve schemes likely to result in an increase in accidents rather than a reduction.

Either the best first year rate of return or the greatest accident reduction need to be set as objectives because the evidence suggests that they are not necessarily inter-dependent.

The information on the schemes needs to be up-to-date and this may need a concerted effort by the operators of the database and by the contributors.

The way ahead for MOLASSES

A uniform format for recording schemes with sufficient resolution to enable prediction to be carried out may be impractical within the limited resources of the MOLASSES project and its contributors. However, if such a database could improve the performance of schemes and prevent the use of incompatible or "low yield" combinations of strategies, the investment would be worthwhile.

The findings from the new analysis of the MOLASSES database carried out by this project broadly agree with the summary analysis of the database in 2001 (Gorell & Tootill (2001)). This TRL report appears to be the only published analysis of the MOLASSES database prior to the work carried out for this project.

The issues raised above will hopefully be addressed by providing an input method and back- end functionality that not only makes data entry simple but also provides the submitter with a resource for their own use.

If engineers are collecting data for their own use and, as part of that process, the same information can be input directly into MOLASSES with minimum effort, the database may well become an active and valuable tool for the development and study of new local area safety schemes.

5.8 Analysis of existing data provided by local authorities

In addition to the resources of STATS19 and MOLASSES, approaches were made through the County Surveyors Society and other local government bodies, including TAG (Technical Advisors Group) and LOTAG (LOndon Technical Advisors Group), journals and discussion groups, for data relating to local area safety schemes, in particular schemes and in particular those using strategies considered relevant to this project, as listed in the MOLASSES analysis.

The data collection exercise amassed data on over 2000 accident remedial and general resurfacing schemes (not already in MOLASSES) from 13 sources covering a 11 year period (1990 to 2001), 350 of these schemes were then classified as sufficiently detailed to provide the equivalent level of information to those schemes in the MOLASSES dataset.

As each authority submitted data from existing data stores in a unique format, the resource and time constraints of this project made the development of a small MOLASSES style database impracticable.

As there is no standard national format for recording data for local authority safety schemes, both the variable detail of information and the manner in which it was recorded provided a useful insight into why a working equivalent of MOLASSES is required to enable valuable information to be shared for the common good between local authorities.

There was some evidence of resourcing issues affecting the collection of “after” data, which is the accident information to support the efficacy of the schemes. Some authorities had a comprehensive list of schemes but the “after data” needed updating. Many schemes did not have associated costs preventing First Year Rates of Return (FYRR: a measure of cost effectiveness) being calculated.

Control sections and comparison with network wide performance

There was little or no evidence of the use of control sections or whole network benchmark levels of accidents and casualties to provide a statistical measure of the background change in accidents for the area where a given scheme was located. If accident rates or traffic flows have decreased over a whole area it can affect the significance of any changes for a specific scheme.

Leeds and several other authorities carry out a valuable prioritisation exercise in their annual “lengths for concern” exercise that identifies and prioritises accident sites based on their accident rates relative to the local area, the authority as a whole, and the country as a whole providing a relative measure of the severity of the situation at each location.

Integration of paper and electronic records

Records giving precise details of the layout and structure of schemes commonly existed but were not in electronic form and resources often did not exist to provide this even though it was often perceived as valuable because of the increasing need to satisfy 'best value' performance requirements.

The detail of information recorded

Some schemes were described in detail with up to 6 strategies listed, others had only a single category, which may or may not have had other associated works.

One particular recording system, TADS (the Traffic Accident Diary System of the London Accident Analysis Unit), generates a sequential record of treatments carried out over the life of a scheme and includes additional works carried out subsequently.

This contrasts with most systems, where the effect of further modifications to an existing scheme are commonly either not incorporated in safety scheme data or not flagged up in the records thereby reducing their value as a prediction/modelling tool for use elsewhere in the authority.

Accident data for local areas safety schemes

Accidents were variously recorded as serious slight and fatal, or slight and KSI (fatal & serious) and were expressed as accidents per year, with or without the number of years of study, or as absolute numbers.

The simple combination of schemes into treatment types again posed a problem as the data had to be converted to a common descriptive base together with the total ‘before’ and total ‘after’ accidents and the duration of 'before' and 'after' accident study in months.

Standard recording procedures are needed

There is a need for a nationally adopted format, along the lines of MOLASSES and STATS19, for recording local safety schemes and their effects. This would ensure that this data can be shared for the common good and provide the statistical rigour to support future decisions made on the basis of the performance of past schemes.

5.9 Observations

The STATS19 database

Continuing efforts by the Police, local authorities and central government have led to an improvement in the quality of data in STATS 19, particularly in locational referencing and the inclusion of Contributory Factors in the database will provide local authorities with additional information to support their accident prevention measures.

It should be noted that the Department for Transport's Standing Committee on Road Accident Statistics (SCRAS), provides the route for national issues (relating to the accuracy, content and logistics of collections and re-diffusion of the STATS19 data) to be addressed and SCRAS are proactive in this area.

However, what must be borne in mind is that the database is designed to provide statistics for central government; other users of the data must carry out their own vetting to ensure a level of resolution capable of providing the safety critical data for accident analyses. Any failure to either understand the limitations of the dataset or to adequately pre-vet data may result, at best, in wasted resources and, at worst, in a failure to identify a fatal accident cluster.

The future for data-mining accident data

Data-mining, applying complex modelling and prediction tools to large databases, is an increasingly common business tool. The same processes are likely to be effective when applied appropriately to accident databases. The efficacy of the data-mining is limited by the sensitivity of the data to reflect responses to the properties under investigation, as can be seen from the examination of the influence of glare from the sun on accidents. STATS19 did not provide sufficient relevant information to address the issues of concern for this project, however, the feedback from the results of the SolEuNet exercise suggest a future application for data-mining techniques with the STATS19 database, and with other large datasets held by national organisations.

The effective use of data-mining requires an effective liaison between the "data-miner", usually an IT specialist, and the provider of the accident data, usually from an engineering or road safety background.

MOLASSES

The MOLASSES database is a valuable resource of information on local area safety schemes but has shortcomings in terms of its architecture, subscription and resolution; it needs to be easier to add data and to offer better resolution as a prediction tool both locally and nationally.

A lack of investment in MOLASSES and a tailing off of contributions over the past five years has meant that it will be a number of years before it can be considered representative of present trends.

The work carried out on MOLASSES for this project represents only the second analysis of the database to be published and provides some valuable evidence of the way the efficacy of common single interventions can vary between different locations and the way additional strategies can affect safety.

Evidence has been found of the high levels of accident reduction delivered by high friction or other new surfacings together with variable first-year rates of return.

The analysis points to the potential for the same philosophy to be directed at a larger successor to MOLASSES and for a need to decide whether the greatest accident reduction or the greatest cost benefit should be the objective because both may not be achieved simultaneously.

TRL Fatal Accidents Database / OTS

The DfT Fatal Accidents Database offers a well established though under-utilised source of detailed fatal accident information. Data-mining techniques could be used with this database in association with STATS 19 in order to investigate in more detail the factors associated with fatal accidents.

The On The Spot (OTS) project will deliver an up-to-date pen-picture of the fundamental characteristics of typical road accidents. This will enable a review of the prioritisation of actions be undertaken.

5.10 Conclusions

STATS19 Database.

STATS19 is a valuable and continuously-improving database of information on personal injury road accidents in the UK:

- STATS19 provides data, recorded after the event, about the general layout of the accident location, the time and weather, and the vehicles and drivers involved.

- STATS19 lacks detailed information on the nature of the tyre/road interface.

- The inclusion of Contributory Factors in the STATS 19 data will provide an additional source of information on accident causation.

- *Studies of the Contributory Factors data included within STATS19 should be encouraged because they may provide a better picture of the circumstances leading to an accident.*

Data-mining and accident data.

Data-mining may provide a valuable tool for investigating trends, patterns and associations within databases:

- Data-mining relies on the "domain expert" to guide the data-miner towards new and relevant, rather than obvious and known patterns in the dataset.

- Data-mining may be effective on a STATS19 database containing contributory factors.

- *The application of data-mining to local authority accident data may complement existing established analytical techniques.*

MOLASSES

The MOLASSES database was established to provide information on the processes used in local area safety schemes and their subsequent performance:

- The MOLASSES database is a valuable central resource, detailing over 4500 local area safety schemes installed since the late 1970s.
- There has been a significant decline in submissions of new schemes from local authorities to the MOLASSES database since the mid 1990s.
- The overly complex database structure makes analysis difficult.
- *MOLASSES should be revised and made available on-line for the benefit of those investing time and resources in the providing data.*

Chapter 6 Overall conclusions

There are detailed conclusions in the individual chapters of this report and it is not the intention to rehearse them in this Section but to refine some strategies that could be developed to deal with some of the more important aspects.

In taking this step, it has been recognised that many of the factors contributing to accidents are not within the control of the vehicle, tyre or highway engineer. Therefore, the engineer has to pursue a course that will, as far as possible, remove these factors from the conflict situation, thereby reducing the risk of an accident occurring. It is proposed that this could be done by:

SMART tyre technology

- Prioritising the development of the SMART tyre technology whereby drivers are informed, by displays in the vehicle, of the condition of their tyres. In the interim, policies should be developed that provide greater assurance that the condition of tyres on the national car fleet comply with national Standards and with manufacturers' recommendations.

New generation road surfaces

- The new generation of road surfaces do not appear to have their designed frictional properties until they have been trafficked for a considerable, as yet undefined, period. Thus, there is a need to develop ways of advising the motorist of this situation and of accelerating the development of the designed frictional properties of the surfacing.

The STATS19 database

- The STATS19 database is being extended to include records of Contributory Factors to accidents as well as the information on location etc that has been routinely collected. All organisations should support the collection of this additional information because it will greatly assist the engineer in designing measures to minimise the risk of accidents occurring.

The MOLASSES database

- The MOLASSES database has provided very useful information on the performance of accident alleviation schemes. However, in recent years, there has been a marked reduction in the number of schemes that have been input into the database. This should be reinvigorated because this type of scheme has an important contribution to make to the 2010 accident reduction targets. A more comprehensive database will provide useful information for engineers, designing safety schemes, on the performance of measures that they are considering introducing.

The motorist exploiting safety factors

Various ways of enhancing the properties of the tyre/road interface have been outlined in this report. However, there is general concern about the ability of the motorist to exploit to the maximum the safety factors that the engineer introduces thereby mitigating the benefits to some extent.

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AA Foundation: Brian Langer (2001-2002), Ruth Bridger (2002), Dr Steve Lawson (2002-2004).

County Surveyors' Society: Steve Marsh (Leicestershire CC).

Hampshire CC (the host authority) were represented by Terry Lomas.

The Technical Director of the AA Foundation, Professor Rod Kimber, appointed Doug Colwill OBE, TRL, to chair the Committee.

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