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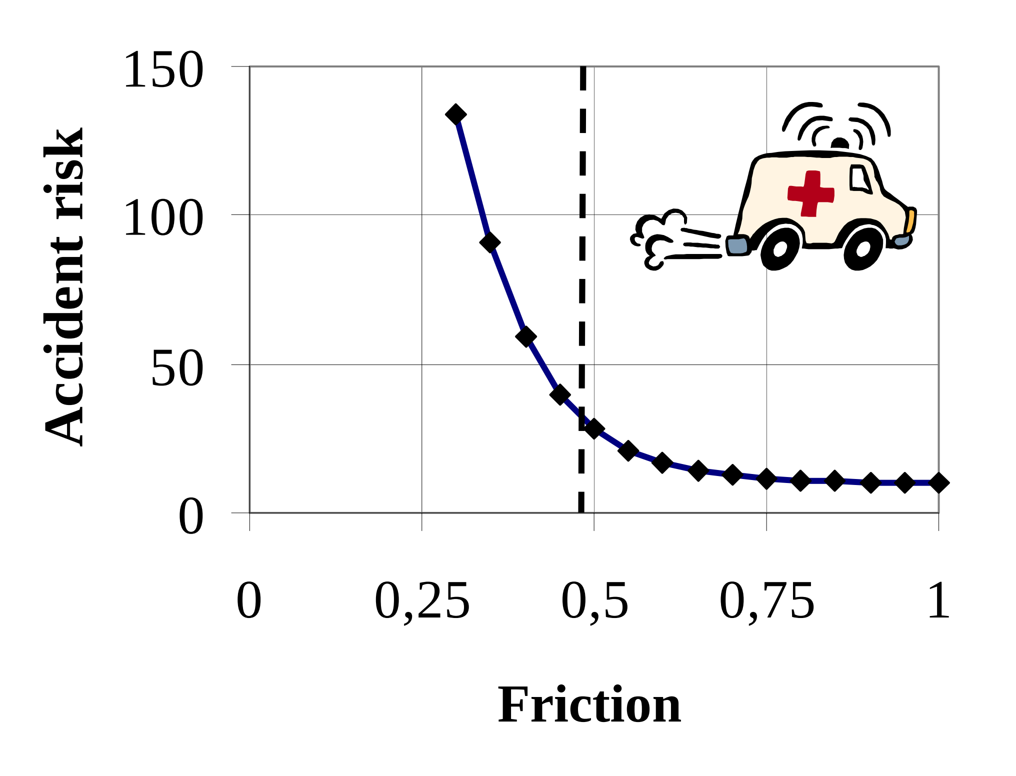
# Friction measurement methods and the correlation between road friction and traffic safety.

## A literature review.


*Carl-Gustaf Wallman*
*Henrik Åström*



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**Abstract**

Doubtless, there is a strong correlation between road friction and accident risk. The problems arise when we demand a more detailed view of that correlation. The aim of the project behind this report was to gather information about the different friction methods in use and about published quantitative relations between road friction and accident risk.

Regarding friction measurements, every country has instruments and methods of its own, and the friction values reported from different international investigations are therefore not directly comparable. Work on harmonisation of friction measurements is in progress.

Road friction is very important for traffic safety, but it is difficult to single out the effect of poor friction on the accident risk. Drivers adjust their driving behaviour depending on many factors, e.g. the appearance of the road environment, the weather, the sound from the tyres, and the sliding and skidding movements of the vehicle.

For dry or wet bare roadway, however, the conditions are comparably homogeneous, and several studies show a dramatic increase in accident risk when the friction numbers decrease below certain threshold values.

For winter circumstances there are few and unreliable estimations of the correlation between accident risk and friction.

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*Henrik Åström*
*Project leader and author*

*Carl-Gustaf Wallman*
*Author*

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**Friction measurement methods and the correlation between road friction and traffic safety.**
**A literature review.**
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## Summary

Doubtless, there is a strong correlation between road friction and accident risk. The problems arise when we demand a more detailed view of that correlation. A number of different methods exists for evaluating and quantifying the road friction and also a number of ways to treat and categorise accident data.

The aim of the project behind this report was to gather information about the different friction methods in use and about published quantitative relations between road friction and accident risk.

Regarding friction measurements, every country has instruments and methods of its own, and the friction values reported from different international investigations are therefore not directly comparable. Work on harmonisation of friction measurements is in progress. One suggested solution is to introduce an International Friction Index, a common device-independent friction scale. An ambitious international calibration scheme is needed to get the necessary constants for the Friction Index calculations.

Road friction is very important for traffic safety, but it is difficult to single out the effect of poor friction on the accident risk: drivers adjust their driving behaviour depending on many factors, e.g. the appearance of the road environment, the weather, the sound from the tyres, and the sliding and skidding movements of the vehicle.

For dry or wet bare roadway, however, the conditions are comparably homogeneous, and several studies show a dramatic increase in accident risk when the friction numbers decrease below certain threshold values.

At winter conditions, similar-looking roadways may have very different friction conditions; on the other hand, different-looking roadways may have the same friction conditions. In both cases, the drivers mainly adapt to the appearance of the environment and not to the friction conditions. Consequently, for winter circumstances there are few and unreliable estimations of the correlation between accident risk and friction.

# 1 Introduction

Road friction, its measurement and relation to traffic accident risks, is a problem that has engaged thousands of road engineers through out the world. In many countries there exist specified road friction threshold values that defines the lowest acceptable road friction. If the friction level is below this value then the risk of accidents may increase. These threshold values are the result of research into the relation between road friction and accident risks.

The aim of this literature review is to gather information about the different friction methods in use and about published quantitative relations between road friction and accident risk.

The coupling between friction and accident risk is partly obvious, if the road is very slippery then the risk of skidding accidents would of course be high, but finding the threshold values of the friction that is supposed to guide the maintenance and production of roads, is not easy. The problem can be split into two parts, the friction measurement methods and the relation between friction and accident risks. These two subjects are treated separately in this literature review, chapter 3 gives an overview of friction measurement devices and methods, and chapter 4 summarises the relation between friction and accident risk.

A similar problem exists for the airfields. A large amount of references can be found regarding airfield friction measurements but the airfield friction problem was out of the scope of this report and has consequently not been regarded here.

# 2 Friction vocabulary

A brief description of the friction related terminology used in this report.

**Friction**
The resistance an object encounters in moving over another object. Often the force needed to move the object, the frictional force.

**Friction value, friction number**
The numerical value of the friction given by a specific measuring device. For some devices it corresponds to the friction coefficient or the friction coefficient multiplied by 100. Important to notice is that a certain friction value is always connected with a specific measuring device, a specific measuring tyre and specific operating conditions.

**Friction coefficient**
Normalised friction. The frictional force divided by the normal force (the load).

**Skid**
Sliding on slippery ground. In road circumstances skidding is the sliding of the locked wheel on the pavement.

**Skid resistance**
The resistance to skidding or the friction for locked wheel tests. Also used to describe results from tests using the SRT pendulum, se figure 3.11. According to ISO 8855 the longitudinal friction coefficient obtained on a locked wheel is called sliding braking force coefficient.

**Skid number**
The friction value as measured according to ASTM 274 which describes the friction measurement using a locked, smooth or ribbed standard test tyre. The skid number is the measured friction coefficient multiplied by 100. It is designated as SN *test speed* R for ribbed tyre (ASTM E501) and SN *test speed* S for smooth tyre (ASTM E524), e.g. SN65S = 55. The test speed is normally 65 km/h (40 mph).

**Slip speed**
The relative speed between the tyre and the travelled surface at the centre of the contact area.

**Longitudinal slip, longitudinal slip ratio**
The quotient of the slip speed by the operating speed.

**Slip angle**
The angle between the wheel and direction of travel of the centre of tyre contact.

**Slip resistance**
The resistance to slip (to lose one's footing) for pedestrian surfaces. Can be the friction coefficient of that surface measured with special slip resistance devices, the British pendulum or the VTI PFT.

# 3 Road friction measurement

Friction is an important road parameter that unfortunately is very difficult to measure. The devices used for friction measurement are not very complicated but the friction forces they try to measure are very sensitive to a number of parameters that are difficult to control. Meyer et al. [32] have summarised investigations of several influencing parameters on the locked wheel friction value, friction measurements according to the ASTM[1] E274. In the UK the SCRIM (Side force Coefficient Road Inventory Machine) is used and the factors influencing the SCRIM friction value has been reported in a series of investigations [24-26]. It is not surprising to have a difference in friction of about 5% between two consecutive measurements of the same road surface, using the same device. That difference may increase when using another friction device or with increasing time between measurements.

In a friction measurement there are often three bodies involved, the measuring tyre, the road surface and some kind of contaminant interacting with both tyre and road like for example water (wet friction), dust or wear particles etc. The friction values measured depend to a great extent on all three bodies, their material properties, the local contact pressures, relative velocities etc. A summary of the important factors influencing the road surface friction is given in table 3.1.

***Table 3.1*** *Factors influencing road surface friction (extracted from Kummer [29] and Sandberg [46]).*

| Road | Contaminant (fluid) | Tyre |
|---|---|---|
| Macrotexture | Chemical structure | Tread pattern design |
| Microtexture | Viscosity | Rubber composition |
| Unevenness/Megatexture | Density | Inflation pressure |
| Chemistry of materials | Temperature | Rubber hardness |
| Temperature | Thermal conductivity | Load |
| Thermal conductivity | Specific heat | Sliding velocity |
| Specific heat | Film thickness | Temperature |
| | | Thermal conductivity |
| | | Specific heat |

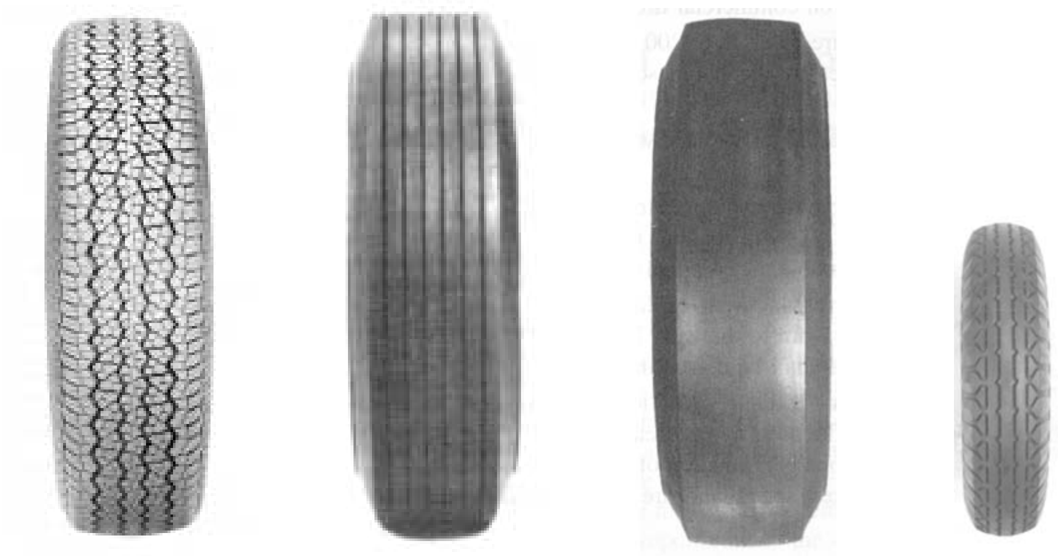
Of the road parameters, the texture is the most important and the influence of macrotexture has also gained most interest in road friction research. A very good overview of road surface texture measurements can be found in a report by Sandberg [46]. The differences between micro, macro and megatexture is defined in table 3.2, from Sandberg [46] and ISO 13473-1.

[1] American Society for Testing and Materials

***Table 3.2*** *Different ranges of road surface texture (from Sandberg [46] and ISO 13473-1).*

| | Texture wavelength range | Typical peak-peak amplitudes |
|---|---|---|
| **Microtexture** | < 0.5 mm | 1 – 500 µm |
| **Macrotexture** | 0.5 – 50 mm | 0.1 – 20 mm |
| **Megatexture** | 50 – 500 mm | 0.1 – 50 mm |
| **Unevenness** | 0.5 – 50 m | - |

When evaluating road friction the typical approach is to keep all influencing parameters except the road surface constant. The surface is normally wetted with a specified amount of water and a standardised measuring tyre is used. A smooth tyre like the one specified in ASTM E524 or the PIARC[2] smooth test tyre, ribbed tyres like ASTM E501 or the patterned tyre in ASTM E1136 are examples of common tyres for road surface friction evaluation, figure 3.1. The ASTM E524 and E501 have an outer diameter of 703 mm, the ASTM E1136 has an outer diameter of 648 mm and the PIARC smooth and ribbed test tyres have an outer diameter of 646 mm.



a) b) c) d)

***Figure 3.1*** *Four standard friction test tyres. a) Patterned ASTM E1136 b) Ribbed ASTM E501 c) Smooth ASTM E524 d) Patterned T49 (Swedish standard friction test tyre)*

In Figure 3.1 also the Swedish standard tyre for road friction measurements, Trelleborg T49, is shown. With its outer diameter of 420 mm it is smaller than the ASTM and PIARC test tyres. Another standard test tyre of smaller size is the smooth ASTM E1844-96 test tyre for the GripTester (described in chapter 3.1.1). This tyre has an outer diameter of 258 mm.

[2] World Road Association

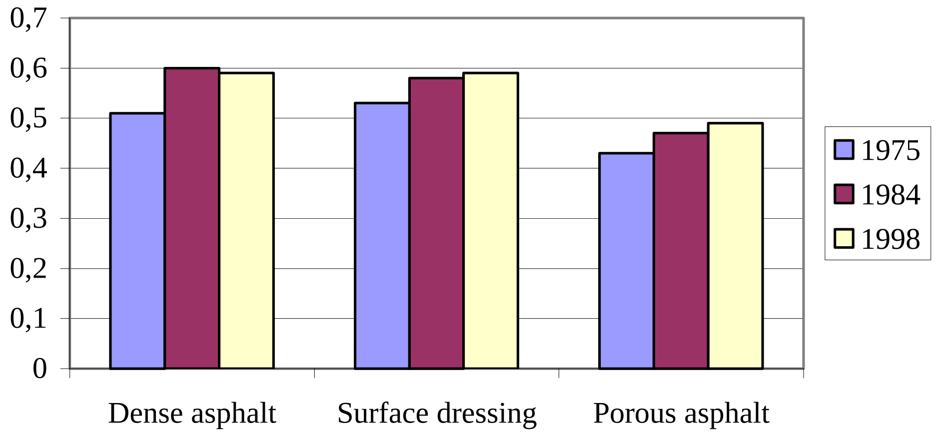



***Figure 3.2*** *Friction coefficient measured with three different batches of PIARC test tyres [10]*

Friction values are very sensitive to the tyre used and even apparently identical samples from two different batches of a standardised tyre can produce different friction results, maybe not large differences but significant. The reasons for that are for example small differences in the tyre rubber composition and maybe also small differences in tyre geometry. For most manufacturers the market for standardised test tyres is very small compared to their other products and therefore test tyres are normally produced in larger batches say every fourth year and also often by different producers. KOAC, WMD (Dutch Road Research Laboratories) [10] has compared PIARC test tyres from the batches 1975, 1984 and 1998 and found differences in the friction values partly explained by differences in the compound chemistry, see figure 3.2. In the case of the 1975 tyres the difference is quite large which in the Netherlands also led to the introduction of a friction correction formula.

According to investigations by Henry [22] and Bachmann [12] the ribbed and smooth standard test tyres (ASTM and PIARC) have a lower friction coefficient on a normal wet road than a commercial passenger car tyre. As water depth is increased, the ribbed test tyre increases in performance and was found to give higher friction values than a slightly worn normal passenger car tyre.

Friction of the road pavement is usually evaluated in the summer period. There is a seasonal variation that has to be considered. The wet friction of a specific pavement is normally higher in the spring than in the autumn [23; 27] due to a depolishing effect from the snow removal activities and the studded tyres.

During the winter period there is a risk that the water spread during the wet friction measurement freezes. The pavement can also be covered with snow or ice. Friction measurements during winter are therefore typically aimed at winter maintenance evaluation.

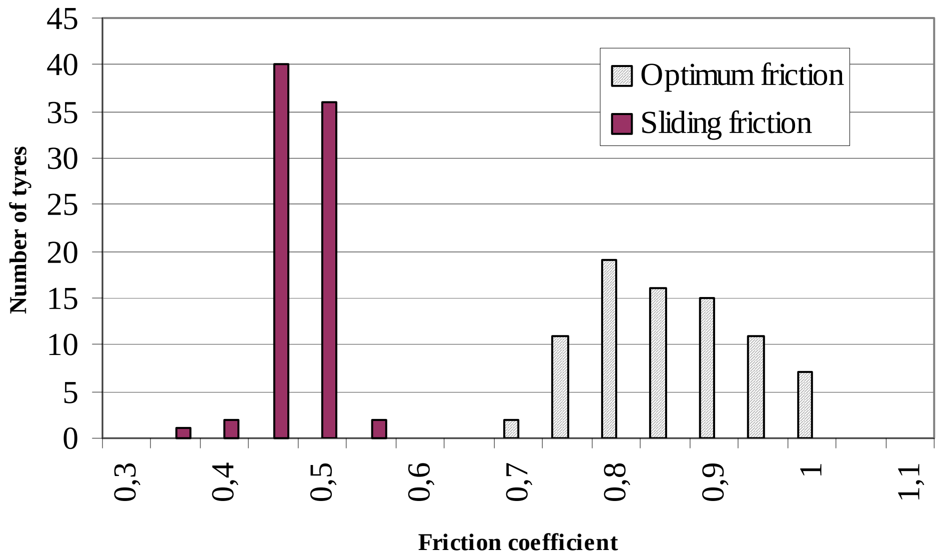



***Figure 3.3*** *Optimum and sliding wet friction for 82 different passenger car tyres [39; 47] measured on a normal road with asphalt concrete.*

Using results from an investigation of tyre friction and noise [47] the difference between the optimum friction and the sliding (locked wheel) friction can be illustrated, see figure 3.3.

Here also the difference between tyres of different brands can be seen, in the investigation the wet grip of about 82 different tyres was measured. All measurements were performed on the same asphalt road surface. The best tyre has an optimum wet friction coefficient of about 1.0 and the worst tyre about 0.7. Nordström and Gustavsson [38] found a range for the optimum friction coefficient between 0.6 and 0.85 in a similar investigation using a different measuring principle and about 250 different passenger car tyres.

This clearly indicates the importance of the tyre when evaluating road friction, and also clearly show that individual cars can experience different friction levels even if the friction of the pavement is constant as evaluated using one standard tyre.

## 3.1 Wet pavement friction

Friction values of the wetted pavement are used for pavement assessment and guideline for repaving and pavement production. In Sweden, for example, the Swedish National Road Administration (SNRA) stipulates that the road surface should have a wet friction value of at least 0.5 [5; 9] measured with a BV11 or a Saab Friction Tester, see chapter 3.1.1 below. Similar regulations also exist in other countries, see chapter 3.1.2 below.

Wet friction is the overall most common friction measurement. The reason for measuring a wet surface instead of a dry surface is that the dry surface, with its higher friction values, is not considered to be a problem. It is when the pavement surface is wet that the risk of skidding is large.

### 3.1.1 Friction measurement devices

When a tyre is braked from a free rolling situation to locked wheel the friction force experienced by the wheel hub changes depending on the slip (the ratio between slip speed and operating speed). This is illustrated in the typical friction-slip curve shown in figure 3.4. The maximum friction is normally found at a slip rate of about 7–20% and can be considerably higher than the locked wheel friction (100% slip).

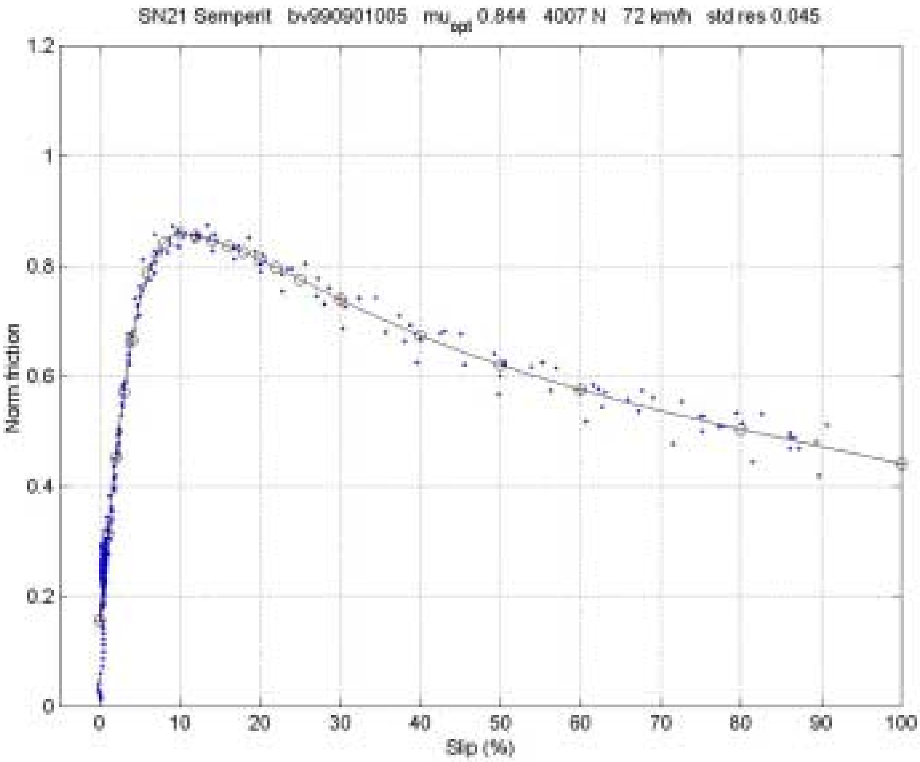



***Figure 3.4** Friction-slip curve of a braking tyre showing the friction variation from free rolling (0% slip) to locked wheel (100% slip).*

Road friction can be measured using one out of five different principles: locked wheel (100% slip), constant slip (normally between 10 and 20% slip), variable slip (0 to 100% slip), constant slip angle (usually 20 degrees) and retardation measurement of a normal ABS braked car. The influence of slip angle on the side force (lateral force) is illustrated in figure 3.5.

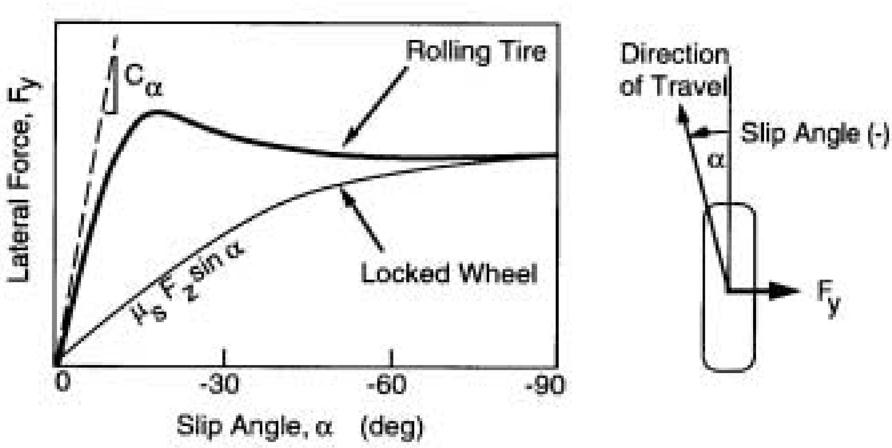



***Figure 3.5*** *Lateral friction force as a function of slip angle (from Gillespie[17]).*

Almost every country has its own friction-measuring device. Some devices are more popular and are used by several countries, like the SCRIM (Side force Coefficient Road Inventory Machine) or the Griptester. Many countries may have several different devices for example for different purposes, one device for road friction screening measurements and one smaller device for measuring special interesting spots on the road system.

A large number of friction measurement devices are listed in a report from 1972 by Ohlsson et al. [41], see table 3.3. Since 1972 many things has changed. Today in Sweden, for example, the BV11 [40] is used instead of BV5 according to table 3.3, but generally the situation is the same with a variety of different devices in different countries and SCRIM as the most common device in Europe.

The Swedish road friction devices used today are the BV11 [40] and the SFT (Saab Friction tester), see figure 3.6 and 3.7. Both are braking friction type devices with a constant slip of about 17%. The test tyre used is a patterned standard tyre, size 4.00-8 marked Trelleborg T49.

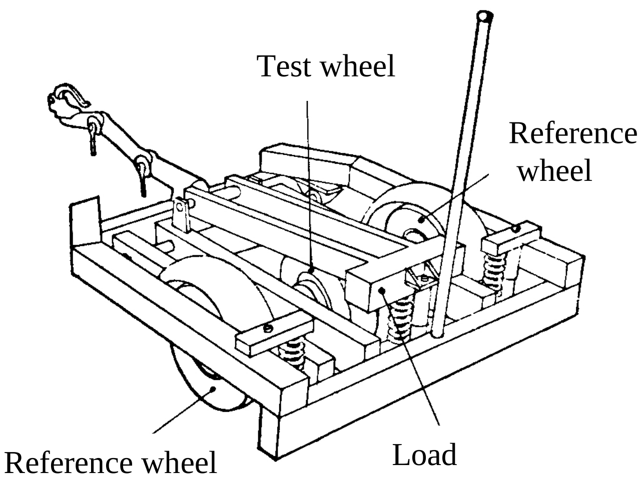



***Figure 3.6*** *The Swedish skiddometer BV11*

BV11 is a trailer with the water tank placed in the car. In the SFT the measuring equipment is built into a normal passenger car which then also holds the water tank. Both BV11 and SFT are common friction measurement devices for airfields, with an alternative test tyre, actually they are much more common on airfields than on normal roads. There are a number of different versions of the SFT, e.g. the passenger car used as a base differs, but a recent comparison between two different versions [37] concluded that the friction values could be compared on a one to one basis.

***Table 3.3*** *Summary of friction measurement devices from different countries, from Ohlsson et al.* [41]

| | B | DK | GB | FIN | F | NL | I | N | PL | CH | E | S | CZ | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measured force | Side | Side | Side | Braking | Braking or side | Braking | Braking | Side | Braking | Braking | Braking | Braking | Braking | Braking |
| Slip (%) | - | - | - | 100 | 100 | 86 | 100 | - | 100 | 13 | 13 | Optimal | 100 | 100 |
| Slip angle (deg) | 15 | 12 | 20 | - | 15 | - | - | 7.5 | - | - | - | - | - | - |
| Load (kN) | 2.5 | 2.45 | 2 | 1.8 | 2.5 | 2.0 | - | 1.0 | 4.0 | 4.93 | 4.93 | 3.0 | - | 3.5 |
| Tyre type | Radial | Radial | Diagonal | Diagonal | Radial | Diagonal | Diagonal | Diagonal | Diagonal | Diagonal | Diagonal | Diagonal | Diagonal | Diagonal |
| Tread | Smooth | Smooth | Smooth | Patterned | Smooth | Patterned | Smooth | Smooth | Patterned | | | Patterned | Patterned | Patterned |
| Dimension | 165-400 | 165-15 | 3.00-20 | 4.00-8 | 165-400 | 5.60-13 | - | 4.00-8 | 6.70-15 | 7.50-14 | 7.50-14 | 165-15 | 155-14 | 6.40-13 |
| Name | Stradographe | Stradograf | SCRIM | RRL-Trailer | Stradographe CEBTP | RWL-Trailer | Model Ariano | Mu-meter | | Skiddometer BV8 | Skiddometer BV8 | Skiddometer BV5 | VUD-1 | Stuttgarter Gerät |
| Friction value | 0.50[3] | 0.50[4] | 0.55 | | | 0.51 | | 0.40 | 0.35 | 65[5] | 40[3] | | | 0.26 |
| Speed (km/h) | 80 | 60 | 50 | | | 50 | | 60 | 60 | | | | | 80 |
| Type of road | Brushed concrete | Max 2 years old | Difficult places | | | All roads | | | All roads | Difficult places | All roads | | | Difficult places |
| Friction value | 0.45 | 0.40[2] | 0.50 | | | | | | | 60[3] | | | | 0.33 |
| Speed (km/h) | 50[1] | 60 | 50 | | | | | | | | | | | 60 |
| Type of road | Asphalt | Other roads | Main roads | | | | | | | Main roads | | | | Difficult places and main roads |
| Friction value | | | 0.40 | | | | | | | 55[3] | | | | 0.42 |
| Speed (km/h) | | | 50 | | | | | | | | | | | 40 |
| Type of road | | | Other roads | | | | | | | Other roads | | | | Main roads |

[3] New roads only

[4] In addition, the maximum reduction in friction value when increasing measuring speed with 20 km/h is 0.1.

[5] Measured with the Portable Skid-Resistance Tester (SRT, British Pendulum)

***Figure 3.7*** *The VTI Saab Friction Tester (SFT). The measuring wheel is situated in the middle of the rear axle. The water tank is in the back seat, slightly visible through the back window*

An ambitious programme for comparing different friction measurement devices was performed in 1992, the PIARC experiment [54]. There about 19 different apparatuses were compared on a large number of different surfaces. A list of the participating instruments can be seen in table 3.4.

One of the main goals of the PIARC experiment was to find ways of harmonising the different friction measurement devices, see also chapter 3.4.

Some of the apparatuses in table 3.4 are widely spread like for example the SCRIM [26]. This machine was originally developed by TRRL in UK about 1953 and is a rebuilt truck with a measuring wheel placed between the front and the rear axle. The measuring wheel is a special motorcycle wheel mounted with a constant side slip angle of 20 degrees. During measurement the wheel is rotating freely and the road surface friction is evaluated as the lateral force acting on the free rolling wheel divided by the load on the wheel, the Sideway-Force Coefficient (SFC). SCRIM uses the sideway-force method of measuring resistance to skidding because it is more suitable for routine measurement [26] than e.g. the locked wheel method. In 1976 there were about 18 SCRIMs around the world and the number of devices has increased since then. Tests are normally carried out at 50 km/h.

Another widely spread device is the Griptester [30; 54], see figure 3.8, which is a fixed slip trailer developed by Findlay Irvine Ltd in UK[6]. This device is also extensively used in the UK as a complement to the SCRIM routine road measurements. More than 20 Griptester devices are placed at the local road administration offices around the country.

[6] Findlay Irvine Ltd, Bog Road, Penicuik, Midlothian, EH26 9BU, Scotland, UK

*Table 3.4* *Friction measurement devices participating in the PIARC experiment [54]*

| Name | Tyre | Measurement Method | Country |
|---|---|---|---|
| Stuttgarter Reibungsmesser | Ribbed | Fixed slip (20%) and locked wheel | CH |
| Skiddometer BV8 | Ribbed | Fixed slip (20%) | CH |
| Skiddometer BV11 | Patterned | Fixed slip (17%) | S |
| Norsemeter Oscar | Blank | Variable slip | N |
| Stuttgarter Reibungsmesser | Ribbed | Fixed slip (20%) and locked wheel | A |
| ASTM E274 trailer | Blank | Locked wheel | US |
| SRT Pendulum tester | “Blank” | Slider | CH |
| MuMeter | Patterned | Side force (7.5°) | E |
| Skid Resistance Tester | Patterned | Locked wheel | PL |
| SCRIM | Blank | Side force (20°) | B |
| SCRIM | Blank | Side force (20°) | E |
| Komatsu skid tester | Blank | Variable slip | J |
| DWW trailer | Blank | Fixed slip (86%) | NL |
| SCRIM | Blank | Side force (20°) | E |
| Stradograf | Blank | Side force (12°) | DK |
| CRR Odoliograph | Blank | Side force (20°) | B |
| SCRIM | Blank | Side force (20°) | D |
| SCRIM | Blank | Side force (20°) | E |
| SCRIM | Blank | Side force (20°) | F |
| SUMMS | Blank | Side force (20°) | I |
| SCRIMTEX | Blank | Side force (20°) | UK |
| LCPC Skid Trailer Adhera | Blank | Locked wheel | F |
| Dagmar/Petra Trailer | Patterned | Variable slip | D |
| Griptester | Blank | Fixed slip (14.5%) | UK |

***Figure 3.8*** *The Griptester device*

Some devices use a fixed slip, like the Griptester or the BV11. There are at least two reasons for that, the slip is chosen so that it will represent the optimum braking friction and the wear of the tyre is limited compared to tests with locked wheel. One trailer used in the Netherlands, measures with about 86% longitudinal slip [54]. In that case the argument is to reduce the wear of the tyre, the friction values achieved correspond more to the locked wheel friction than to the optimum friction.

In Norway Norsemeter AS[7] has developed a flexible friction measurement unit called ROAR [48]. In figure 3.9 it can be seen in the form of a friction measurement trailer, including the water supply for wet friction measurements. The measuring wheel has a smooth tyre with an outer diameter of 410 mm, ASTM E1551. It is placed on a separate unit, which include all mechanical parts necessary for the measurement so that this small unit can act alone and for example measure dry friction (e.g. winter maintenance evaluation) placed directly on a road maintenance truck. During one measurement cycle (about 1 second) ROAR measures the complete friction-slip curve, from pure rolling to locked wheel. The device can operate at speeds between 20 and 130 km/h.


***Figure 3.9*** *Norsemeter Roar friction measurement trailer.*

### 3.1.2 The use of friction measurement in different countries

It is safe to say that the friction of the pavement is one of the most important properties of the road. Almost every country has some kind of device that measures road friction and many countries have regulations or guidelines concerning acceptable road friction levels. The major argument being the connection between pavement friction and accident risks.

According to the Swedish National Road Administration the wet friction of the pavement is not a problem in Sweden and friction measurements is very seldom done, even on the major road network. There exists only very few (about three)

[7] Norsemeter AS, P.O.Box 42, N-1351 Rud, Norway

working devices for road friction measurement and there exists no national database for friction measurement values. Friction is measured when for example skid problems has been reported or in some cases after a new road has been constructed or an old road repaved.

Polishing of pavements reduces the friction to, in some cases dangerous levels [27]. 1996 several accidents were reported in connection with a specific tunnel in Stockholm and friction measurements using the Saab Friction Tester (SFT) [28] also showed that local polishing of the pavement had reduced the friction value below the acceptable level of 0.50. The road surface had to be milled, increasing the friction value to about 0.7. Wet friction can thus be a problem, and friction monitoring of, at least the major roads, could give additional input into a PMS (Pavement Management System). The pavement friction is one indicator of the need for pavement measures.

In Norway and Finland the wet friction situation is very similar to the situation in Sweden, very few wet friction measurements are done and no friction database exists. In Finland the levels of acceptable friction depend on the speed limit. For roads where 80 km/h is the highest speed the acceptable friction value is 0.4 measured according to PANK 5201 or TIE 475 (a Finnish standard). With a speed limit of 100 km/h, the acceptable friction value is 0.5 and with a speed limit of 120 km/h the friction value should be at or above 0.6.

In Denmark wet pavement friction is an important parameter in a national road database [21], and wet pavement friction is regularly measured, ones every third year according to a Nordic inventory made 1996 [13]. This was very useful in the TOVE project [21] where Denmark, Finland, Norway and Sweden together investigated the connection between traffic safety and the properties of the road surface. The Danish friction database was used for evaluation of the connection between friction and accident risks, see also chapter 4.2.

One of the leading countries regarding road friction monitoring is the United Kingdom. There a fleet of SCRIM devices has been measuring the road network for many years. The devices are compared and calibrated every year and friction data are stored, a common, national database is under construction. In the UK the level of acceptable friction varies with type of road and traffic situation [3]. A higher level of friction, e.g. friction values about 0.55 measured with SCRIM, is indicated for crossings and at approach to roundabouts. Friction levels are called investigatory levels, which means that if friction is at or below this level an investigation has to be made and, if necessary, the surface has to be treated. Other countries also use a similar friction differentiation, the situation in 1972 is shown in table 3.3.

In the Netherlands friction of the major road network is monitored, about eight friction trailers are in use, and each section on the major roads are measured every second year. The devices are calibrated each year.

## 3.2 Winter road friction

Friction measurement during winter is a way of assessing the winter maintenance more than the pavement quality. The measurement has, because of the winter temperatures, to be done dry and it is thus the presence of ice, snow or slush on the road surface that governs the friction value. In this report the winter friction measurement methods of the Nordic countries (Sweden, Norway and Finland) are in focus.

In Sweden mainly three friction measurement devices are used, BV11 and SFT, in this case without water, and BV14. BV14, shown in figure 3.10, is a twin friction tester especially developed for winter maintenance evaluation [35; 36]. BV14 is directly attached to the measuring vehicle, measures the dry friction simultaneously in both wheel paths and uses the same measuring wheel and measuring technique as the BV11.


*Figure 3.10 The VTI BV14 twin friction tester, here mounted on the Swedish winter road condition monitoring vehicle.*

Up to now BV14 has mainly been used in research projects. One BV14 is e.g. mounted on the Swedish winter road condition monitoring vehicle [8; 33], developed for research purposes.

In Finland a friction measurement truck (TIE 475) is used also for winter maintenance evaluation and in Norway mainly the ROAR friction measurement device is used, without water.

The majority of friction measurements during winter carried out in Sweden, Norway and Finland are done with normal passenger cars with ABS and instrumentation to measure deceleration during braking. By applying the brakes hard, the evaluated deceleration of the car is a measure of the available road friction. The advantage with this method is that it is simple and relatively inexpensive, the road engineer can also use his own normal car. The main disadvantage is that the precision of the method is low. The friction value derived depends for example to a great extent on the tyres of the car which are normal commercial passenger car tyres whose brand and type differ between different friction evaluation vehicles. It is a practical approach and it apparently works well for judging the level of friction on a winter road.

In Sweden the road administration requires that the friction evaluation car (with ABS and deceleration measurement equipment) should be regularly calibrated against a BV11, a Saab Friction tester or a BV14 [6] on several typical winter road surfaces like ice and compacted snow.

## 3.3 Friction of road markings

Road markings reduce the accident risk [2] because they provide the driver with important information regarding his position on the road, especially when driving in darkness. The road marking materials have, however, normally a lower friction value than the pavement surface. If marking material covers a larger area of the road surface there is a risk for driving on a split friction surface, the braking distance could increase as could the accident risk [23]. Additionally there is a risk for pedestrian skidding accidents at road crossings if the crossing marking material has a too low friction.

The Swedish road administration, as well as road authorities in other countries, has decided upon a lowest acceptable friction level for the road marking material. A European standard for road marking material performance also exists, EN 1436. Consequently friction of road marking materials has to be measured. In Sweden the friction of a road marking material can be measured with two devices [4], the Portable Skid Resistance Tester (British Pendulum, SRT), illustrated in figure 3.11, and the VTI PFT, shown in figure 3.12. According to Swedish and Norwegian regulations [9; 13] and the European standard EN 1436 the SRT value should be higher than 45, which correspond to a VTI PFT value of 0.60 [57]. In Finland friction of road markings is not measured. In Denmark the friction should be above 50 SRT units [13] or at least 0.40 measured with the Stardograph.

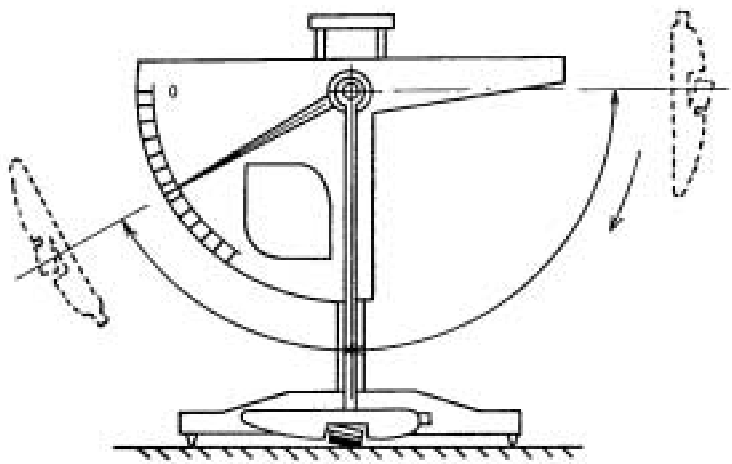


***Figure 3.11*** *The Portable Skid Resistance Tester (SRT). A pendulum with a rubber shoe that slides over the test surface.*

Internationally the Portable Skid Resistance Tester (SRT) is the instrument used for measuring road marking material friction. The instrument has a long history and is widely spread, descriptions of the instrument can be found in e.g. [1; 16; 23; 57]. The SRT has some disadvantages, though. It is complicated to use and it is not possible to measure friction on many of the profiled road markings that are often used on roads today.

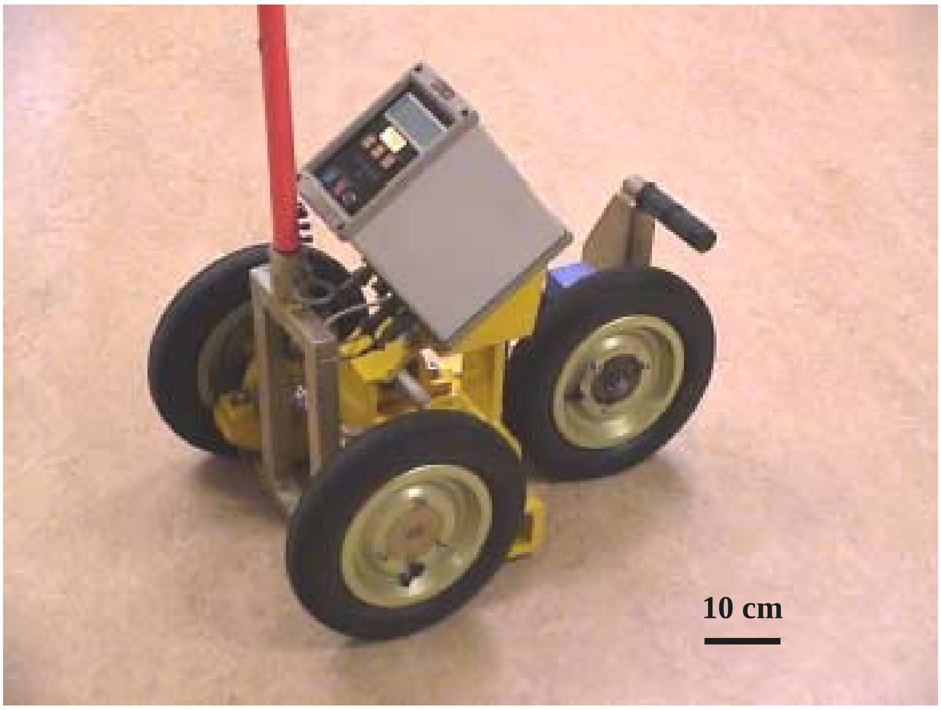



***Figure 3.12*** *VTI Portable Friction Tester (PFT)*

At VTI a portable friction tester called PFT has been developed and used for measuring road-marking friction. It has been shown to compare well with the SRT instrument [15; 31; 57]. It is easier to use, the operator can measure in upright position, measured data can be saved in a computer, and the PFT can measure also most of the profiled road markings. Unfortunately the PFT instrument so far only exists in very few numbers.

## 3.4 Harmonisation

The most ambitious attempt to harmonise the different road friction devices used today is the PIARC experiment [54]. In many situations, e.g. in joint European or international research projects, there is a need for comparing friction values measured in different countries using their specific devices. It is well known that the friction value depend on the device with which it is measured. Measuring tyres, load, slip speed, measuring speed etc all can differ between the devices. The aim of the PIARC experiment was to make it possible to calculate an international friction index from a friction measurement using any device and a measurement of the road surface macrotexture (e.g. the Mean Profile Depth, MPD, value). This friction index should be independent of the device used. The macrotexture is needed because the influence of slip speed on the friction value differs between different pavements, with different macrotexture. The friction index equation yields [54]:

$$FI = A + B * F * e^{\left(\frac{S-60}{S_p}\right)} + C * Tx$$

$$S_p = a + b * Tx$$

Where *FI* is the friction index (at 60 km/h slip speed), *A*, *B* and *C* are device specific constants, *F* is the measured friction value with the specific device using slip speed *S* in km/h. $S_p$ is the predicted so called golden value speed number, Tx is a measure of the macrotexture (for example MPD in mm), *a* and *b* are constants depending on the macrotexture measurement device. For smooth tyres the constant *C* is equal to zero [54].

Using one friction measurement at one slip speed and a measure of the surface texture the friction at any slip speed, for that device, can be estimated. This relation between friction and slip speed is illustrated in figure 3.13 where also the method of friction index calculation is shown.

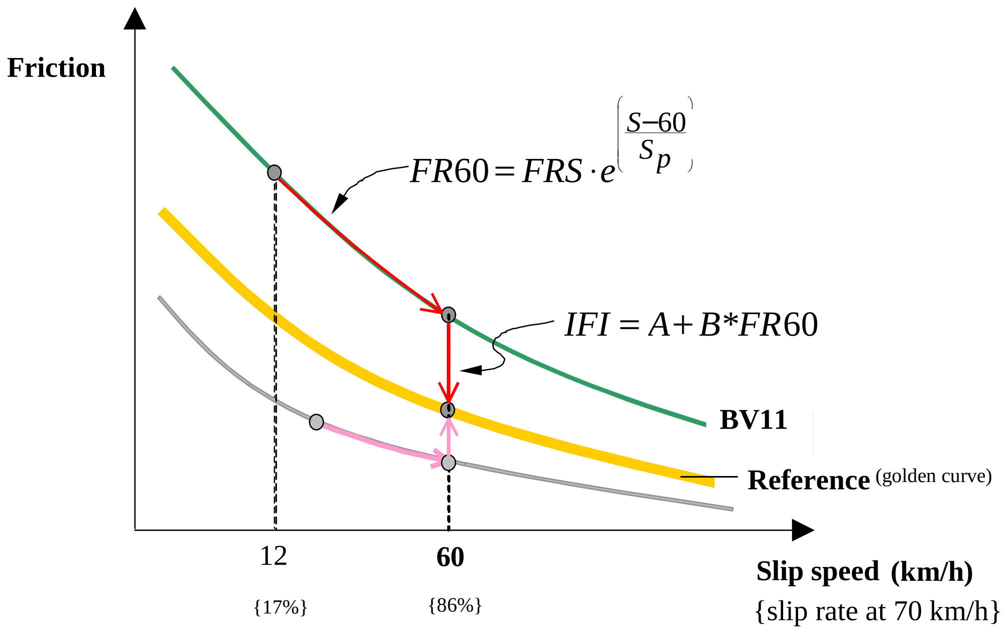



***Figure 3.13*** *Demonstration of the calculation of the International Friction Index*

In the report from the PIARC experiment [54] the friction index was calculated at a slip speed of 60 km/h, also demonstrated in figure 3.13. This slip speed was by some researchers considered to be too high and a revised version was presented, also found in the draft to an European standard (prEN13036), using a reference slip speed of 30 km/h:

$$FI = A + B * F * e^{\left(\frac{S-30}{S_p}\right)}$$

$$S_p = 57 + 56 * MPD$$

Where *FI* is the friction index (now at 30 km/h slip speed), *A* and *B* are device specific constants, *F* is the measured friction value with the specific device using slip speed *S* in km/h. $S_p$ is the predicted so called golden value speed number calculated from the macrotexture given as the MPD (Mean Profile Depth) value.

The concept of international friction index has been applied in several other investigations, for example in one by Lund [30]. He compared the Danish Stradograf, the Griptester and ROAR and used the *FI* concept (with 60 km/h slip speed) to correlate the results from the instruments. After calibration and adjustment of the device specific constants, with the Stradograf as reference device, the calculated *FI* values for the different devices fit well together. In the conclusions it is recommended to include also the vehicle speed in the *FI* calculation, not only slip speed.

Three Nordic friction measurement devices, one Finnish measurement truck, the Danish Stradograf and the Swedish BV11 were compared by Arnberg and Sjögren [11]. They found a rather poor correlation between the different devices. Good correlation was found between ROAR and the Danish Stradograf in an investigation by Schmidt [48] and he recommended ROAR as a road friction measurement device for Denmark.

Using the *FI* calculated according to the draft norm PrEN 13036, a theoretical comparison between for example the SCRIM and BV11 can be done. The device specific constants are collected from the draft norm and the SCRIM is represented as an average over four different SCRIM devices (UK, F, E, D). Assuming standard measuring speeds (70 km/h for the BV11 and 50 km/h for the SCRIM) and an MPD value of the road of 1 mm, the friction value for the SCRIM devices are about 10% lower than the friction value given by BV11. If we could find a Swedish road with a friction level on the limit according to Swedish standards, that is a friction value of 0.50 measured with BV11, then a SCRIM device would measure about 0.45.

This exemplifies the difficulty with setting a level of acceptable friction for the road. Instead of using friction values from a specific device the level of acceptable friction should be given in the International Friction Index scale.

**There is a need for a continued harmonisation work regarding road friction measurement in order to achieve better specifications of acceptable road surface friction and to facilitate the comparisons of friction and accident rate data between different countries.**

# 4 Friction and traffic safety

## 4.1 Introduction

One of the main factors influencing traffic safety is the friction between the vehicles' tyres and the road surface. Maintaining a certain safety level demands that driver adapt their behaviour to changing friction conditions, mainly by adjusting their speed.

Driving a car is a complex task placing high demands on the driver's perceptual and cognitive processes. To operate the vehicle, the driver uses visual, auditory, and kinesthetic information (cues), for example how the road and its environment appears, the sound from the tyres, and the longitudinal and lateral motion of the vehicle. This information is utilised by the driver to judge the friction level. Social Judgement Theory, Hammond et al. [19], may be used to describe this kind of relationship between drivers and the road environment, Figure 4.1.

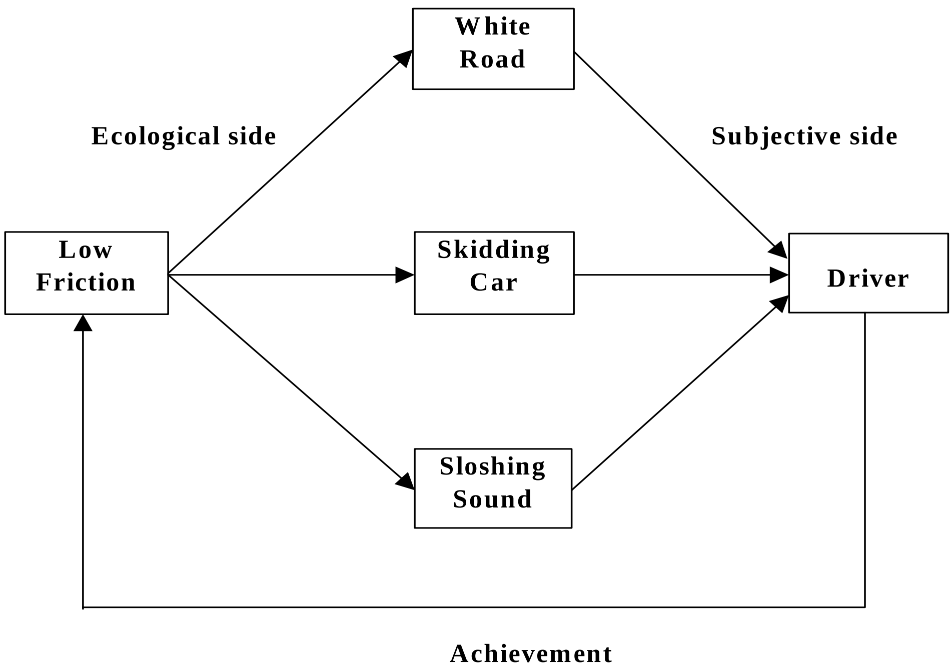



***Figure 4.1*** *Model for a driver's experience of low friction.*

However, the relation between each cue and friction is not perfect, what is more, drivers are inconsistent or do not fully utilise the cues. The drivers' estimations of the friction conditions are generally very poor.

Several studies support this view: by speed measurements at different roadway conditions, by driver interviews at slippery road conditions, and by driving simulator experiments. The underlying assumption for the studies is that *if* the stopping distance at dry, bare roadway conditions is considered as an indicator of safe speed, *then* a correct speed adaptation to poorer friction should result in the same stopping distance. In reality, the speed is usually far from reduced to the necessary level.

Öberg [60] has compiled measurements of car speeds under different road conditions. For roads 7 metres wide with a typical posted speed of 90 km/h, average speeds are 85 to 95 km/h on dry, bare roads. Speeds are reduced in winter conditions with ice or hard-packed snow on the road surface, typically by 6 to 10 km/h. If the driver reaction time is assumed to be 1 second and the friction coefficients 0.8 and 0.25, respectively, then the stopping distance is almost doubled, from 65 to 129 metres. To maintain the distance, the required speed should have been about 56 km/h.

The poor speed adaptation is also illustrated in Figure 4.2, from Öberg [59]. Median stopping distances (calculated from measured speeds) are plotted against actual median friction coefficients on five rural roads.

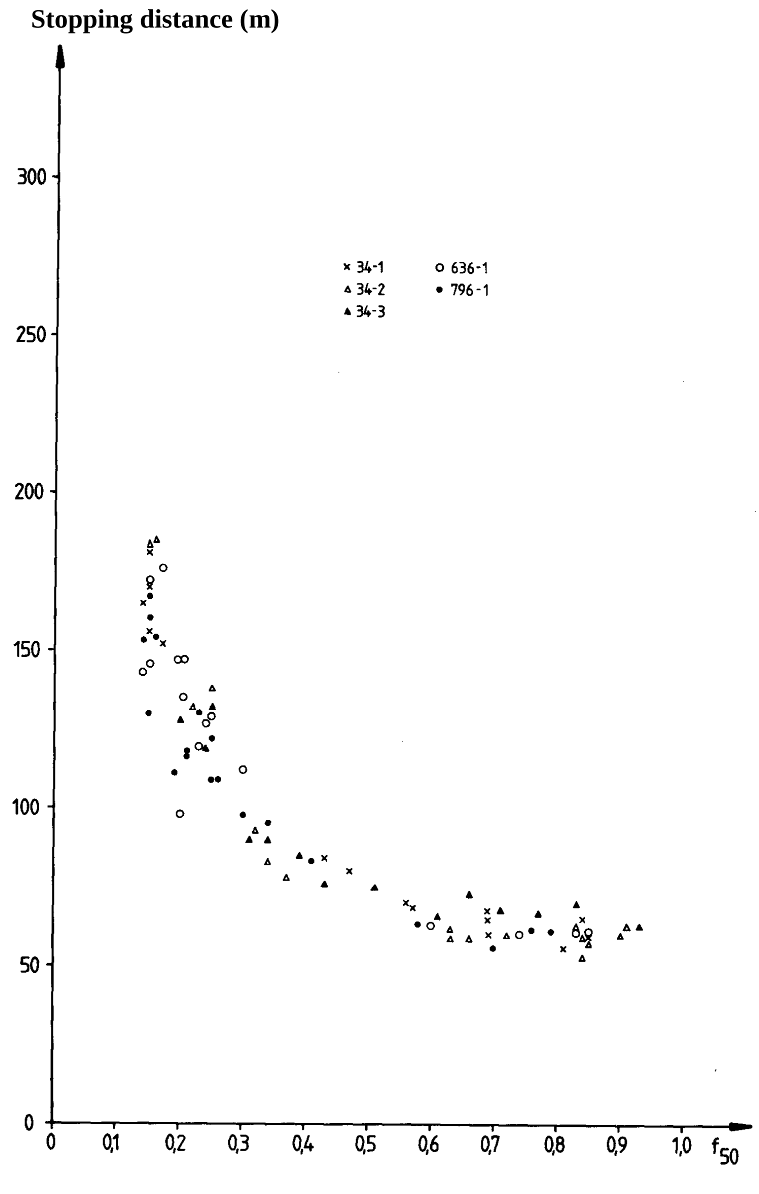



***Figure 4.2*** *Actual stopping distance at different friction coefficients. Passenger cars with unstudded tyres.*

Ruud [43] measured mean speeds on road E18 in Norway. The speeds were 81, 76 and 74 km/h when the friction numbers were 0.65, 0.40 and 0.25, respectively. This implies stopping distances of 62, 78 and 107 metres, respectively. On two national roads the speeds were recorded to be 76, 71 and 69 km/h, when the friction numbers were 0.70, 0.39 and 0.26, leading to the stopping distances 54, 71 and 91 metres.

Three reports from the Finnish National Road Administration contain very relevant results for the issue. Heinijoki [20] examined the extent to which drivers take slipperiness into consideration in winter through driver interviews and measurements of car speeds. Roadway slipperiness was measured and divided into four categories of friction coefficients: good grip ($f > 0.45$), fairly good grip ($0.35 < f \leq 0.45$), fairly slippery ($0.25 < f \leq 0.35$), and slippery ($f \leq 0,25$). The drivers were asked to evaluate the slipperiness on the same scale. Generally, the drivers were poor at evaluating the actual road conditions. Less than 30% of the evaluations coincided with the measured values, and more than 27% differed by 2-3 categories. The more slippery conditions were, the more evaluations differed from reality, and consequently the slipperiness did not have any appreciable effect on driving speed.

Saastamoinen [44] found that driving speed declined mostly as a function of wintry weather or reduced speed limits. Road conditions were significant, then, only in the case of snowy weather. Compared with good driving conditions, speed decreased by 0–3 km/h when the grip was only fairly good (see above), 3-6 km/h under fairly slippery conditions, and 4-7 km/h under slippery conditions. The speed did not change to any appreciable extent when the conditions changed from fairly slippery to slippery.

Roine [42] examined driving speed in sharp curves. The average speed was about 6 km/h less in sharp curves under slippery compared with dry or wet road conditions.

Wallman [51] performed a controlled experiment in the VTI driving simulator, where subjects drove on a road under summer conditions with a friction coefficient of 0.8. Then the subjects drove the same road in a winter environment, and with friction coefficients 0.8, 0.4 and 0.25. Two test designs were envisaged, with different friction distributions along the road in the winter scenarios. The mean speed difference between summer and winter scenarios were 11-12 km/h and 16-17 km/h for the first and the second design, respectively. The differences between the winter scenarios were only about 1 km/h, independent of the friction numbers (even for the winter road with good friction). The conclusion was that actual friction has little to do with the driver’s choice of speed; the visual information is much more relevant.

This conclusion has also been drawn by Öberg [58], where the increase in speed after a road had been sanded did not correspond to the provided friction but rather to an expected, good friction.

According to the studies mentioned above, where the poor speed adaptation is established, we should expect a greater accident rate at low friction conditions. There are often, however, considerable difficulties in attaching accidents to specific friction numbers, especially under winter conditions. There are also fundamental differences between a bare roadway and an icy or snowy roadway, for example the perceptual and driving conditions as well as the stability and homogeneity of the surface conditions. Therefore, the literature review is separated into two sections: accident rate at dry or wet road surface, and accident rate at icy or snowy road surface.

## 4.2 Dry or wet roadway

In the previously mentioned report from Road Research Laboratory [16], the correlation between skid numbers and skidding accidents was investigated. The skid-resistance was measured with the SRT pendulum, see figure 3.11, at sites where frequent skidding accidents had been reported in wet weather. For comparison, measurements were also made on a sample of sites chosen at random. The distributions of the measurements at the skidding accident sites and at the random sample of roads are shown in Figure 4.3; for the accident sites the mean skid-resistance was 45, and for the random sample it was 60. From these measurements, the relative likelihood of a surface being a skidding-accident site can be derived. This is shown in Figure 4.4, in which the curve was obtained by taking the ratio of the percentage of results from the skidding-accident sites in each range of values of skid-resistance to the corresponding figure from the random sample sites and plotting it against skid-resistance.

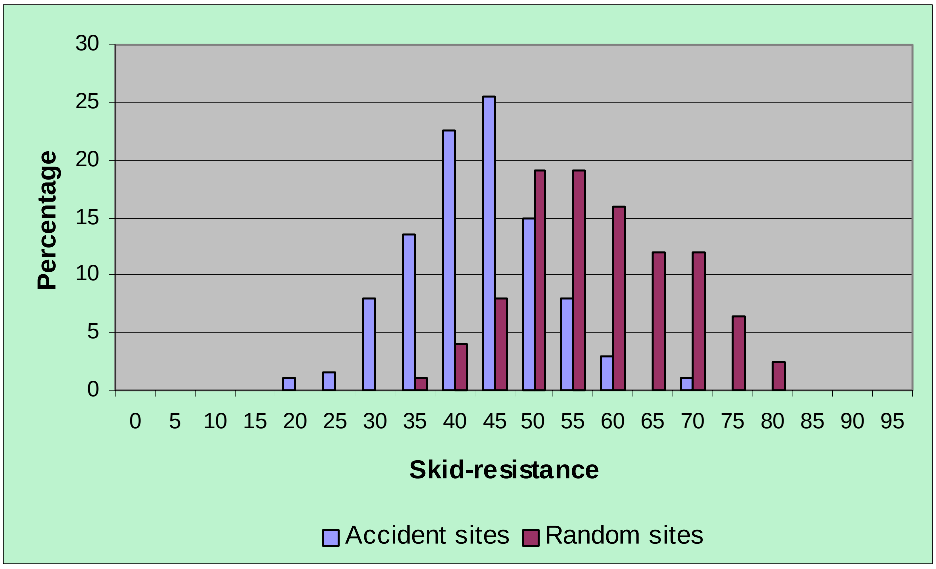



***Figure 4.3** Distributions of skid-resistance measured at skidding-accident sites and samples of sites selected at random.*

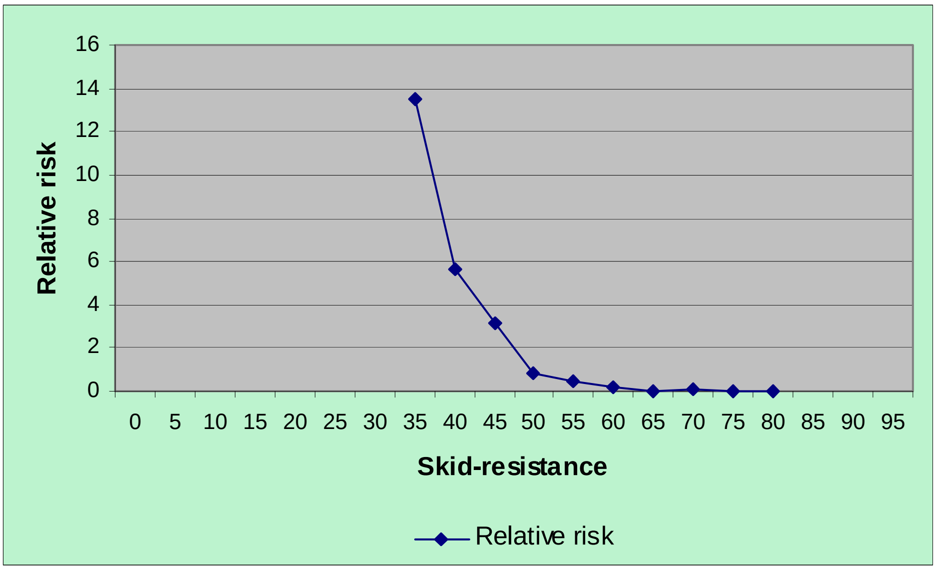



***Figure 4.4*** *Relative rate of a surface being a skidding-accident site for different values of skid-resistance.*

The rate becomes measurable below 65 and increases sharply below values of 50 to 55. The form of the curve suggests that values below 55 are likely to be accepted only on roads with easy traffic conditions, and values below 45 probably indicate potentially slippery conditions whatever the road layout and traffic conditions.

Schulze, Gerbaldi and Chavet [49] account for analyses from the Netherlands, the Federal Republic of Germany, and France. In the Netherlands all accidents on state roads during two years, 1965 and 1966, have been used in a regression analysis. The accident rate was derived from the number of accidents during a certain period on a selected section of road and the total vehicle-kilometres over the same period and section. Friction numbers for each road section were measured by the Dutch standard test method (86% slip). Wet friction numbers were used for all accidents that occurred in wet weather, and dry friction numbers for those accidents that occurred in dry conditions. Figure 4.5 shows the relationship between friction level and accident rate.

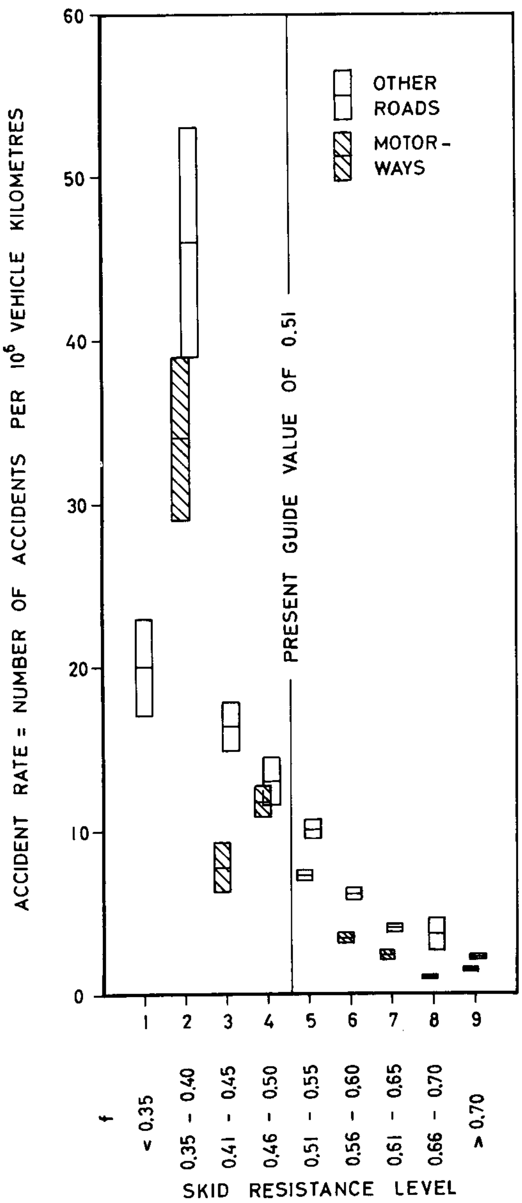



***Figure 4.5*** *Accident rate (mean and standard deviation) against friction level.*

In the Federal Republic of Germany [49] a regression analysis between friction numbers and accidents was based on the proportion of accidents that occurred under wet conditions. In general, on most road sections the proportion of accidents in the wet, i.e.

$P_w = (A_w/A_t) \times 100$ (%)
$A_w$: Number of accidents in wet conditions
$A_t$: Total number of accidents (in wet and dry conditions)

varies between zero per cent and approximately 50 per cent and averages about 33 per cent for the road network with slightly different figures from year to year. If on any particular section of road the proportion of wet-road accidents significantly exceeds this range of percentages, then this can be taken as an indication of reduced traffic safety under wet conditions. The skid numbers (locked wheel braking force coefficients) were measured at a speed of 80 km/h. Although there is a large scatter in the percentage of wet-road accidents for each friction level, the general trend of the increasing percentage of wet-road accidents with the decreasing friction level is unmistakable, (Figure 4.6).

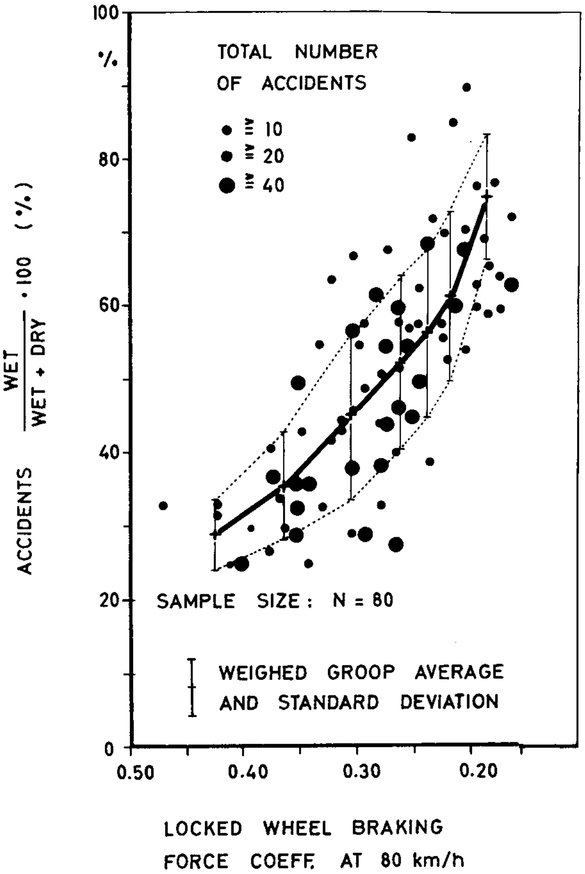



***Figure 4.6*** *Percentage of wet-road accidents against friction number.*

In France [49], skid-prone sites were compared with a random sample of sites, Figure 4.7. When the friction coefficient decreases, the relative proportion of accidents at skid-prone sites increases sharply. The braking force was measured with locked wheel.

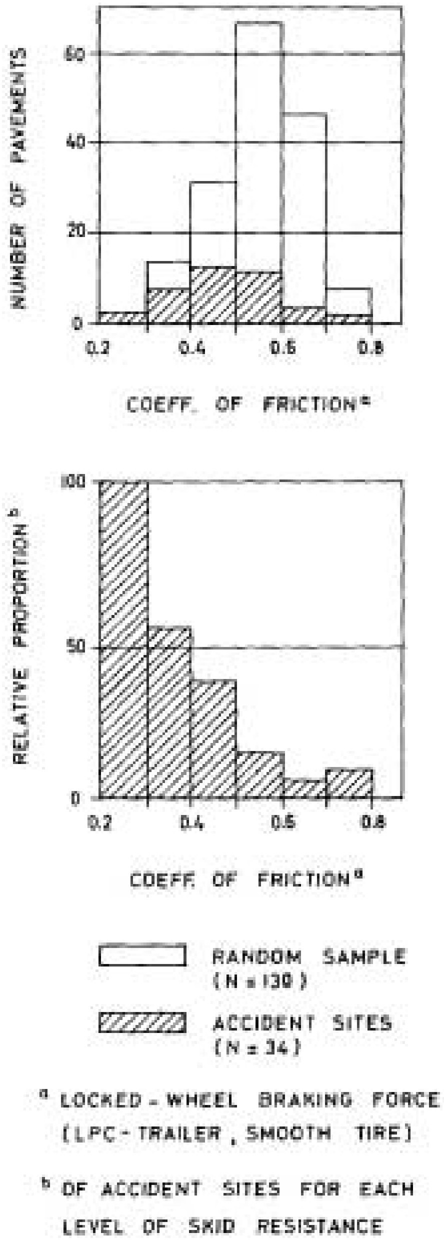



***Figure 4.7*** *Histograms of locked wheel braking force coefficients on accident sites and on randomly selected sites.*

Griffin [18] accounts for a study of wet weather accidents. Several variables were used as surrogates for vehicle demand for friction in a multiple linear-regression model:

| | |
|---|---|
| ADT: | average daily traffic |
| ACC: | access (a standardised subjective scale of roadway congestion) |
| SN: | skid number at 40 mph |
| TW: | proportion of time wet |
| VM: | mean traffic speed |
| V: | standard deviation of the speed distribution |
| LN: | lanes of traffic. |

Approximately 58 percent of the variance in wet accident rate (WAR) on high-speed roads (55 mph) could be accounted for by the following equation:

$$WAR = -21.7 + 0.0009 \times ADT + 2.34 \times ACC - 0.40 \times SN + 286 \times TW + 1.32 \times LN$$

Approximately 46 percent of the variance in WAR on low-speed roads could be accounted for by the following equation:

$$WAR = -0.75 + 0.0001 \times ADT - 0.053 \times VM + 0.54 \times V + 0.69 \times ACC - 0.025 \times SN.$$

(Note that the units of WAR are wet pavement accidents per mile per year.)

No more relevant information about the equations was provided in the reference.

In the Nordic TOVE project [21] – Traffic safety and the road surface properties – the effects of the road surface friction on the accident rates were studied. Friction data was, however, only obtained from Denmark, the friction was probably measured by the Stradograf. The tendency is that accident rate decreases with increasing friction see Figure 4.8. The tendency is valid for accidents with personal injuries as well as for accidents with only property damage. Figure 4.8 show the result for a two-lane, asphalt-paved road. However, deviations from this tendency were obtained for certain types of roads.

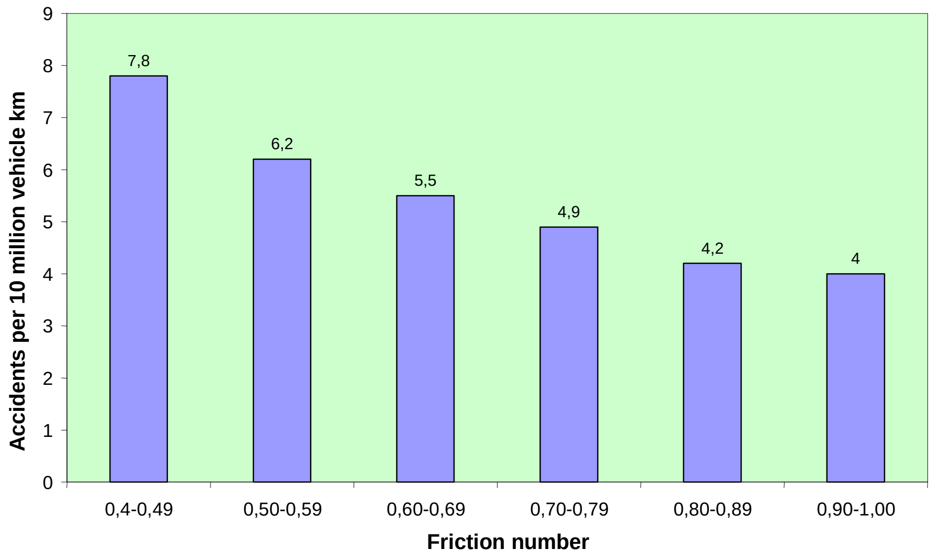



***Figure 4.8*** *Accident rates as a function of friction number. Police reported accidents.*

## 4.3 Winter road conditions

Assessing the accident rate for different icy or snowy roadway conditions is a very complex task. There are often swift changes and short duration, so the friction may vary to a great extent with time as well as spatially – longitudinally and laterally on the road. The accident rate is to a high degree depending on the adaptation of the driver behaviour. Figure 4.9 is an attempt to explain the causal relations in a broad outline.

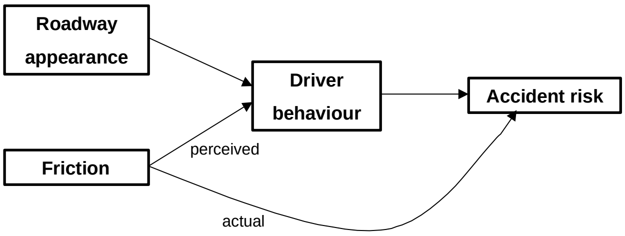



***Figure 4.9*** *Surface conditions, driver behaviour and accident rate.*

The friction perceived by the driver influence on his/her behaviour, but usually far from the necessary extent, so the actual friction will have a strong influence on the resulting accident rate.

A comprehensive survey by Öberg [59] comprised measurements of friction with the SFT at specified states of the road. The results are displayed in Figures 4.10 and 4.11. The friction span is usually very large within each specific condition, often larger than variations between the mean values for different conditions. A critical issue is if the tyres have contact with the pavement surface. If that is the case then the friction number will be comparably high. Consequently, a coarser texture of the road surface often implies higher friction than smoother surface. A striking example is illustrated in Figure 4.12, from Björketun et al. [14]. The roadway condition is about 1 cm wet snow along the whole stretch. On the coarse double surface dressing there is "bare-ground friction", while on the smooth asphalt concrete there is "ice/snow friction".

Friction and texture are closely related factors, but a literature review of texture-related surveys is beyond the scope of this study. Instead, see for example Wretling [56].

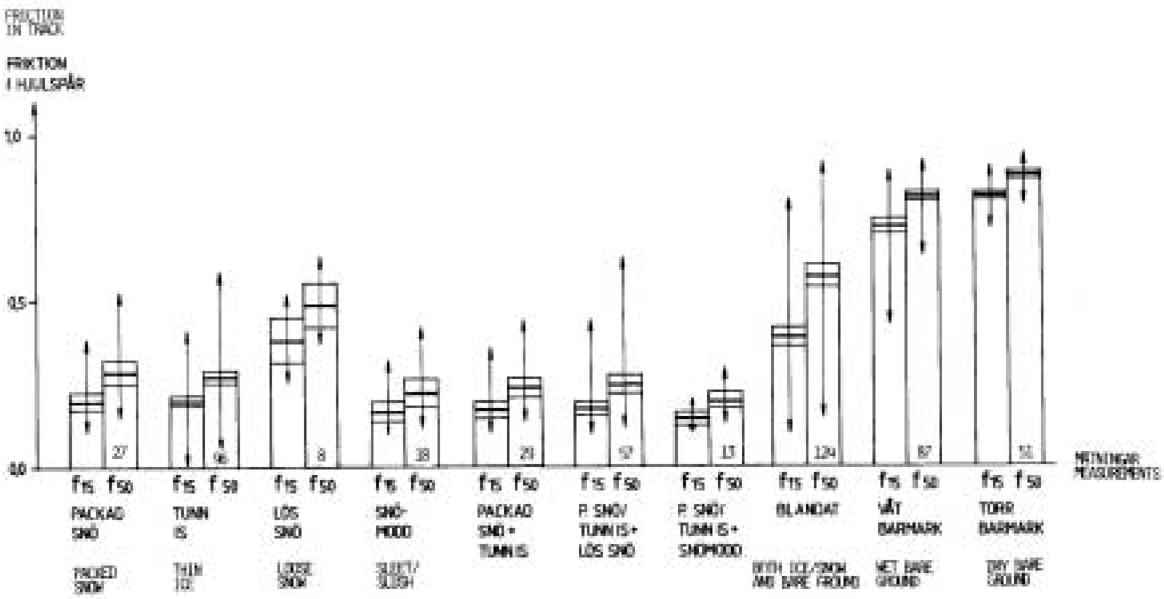



***Figure 4.10*** *Results of friction measurements in wheel-paths for different road conditions. The mean and the confidence limits (95%) are illustrated as bars for the 15- and 50-percentiles ($f_{15}$ and $f_{50}$) of the distribution of friction values along the road. The arrows indicate maximum and minimum values.*

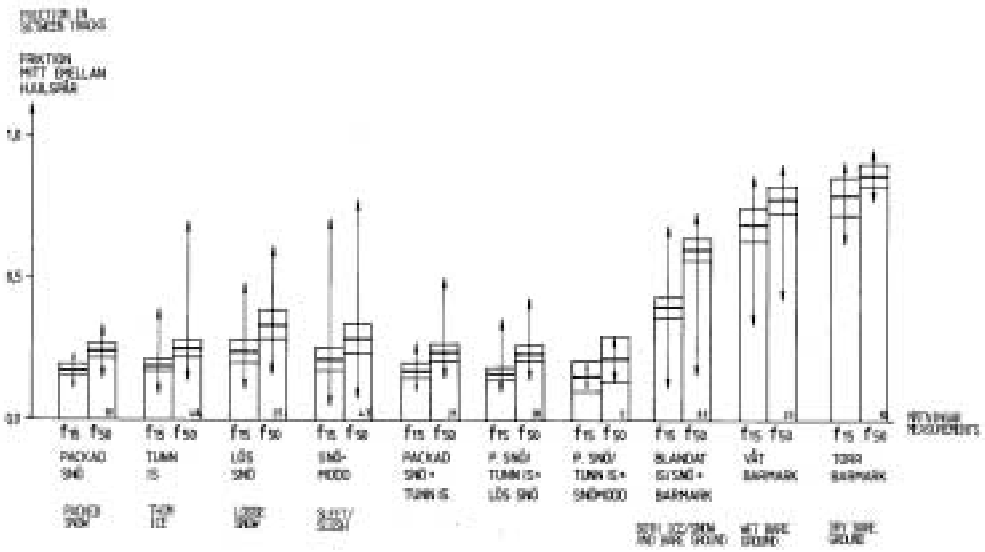


*Figure 4.11* *Results of friction measurements between wheel-paths for different road conditions. The mean and the confidence limits (95%) are illustrated as bars for the 15- and 50-percentiles ($f_{15}$ and $f_{50}$) of the distribution of friction values along the road. The arrows indicate maximum and minimum values.*

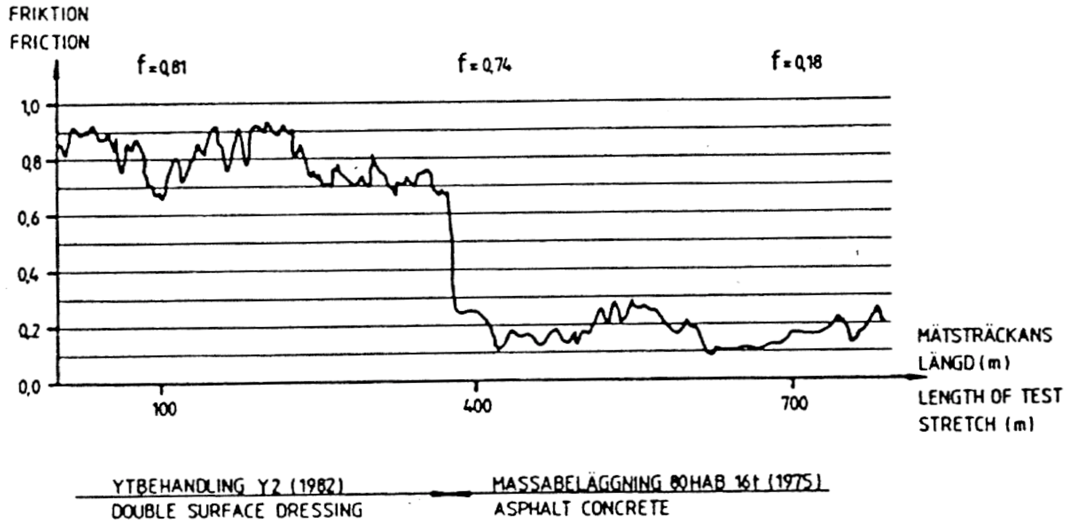



*Figure 4.12* *Friction measurements on two types of surfaces. 1 cm wet snow, air temperature +2°C. Mean friction values over the last 300 m passed are displayed at the top of the strip.*

A number of surveys of friction numbers for different road conditions, mainly the one mentioned above, and Öberg and Gregersen [61], can be summarised as follows:

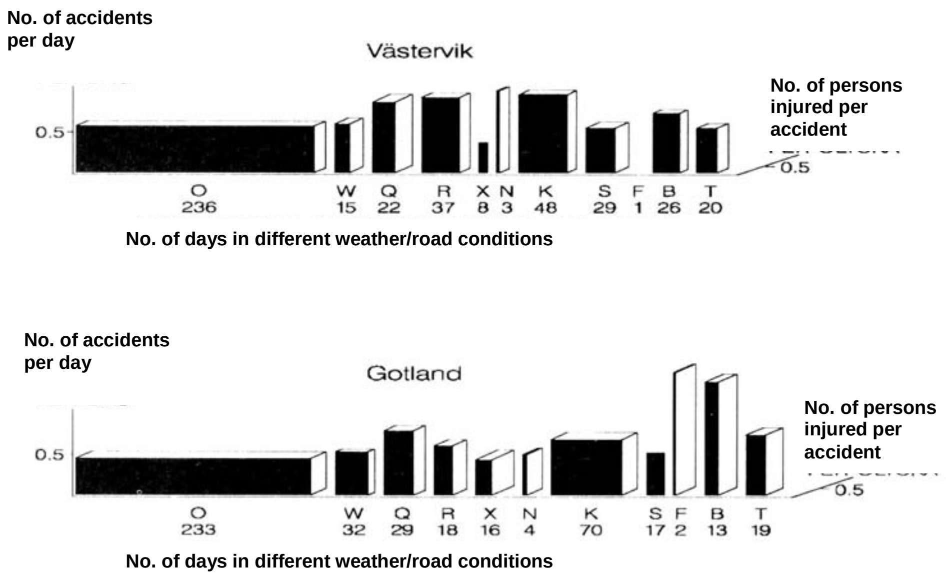
| | |
|---|---|
| Dry bare surface | 0.8–1.0 |
| Wet, bare surface | 0.7–0.8 |
| Packed snow | 0.20–0.30 |
| Loose snow/slush | 0.20–0.50 (the higher value when the tyres are in contact with the pavement) |
| Black ice | 0.15–0.30 |
| Loose snow on black ice | 0.15–0.25 |
| Wet black ice | 0.05–0.10 |

The friction numbers were obtained by skiddometer measurements with 17% slip (BV11 and SFT).

There are few surveys where the accident rates at winter conditions are estimated as a function of the friction number. The reasons are quite obvious: there is never any information of the prevailing friction at the accident, or even information of the distribution of friction numbers on different roads during the winter season. This would call for continuous measuring resources that are not available. Instead, visual observations of the roadway condition are used.

A sound hypothesis is that prevailing friction is a major factor influencing on the risk level. Then, if the accident rate is assessed on the basis of visual observations of the roadway condition, consequently large risk variations within each specified condition should be expected.

Another matter is the durability and frequency of winter road conditions that are very important for the adaptation of driver behaviour. In the MINSALT project, Öberg et al. [62], an unsalted test area (Gotland) was compared with a salted control area (Västervik). In Figure 4.13 the number of accidents and injures per accident are plotted against the number of days with different weather/road conditions. States of short durability, such as wet roads that freeze or frost (especially in the autumn) are very risky, but can be effectively controlled by salt.




O = bare ground
W = bare ground, snowfall < 2 mm in melted form
Q = bare ground, wet snowfall
R = bare ground, snowfall > 2 mm in melted form
X = ice/snow, snowfall < 2mm in melted form
N = ice/snow, wet snowfall
K = ice/snow, snowfall > 2 mm in melted form
S = ice/snow, dry, cold
F = wet road that freezes
B = frost in autumn
T = frost in winter

***Figure 4.13*** *Accidents reported to the police on Gotland (unsalted roads) and its control area Västervik during the winters of 1986/87 to 1988/89, distributed according to the categories "worst weather/road conditions" during one day.*

The roadway conditions are very different in Sweden between the northern and southern areas, which can be noticed in the accident rates. In this context, another matter should be mentioned. The ice surface temperature affect the friction to a high extent: the higher the temperature, the more slippery road, e.g. at black ice conditions. In Northern Sweden, black ice conditions may prevail for weeks at low temperature, while the friction number is comparatively high. Whitehurst and Ivey [55] state a relation between locked-wheel stopping distance and ice surface temperature. The relation is shown in Figure 4.14, as a multiplier for stopping distance with reference to the stopping distance at 25$^{o}$F (-4 °C).

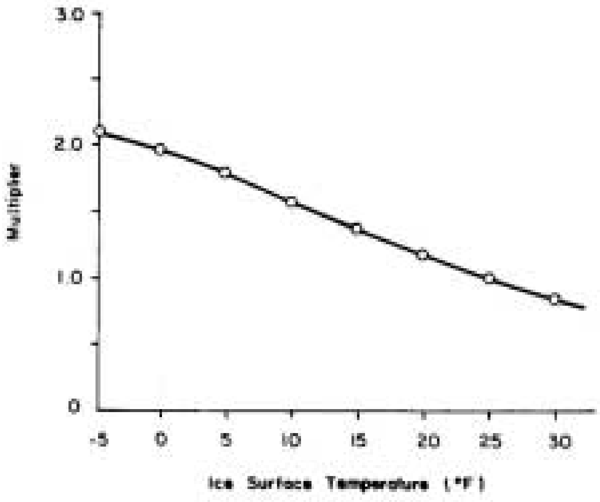



***Figure 4.14*** *Multiplier for locked-wheel stopping distance (reference temperature is 25 °F = -4 °C, 0 °F = -18 °C).*

Accidents reported to the police, traffic measurements, and observations of road conditions were used for assessing the accident rate at different conditions. Table 4.1 shows accident rates, from Wallman et al. [53], the assessments were based on data from Nilsson [34].

***Table 4.1*** *Accident rates at different conditions (accidents per million axle-pair kilometres).*

| | | **Bare road, all year** | **Bare road, summer** | **October - April** | |
|---|---|---|---|---|---|
| | | | | **Bare road** | **Ice/snow** |
| **Northern Sweden** | Daylight | 0.37 | 0.41 | 0.28 | 1.07 |
| | Darkness | 0.83 | 1.38 | 0.60 | 1.43 |
| **Central Sweden** | Daylight | 0.46 | 0.51 | 0.39 | 2.67 |
| | Darkness | 1.01 | 1.69 | 0.76 | 3.30 |
| **Southern Sweden** | Daylight | 0.55 | 0.59 | 0.49 | 5.29 |
| | Darkness | 1.06 | 1.48 | 0.91 | 7.93 |

The accident rates in Table 4.1 are averages over the year or over the winter season, so it is not possible to associate them with any friction numbers. However, the geographical differences are clearly visualised.

Data on winter road maintenance measures, accidents reported to the police, and vehicle mileage was used by Sävenhed [50] to estimate the accident rate before and after maintenance measures. Figure 4.15 shows a comparison between de-icing and anti-icing (precautionary) actions with salt. De-icing actions are undertaken when the friction has decreased, while precautionary actions should preserve good friction. The increased risk for the de-icing actions is probably entirely related to impaired friction. Precautionary actions imply much less variations in the accident rate.

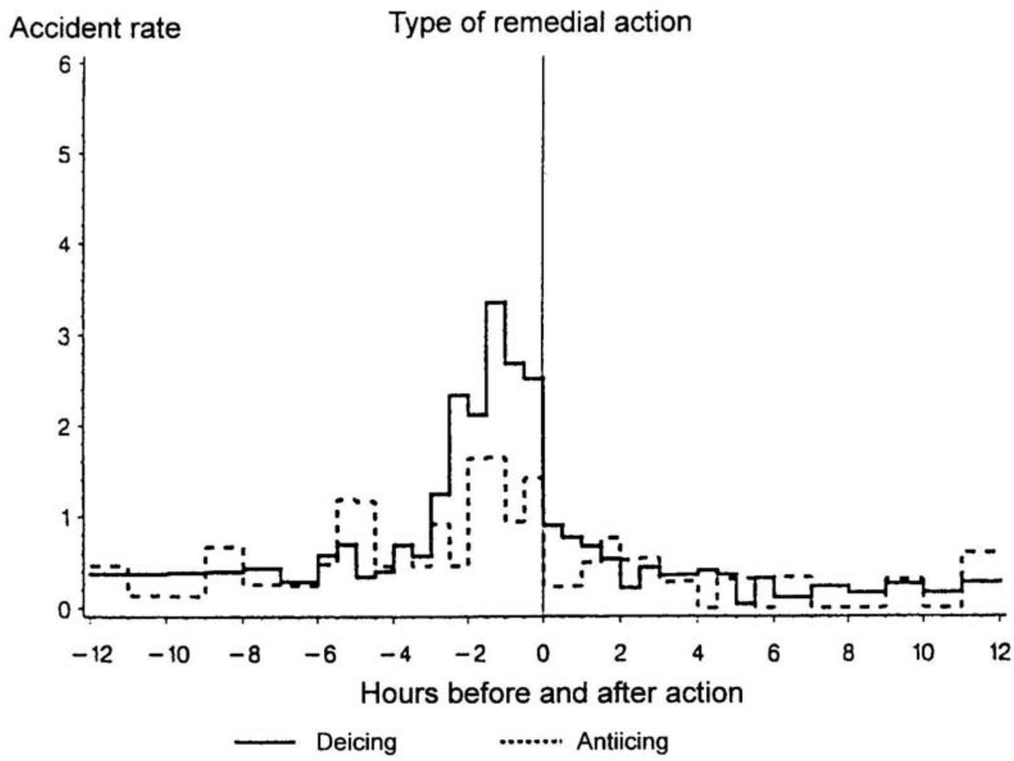



***Figure 4.15*** *Accident rate (accidents per million axle-pair kilometres) during the hours before and after salting.*

Nation-wide observations of roadway conditions were done during the winter seasons 1993/94 to 1996/97. This data was used together with accidents reported to the police and the mileage on different road categories to assess the accident rates at the same roadway conditions as were used by the police, Wallman [52]. The risk was assessed for each road maintenance class in four climate regions. Table 4.2 shows the result across Sweden for the six different roadway conditions. The maintenance classes are grouped into A1-A4, which are roads treated with salt, normally they shall be free from ice and snow, and into B1-B2, which are roads where sanding or gritting is the normal skid-prevention treatment. The accident rate is estimated for all accidents (except wildlife), and accidents with killed or seriously wounded, respectively.

*Table 4.2 Accident rates at different road conditions across Sweden.*

| Roadway condition | All roads | | A1 – A4 | | B1 – B2 | |
|---|---|---|---|---|---|---|
| | All | D+SI | All | D+SI | All | D+SI |
| Dry, bare road | 0.25 | 0.02 | 0.25 | 0.02 | 0.20 | 0.03 |
| Wet/moist road | 0.30 | 0.03 | 0.30 | 0.03 | 0.30 | 0.03 |
| Loose snow/slush | 1.40 | 0.14 | 1.60 | 0.15 | 0.90 | 0.12 |
| Thick ice/ packed snow | 0.70 | 0.07 | 1.90 | 0.13 | 0.55 | 0.05 |
| Black ice/ hoarfrost | 1.30 | 0.13 | 2.80 | 0.26 | 0.55 | 0.07 |

In the Norwegian Veg-grepsprosjektet [7] – the Road-Grip Project – data from a survey by Sakshaug and Vaa [45] was used. Comprehensive friction measurements were done, and also roadway observations. Accident rates for different roadway conditions as well as for different friction intervals was assessed which are displayed in Table 4.3 and 4.4. The risk unit is accidents with personal injuries per million vehicle kilometres. Even in this comprehensive study, the friction intervals are rather large.

***Table 4.3*** *Accident rates (personal injuries per million vehicle kilometres) at different roadway conditions.*

| Roadway condition | Accident rate |
|---|---|
| Dry bare roadway, winter | 0.12 |
| Wet bare roadway, winter | 0.16 |
| Slush | 0.18* |
| Loose snow | 0.30 |
| Ice | 0.53 |
| Hoarfrost | 0.53 |
| Packed snow | 0.31 |
| Bare ruts | 0.12* |
| Black ice in ruts | 0.30* |
| Dry bare roadway, summer | 0.14 |
| Wet bare roadway, summer | 0.18 |

* Unreliable figure

*Table 4.4* ***Accident rates (personal injuries per million vehicle kilometres) at different friction intervals.***

| Friction interval | Accident rate |
|---|---|
| < 0.15 | 0.80 |
| 0.15 – 0.24 | 0.55 |
| 0.25 – 0.34 | 0.25 |
| 0.35 – 0.44 | 0.20 |

## 4.4 Comment

The relation between friction and accident rate is certainly no easy problem to explain. Many different factors pertaining to the road environment – in addition to the friction – affect the driver behaviour, as was indicated in chapter 4.1. The driver behaviour variability is of great importance for the accident rate.

The complexity of the problem is especially pronounced at winter conditions, as has been found in this review, similar-looking roadway conditions may have very different friction numbers. Also, the friction may vary both across and along the road. Friction conditions are much more stable at dry or wet bare road surface.

Surveys of winter accident rates thus imply very varying results, but always with much larger risks than at bare road conditions. Future studies must have much closer control of factors as roadway conditions, friction coefficients, and exposure etc. to make a more detailed assessment of accident rates possible. This involves frequent observations of the roadway condition and extensive friction measurements, as well as a much more detailed description of each accident (crash investigations).

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