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COST 354
Performance Indicators for Road Pavements

WP 2 "Selection and assessment of individual performance indicators"

Report

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Selection and assessment of individual performance indicators

Report

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INTRODUCTION

COST Action 354 - Performance Indicators for Road Pavements started in April 2004. The main objective of the Action is the definition of uniform European performance indicators and indices for road pavements taking the needs of road users and road operators into account.

A quantitative assessment of individual performance indicators provides guidance regarding present and future needs in road pavement design and maintenance at both the national and the European levels. By specifying limits and acceptance values for individual performance indicators minimum standards can be laid down for both projected and existing road pavements. Performance indicators should be defined for different types of pavement structures and road categories.

The specification of performance criteria from the perspectives of both road users and road operators is a key prerequisite for the efficient design, construction and maintenance of road pavements. Particularly the increasing use of life-cycle analyses as a basis for the selection of road pavements and the decision of whether or not to implement a systematic road maintenance scheme calls for an exact definition of the goals to be achieved and/or the performance criteria to be satisfied. The extent to which goals are reached or performance criteria satisfied can be quantified by calculating special indices characterizing the road pavement, which in turn permits an assessment of the efficiency of certain approaches from both a commercial and a macro-economic standpoint.
For a Europe-wide harmonization of standards to be met by road pavements it therefore appears useful and appropriate to specify pavement characteristics in terms of uniform “performance indicators” for different road categories (motorways, national roads, local roads, etc.).

It is envisaged that the application of such uniform indices will allow the specification of minimum European standards for road pavements. In addition, it would also be feasible and useful to filter out those areas of the European road network where more investment is needed to attain such minimum standards (depending on the road category). Performance indicators for road pavements could, however, also be used as inputs to pavement management systems (PMS), for calculating maintenance needs and thus to provide objective arguments for the need of reinvestment in road pavements.

Based on previous results of COST Actions and European research projects the definition and assessment of individual representative performance indicators and the development of combined performance indices will be conducted. A separate COST Action offers an excellent framework to bring together the existing knowledge from a large number of COST countries and USA. This knowledge is gathered from national road administrations, including experts from research laboratories and universities.

The work program to be carried out under this COST Action is subdivided into five work packages, each producing one of the five deliverables. This report describes the work carried out in Work Package 2 “Selection and assessment of individual performance indicators”.

The aim of this WP was to identify a set of “Performance Indices” to represent in a unitless scale the following Performance Indicators:
- Longitudinal evenness;
- Transverse evenness;

- Macrotexture;
- Friction;
- Noise;
- Air Pollution;
- Bearing Capacity.

Cracking was initially considered as a single performance indicator but it was then decided to consider this as a combined performance indicator and it is therefore tackled by WG3 of COST 354 action.

Within the COST 354 action a “Performance Index” has been defined as a dimensionless figure in a 0 to 5 scale with 0 representing a pavement in very good conditions and 5 a very poor one, with respect to a specific pavement condition property.

A Performance index can usually be derived from a “Technical Parameter” that is a physical characteristic of the road pavement condition obtained from measurements by a device or collected by other forms of investigation (e.g. rut depth, friction value, etc.)

In this context a “Performance Indicator” for road pavement is the superior term of a technical road pavement characteristic, that indicates the condition of it (e.g. transverse evenness, skid resistance, etc.). A performance indicator can be defined in the form of technical parameters (as a rule dimensional) and/or in form of dimensionless indices.

The planned activities for WG2 were:
- Select suitable performance indicators
- Define target values and limits
- Develop transformation functions from Technical Parameters to performance indices
- Provide a practical guide for the calculation of the performance index

These have been performed mostly based on the results of the work of WG1 of this COST action using the data contained in the so-called COST-354 database. In some cases it was deemed necessary to integrate the data in the database with an additional literature review to obtain a Performance Index for a given indicator.

The main aim of defining dimensionless Performance Indices is that they will then be combined into “Combined Performance Indices” in WP3 of this action and then into a “Global Performance Index” in WP4 of this same action.

Given the wide variety of potential users of the COST 354 final procedure it was deemed necessary in WP2 to develop a procedure that could be applied at all different levels depending on the type of measurement and analysis approach already in place in the road authority applying the procedure.

The different levels can be summarized as follows:
- The user provides the value for the Technical Parameter identified as the “most suitable” by WG2 and, by means of the transfer functions described in this report, derives a value for the dimensionless Performance Index;
- The user provides the value for the Technical Parameter identified as the “most suitable” by WG2 but applies a different transfer function to derive a value for the dimensionless Performance Index (always in the same 0 to 5 scale as above);
- The user provides the value for a different Technical Parameter and applies his own transfer function to derive a value for the dimensionless Performance Index (always in the same 0 to 5 scale as above);

- The user provides directly a value for the dimensionless Performance Index (always in the same 0 to 5 scale as above).

As far as the target values and limits are concerned, it was decided to analyse them and use them as a surrogate measure for defining transfer functions, these will therefore be described in this report. On the other hand, no target values or limit will be proposed as “reference” in this report as these strongly depend on the type of road and on the serviceability level that the road authority wants to achieve.

This report is intended for use only within this Action and therefore it is effectively a snapshot in time of the individual and combined pavement performance indicators being used currently throughout Europe and USA.

The number of countries included in the COST 354 Action is 24 (23 European + USA). For the purpose of this report only 22 out of the 24 countries were considered. This was because the information provided by Bulgaria and Romania was included in the database after version 2 (dated 15 October 2005), which served as the basis for the WG2 activities. Some minor adjustments to the data contained in version 2 of the database have been included in the report based on the comments of the WG2 members. All of these adjustments have been included in later revisions of the database.

Some of the data from Croatia was rectified or integrated during the WG2 work and therefore could not be considered in the distribution analysis. In the tables the rectified figures are indicated with a note explaining the change as compared to the available database.

SECTION 1: LONGITUDINAL EVENNESS

1.1 LONGITUDINAL EVENNESS INDICATORS FROM THE COST 354 DATABASE

The number of countries included in the COST 354 Action is 22. All of the countries filled in the longitudinal evenness performance indicator group but the number of questionnaires analyzed is 24 because France and Belgium reported two each.

An initial examination of the longitudinal evenness performance indicator group found some inconsistencies that needed to be sorted out before the analysis could begin. Two indicators were found which did not fit into this group, one detailing durability cracking and the other spalling of longitudinal and transverse joints (both on rigid pavements, taken with visual inspection). They were both excluded from further analyses regarding longitudinal evenness and moved into the groups Cracking and Joint Spalling Width, respectively.

Analysing the database further it was found out that several answers from one country mean that in fact it goes for different measuring devices or different technical parameters and therefore it is correct that they are included in further analyses. The only exception is Czech Republic where two answers mean the same performance indicator and the only difference between them is the Field of Application (first for Motorways and Other Primary Roads and the second one for Secondary Roads and Other Roads), resulting in the difference only in threshold values and transformation functions of indices. Therefore they were merged.

Table 1 shows the number of records analyzed. It doesn't fit with the number of questionnaires. The reason is that Belgium, France, Germany and United Kingdom gave 3 answers and Spain and Sweden reported 2 answers. That means that the total number of records analyzed for longitudinal evenness performance indicator is 32.

Furthermore answers from Bulgaria and Romania were received, but not included in the evaluation because they were received to late for the analysis.

Table 1: Number of countries, questionnaires and records referred to the longitudinal evenness performance indicator

COUNTRY	TOTAL Nº QUESTIONNAIRES	LONGITUDINAL EVENNESS Nº RECORDS
AUSTRIA (AT)	1	1
BELGIUM (BE)	2	3
CROATIA (HR)	1	1
CZECH REPUBLIC (CZ)	1	1
DENMARK (DK)	1	1
FINLAND (FI)	1	1
FRANCE (FR)	2	3
GERMANY (DE)	1	3
GREECE (EL)	1	1
HUNGARY (HU)	1	1
ITALY (IT)	1	1
NETHERLANDS (NL)	1	1
NORWAY (NO)	1	1
POLAND (PL)	1	1
PORTUGAL (PT)	1	1
SERBIA AND MONTENEGRO (CS)	1	1
SLOVENIA (SI)	1	1
SPAIN (ES)	1	2
SWEDEN (SE)	1	2
SWITZERLAND (CH)	1	1
UNITED KINGDOM (UK)	1	3
USA (US)	1	1
22	**24**	**32**

1.1.1 General information

The longitudinal unevenness is the deviation of the longitudinal profile from a straight reference line in a wavelength range of 0.5m-50m. The range from 0.5 to 50m is the common range for roads. This limit can be extended to 100m for runways. Higher values don't deal with unevenness but depend on road geometry.

Different technical parameters for the longitudinal evenness performance indicator are used in individual countries.

In the database TPs are described with:

- the name,
- the description,
- the abbreviation,
- the unit
- the measuring equipment and measuring principle.

As the abbreviation is not the same for different countries, it is not included in this analysis. The situation is the same when considering the name and description. Therefore a new field, "Unified Name of TP" was added to the database by the WG 1 to be able to group the technical parameters.

In the database there are 7 unified types of technical parameters describing longitudinal evenness:

- international roughness index
- wave length
- evenness
- longitudinal profile variance
- longitudinal profile
- spectral density
- standard deviation.

It was very important to take into account the measuring principle and the device used to collect the data. Table 2 includes the unified name of the TP, the description, the unit, the equipment name and the measuring principle reported in the database.

Table 2: Description of longitudinal evenness technical parameters from the COST-354 database

COUNTRY	NAME	NAME TP (Unified)	DESCRIPTION	UNIT	EQUIPMENT NAME	MEASURING PRINCIPLE
AUSTRIA (AT)	Longitudinal evenness	International roughness index	International roughness index	m/km	RoadSTAR	Laser
BELGIUM (BE) 1	Evenness	Evenness	Vlakheid	other	ARAN or Apl	Accelerometer with laser
BELGIUM (BE) 2	Longitudinal eveness	Evenness	Coefficient de planéité 2,5	other	APL	Accelerometer
BELGIUM (BE) 3	Longitudinal evenness	Evenness	Coefficient de planéité 10	other	APL	Accelerometer
CROATIA (HR)	Longitudinal evennes	International roughness index	International roughness index	m/km	Laser profil	Laser (inertially referenced)
CZECH REPUBLIC (CZ)	Longitudinal evenness	Evenness	severity of evenness	-	ARAN	Laser
DENMARK (DK)	Evenness	International roughness index	International Roughness Index	m/km	Profilograph	Laser
FINLAND (FI)	Longitudinal unevenness	International roughness index	Roughness	mm/m	RST	Laser
FRANCE (FR) 1	Longitudinal profile	Wave length	Short wavelength	-	APL (SIRANO)	Mechanical (inertially referenced) profilometer
FRANCE (FR) 2	Longitudinal profile	Wave length	Long wavelength		APL (SIRANO)	Mechanical (inertially referenced) profilometer
FRANCE (FR) 3	Longitudinal profile	Wave length	Medium wavelength	-	APL (SIRANO)	Mechanical (inertially referenced) profilometer
GERMANY (DE) 1	General unevenness	Spectral density	Spectral Density	cm^3		Laser
GERMANY (DE) 2	Periodical unevenness	Wave length	Wave length	m		Laser
GERMANY (DE) 3	Single obstruction	Wave length	Wave length	m		Laser
GREECE (EL)	Longitudinal evenness	International roughness index	Elevation	m/km	Laser Profiler	Laser
HUNGARY (HU)	Longitudinal unevenness	International roughness index	International Roughness Index	m/km	Road Survey Tester (RST)	Laser
ITALY (IT)	Longitudinal evenness	International roughness index	International Roughness Index	m/km	Profilometer	Laser
NETHERLANDS (NL)	Longitudinal evenness	International roughness index	IRI	m/km	ARAN	Laser
NORWAY (NO)	Longitudinal unevenness	International roughness index	IRI	mm/m	ALFRED	Laser
POLAND (PL)	Longitudinal evenness	International roughness index	International Roughness Index	mm/m	Greenwood Profilograph	Laser
PORTUGAL (PT)	Longitudinal unevenness	International roughness index	Longitudinal Unevenness	m/km	Laser profilometer	Laser
SERBIA AND MONTENEGRO (CS)	Longitudinal evenness	International roughness index	Longitudinal Evenness	m/km	ROMDAS Bump Integrator	Accelerometer
SLOVENIA (SI)	Longitudinal evenness	International roughness index	IRI	m/km	Profilograph ZAG	Accelerometer with differential transformer
SPAIN (ES) 1	Longitudinal evenness	International roughness index	Roughness longitudinal profile	m/km	Dipstick	Walking profiler

COUNTRY	NAME	NAME TP (Unified)	DESCRIPTION	UNIT	EQUIPMENT NAME	MEASURING PRINCIPLE
SPAIN (ES) 2	Longitudinal evenness	International roughness index	Roughness longitudinal profile	m/km	Laser profilometers	Laser
SWEDEN (SE 1)	Longitudinal unevenness	International roughness index	IRI	mm/m	Laser RST	Laser
SWEDEN (SE) 2	Longitudinal unevenness	Longitudinal profile	Longitudinal profile	mm	Laser RST	Laser
SWITZERLAND (CH)	Longitudinal evenness	Standard deviation	Standard deviation	‰		
UNITED KINGDOM (UK) 1	Ride Quality (3m)	Longitudinal profile variance	3m Longitudinal Profile Variance	other	Road Assessment Vehicle (RAV)	Laser
UNITED KINGDOM (UK) 2	Ride Quality (10m)	Longitudinal profile variance	10m Longitudinal Profile Variance	other	Road Assessment Vehicle (RAV)	Laser
UNITED KINGDOM (UK) 3	Ride Quality (30m)	Longitudinal profile variance	30m Longitudinal Profile Variance	other	Road Assessment Vehicle (RAV)	Laser
USA (US)	Smoothness	International roughness index	International Roughness Index	inch/mi	ARAN, ICC profiler …etc.	Laser

In most of the cases with data available, the technical parameter measured is International Roughness Index IRI (17 cases of 32 total answers). In 5 records the technical parameter is Wavelength (from 2 questionnaires), in 4 records (3 are from the same questionnaire) the technical parameter is Evenness and in 3 records Longitudinal Profile Variance (all from 1 questionnaire). There are also single records for technical parameters Spectral Density, Longitudinal Profile and Standard Deviation. The results are shown in Figure 1.

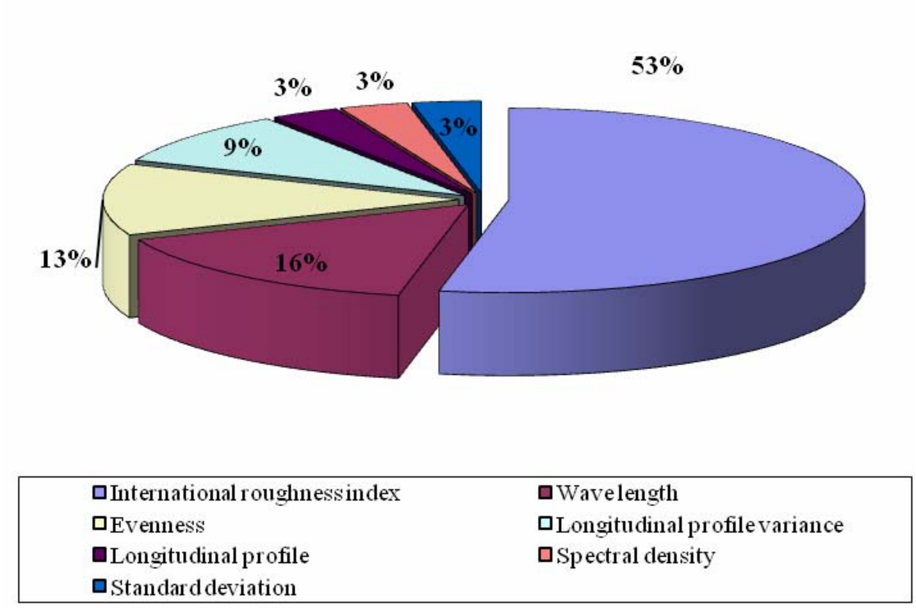

Figure 1: Technical parameters for longitudinal evenness performance indicator

Given the fact that the majority or the responders use the IRI, some of the detailed analysis of the COST-354 database responses will have specific reference to IRI (see section 1.2.1). This is because analysing all the data together could lead to erroneous conclusions on the actual use of the specific selected index. In the following paragraphs the more "general" issues (standard practice or research, standardization etc) will be analysed with reference to all the different technical parameters included in the database.

1.1.2 Standard practice or application for research

Figure 2 shows the distribution of answers for standard practice and practice for research for technical parameters of longitudinal evenness.

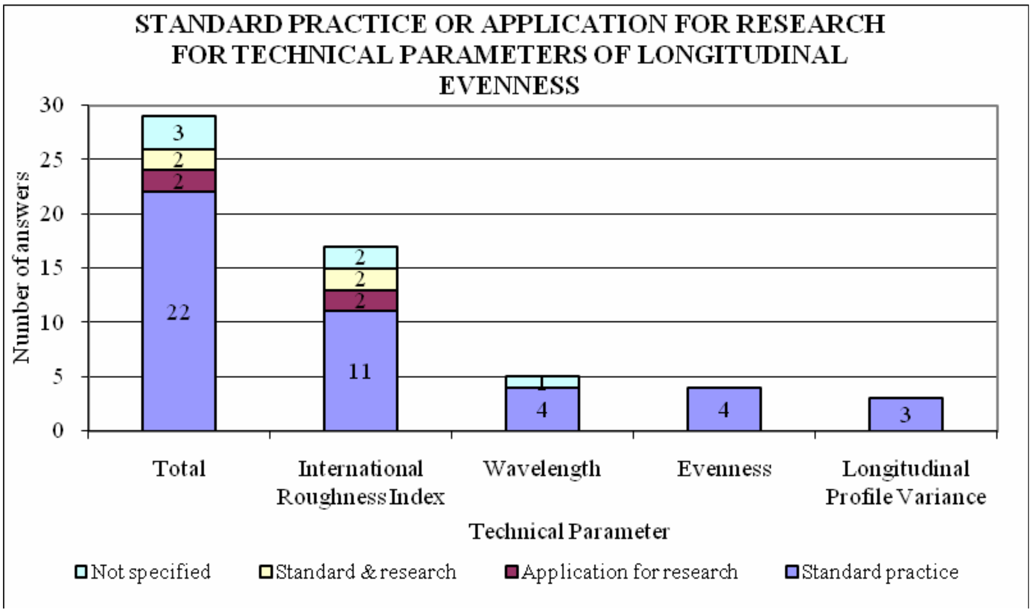

Figure 2: Number of answers for standard practice and application for research for technical parameters of longitudinal evenness

Longitudinal evenness measurements are a standard practice in the majority of countries.

1.1.3 Standardization

The first question included in the chapter of data collection in the COST 354 database, is whether the technical parameter is measured according to a Standard. The answers obtained are shown in Figure 3.

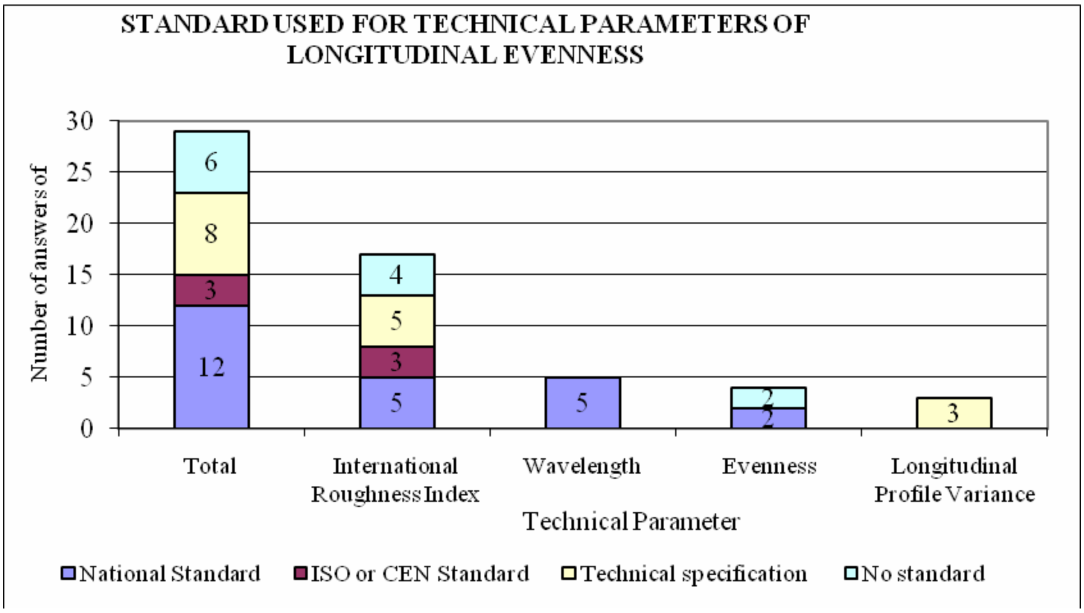

Figure 3: Number of answers for used standard for technical parameters of longitudinal evenness

The most common way of measuring technical parameters is following a national standard. Only 3 countries stated ISO or CEN standards.

1.1.4 Measuring principle

There are four groups of measuring principles in the database for assessing the longitudinal evenness performance indicator:

- laser,
- accelerometer,
- mechanical (inertial referenced) single wheel trailer,
- walking profiler Dipstick.

The records included in the COST 354 database about the measuring principle for longitudinal evenness performance indicators are shown in Figure 4.

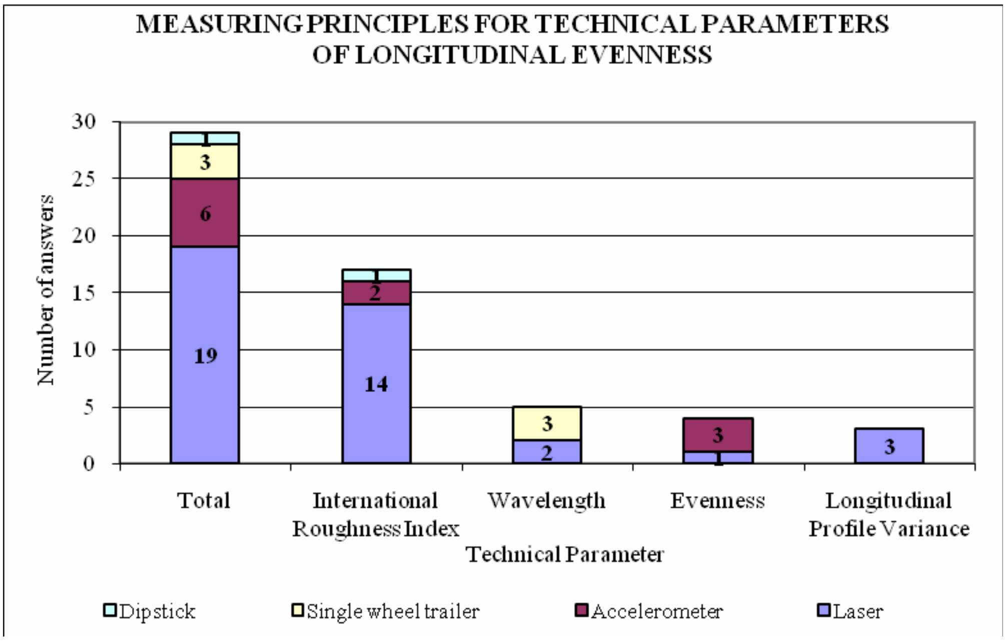

Figure 4: Number of answers for measuring principle for technical parameters of longitudinal evenness

From the answers it can be concluded that lasers are mainly used for measuring the longitudinal evenness performance indicators.

1.1.5 Quality assurance

Figure 5 shows the distribution of answers for quality assurance for technical parameters of longitudinal evenness.

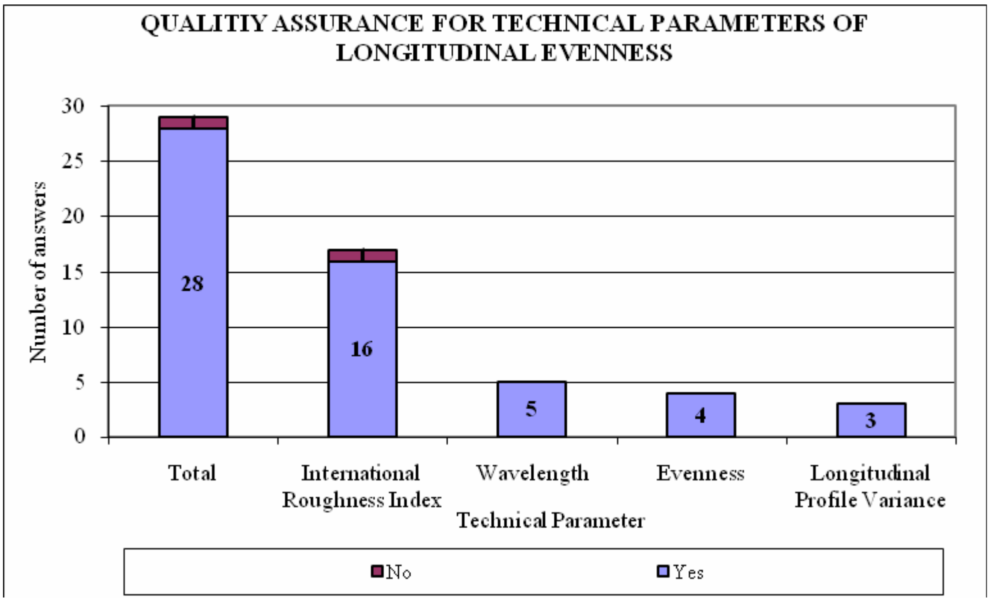

Figure 5: Number of answers for quality assurance for technical parameters of longitudinal evenness

From the answers it can be concluded that quality assurance is taken into account for longitudinal evenness measurements.

1.2 EVALUATION OF THE MOST SUITABLE INDIVIDUAL PERFORMANCE INDICATORS

Four technical parameters from the COST 354 database were further analysed, namely International Roughness Index, Wavelength, Evenness and Longitudinal Profile Variance. From them, the International Roughness Index is most commonly used (in 53%) and is analysed in more detail.

1.2.1 TP International Roughness Index (IRI)

Table 3 shows the information concerning the data collection for the technical parameter International Roughness Index (IRI). There are 17 answers in the database.

Table 3: Technical parameter "International Roughness Index" information from the database

COUNTRY	STANDARD	STANDARD NAME	STANDARD PRACTICE OR RESEARCH	TYPE OF INSPECTION	COLLECTED DATA	OPERATING SPEED [Km/h]	SECTION LENGTH [m]	HOMOGENI-ZATION	INTERVAL [years]	QUALITY ASSURANCE
AUSTRIA (AT)	National Standard	RVS 11.066 - Teil VIII, Laengsebenheitsmessung mit dem System RoadSTAR	Standard	Contactless Measurement	Severity	60	50	yes	5	yes
CROATIA (HR)	Technical Specification(*)	OPCI Tehnicki OVJETI (OTU) (*)	Standard & Research	Contactless Measurement	Extension	35-100 (*)	100	no	1	yes
DENMARK (DK)	National Standard	Konstruktion og vedligehold af veje og stier, Hæfte 4, Vedligehold af færdselsarealet, Juni 2004. Comming CEN-standard #prEN 13036-5	Standard	Contactless Measurement		20-100	1000	yes	1	yes
FINLAND (FI)	ISO-Standard		Standard	Contactless Measurement	Extension	80	100	no	1	yes
GREECE (EL)	Technical Specification	Draft specification and contract documents in Greece		Contactless Measurement		40-100	10	no		no
HUNGARY (HU)	Technical Specification	ÚT 2-2.116/1998 RST-mérés és -értékelés (RST-measurement and evaluation)	Standard	Contactless Measurement	Extension	30-80	100	no	3	yes
ITALY (IT)	Technical Specification	ASTM E 950-98; World Bank Technical Paper n° 45-46	Standard	Contactless Measurement	Extension & Severity	70-80	20	yes	1	yes
NETHERLANDS (NL)	Technical Specification	National Cooperative Highway Research Program (NCHRP). NCHRP Report 228.	Standard	Contactless Measurement	Severity	80	100	no	2	yes
NORWAY (NO)	ISO-Standard	ISO 13473		Contactless Measurement	Severity	60-70		no		yes
POLAND (PL)	No Standard	System Oceny Stanu Nawierzchni - Wytyczne stosowania, Załącznik B	Standard	Contactless Measurement	Severity	60	1000	no	1	yes
PORTUGAL (PT)	No Standard		Standard	Contactless Measurement	Severity	80		yes	4	yes
SERBIA AND MONTENEGRO (CS)	No Standard	ROMDAS Manuals and User's Guides	Standard	Measurement	Severity	32	25	yes	3	yes
SLOVENIA (SI)	Technical Specification	TSC 06.610: 2003 Lastnosti voznih površin, Ravnost (Pavement surface properties, Evenness)	Research	Contactless Measurement	Severity	80	20	yes	5	yes
SPAIN (ES) 1	National Standard	NLT 331/98 Medida de la regularidad con perfilómetro pivotante de alta precisión		Measurement				no		yes
SPAIN (ES) 2	National Standard		Research	Contactless Measurement		Traffic		no	3	yes
SWEDEN (SE 1)	National Standard	RVS 11.066 - Teil VIII, Laengsebenheitsmessung mit dem System RoadSTAR	Standard	Contactless Measurement	Severity	60	50	yes	5	yes
USA (US)	No Standard		Standard	Contactless Measurement	Extension		100	no	1	yes

(*) information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses.

1.2.1.1 Distribution of TP International Roughness Index (IRI) by the PI category

In the Questionnaire there are four categories to choose from:
- Road Safety PI,
- Riding Comfort PI,
- Pavement Structure PI and
- Environmental PI.

Figure 6 shows the distribution by the category of performance indicator for the TP IRI. No country included TP IRI into environmental PI.

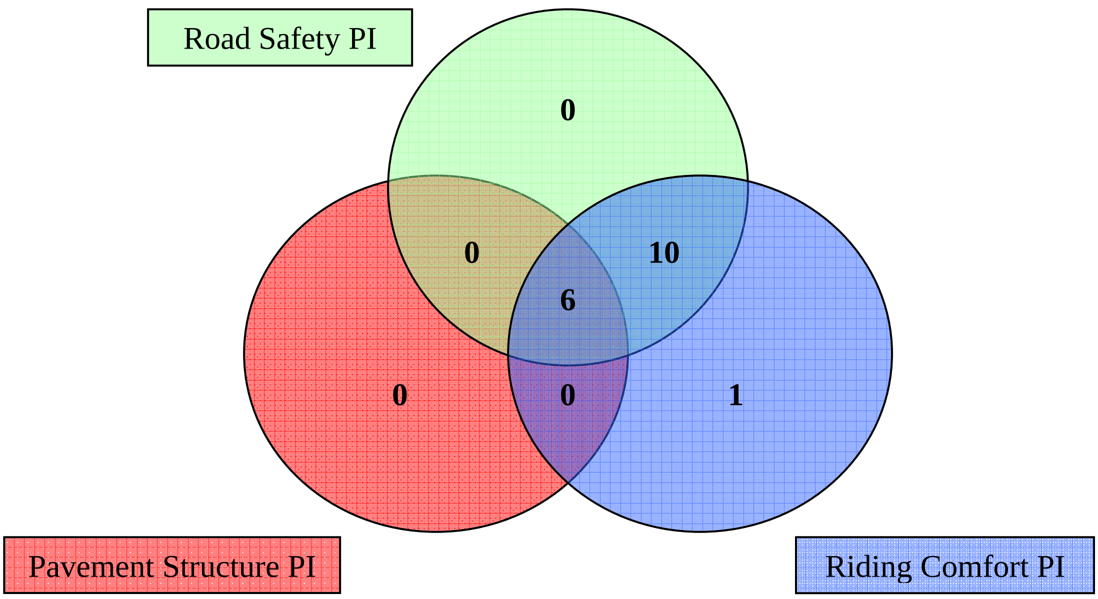

Figure 6: Distribution by the category of PI for TP IRI

All of the responders included IRI as a Riding comfort performance indicator, 94% as a Road safety and Riding comfort performance indicator and 35% as a Pavement structure, Road safety and Riding comfort performance indicator.

1.2.1.2 The distribution of TP International Roughness Index (IRI) by the road category

The question about the road network gave responders four possibilities:
- motorways,
- other primary roads,
- secondary roads and
- other roads.

Figure 7 shows the distribution by road network for the TP IRI.

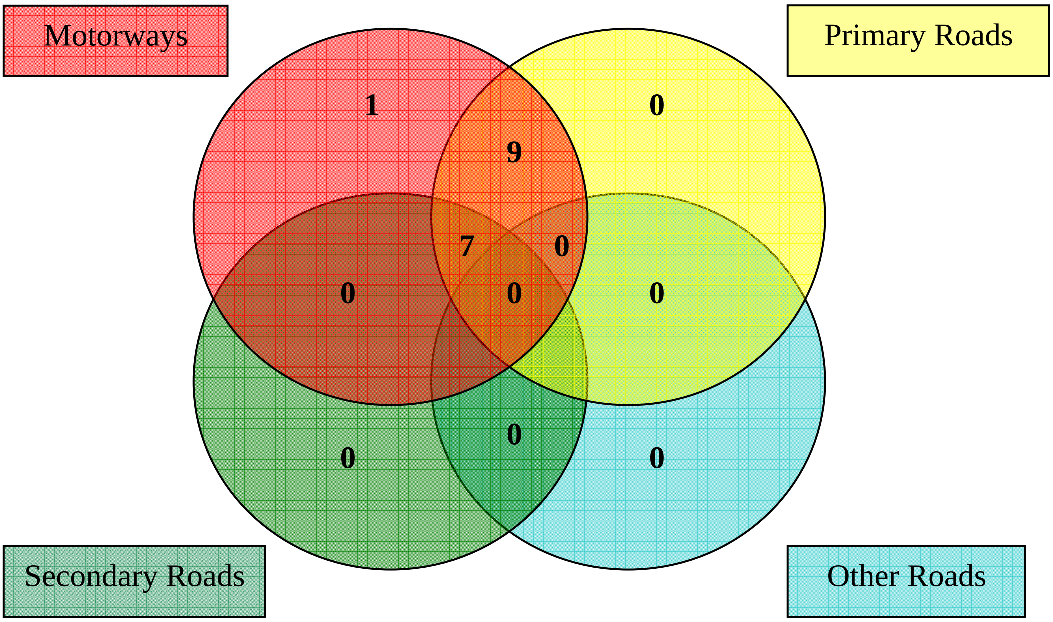

Figure 7: The distribution by road category for TP IRI

All of the responders (17) gave answers for Motorways. 9 of them (53%) stated that TP IRI is used on Motorways and Other Primary Roads and 7 of them (41%) on Motorways, Other Primary and Secondary Roads. There were no answers for Other Roads.

From the database it is not possible to define whether they do not perform measurements of longitudinal evenness using TP IRI on lower trafficked roads, or they just did not give answers for them.

1.2.1.3 The distribution of TP International Roughness Index (IRI) by the pavement type

The question about the pavement type gave responders three possibilities:
- flexible pavements,
- rigid pavements and
- semi-rigid pavements.

The answers, obtained from the database are shown in Figure 8.

From the analysis of Figure 8 it seems clear that all of the countries (17) use TP IRI on flexible pavements. It is also obvious that 9 of the countries (53%) use TP IRI on all of the pavement types, that 2 countries use TP IRI only on flexible pavements, 3 countries only on flexible and rigid pavements (and not on semi-rigid pavements, maybe due to the fact that in those countries they do not use semi-rigid pavements) and 3 countries only on flexible and semi-rigid pavements (in this case it is likely that they do not have rigid pavements). No country distinguished between pavement types when giving TP limits and threshold, warning, acceptance and target values. It was therefore assumed that TP IRI is used on all pavement types and that TP limits and index limits are independent of the pavement type.

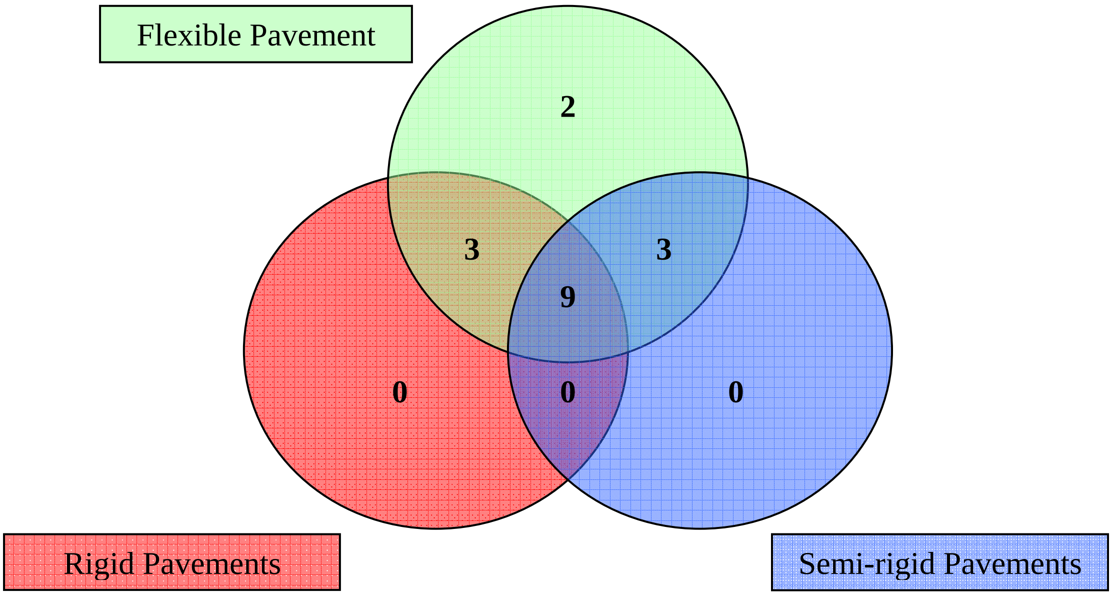

Figure 8: The distribution by the pavement type for the TP IRI

1.2.1.4 Distribution by the type of application

The question about the type of application gave responders two possibilities:
- standard application and
- application for research.

Figure 9 shows the distribution by the type of application for TP IRI. 2 of the responders gave no indication therefore there are 15 answers analysed. 13 responders stated that they use the TP IRI as a standard application. 2 countries use TP IRI only for research.

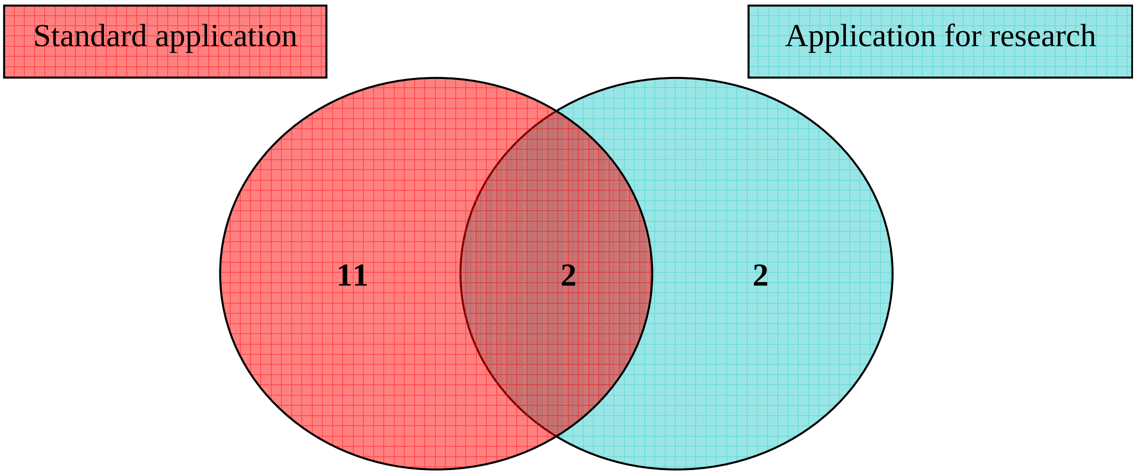

Figure 9: The distribution by the type of application for the longitudinal evenness performance indicator

1.2.1.5 Measuring interval for TP International Roughness Index (IRI)

The measuring interval for technical parameter IRI is shown in Figure 10.

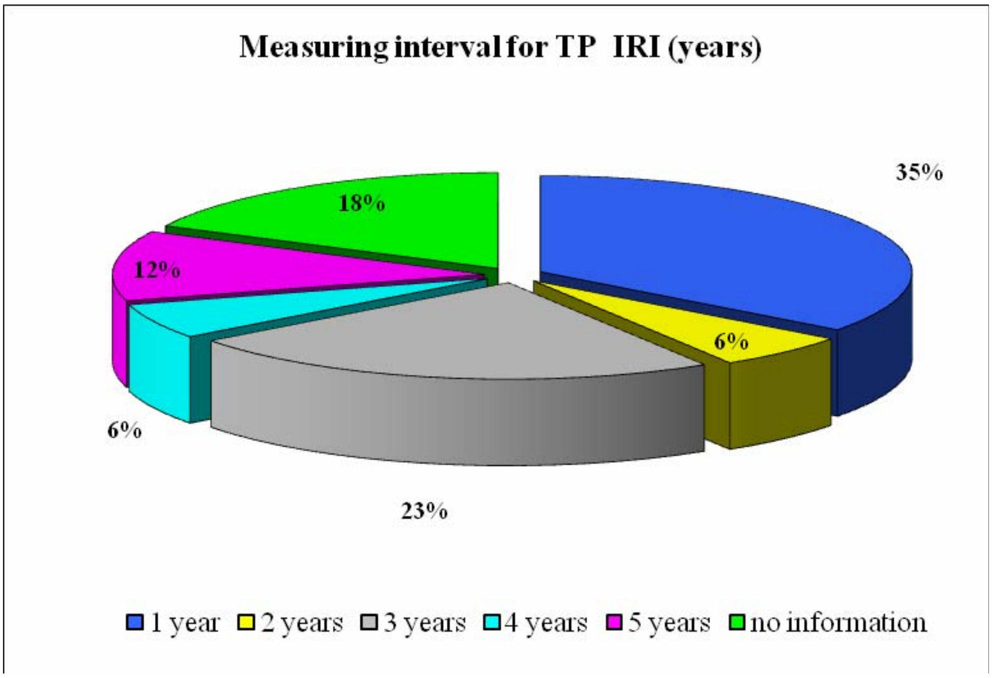

Figure 10: Number of answers for measuring interval for technical parameter IRI

The majority of countries perform measurements of IRI every year (35%).

1.2.2 Technical Parameters Wavelength, Evenness and Longitudinal Profile Variance

From the 29 records of longitudinal evenness performance indicators analysed, 5 refer to the technical parameter Wavelength (from 2 questionnaires), in 4 records (3 are from the same questionnaire) the technical parameter is Evenness and in 3 records the technical parameter is Longitudinal Profile Variance (all from 1 questionnaire).

Because those technical parameters are used only in a country or two they are not analysed to the same level of detail as the technical parameter IRI.

In Table 4 to Table 6 the information about the data collection for technical parameters Wavelength, Evenness and Longitudinal Profile Variance are summarized.

<u>Wavelength</u>

In order to perform wave band analysis, the pre-processed profile is split into different wave band limited profiles using filters. The definition of the wave bands used as well as the characteristics of the filters used to obtain band limited signals, from the original longitudinal profile must be given. How indices are derived from the band limited signals must also be defined.

In most cases the profile can be adequately described as a sum of sine functions such as:

$$A \cdot \sin\left(\frac{2\pi \cdot (x - x_0)}{\Lambda}\right)$$

where

Λ defines the wavelength of the sine in metres,
A is the amplitude of the sine in metres,
x is the abscissa of the current point in metres,
x_0 is the phase of the sine in metres.

The measuring procedure often follows a national standard, as in France (mechanical profilometer for short, medium and long wavelength), in Germany (wavelength with laser) and in Belgium (accelerometer with laser).

<u>Evenness</u>

A profile is the intersection between the surface of the pavement and the plane which contains both the vertical of the measured pavement and the line of travel of the measuring instrument. When the measuring instrument travels in a curve the line of travel is the tangent to that curve, when travelling in a straight line the line of travel is this line. In this plane, a point of the profile can be adequately described by its coordinates x (abscissa) and z (elevation), in any orthonormal reference system (X, Z), where Z is parallel to the aforementioned vertical.

A longitudinal profile is one of the profiles obtained when the measuring instrument travels in the same direction as the usual traffic. Usually one of the profiles measured in the wheel tracks is used.

The measuring procedure does not necessarily follow a national standard, as in Belgium (accelerometer).

Longitudinal Profile Variance

The longitudinal profile variance is carried out by considering the differences between the profile and its moving average over three separate moving average lengths:

- 3 m,
- 10 m and
- 30 m.

The level of roughness in the profile over the three moving average lengths is then reported as the 3 m, 10 m and 30 m "longitudinal profile variance", which is the square of the difference between the moving average of the profile and the measured profile.

This type of technical parameter is used in the UK (laser with technical specification).

Table 4: Technical parameter "Wavelength" information from the database

COUNTRY	STANDARD	STANDARD NAME	STANDARD PRACTICE OR RESEARCH	TYPE OF INSPECTION	COLLECTED DATA	OPERATING SPEED [Km/h]	SECTION LENGTH [m]	HOMOGENI-ZATION	INTERVAL [years]	QUALITY ASSURANCE
FRANCE (FR) 1	National Standard	NF 98218-3	Standard	Measurement	Severity	70	100	No	3	Yes
FRANCE (FR) 2	National Standard	NF 98218-3	Standard	Measurement	Severity	70	100	No	3	Yes
FRANCE (FR) 3	National Standard	NF 98218-3	Standard	Measurement	Severity	70	100	No	3	Yes
GERMANY (DE) 2	National Standard			Contactless Measurement	Severity		100	No	4	Yes
GERMANY (DE) 3	National Standard		Standard	Contactless Measurement	Severity		100	No	4	Yes

Table 5: Technical parameter "Evenness" information from the database

COUNTRY	STANDARD	STANDARD NAME	STANDARD PRACTICE OR RESEARCH	TYPE OF INSPECTION	COLLECTED DATA	OPERATING SPEED [Km/h]	SECTION LENGTH [m]	HOMOGENI-ZATION	INTERVAL [years]	QUALITY ASSURANCE
BELGIUM (BE) 1	National Standard	Standaardbestek 250	Standard	Contactless Measurement	Extension	35-55	100	No	2	Yes
BELGIUM (BE) 2	No Standard		Standard	Measurement	Severity	21.6-72	100	Yes	2	Yes
BELGIUM (BE) 3	No Standard		Standard	Measurement	Severity	21.6-72	100	No	2	Yes
CZECH REPUBLIC (CZ)	National Standard	ČSN 73 6175 - Pavement Roughness Measurement	Standard	Contactless Measurement	Severity	35-90		Yes	5	Yes

Table 6: Technical parameter "Longitudinal profile variance" information from the database

COUNTRY	STANDARD	STANDARD NAME	STANDARD PRACTICE OR RESEARCH	TYPE OF INSPECTION	COLLECTED DATA	OPERATING SPEED [Km/h]	SECTION LENGTH [m]	HOMOGENI-ZATION	INTERVAL [years]	QUALITY ASSURANCE
UNITED KINGDOM (UK) 1	Technical Specification	Interim Advice Note: Traffic Speed Condition Surveys	Standard	Contactless Measurement	Severity	20-100	10	No	1	Yes
UNITED KINGDOM (UK) 2	Technical Specification	Interim Advice Note: Traffic Speed Condition Surveys	Standard	Contactless Measurement	Severity	20-100	10	No	1	Yes
UNITED KINGDOM (UK) 3	Technical Specification	Interim Advice Note: Traffic Speed Condition Surveys	Standard	Contactless Measurement	Severity	20-100	10	No	1	Yes

1.3 SELECTION OF THE PROPOSED INDIVIDUAL PERFORMANCE INDICATOR

In Working Group 2 a list of parameters was set up for the decision of the most suitable technical parameter for a specific performance indicator, namely:

1. Based on European standard (or international standard)?
2. Standard practice or research?
3. Wide use?
4. Device independent?
5. Safe to collect, both for operators and other road users e.g. traffic speed collection (Operating speed, Type of inspection, Contactless measurement)?
6. Reliable (Quality assurance)?
7. Sustainable?

The result of the application of these criteria to longitudinal evenness technical parameters is shown in Table 7.

Table 7: Selection table for technical parameters

	TECHNICAL PARAMETER			
	IRI	Wavelength	Evenness	Longitudinal Profile variance
BASED ON EUROPEAN STANDARD	[green]	[red]	[red]	[red]
STANDARD PRACTICE	[green]	[green]	[green]	[green]
RESEARCH	[green]	[red]	[red]	[red]
WIDE USE	[green]	[red]	[red]	[red]
DEVICE INDEPENDENT	[green]	[green]	[green]	[green]
SAFE TO COLLECT				
RELIABLE		[green]	[green]	N/A
SUSTAINABLE		[green]	[green]	N/A

[green]	GOOD
[yellow]	MEDIUM
[red]	BAD

Based on the criteria listed above International Roughness Index (IRI) has been selected as single technical parameter for longitudinal evenness, as far as the current practice is concerned.

From several studies it has become apparent that IRI might not be the best index to measure ride comfort on European roads. In some countries, systems have been developed, or are being developed, based on wavelength analysis on the measured longitudinal profiles. These types of systems are considered to be much better for the European roads (PARIS project (8)) and it can therefore be envisaged that soon there could be a much wider use of such indices.

1.4 PROTOCOLS AND TEST METHODS FOR MEASURING THE PROPOSED INDIVIDUAL INDICATOR

IRI is an index computed from a longitudinal road profile measurement using a virtual response type system, quarter-car simulation and running at a speed of 80 km/h (Figure 11). The simulation applied on the digitised road profile calculates the accumulated suspension motions divided by the distance travelled. The IRI has the unit of slope, e.g. mm/m or m/km. A complete computation of IRI is described in World Bank Technical Papers 45 and 46, [1], [2].with additional information in [3], [4] and [5]

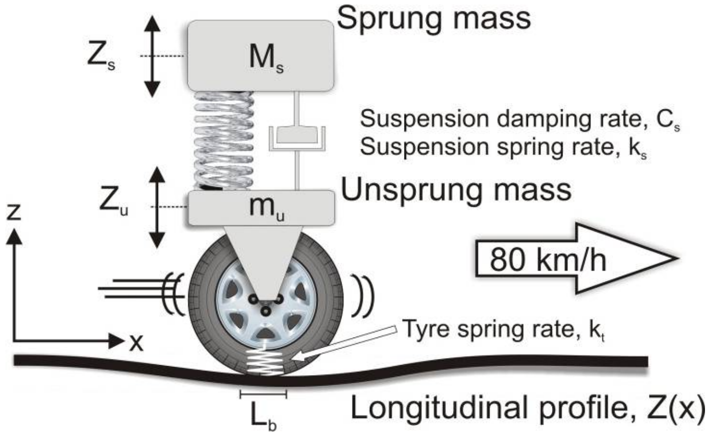

Figure 11: the IRI model

IRI is a widely used and well established roughness index since it is considered to be a good indicator of pavement condition in respect to road roughness. It is developed in order to be linear, portable and stable with time. It is portable since it can be measured with a wide range of equipment giving the same results, and stable with time since it is defined as a mathematical transform of a measured profile, thus it is not affected by the measurement procedure nor the characteristics of the vehicle used for profile measurement.

1.4.1 Measurement equipment

Today many different types of equipment have been developed around the world, and there are many different philosophies of how much must be measured in order to get a good picture of the pavement surface and to determine the longitudinal evenness of a road.

The principles of physical measurement can be described in the following different categories [6]:

- Geometric methods
    - rod and level measurements

  - o measurement of the difference between a straightedge and the pavement surface
  - o measurement with a horizontal laser beam as reference
  - o measurement in relation to a moveable plane
  - o measurement of the slope and inclination
  - o superposition of measurement results from laser sensors positioned on a straightedge
- Combination of geometric methods and accelerometer methods
- Initially held horizontal pendulum
- Distance measurement between vehicle axle and chassis
- Accelerometer signals

1.4.2 Calculation algorithms and data processing

The European standard *prEN 13036-6 – Surface Characteristics of Road and Airfield Pavements – Test Methods – Part 5: Determination of Longitudinal Unevenness Indices* [7] standardises various possible characterisations of the road profile unevenness such as the International Roughness Index (IRI) computation procedure, wave bands analyses as well as Power Spectral Density (PSD) analyses.

The computation of unevenness indices, involves three steps: the measurement and pre-processing of the profile, the output of which is a filtered and re-sampled (or pre-processed) profile, the computation of one or more index(es), and the creation of a report (Figure 12).

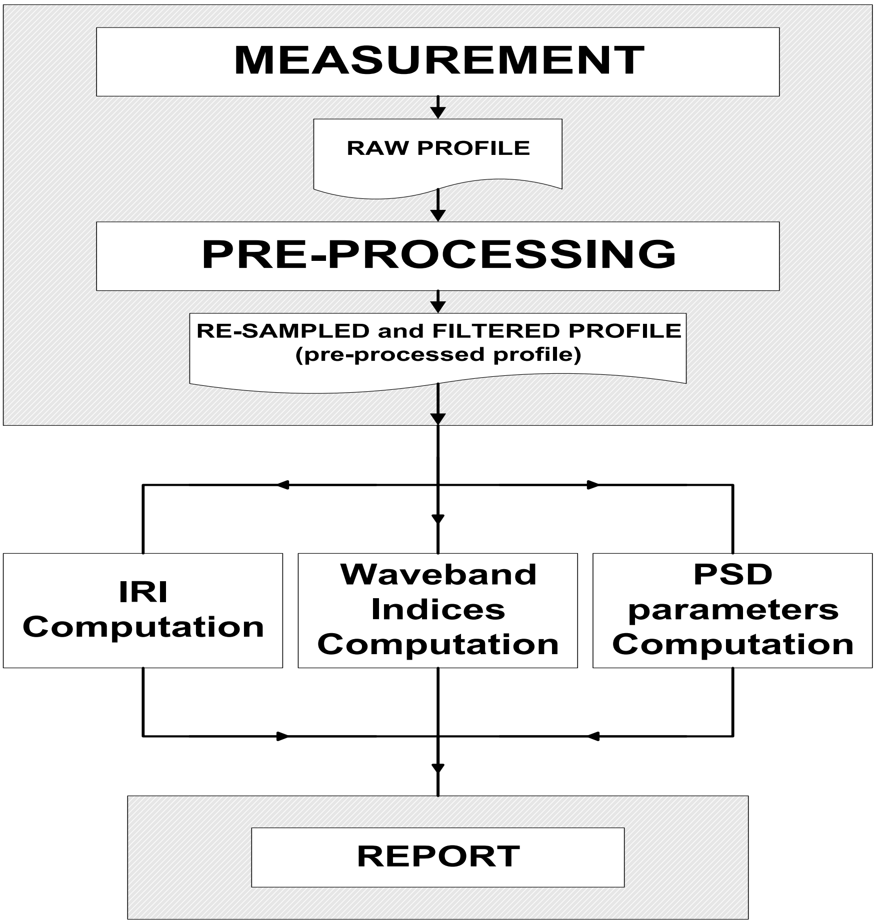

Figure 12: General overview of the IRI computation (1)

1.5 ASSESSMENT OF THE TRANSFORMATION FUNCTIONS

1.5.1 General information

Each country created classes expressing the condition of the pavement (using a scale from very good to very poor) for their technical parameters. The aim of this COST action is to develop European harmonized individual performance indicators (or indices) which can then be combined into combined performance indicators and finally into general performance indicator (or index).

To enable the combination of different individual performance indicators into combined performance indices it is necessary to convert each of the individual performance indicators into dimensionless index (i.e. scale from 0-very good to 5-very poor). Therefore an overview across individual countries' classification was performed in this chapter. According to the Database different countries use different ways of classification to describe the condition of the pavement. Some use classification in three classes, some in five. Some countries transform TP to Indices and describe the condition of the pavement with indices, some use technical parameter limits to describe the condition of the pavement and some use threshold, warning and acceptance limits of technical parameters.

For the development of a European harmonized transformation function from IRI (m/km) to an IRI Index (dimensionless), a harmonized classification had to be developed (chapter 1.5.2). Once the harmonized classification was developed it was then possible to develop a harmonized transformation function (chapter 1.5.3).

1.5.2 Classification for technical parameter International Roughness Index (IRI)

From the 29 records about the performance indicator longitudinal evenness analysed, 17 refer to the technical parameter "International Roughness Index".

From those 17 only 3 countries use transformation to a dimensionless Index, IRI (Table 8), of which only one actually gave two transformation functions from IRI to Index IRI with the classification criteria depending on road category. One country gave TP and Index limits for two traffic volumes. The third country gave transformation function and corresponding Index limits but no classification criteria.

From the remaining 14 records, only 8 responders gave information about the classification of the technical parameter International Roughness Index, using TP limits or threshold, warning, acceptance and/or target values (Table 9). Some of them also stated that they use classification to indices but did not give any information about the transformation function from technical parameter to index.

The remaining 6 records give no classification information and are excluded from further analyses.

Table 8: Transformation information for IRI to Index IRI from the database

	AUSTRIA (AT)	POLAND (PL)	SLOVENIA (SI)
NAME OF TECHNICAL PARAMETER	International roughness index	International roughness index	International roughness index
MOTORWAYS	Yes	Yes	Yes
OTHER PRIMARY ROADS	Yes	Yes	Yes
SECONDARY ROADS	No	No	Yes
SECTION LENGTH	50 m	1000 m	100 m
INDEX NAME	Index roughness	Index roughness	Index roughness
INDEX DESCRIPTION	Index_IRI	Representative IRI	Index IRI
NUMBER OF CLASSES	5	4	5
SCALE VERY POOR	5	D	5
SCALE VERY GOOD	1	A	0
NAME CLASS 1	1 – very good	A – good	very good
NAME CLASS 2	2 – good	B – fair	good
NAME CLASS 3	3 – fair	C – poor	fair
NAME CLASS 4	4 – poor	D - bad	poor
NAME CLASS 5	5 – very poor		very poor
CLASSIFICATION CRITERIA 1	1.0<=I_IRI<=5.0; road category A and S		AADT>2000 Or ESAL82kN/day>80
CLASSIFICATION FUNCTION 1	1+0.7778*IRI	10*IRIp	
THRESHOLD TP 1	4.5	5.7	
THRESHOLD IND 1	4.5	57	
WARNING TP 1	3	4.5	
WARNING IND 1	3.5	44	
CLASSIFICATION CRITERIA 2	1.0<=I_IRI<=5.0; road category B		AADT<2000 Or ESAL82kN/day<80

CLASSIFICATION FUNCTION 2	1+0.5833*IRI		
THRESHOLD TP 2	6		
THRESHOLD IND 2	4.5		
WARNING TP 2	3.8		
WARNING IND 2	3.5		
INDEX LIMIT 1	1	0	0
INDEX LIMIT 2	1.5	20	1
INDEX LIMIT 3	2.5	44	2
INDEX LIMIT 4	3.5	57	3
INDEX LIMIT 5	4.5		4
INDEX LIMIT 6	5		5
TP LIMIT 1 (CRITERIA 1)	0	0	0
TP LIMIT 2 (CRITERIA 1)	1	2	1.2
TP LIMIT 3 (CRITERIA 1)	1.8	4.4	1.5
TP LIMIT 4 (CRITERIA 1)	3	5.7	2.2
TP LIMIT 5 (CRITERIA 1)	4.5		3.1
TP LIMIT 1 (CRITERIA 2)	0		0
TP LIMIT 2 (CRITERIA 2)	0.9		2.6
TP LIMIT 3 (CRITERIA 2)	2.6		3.5
TP LIMIT 4 (CRITERIA 2)	3.8		4.3
TP LIMIT 5 (CRITERIA 2)	6		4.9

Table 9: TP limits information for IRI from the database

	CROATIA (HR)	DENMARK (DK)	FINLAND (FI)	HUNGARY (HU)	ITALY (IT)	NETHERLANDS (NL)	PORTUGAL (PT)	SERBIA AND MONTENEGRO (CS)
NAME OF TECHNICAL PARAMETER	International roughness index	International roughness index	International roughness index	International roughness index	International roughness index	International roughness index	International roughness index	International roughness index
MOTORWAYS	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
OTHER PRIMARY ROADS	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
SECONDARY ROADS	YES (*)	Yes	Yes	Yes	No	No	No	Yes
SECTION LENGTH	100 m	1000 m	100 m	100 m	20 m	100 m	N/A	25 m
NUMBER OF CLASSES	5		5	5	5		3	5
SCALE VERY POOR	5		1	5	E			10
SCALE VERY GOOD	1		5	1	A			1
NAME CLASS 1	very good		very good	1	A – Excellent		Good	very good
NAME CLASS 2	good		good	2	B – Good		Fair	good
NAME CLASS 3	fair		fair	3	C – Sufficient		Poor	fair
NAME CLASS 4	poor		poor	4	D – Mediocre			poor
NAME CLASS 5	very poor		very poor	5	E – Poor			very poor
CLASSIFICATION CRITERIA 1			AADT < 1500					
CLASSIFICATION CRITERIA 2			AADT 1500 - 6000					
CLASSIFICATION CRITERIA 3			AADT > 6000					
THRESHOLD TP 1	5		4.1			3.5		
THRESHOLD TP 2			3.5					
THRESHOLD TP 3			2.5					
WARNING TP 1	3.5					2.6		
ACCEPTANCE TP 1	2.5							
TP LIMIT 1 (CRITERIA 1)	1	0		0	0		0	1
TP LIMIT 2 (CRITERIA 1)	1.5	1.5		1.5	1.5		2	2.5
TP LIMIT 3 (CRITERIA 1)	2.5	2.5		2.2	2		3	3.5
TP LIMIT 4 (CRITERIA 1)	3.5	5		3	2.5			5.5
TP LIMIT 5 (CRITERIA 1)	5			4.5	3			7

(*) information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses.

For 3 responders that provided transformation from IRI to Index IRI, both TP limits and Index limits are available in the COST 354 database. Taking into account that the vast majority of countries do not use transformation into indices (they use TP limits to describe the condition of the pavement) further analyses have been made from the TP limits.

For the further analyses some assumptions had to be made:

– Where only threshold level of the TP is provided it is assumed it represents the limit between poor and very poor condition;
– Where only warning level of the TP is provided it is assumed it represents the limit between fair and poor condition.
– Where no classification criterion is given it is assumed that TP limits and threshold, warning and acceptance levels are given for motorways and other primary roads.

As the majority of countries use 5 condition classes to describe the condition of the pavement, a transformation of the database information was performed according to the above assumptions and all of the limits were distributed into 5 classes (Table 10). Classes were named very good, good, fair, poor and very poor.

Table 10: TP limits for IRI

Country	Very good	Good	Fair	Poor	Very poor	Section length [m]
AUSTRIA (AT)	< 1,0	1,0 to 1,8	1,8 to 3,0	3,0 to 4,5	> 4,5	50
CROATIA (HR)	< 1,5	1,5 to 2,5	2,5 to 3,5	3,5 to 5,0	> 5,0	100
DENMARK (DK)	< 1,5	1,5 to 2,5		2,5 to 5,0	> 5,0	1000
FINLAND (FI)		0,0 to 2,5	2,5 to 3,5	3,5 to 4,1	> 4,1	100
HUNGARY (HU)	< 1,5	1,5 to 2,2	2,2 to 3,0	3,0 to 4,5	> 4,5	100
ITALY (IT)	< 1,5	1,5 to 2,0	2,0 to 2,5	2,5 to 3,0	> 3,0	20
NETHERLANDS (NL)			< 2,6	2,6 do 3,5	> 3,5	100
POLAND (PL)		0,0 to 2,0	2,0 to 4,4	4,4 to 5,7	> 5,7	1000
PORTUGAL (PT)		0,0 to 2,0	2,0 to 3,0	> 3,0		N/A(*)
SERBIA AND MONTENEGRO (CS)	< 1,0	1,0 to 2,5	2,5 to 3,5	3,5 to 5,5	> 5,5	25
SLOVENIA (SI)	< 1,2	1,2 to 1,5	1,5 to 2,2	2,2 to 3,1	> 3,1	100
(*) in the following analyses it is assumed to be < 100 m						

The information from Table 10 was divided into two groups, according to the stated section length in the database. Figure 13 and Figure 14 show the TP limits for IRI on Motorways and Other Primary Roads for section length < 100 m and for section length ≥ 100 m, respectively.

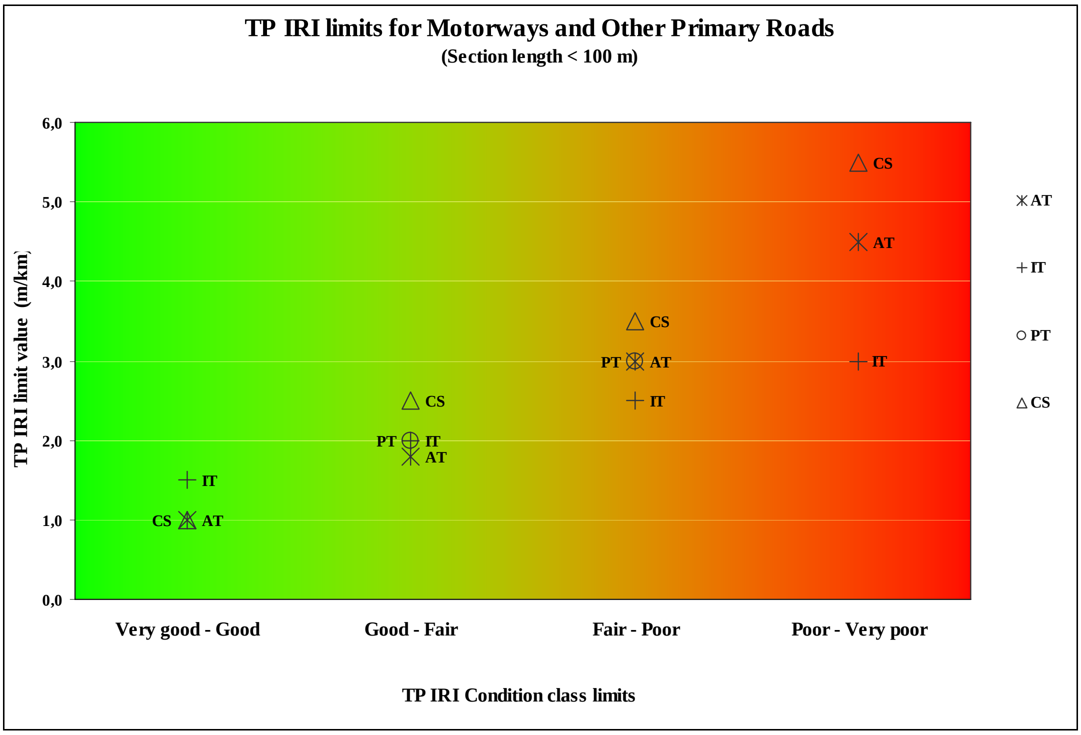

Figure 13: TP limits for IRI on Motorways and Other Primary Roads for section length < 100 m

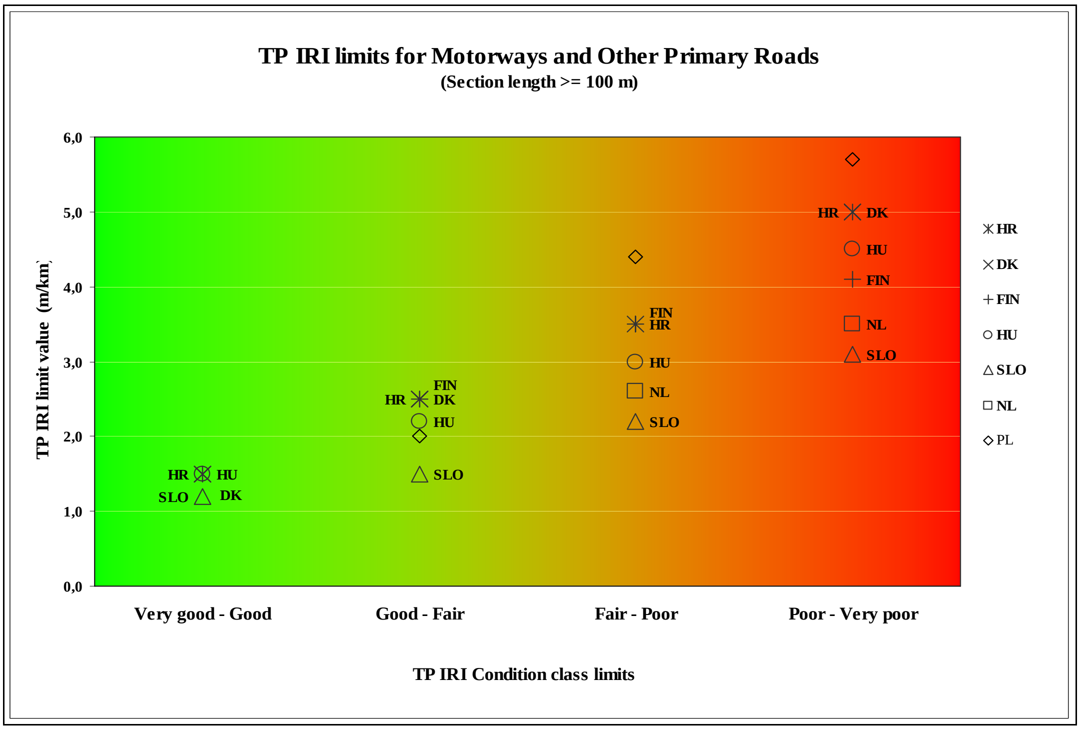

Figure 14: Technical parameter limits for IRI on Motorways and Other Primary Roads for section length ≥ 100 m

Because of large scatter of individual values in Figure 13 and Figure 14 and the lack of classification criteria regarding road category or traffic in the database already mentioned, another set of analyses was performed, where section length as a parameter was excluded.

The information from Table 10 was divided into two groups. The first group contains the lower TP limits (More restrictive group) and the second group contains the higher ones (Less restrictive group) (Table 11).

Table 11: TP limits for IRI grouped in "more restrictive" and "less restrictive" values

	Very good – Good	Good – Fair	Fair – Poor	Poor – Very poor
More restrictive group				
ITALY (IT)	1,5	2,0	2,5	3,0
NETHERLANDS (NL)			2,6	3,5
PORTUGAL (PT)		2,0	3,0	
SLOVENIA (SI)	1,2	1,5	2,2	3,1
MIN	**1,2**	**1,5**	**2,2**	**3,0**
MAX	**1,5**	**2,0**	**3,0**	**3,5**
AVERAGE	**1,3**	**1,8**	**2,6**	**3,2**
Less restrictive group				
AUSTRIA (AT)	1,0	1,8	3,0	4,5
CROATIIA (HR)	1,5	2,5	3,5	5,0
DENMARK (DK)	1,5	2,5		5,0
FINLAND (FI)		2,5	3,5	4,1
HUNGARY (HU)	1,5	2,2	3,0	4,5
POLAND (PL)		2,0	4,4	5,7
SERBIA AND MONTENEGRO (CS)	1,0	2,5	3,5	5,0
MIN	**1,0**	**1,8**	**3,0**	**4,1**
MAX	**1,5**	**2,5**	**4,4**	**5,7**
AVERAGE	**1,3**	**2,3**	**3,5**	**4,9**

Figure 15 and Figure 16 are graphical presentations of the "More restrictive" group and the "Less restrictive" group of TP limits for IRI, respectively.

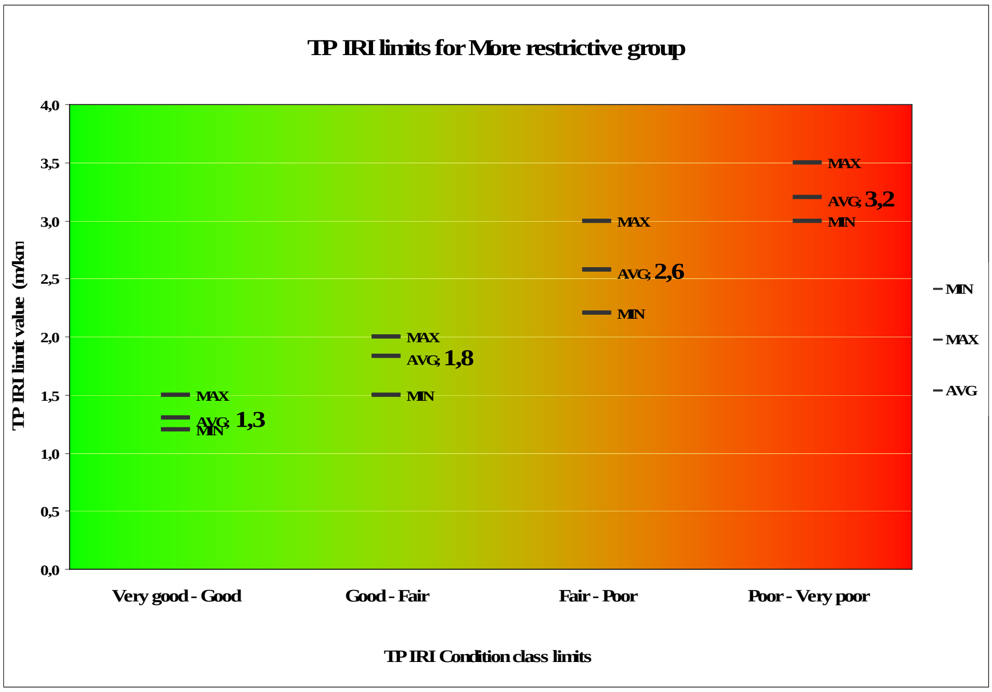

Figure 15: Technical parameter limits for IRI in More restrictive group

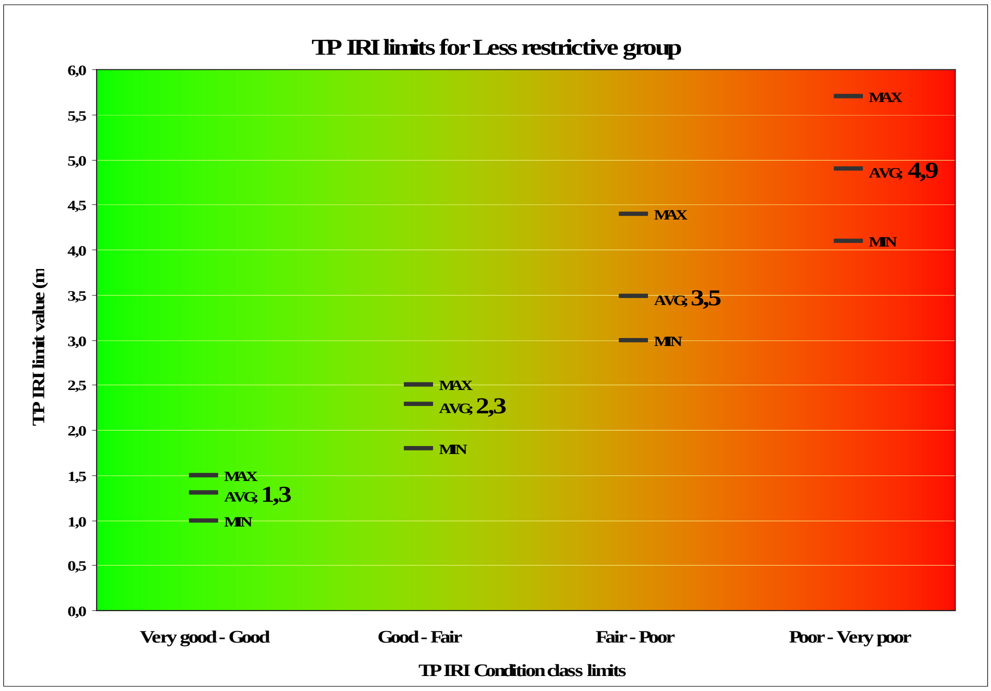

Figure 16: Technical parameter limits for IRI in Less restrictive group

The scatter is much lower for this approach, and therefore the average values of IRI limits for these groups were calculated.

1.5.3 Assessment of transformation functions for IRI

For the definition of a transformation function it was necessary to associate to each "condition class" ("very good" to "very poor") a PI range, as shown in Table 12. This can be different from the condition classification used in practice by the road administrations.

Table 12: Definition of condition classes for PI_E

Condition class name	PI_E
Very good	[0 to 1)
Good	[1 to 2)
Fair	[2 to 3)
Poor	[3 to 4)
Very poor	[4 to 5]

From the TP limits and Index limits two transformation functions were derived, one for the More restrictive group and one for the Less restrictive group (Figure **17**).

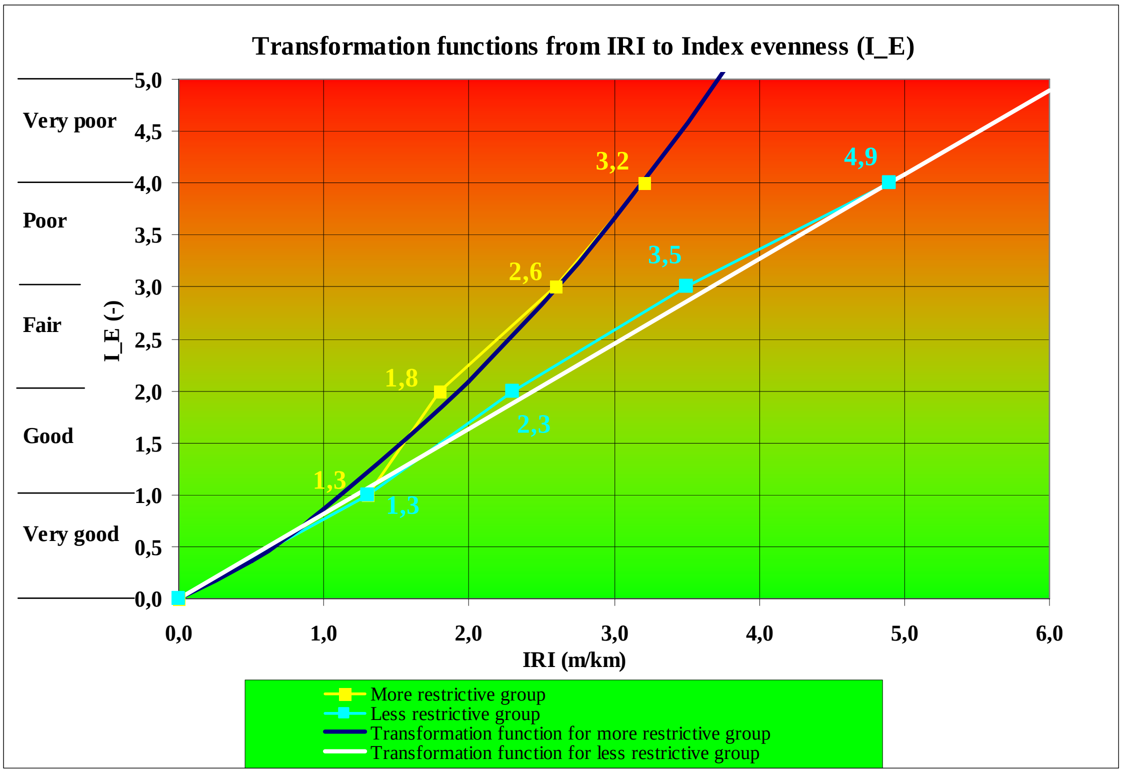

Figure 17: Proposed transformation functions from TP IRI to PI_E

The proposed mathematical transformation functions from IRI to PI_E are as follows:

For the more restrictive group:

$$PI\_E = MIN\,(5;0.1733 \cdot IRI^2+0.7142 \cdot IRI-0.0316) \qquad \text{with IRI in mm/m}$$

For the less restrictive group:

$$PI\_E = MIN\,(5;\ 0.816 \cdot IRI) \qquad \text{with IRI in mm/m}$$

The proposed Index limits and corresponding IRI are shown in Table 13.

Table 13: TP limits and PI_E limits

Condition class name	PI_E	IRI for More restrictive group	IRI for Less restrictive group
Very good	[0 to 1)	< 1,1	< 1,2
Good	[1 to 2)	1,1 to 1,9	1,2 to 2,5
Fair	[2 to 3)	1,9 to 2,6	2,5 to 3,7
Poor	[3 to 4)	2,6 to 3,2	3,7 to 4,9
Very poor	[4 to 5]	> 3,2	> 4,9

1.5.4 Technical Parameters Wavelength, Evenness and Longitudinal Profile Variance

Although the majority of European countries use IRI as technical parameter describing the longitudinal evenness of a pavement, some countries use other technical parameters:

- Wavelength,
- Evenness
- Longitudinal Profile Variance.

Table 14 includes the information about the transformation of those technical parameters from the database, where available.

Table 14: TP limits information for other longitudinal evenness technical parameters from the database

COUNTRY	NAME OF TECHNICAL PARAMETER	INDEX NAME	INDEX DESCRIPTION	NUMBER OF CLASSES	SCALE VERY POOR	SCALE VERY GOOD	TRANSFORMATION							
							CRITERIA 1	FUNCTION 1	CRITERIA 2	FUNCTION 2	CRITERIA 3	FUNCTION 3	CRITERIA 4	FUNCTION 4
BELGIUM (BE) 1	Evenness	Index roughness	index evenness	5	0	1	Motorways	1-VLK/400	Primary	1-VLK/400	Secondary	1-VLK/400		
BELGIUM (BE) 2	Evenness			5	E	A								
BELGIUM (BE) 3	Evenness			5	E	A								
CZECH REPUBLIC (CZ)	Evenness	Index roughness	Index IRI	5	5	1	for all	1.23*C^0.23						
FRANCE (FR) 1	Wave length	Index roughness	Short wavelength index	5	E	A								
FRANCE (FR) 2	Wave length	Index roughness	Long wavelength index	5	E	A								
FRANCE (FR) 3	Wave length	Index roughness	Medium wavelength index	5	E	A								
GERMANY (DE) 2	Wave length	Index roughness	Index Periodical Unevenness	8	5	1	v<=0, function class 1	IF(v<=-0.549;1;3.5+v*4/(ln3))	v>0, function class 1	IF(v>0.549;5;3.5+v*2/(ln3)				
GERMANY (DE) 3	Wave length	Index roughness	Index Single Obstruction	8	5	1	v<=0, function class 1	IF(v<=-0.549;1;3.5+v*4/(ln3))	v>0, function class 1	IF(v>0.549;5;3.5+v*2/(ln3)				
UNITED KINGDOM (UK) 1	Longitudinal profile variance	Index roughness	3m LPV Index	4	4	1	3mLPV <0.7 (1), <0.8 (2), <1.4 (3)	1	3mLPV >=0.7 (1), >=0.8 (2), >=1.4 (3)	2	3mLPV >=2.2 (1), >=2.2 (2), >=3.8 (3)	3	3mLPV >=4.4 (1), >=5.5 (2), >=9.3 (3)	4
UNITED KINGDOM (UK) 2	Longitudinal profile variance	Index roughness	10m LPV Index	4	4	1	mLPV <1.6 (1), <2.8 (2), <6.1 (3)	1	3mLPV >=1.6 (1), >=2.8 (2), >=6.1 (3)	2	3mLPV >=6.5 (1), >=8.6 (2), >=16.3 (3)	3	3mLPV >=14.7 (1), >=22.8 (2), >=36.6 (3)	4
UNITED KINGDOM (UK) 3	Longitudinal profile variance	Index roughness	30m LPV Index	4	4	1	mLPV <22 (1), <30 (2), <48 (3)	1	3mLPV >=22 (1), >=30 (2), >=48 (3)	2	3mLPV >=66 (1), >=75 (2), >=97 (3)	3	3mLPV >=110 (1), >=121 (2), >=193 (3)	4

1.6 REFERENCES

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4. Sayers, M.W., "On the calculation of International Roughness Index from Longitudinal Road Profile" Transportation Research Record 1501, Transportation Research Board, pp. 1-12", Washington D.C., 1995

5. ASTM, "Computing International Roughness Index of Roads from Longitudinal Profile measurements", E1926-98, ASTM Standards

6. International Experiment to Harmonize Longitudinal and Transverse Profile Measurement and Reporting Procedures, PIARC, 2000

7. prEN 13036-6 – Surface Characteristics of Road and Airfield Pavements – Test Methods – Part 5: Determination of Longitudinal Unevenness Indices

8. PARIS Project "*Performance analysis of road infrastructure*", Published by the EU, 1999 ISBN 92-828-7827-9

SECTION 2: TRANSVERSE EVENNESS

There are several different performance indicators for transverse evenness that are used in pavement management systems and road databases in different countries. They differ in their technical meaning, as well as in the way they are collected (manual or automated, equipment, speed and sampling interval) and in the purpose and level of application (construction quality control, or project or network level pavement management). The transverse evenness is very important for road safety and the rut depths should be limited to a certain value to avoid aquaplaning in wet conditions.

The objective of this section is to evaluate the transverse evenness indicators available in the COST-354 database, as well as to provide evaluation of the transverse evenness indicators available in the literature.

Based on the analysis of the available indicators, the recommendation for the appropriate transverse evenness indicators will be provided, together with the corresponding transformation functions.

2.1 TRANSVERSE EVENNESS INDICATORS FROM THE COST 354 DATABASE

The total number of countries that provided questionnaires in the COST 354 database is 24. However, two questionnaires (Romania and Bulgaria) were not used in the analysis because of their late arrival. Of the remaining 22 countries, 20 (90.9 %) submitted responses about transverse evenness. Most of these countries supplied one questionnaire each. However, Belgium and France submitted two questionnaires each. Italy and Spain did not provide data regarding transverse evenness performance indicators.

The list of countries that submitted questionnaires, together with the number of records is presented in Table 15. Several countries provided data about more than one index, and therefore, the total number of records analyzed is 36.

Two records (“faulting” and “patch deterioration”) had been associated with transverse evenness performance indicator (PI) but they have both been excluded from the further analysis, which reduced number of processed records to 34.

Analyzing the database further it was found that several answers from one country refer to different measuring devices or different technical parameters and therefore it is correct that they are included in further analyses. In some instances (i.e. France) there were multiple records for the same technical parameter (rut depths in left and right wheel paths, water heights in left and right wheel paths, or simply four records named “rut depth” that refer to the extend and severity of the rutting). If the same methodology, transformation functions and threshold values were used for data processing, these records were merged for the analysis.

In the case of Czech Republic there were two answers for the same performance indicator and the only difference between them was the Field of Application (the first for Motorways and Other Primary Roads and the second one for Secondary Roads and

Other Roads), resulting in the difference only in threshold values and transformation functions of indices. These records were also merged for the analysis.

Therefore the total number of records analyzed was 28, and they are presented in Table 15.

Table 15: Numbers of countries, questionnaires and records referred to the transverse evenness performance indicator

Country	Total	Transverse evenness		
	Nº Questionnaires	Nº Questionnaires	Nº Records Total	Nº Records Analysed
Austria	1	1	1	1
Belgium	2	2	3	2
Croatia	1	1	1	1
Czech Republic	1	1	2	1
Denmark	1	1	1	1
Finland	1	1	1	1
France	2	2	9	4
Germany	1	1	2	2
Greece	1	1	1	1
Hungary	1	1	1	1
Italy	1			
Netherlands	1	1	1	1
Norway	1	1	2	2
Poland	1	1	1	1
Portugal	1	1	1	1
Serbia and Montenegro	1	1	1	1
Slovenia	1	1	1	1
Spain	1			
Sweden	1	1	3	3
Switzerland	1	1	1	1
United kingdom	1	1	1	1
United States of America	1	1	2	1
TOTAL	**24**	**22**	**36**	**28**

2.1.1 General information

In the COST 354 database there are 4 different technical parameters (TP) describing the transverse evenness performance indicator:

- Rut Depth
- Cross-fall
- Water Height
- Edge Deformation

Table 16 shows the overview of the transversal profile performance indicators, which includes the name of the TP, the description, the unit, the equipment name and the measuring principle reported in the database.

Table 16: Description of transverse evenness technical parameters from the COST-354 database

COUNTRY	NAME	NAME TP (Unified)	TP DESCRIPTION	UNIT	EQUIPMENT NAME	MEASURING PRINCIPLE
AUSTRIA (AT)	Transverse evenness	Rut depth	Rut depth	mm	RoadSTAR	Laser
BELGIUM (BE) 1	Rutting	Rut depth	Rutting	mm	ARAN	Ultrasonic
BELGIUM (BE) 2	Transverse evenness	Rut depth	Ornière caractéristique	mm	TUS	Ultrasonic
CROATIA (HR)	Transverse evenness	Rut depth	Rut depth	mm	Laser profilograph (DK)	Laser
CZECH REPUBLIC (CZ)	Transverse evenness	Rut depth	Rut depth – 2 records	mm	ARAN	Laser
DENMARK (DK)	Rutting	Rut depth	Rut depth	mm	Profilograph	Laser
FINLAND (FI)	Transverse evenness	Rut depth	Rut depth	mm	RST	Laser
FRANCE (FR) 1	Transverse profile	Water height	Water height – 2 records (in right and left wheel paths)	mm	PALAS	Laser
FRANCE (FR) 2	Transverse profile	Rut depth	Rut depth – 2 records (in right and left wheel paths)	mm	PALAS	Laser
FRANCE (FR) 3	Transverse profile	Cross-fall	Transverse slope	%	PALAS	Laser
FRANCE (FR) 4	Rut depth	Rut depth	Rut depth – 4 records (Extend and Severity)	mm	TUS, PALAS	Ultrasonic and laser
GERMANY (DE) 1	Transverse evenness	Water height	Fictive water depth	mm		Laser
GERMANY (DE) 2	Transverse evenness	Rut depth	Rut depth	mm		Laser
GREECE (EL)	Transverse evenness	Rut depth	Rut depth	mm		
HUNGARY (HU)	Transversal unevenness	Rut depth	Rut depth	mm	Road Survey Tester (RST)	Laser
NETHERLANDS (NL)	Transverse evenness	Rut depth	Rut depth	mm	ARAN	Ultrasonic
NORWAY (NO) 1	Transverse evenness	Rut depth	Rut depth	mm	ALFRED	Ultrasonic
NORWAY (NO) 2	Transverse evenness	Cross-fall	Cross-fall	%	ALFRED	Ultrasonic
POLAND (PL)	Transverse evenness	Rut depth	Rut depth	mm	Greenwood Profilograph	Laser
PORTUGAL (PT)	Transverse evenness	Rut depth	Rut depth	mm	Laser profilometer	Laser
SERBIA AND MONTENEGRO (CS)	Transverse evenness	Rut depth	Rut depth	mm	Straightedge and pin	Manual measurement
SLOVENIA (SI)	Transverse evenness	Rut depth	Rut depth	mm	4 m straight edge	Manual measurement
SWEDEN (SE) 1	Edge deformation	Edge deformation	Transverse profile	mm	Laser RST	Laser
SWEDEN (SE) 2	Geometrical/Transversal unevenness	Cross-fall	Cross-fall	%	Laser RST	Laser
SWEDEN (SE) 3	Transverse unevenness	Rut depth	Rut depth	mm	Laser RST	Laser
SWITZERLAND (CH)	Transverse evenness	Rut depth	Rut depth	mm		
UNITED KINGDOM (UK)	Rut depth	Rut depth	Rut depth	mm	Road Assessment Vehicle (RAV)	Laser
USA (US)	Transverse evenness	Rut depth	Rut depth	mm	ARAN	Laser

In most of the cases where data is available, the “Rut Depth” is used as the technical parameter for transverse evenness (22 out of 28 total answers). In three of the records the technical parameter is “Cross-fall”, in two records “Water Height” and there is one record where the technical parameter is the “Edge Deformation”.

Figure 18 and Table 17 provide a summary of analyzed technical parameters and corresponding countries where they are used.

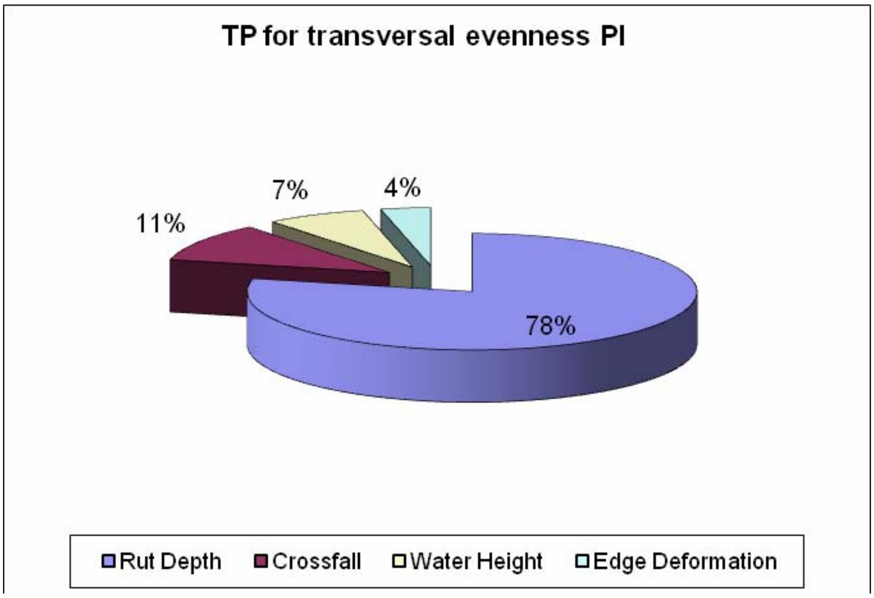

Figure 18: Technical parameters for transverse evenness performance indicator

Table 17: Summary of technical parameters specified for the transverse evenness

Technical Parameter	Nº Countries	Nº Records Analyzed	Countries
Rut Depth	20	22	AT, BE(2), CH, CS, CZ, DE, DK, EL, FI, FR(2), HR, HU, NL, NO, PL, PT, SE, SI, UK, US
Cross-fall	3	3	FR, NO, SE
Water Height	2	2	DE, FR
Edge Deformation	1	1	SE

2.1.2 Category of performance indicator

All responders classified transverse evenness as a Road Safety PI. In addition, 11 of them (39.3 %) classified it as index related to Riding Comfort, 1 (3.6 %) as index related to Pavement Structure, and 11 (39.3 %) as index related to both Riding Comfort and Pavement Structure. It should be noted that for the French TP that was created from four records (i.e. FRANCE (FR) 4), two of these records are classified as Riding Comfort PI, and two as Pavement Structure PI. For this analysis this TP was counted as being related to both Riding Comfort and Pavement Structure.

The distribution by category is presented in Figure 19.

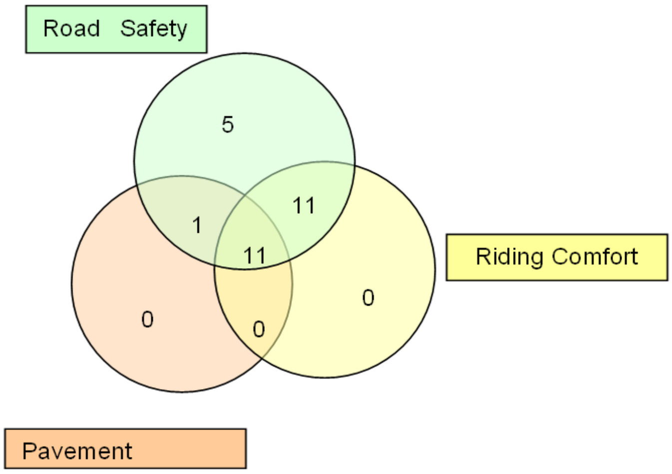

Figure 19: Distribution of transverse evenness PI by category

2.1.3 Field of application – distribution by road network

Most of the answers specified that transverse evenness PIs are used on motorways alone (5 answers or 17.9 %), motorways and primary roads (8 answers or 28.6 %) or motorways, primary and secondary roads (12 answers or 42.9 %). Three performance indicators (10.7 %) are being used on all four road categories (Figure 20). As previously said, for two merged records from the Czech Republic the only difference was the field of application and this record is included in the last category.

It appears that transverse evenness performance indicators are primarily used on higher trafficked roads.

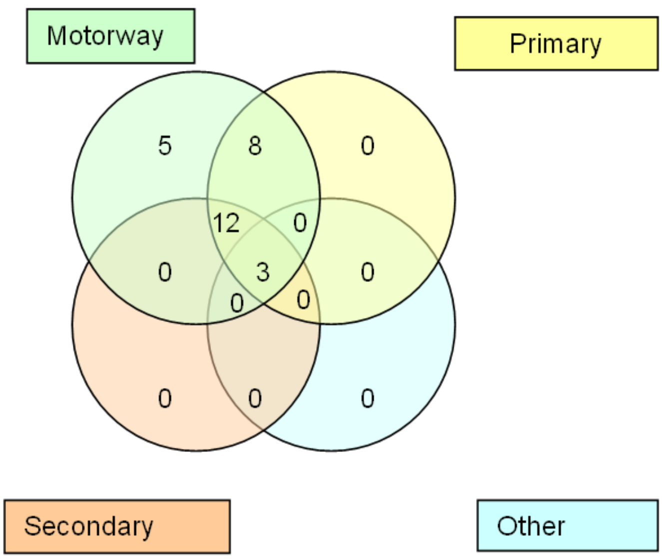

Figure 20: Distribution of Transverse evenness PI by road network

The transverse profile data provided in the database indicate that for most of the countries, transverse profile performance indicators are used for all road categories provided in the COST 354 database. Two exceptions are Portugal and Slovenia which indicated that transversal profile PIs are only used on motorways, although there are other indicators defined for other road categories. Also, in Germany and the Netherlands they are not used on the least trafficked road categories. According to the COST 354 database, it appears that Denmark is only collecting rutting data out of all other condition indicators on other/local roads.

2.1.4 Distribution by Level of Application

The distribution by the level of application indicates that transverse evenness PIs are used either on network level (12 records – 42.9 %), or on network and project level (16 records – 57.1 %), as presented in Figure 21.

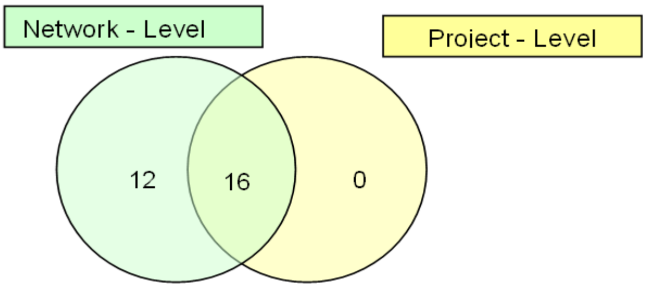

Figure 21: Distribution of Transverse evenness PI by Level of Application

2.1.5 Distribution by Pavement Type

As expected, the transverse evenness PIs are primarily collected on flexible pavements. Six indicators (21.4 %) are used only on flexible pavements, 10 (35.7 %) on flexible and semi-rigid, 8 (28.6 %) on all three types of pavements, and 3 (10.7 %) on flexible and rigid. For one (3.6 %) indicator the pavement type was not specified (Figure 22).

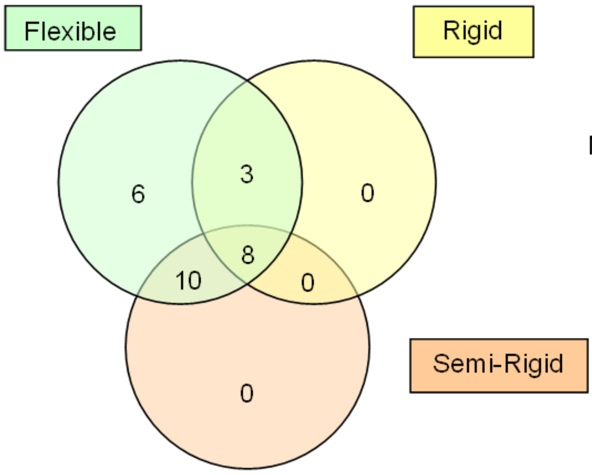

Figure 22: Distribution by pavement type

2.1.6 Distribution by Type of Application

The majority of transverse evenness PIs are used for standard purpose alone (21 or 75 %) or for both standard and research purposes (5 or 17.9 %). Only one indicator (3.6 %) is used for research only, and for one indicator (3.6 %) the type of application was not specified (Figure 23).

The detailed distribution by performance indicator is presented in Figure 24. It is interesting to note that all transverse evenness PIs except “rut depth” are used for standard practice.

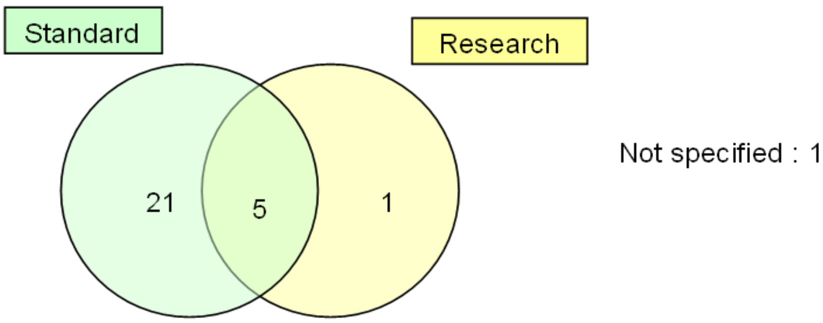

Figure 23: Distribution by type of application

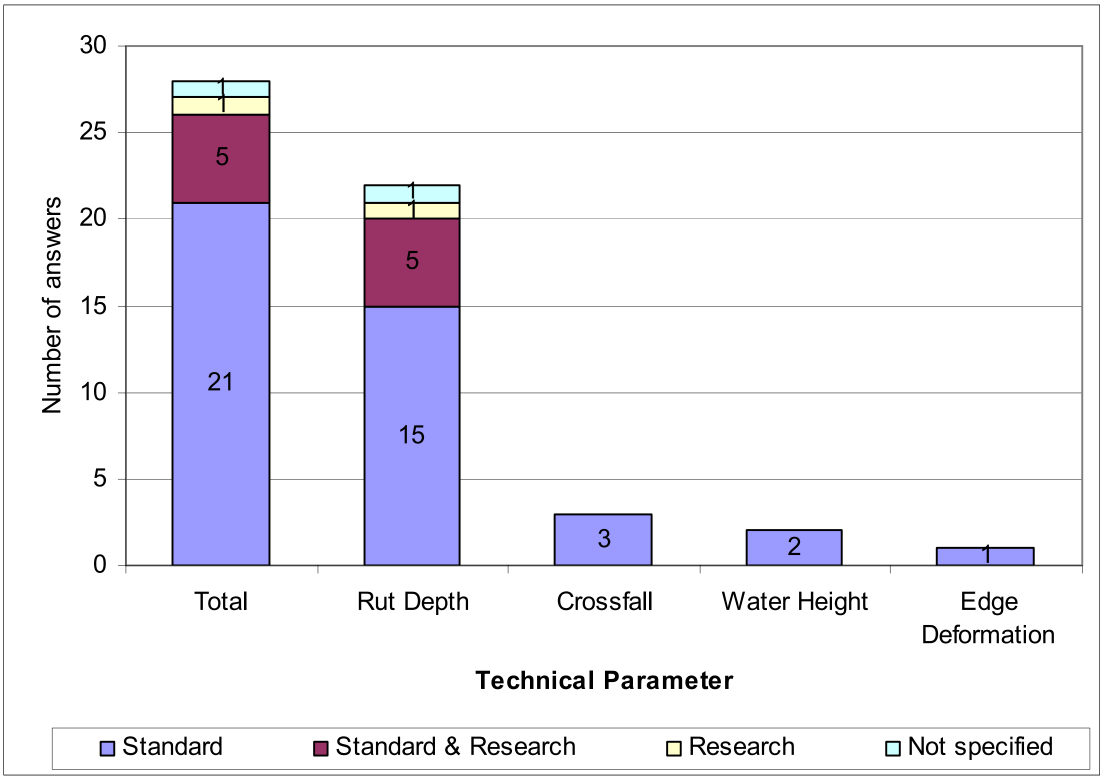

Figure 24: Number of answers grouped by the type of application for transverse evenness PIs

2.1.7 Standardization

One of the questions in the COST 354 questionnaire was whether the technical parameter was measured according to a national or international standard (NS or IS) or a Technical Specification (TS). Table 18 and Figure 25 provide the answers related to the standards used. It can be concluded that the most common way of measuring the technical parameters is following a national standard.

Table 18: Standards and specifications used for transverse evenness performance indicators

Country	Standard	Technical Parameter
Austria	NS: RVS 11.066 - Teil VII, (Roadstar)	Rut Depth
Belgium 1	NS: Standaard-bestek 250	Rut Depth
Belgium 2	*No standard*	Rut Depth
Czech Republic	NS: ČSN 73 6175 - Pavement Roughness Measurement	Rut Depth
Croatia	*No Standard*	Rut Depth
Denmark	NS: Konstruktion og vedligehold af veje og stier, Hæfte 4, Vedlige-hold af fær-dselsarealet, Juni 2004. Comming CEN-standard #prEN 13036-5	Rut Depth
Finland	NS: National Standard	Rut Depth
France 1	NS : NFP 219-1	Water Height
France 2		Rut depth

France 3		Cross-fall
France 4	NS : Méthode LPC n° 49	Rut Depth
Germany 1	NS: National Standard	Water Height
Germany 2		Rut Depth
Great Britain	TS :Interim Advice Note : Traffic Speed Condition Surveys – Revised Assessment Criteria	Rut Depth
Greece	NS : Greek Specifications (P.T.P)	Rut Depth
Hungary	TS : ÚT 2-2.116/1998 RST-mérés és –értéke-lés (RST-measurement and evaluation)	Rut Depth
Netherland	TS	Rut Depth
Norway 1	NS: ALFRED measurements manual	Rut Depth
Norway 2		Cross-fall
Poland	No Standard: System Oceny Stanu Nawierzchni - Wytyczne stosowania, Załącznik C	Rut Depth
Portugal	*No Standard*	Rut Depth
Serbia and Montenegro	TS: AASHTO guidance	Rut Depth
Slovenia	TS: TSC 06.610: 2003 Lastnosti voznih površin, Ravnost (Pavement surface properties, Evenness)	Rut Depth
Sweden 1	National Standard : MB115 & MB116	Edge Deformation
Sweden 2		Cross-fall
Sweden 3		Rut Depth
Switzerland	NS : SN 640 520a "Planéité"	Rut Depth
United States of America	NS: AASHTO PP38-00: Standard Practice for Determining Maximum Rut Depth in Asphalt Pavements	Rut Depth

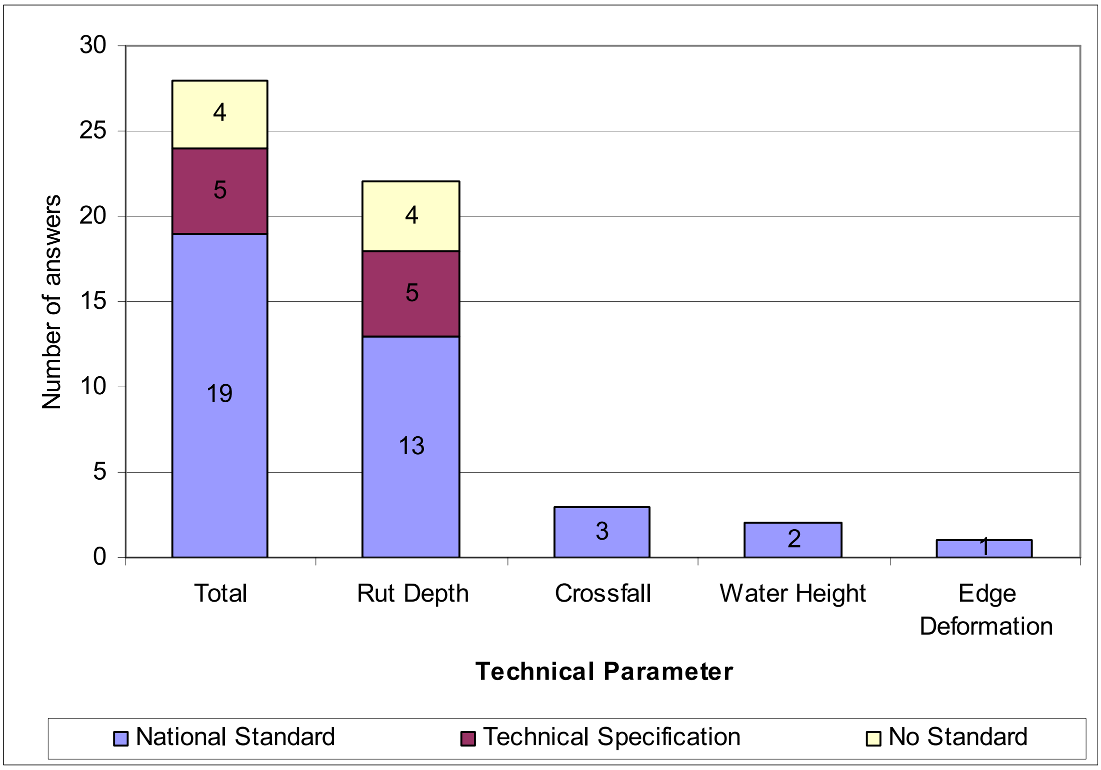

Figure 25: Number of answers grouped by the type of standard for TP of transverse evenness

2.1.8 Measuring principle

The records included in the COST 354 database about the measuring principle for transverse evenness TPs are presented in Figure 26.

The measuring principle and device used for surveys is a very important issue for the transverse evenness performance indicators, particularly when the technical parameter is the rut depth or water height.

The results of the FILTER experiment (2) carried out a few years ago showed that measured technical parameters are very sensitive to the equipment used, particularly on number of sensors and measurement width. Therefore, in addition to the survey device/sensor type used, more details are needed to be able to summarize transverse evenness measurements. A summary of these characteristics is presented in Table 19.

In most countries where automatic survey equipment is used, and according to the available data, the survey width varied between 2 and 3.5 m and the number of sensors varied between 13 and 37. The sampling interval was available only for four countries, but was consistently set to 0.1 m.

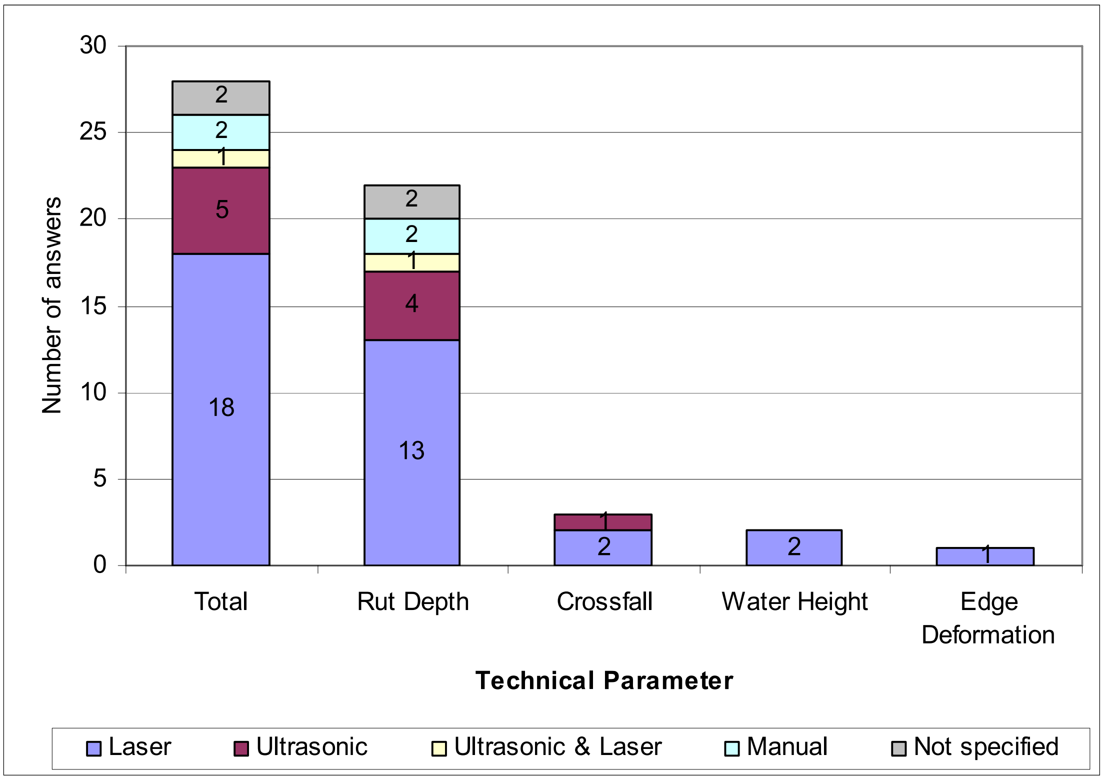

Figure 26: Number of records grouped by measuring principle for transverse evenness TPs

Table 19: Measuring principle details

Country Code	Country	Meas. Principle/ Sensor Type	# Sensors	Measuring Width	Sampling Interval
RUT DEPTH					
AT	Austria	Laser	23	2 m	
BE	Belgium 1	Ultrasonic			
BE	Belgium 2	Ultrasonic	13	3 m	
HR	Croatia	Laser	10	2.75	0.1 m
CZ	Czech Republic	Laser			
DK	Denmark	Laser	25	3.2 m	0.1 m
FI	Finland	Laser			
FR	France 2	Laser		3.5 m	
FR	France 4	Ultrasonic/Laser	13 (US)	3 m	
DE	Germany 2	Laser			
EL	Greece				
HU	Hungary	Laser	17		0.1 m
NL	Netherlands	Ultrasonic	37		
NO	Norway 1	Ultrasonic	17	2 m	
PL	Poland	Laser	15		
PT	Portugal	Laser			
CS	Serbia and Montenegro	Manual			
SI	Slovenia	Manual			
SE	Sweden 3	Laser	17		0.1 m
CH	Switzerland				
UK	United Kingdom	Laser	20		0.1 m
US	United States of America	Laser			
CROSSFALL					
FR	France 3	Laser		3.5 m	
NO	Norway 1	Ultrasonic	23	2 m	
SE	Sweden 2	Laser	17		
WATER HEIGHT					
FR	France 1	Laser		3.5 m	
DE	Germany 1	Laser			
EDGE DEFORMATION					
SE	Sweden 1	Laser	17		

In addition to the measuring principle, the data processing algorithm is also important. There are two basic algorithms that are used for calculation of rut depth: straightedge (with different possible lengths) or tensioned wire. The details of the calculation algorithms will be presented in paragraph 2.5.2 of this section.

In addition, it is important whether the average or maximum value of the left and right wheel path rut depth or water height is used in the analysis. Unfortunately, this data is mostly unavailable in the COST 354 database, as presented in Table 20.

Table 20: Algorithms used for processing of RUT DEPTH performance indicator data

Country Code	Country	Algorithm	Width	Section Length	Max, Avg. Left, Right Long Dir Transv Dir
AT	Austria	Straight edge	2 m	50 m	
BE	Belgium 1	Tensioned wire		100 m	
BE	Belgium 2		3 m	100 m	
HR	Croatia				
CZ	Czech Republic			10 m	
DK	Denmark			1000 m	
FI	Finland			100 m	
FR	France 2	Straight edge	1.5 m	10 m	
FR	France 4	Straight edge	1.5 m	200 m	
DE	Germany 2			100 m	
EL	Greece	Straight edge	3 m	10 m	
HU	Hungary			100 m	
NL	Netherlands	Tensioned wire		100 m	
NO	Norway 1		2 m		
PL	Poland	Straight edge	2 m	1000 m (5 m in comment)	
PT	Portugal				
CS	Serbia and Montenegro	Straight edge	1.2 m	25 m	
SI	Slovenia	Straight edge	4 m	20 m	
SE	Sweden 3	Tensioned wire[1]		20 m	Max, left, right rut depth
CH	Switzerland	Straight edge	4 m	50 m	
UK	United Kingdom			10 m	Average right
US	United States of America			10 – 300 m	

Note : [1]According to the literature (3). Not present in the database

Of course, if the measuring principles and data processing algorithms of the transverse evenness technical parameters are different, then the thresholds and decision values for the PIs related to these parameters, will probably be different as well.

2.1.9 Quality assurance

Figure 27 presents the distribution of answers for quality assurance for transverse evenness technical parameters.

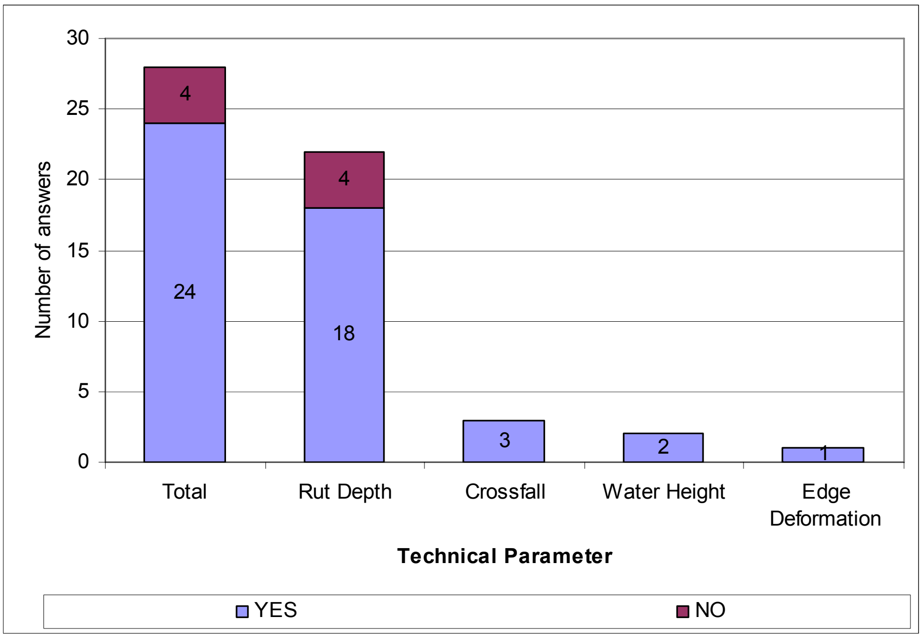

Figure 27: Number of answers for quality assurance for technical parameters of transverse evenness

From the answers it can be concluded that quality assurance is taken into account while performing the transverse evenness surveys and data collection.

2.1.10 Measuring interval

The measuring intervals for the Transverse Evenness technical parameters are presented in Figure 28.

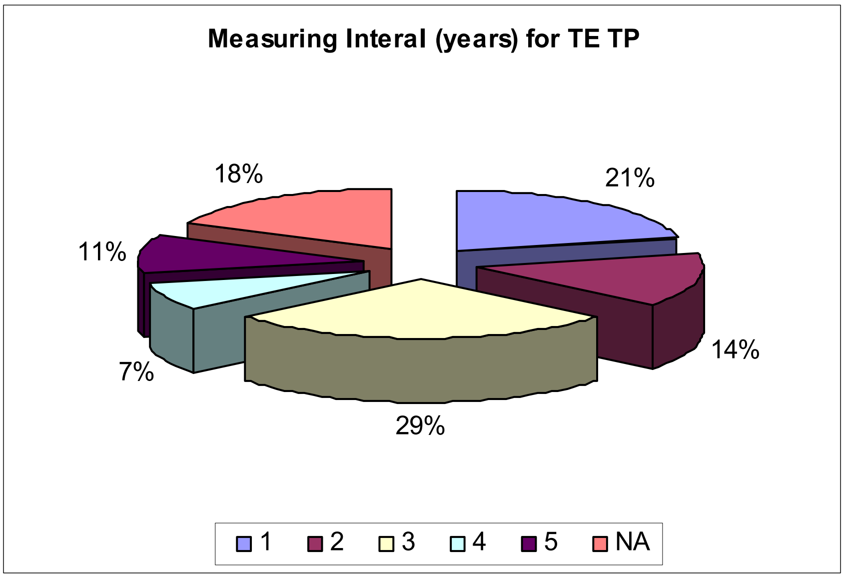

Figure 28: Number of answers for measuring interval (in years) of Transverse Evenness TPs

The majority of countries perform surveys on a 3-year interval (29%).

2.2 COMPLEMENTARY INFORMATION DERIVED FROM LITERATURE

This section provides the literature review of transverse evenness indicators defined in the proposed European standard and other literature sources.

2.2.1 Draft European Standards

The European standard prEN 13036-8 (2006) – *Road and Airfield Surface Characteristics – Test Methods – Part 8: Transverse unevenness and irregularities, definitions, methods of evaluation and reporting* (4) defines transversal unevenness and irregularities of the pavement surface of roads and airfields and appropriate methods of evaluation and reporting.

The transverse evenness parameters defined in this standard are:

- The cross-fall of the transverse profile;
- The heights of different irregular defects in the transverse profile, like steps, ridges/bumps/dips and edge deformation;
- The rut depth in the wheel path;
- The theoretical water depth in the ruts.

Cross-fall is defined as the angle between the horizontal and the regression straight line (according to least squares method) through the transverse profile fixed by at least seven measurement points equally spaced across the profile. This is the so called “regression-line method”.

The draft European standard also includes definition of several irregularities of the transverse profile. Although none of them, except edge deformation, is consistently measured in the countries participating in the COST-354, they are measures of localized irregularities and cannot be considered sufficient to characterize transversal profiles.

The rut depth is defined using the straightedge method (Figure 29) as the maximum deviation of the transversal profile from the straightedge.

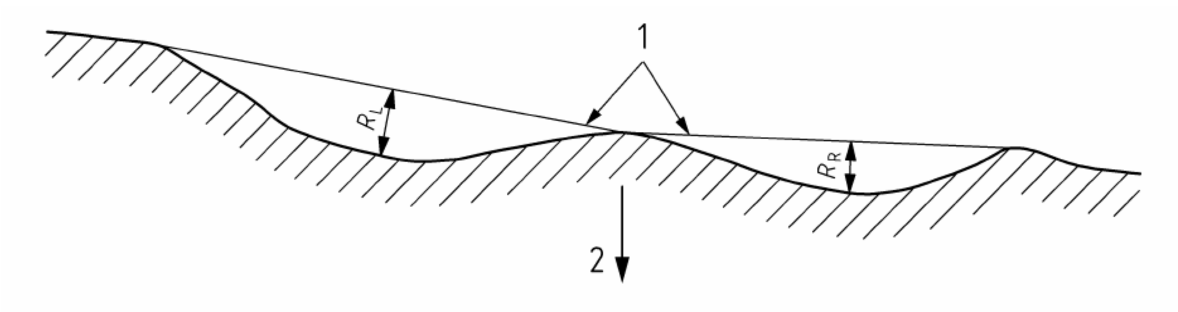

Figure 29: The definition of rut depth in left and right wheel paths according to prEN 13036-8 (4)

The calculation principle of the theoretical water depth according to prEN 13036-8 is shown in Figure 30. Theoretical water depth can be calculated separately for both wheel paths.

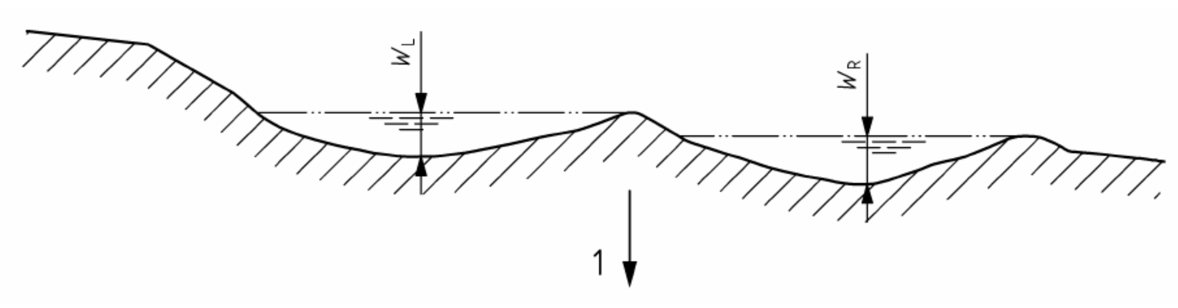

Figure 30: Calculation principle of water depths according to prEN 13036-8 (4)

2.2.2 FILTER – Theoretical Study of Indices – Technical Note 2000/02

The following transverse profile parameters were analyzed in the FILTER theoretical study of Indices (2):

- Maximum theoretical water depth
- Maximum theoretical water depth in left rut
- Maximum theoretical water depth in right rut
- Area of water (sum of both ruts)
- Maximum rut depth
- Maximum rut depth in left rut

- Maximum rut depth in right rut
- Area of rut (sum of both ruts)

The indices are defined according to the Figure 31, Figure 32 and Figure 33.

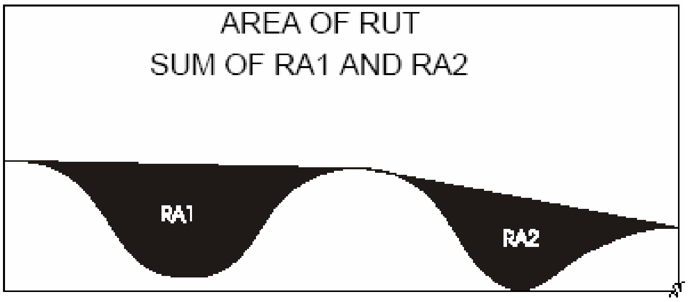

Figure 31: Definition of area of the rut (2)

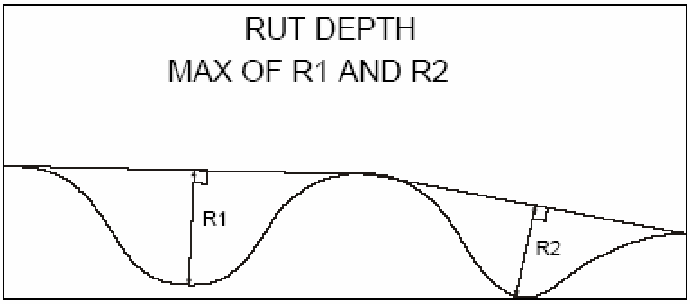

Figure 32: Definition of maximum rut depth (2)

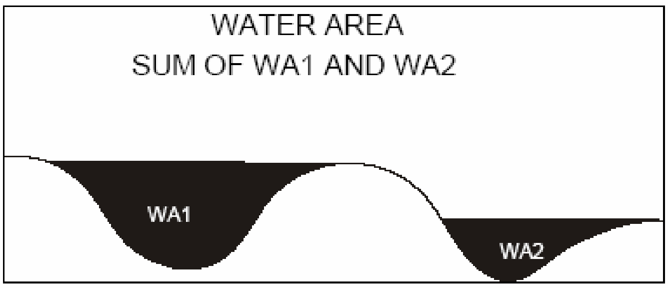

Figure 33: Definition of water area (2)

This study dealt with analysis of the impact of different variables on transverse profile survey results. Some of these conclusions, particularly regarding the impact of the number of sensors and the measurement width are presented in sections 2.5.3.2 and 2.5.3.3.

2.2.3 FHWA Report Characterization of Transverse Profiles, FHWA-RD-01-024, April 2001.

This study (5) examined several indices and their correlations for the evaluation of transversal profiles on the LTPP sections:

- Area of rut below and area of pavement above the ideal straight line connecting the edges of the pavement
- Area between the straight lines connecting the maximum pavement elevation and pavement surface
- Maximum depth for each wheel-path between a 1.2-m straightedge across a wheel-path and the surface of the pavement below the straightedge
- Maximum depth for each wheel-path between a 1.8-m straightedge across a wheel-path and the surface of the pavement below the straightedge
- Maximum depth for the outside wheel-path between a horizontal line from the edge of the pavement and the surface (i.e. depth of water that may accumulate before drainage on the shoulder)
- Maximum depth for the inside wheel-path between a horizontal line from the maximum elevation between the wheel-paths and the surface (i.e. depth of water that may accumulate before drainage into the outer wheel-path assuming elevations in an adjacent lane to be greater than the maximum depth between the wheel-paths)
- Maximum depth for each wheel-path between the wire-line extended above the entire lane width and pavement surface
- Width of rut
- Radius of curvature of deformation

It was concluded that the rut depth is the most widely used index for rutting, and many engineers have a good understanding of what the expected values of rut depths are. However, the disadvantage is that it provides a one-dimensional measure of the rutting and is not capable of describing the severity of rutting.

The rut width provides the second dimension of rutting. However, this parameter is not usually measured. The “area” indices provide a two-dimensional measure of rutting. However, since the area parameters haven’t been measured and analyzed in the past, the disadvantage is that there is no good understanding of the range of the values.

The study finally recommended that five indices should be added to the US National Information Management System:

- Area of rut below and area of pavement above the ideal straight line connecting the edges of the pavement
- Area between the straight lines connecting the maximum pavement elevation and pavement surface
- Maximum depth for each wheel-path between a 1.8-m straightedge across a wheel-path and the surface of the pavement below the straightedge
- Width of rut based on a 1.8-m straightedge.

It was also concluded that the 1.8 m straightedge rut depth and the wire line rut depth provide the same measure of rut depth.

2.2.4 Potential additional transverse evenness indicators

Based on literature survey it can be concluded that all of the indicators used in European countries and are available in the COST 354 database are defined in the draft European standard prEN 13036-8 (4).

Since the rut depth and water height provide one-dimensional measures of rutting, including the other dimension (rut width) would possibly result in the improvement in the ability to describe severity of this distress. Therefore, the following indicators may be considered for measuring and evaluating transverse profiles:

- Area of rut (sum of both ruts)
- Area of water (sum of both ruts)
- Rut width

However, at this point, these indices are primarily used for research purposes and their major drawback is that they are neither widely used, nor defined in the standards.

2.3 EVALUATION OF THE MOST SUITABLE INDIVIDUAL PERFORMANCE INDICATORS

2.3.1 Technical parameter Rut Depth

From the 28 records analyzed, 22 refer to technical parameter Rut Depth. Of those 22, only 5 countries provided explicit transformation functions for Index Rutting. However, two of them gave the transformation function and corresponding Index limits but no classification criteria. In addition, 6 countries provided TP limits that they obviously use to directly define classes. One country gave two classification criteria (depending on the traffic volume) and the corresponding Index limits, from which the two transformation functions could be derived. Some responders only gave information about the classification of the technical parameter Rut Depth, using TP limits or threshold, warning, acceptance and/or target values for the technical parameter Rut depth. Some of them also stated that they use classification to indices but did not give any information about the transformation function from technical parameter to index. Detailed data is presented in Table 21 and Table 22.

Lack of classification criteria in the database could mean two things:

- limits between condition classes are independent of the road category or traffic or
- the responders forgot to provide the classification criteria.

If no classification criteria were supplied then, for the purposes of further analysis, it was assumed that the TP limits and threshold values apply to motorways and other primary roads.

From Table 21 and Table 22 some conclusions were made:

- The majority of the countries use a 5-class classification from very good through good, fair and poor to very poor condition;
- From the TP limits and PI limits a transformation function could be derived;

For those records that provided the transformation function, both, the limits of TP and Index limits are available in the COST 354 database.

Table 21: Technical parameter indices and transformation functions information for Rut Depth in the COST 354 database

	AUSTRIA (AT)	BELGIUM (BE) 1	GERMANY (DE)	POLAND (PL)	SLOVENIA (SI)	SWITZERLAND (CH)[1]	USA
NAME OF TECHNICAL PARAMETER	Rut Depth	Rut Depth	Rut Depth	Rut Depth	Rut Depth	Rut Depth	Rut Depth
MOTORWAYS	Yes	Yes	Yes	Yes	Yes	Yes	Yes
OTHER PRIMARY ROADS	Yes	Yes	Yes	Yes	No	Yes	Yes
SECONDARY ROADS	No	Yes	Yes	No	No	Yes	No
INDEX NAME	Index rutting	Index rutting	Index rutting	Representative Rut Depth	Rut Depth	Index rutting	Index rut depth
INDEX DESCRIPTION	Index rutting	Index rutting	Index rut depth	Representative Rut Depth	Rut Depth	Transverse Evenness Index	Rut Depth Index
NUMBER OF CLASSES	5	5	8	4	5	5	4
SCALE VERY POOR	5	0	Class 8	D	0	0	0
SCALE VERY GOOD	1	1	Class 1	A	5	100	100
NAME CLASS 1	1 – very good	Very good	Class 1 (good)	A – good	Very Good	Good	Good
NAME CLASS 2	2 – good	Good	Class 2-5 (fair)	B – fair	Good	Medium	Fair
NAME CLASS 3	3 – fair	Fair	Class 6-7 (poor)	C – poor	Fair	Sufficient	Poor
NAME CLASS 4	4 – poor	Poor	Class 8 (very poor)	D - bad	Poor	Critical	Very poor
NAME CLASS 5	5 – very poor	Very poor			Very Poor	Bad	
CLASSIFICATION CRITERIA 1	1.0<=I_IRI<=5.0; road category A and S		Function Class 1		AADT>2000 Or ESAL82kN/day>80	Motorways	

CLASSIFICATION FUNCTION 1	1+0.175*RT	1-0.05*RUT (RUT < 4)
		0.9-0.025*RUT (4-12)
		1.2-0.05*RUT (12-16)
		0.8-0.025*RUT (16-32)
		0 (RUT > 32)
			IF(SPT<=4;1;1.5+2*(SPT-4)/6), SPT < 10
			
			IF(SPT>20;5;3.5+(SPT-10)/10), SPT >10
				2*Hp			100-5.62*RT

THRESHOLD TP 1	20	16	20	30			9
THRESHOLD IND 1	4,5	0.4	4.5	60			50
WARNING TP 1	15	14	10	20			
WARNING IND 1	3,5	0.5	3.5	40			
CLASSIFICATION CRITERIA 2	1.0<=I_IRI<=5.0; road category B		Function Class 2		AADT<2000 Or ESAL82kN/day<80	Primary Roads	

CLASSIFICATION FUNCTION 2	1+0.14*RT		IF(SPT<=4;1;1.5+2*(SPT-4)/11), SPT < 15
			
			IF(SPT>25;5;3.5+(SPT-10)/10), SPT >15				

THRESHOLD TP 2	25		25				
THRESHOLD IND 2	4,5		4.5				
WARNING TP 2	15		15				
WARNING IND 2	3,5		3.5				

	AUSTRIA (AT)	BELGIUM (BE) 1	GERMANY (DE)	POLAND (PL)	SLOVENIA (SI)	SWITZERLAND (CH)[1]	USA
CLASSIFICATION CRITERIA 3			Function Class 3			Secondary Roads	

CLASSIFICATION FUNCTION 3			IF(SPT<=4;1;1.5+2*(SPT-4)/16), SPT < 20
			
			IF(SPT>30;5;3.5+(SPT-20)/10), SPT > 20				

THRESHOLD TP 3			30				
THRESHOLD IND 3			4.5				
WARNING TP 3			20				
WARNING IND 3			3.5				
INDEX LIMIT 1	1	1	1	0	0		0
INDEX LIMIT 2	1,5	0.8	1.5	10	1		25
INDEX LIMIT 3	2,5	0.6	3.5	20	2		50
INDEX LIMIT 4	3,5	0.4	4.5	30	3		75
INDEX LIMIT 5	4,5	0.2	5		4		100
INDEX LIMIT 6	5	0			5		
TP LIMIT 1 (CRITERIA 1)	0	0[2]	0		0	0	
TP LIMIT 2 (CRITERIA 1)	5	4[2]	4		6	4	
TP LIMIT 3 (CRITERIA 1)	10	12[2]	10		10	6	9
TP LIMIT 4 (CRITERIA 1)	15	16[2]	20		14	9	
TP LIMIT 5 (CRITERIA 1)	20	32[2]			18	12	
TP LIMIT 1 (CRITERIA 2)	0		0		0	0	
TP LIMIT 2 (CRITERIA 2)	5		4		8	5	
TP LIMIT 3 (CRITERIA 2)	10		15		12	8	
TP LIMIT 4 (CRITERIA 2)	15		25		16	12	
TP LIMIT 5 (CRITERIA 2)	20				20	18	
TP LIMIT 1 (CRITERIA 3)	0		0			0	
TP LIMIT 2 (CRITERIA 3)	5		4			6	
TP LIMIT 3 (CRITERIA 3)	10		20			10	
TP LIMIT 4 (CRITERIA 3)	15		30			16	
TP LIMIT 5 (CRITERIA 3)	20					24	

Note: [1]TP Limits are not in the database and are obtained from the provided literature
[2]Not in the corresponding fields in the database.

Table 22: Technical parameter indices and transformation functions information for Rut Depth in the COST 354 database

	BELGIUM (BE) 2	CROATIA (HR)	CZECH REPUBLIC (CZ)	FINLAND (FI)	FRANCE (FR) 4	HUNGARY (HU)
NAME OF TECHNICAL PARAMETER	Rut Depth	Rut Depth	Rut Depth	Rut Depth	Rut Depth	Rut Depth
MOTORWAYS	Yes	Yes	Yes	Yes	Yes	Yes
OTHER PRIMARY ROADS	Yes	Yes	Yes	Yes	Yes	Yes
SECONDARY ROADS	Yes	No	Yes	Yes	No	Yes
INDEX NAME	Index rutting			Index Rutting	Extend of rut depth	Index rut depth
INDEX DESCRIPTION	Index rutting			Index Rutting	Extend of Severe (Significant) Rut depth	Rut Depth Index
NUMBER OF CLASSES	5		5	5	3	5
SCALE VERY POOR	0		5	1	100	5
SCALE VERY GOOD	1		1	5	0	1
NAME CLASS 1	A - Very good	Very Good	1 – Very good	5 – Very good	A - Good	1
NAME CLASS 2	B - Good	Good	2 - Good	4 - Good	B - Acceptable	2
NAME CLASS 3	C - Fair	Acceptable	3 - Fair	3 - Fair	C - Poor	3
NAME CLASS 4	D - Poor	Bad	4 - Poor	2 - Poor		4
NAME CLASS 5	E - Very poor	Very bad	5 – Very poor	1 – Very Poor		5
CLASSIFICATION CRITERIA 1			Motorways and Primary Roads	AADT < 1500		
CLASSIFICATION FUNCTION 1					Extend of OC > 30 mm (% of section length)	
THRESHOLD TP 1	12	20	22	18		
THRESHOLD IND 1				2	40	
WARNING TP 1	8	15	16			
WARNING IND 1					20	
CLASSIFICATION CRITERIA 2			Secondary and Other Roads	AADT 1500 – 6000	Extend of 15 < OC < 30 mm (% of section length)	
CLASSIFICATION FUNCTION 2						
THRESHOLD TP 2			36	17		
THRESHOLD IND 2				2	50	
WARNING TP 2			25			
WARNING IND 2					25	
CLASSIFICATION CRITERIA 3				AADT > 6000		
CLASSIFICATION FUNCTION 3						

	BELGIUM (BE) 2	CROATIA (HR)	CZECH REPUBLIC (CZ)	FINLAND (FI)	FRANCE (FR) 4	HUNGARY (HU)
THRESHOLD TP 3				16		
THRESHOLD IND 3				2		
WARNING TP 3						
WARNING IND 3						
INDEX LIMIT 1				5	0	
INDEX LIMIT 2				4.5	20 (25)	
INDEX LIMIT 3				3.5	40 (50)	
INDEX LIMIT 4				2.5	100	
INDEX LIMIT 5				1		
INDEX LIMIT 6						
TP LIMIT 1 (CRITERIA 1)	0		0			0
TP LIMIT 2 (CRITERIA 1)	4		6			5
TP LIMIT 3 (CRITERIA 1)	8	8	11			8
TP LIMIT 4 (CRITERIA 1)	12	15	16			12
TP LIMIT 5 (CRITERIA 1)	16	20	22			18
TP LIMIT 1 (CRITERIA 2)			0			
TP LIMIT 2 (CRITERIA 2)			8			
TP LIMIT 3 (CRITERIA 2)			15			
TP LIMIT 4 (CRITERIA 2)			25			
TP LIMIT 5 (CRITERIA 2)			36			
TP LIMIT 1 (CRITERIA 3)						
TP LIMIT 2 (CRITERIA 3)						
TP LIMIT 3 (CRITERIA 3)						
TP LIMIT 4 (CRITERIA 3)						
TP LIMIT 5 (CRITERIA 3)						

2.3.2 Technical parameters Cross-fall, Water Height and Edge Deformation

Technical parameters Cross-fall, Water Height and Deformation are used in a limited number of countries, as shown in Figure 18 and Table 17. It is important to note that in all of these countries, these additional technical parameters were collected in addition to the rut depth.

Cross-fall is measured in three countries, France, Norway, and Sweden. However, neither technical parameter limits nor transformation functions are provided in the COST 354 database. The cross-fall can be described by two definitions – surface line method or regression line method. (3). The surface line method defines a cross-fall as a mean cross profile between two outer points of the lane (at the width of 3.2 m, as used in Sweden), while regression line method calculates regression line (using the least squares method) of the mean cross profile with different number of sensors (i.e. 17, as used in Sweden).

Water depth is consistently measured and evaluated in two countries, France and Germany, according to the COST 354 database.

In France water depth is measured in both wheel paths and water depth is calculated using the 1.5-m straightedge analysis method. Based on the water depth, the roads are divided in 5 classes (from A – very good to E – poor). However, the thresholds between different classes are considered confidential and are not provided in the COST 354 database. The length of the interval used for data averaging is 10 m.

Germany provided threshold limits and transformation functions for three different functional classes of roads, according to fictive water depth, on a scale 5 (very poor) to 1 (very good). They are presented in Table 23 and Figure 34.

Table 23: Transformation functions for Water Height Index used in Germany

Transformation Function		Criteria
1	IF(SPH<=0.1;1;1.5+2*(SPH-0.1)/3.9)	SPH<=4, function class 1
2	IF(SPH>6;5;3.5+(SPH-4)/2)	SPH>4, function class 1
3	IF(SPH<=0.1;1;1.5+2*(SPH-0.1)/5.9)	SPH<=6, function class 2
4	IF(SPH>9;5;3.5+(SPH-6)/3)	SPH>6, function class 2
5	IF(SPH<=0.1;1;1.5+2*(SPH-0.1)/7.9)	SPH<=8, function class 3
6	IF(SPH>12;5;3.5+(SPH-8)/4)	SPH>8, function class 3

Edge deformation is consistently measured and evaluated only in Sweden. However, no further details, like threshold limits and transformation functions are provided in the COST 354 database.

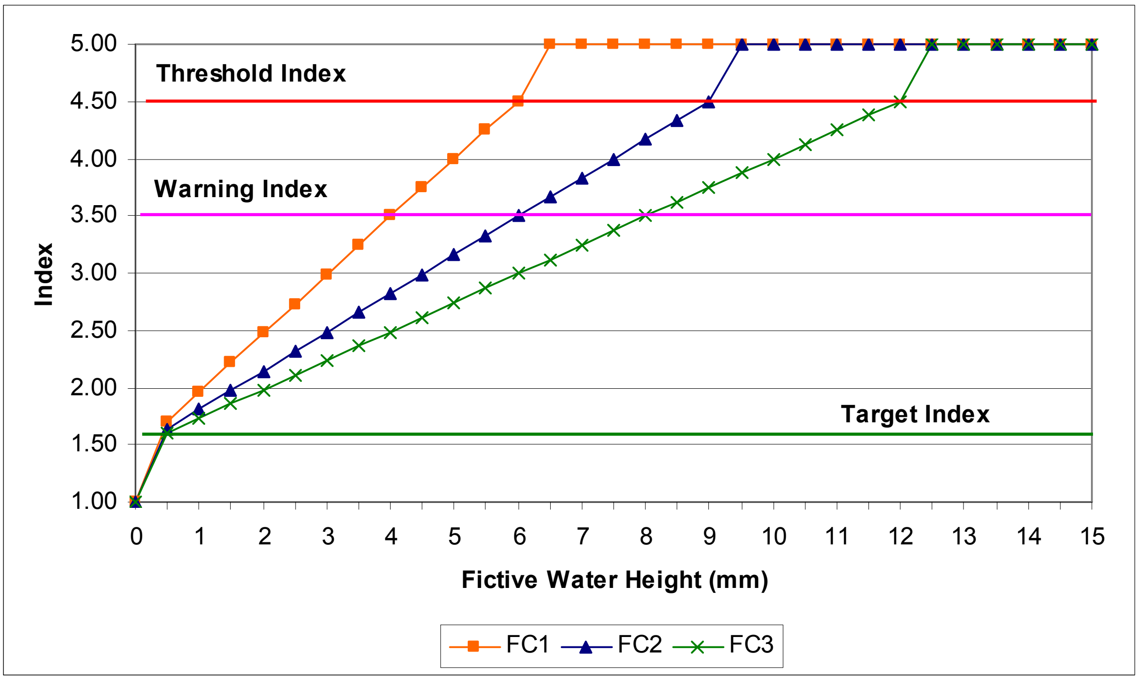

Figure 34: Transformation functions for Water Height Index used in Germany for different road functional classes (FC)

2.4 SELECTION OF THE PROPOSED INDIVIDUAL PERFORMANCE INDICATOR

The decision on the most suitable technical parameter for a specific performance indicator was made using the criteria shown in 1.3.

Based on data on the COST 354 database, all technical parameters (rut depth, water height, cross-fall, and edge deformation) currently present in the database and used in different European countries are also defined in the draft European standards for transverse profile measurements. As discussed earlier the use of these four parameters is primarily based on national standard or technical specifications.

Three other parameters (rut area, water area and rut width) which are presented in chapter 2.2 of this report were not defined in the draft European standards nor in other standards, and they are primarily used for the research at this point.

Regarding the wide use, it was obvious from the COST 354 database that rut depth is used in the majority of the countries participating in COST 354 Action as a technical parameter for transverse evenness. Cross-fall and water height are used in 3 and 2 countries respectively, and edge deformation in just one European country. Rut and water area and rut width are currently not used in any country.

Device independency is relatively complicated issue. Since several different devices (manual and automated) are used for transverse profile surveys, there is significant number of parameters that influence the survey results. Among others, they include device type, sensor type, number of sensors, measurement width, and lateral position of the vehicle. Some of these parameters are even interrelated. However, the impact of these parameters is similar on all technical parameters considered, and therefore, all of them are rated as medium.

Since all of the parameters can be collected with specialized vehicles at highway speeds, and that was the primary way of data collection at the network level, it was considered that their collection is safe. However, in the case of manual data collection this is not the case, but this way of data collection is rarely used at network level.

The last two parameters (reliability and sustainability) were very difficult to estimate based on the available data in the database.

Data presented in the FILTER report (1) provided some insight into importance of some variables on transverse profile measurements. In this report it was found that data collection speed has no significant influence on repeatability and reproducibility of the measurements. However, the averaging distances have significant influence on repeatability, but not on reproducibility of measurements. Average repeatability standard deviations were 0.1 % for cross-fall, 0.5 – 0.9 mm on rut depth and 0.25 mm on water height. Average reproducibility standard deviations were 0.5 % on cross-fall, 1.7 – 2.7 mm on rut depth and 2.1 – 2.2 mm on water height. The other parameters are not presented in the report.

One important issue when reliability is considered is the type of survey equipment used for data collection. The laser sensors have slightly higher accuracy than ultrasonic sensors. However, both of them are mostly used for all of the parameters derived from transverse profile measurements, and it can be considered that they provide reliable data.

Since the same technology is used for collection of all considered technical parameters, it should be expected that this technology will be available in the future, and therefore, all parameters are considered sustainable.

Table 24 presents all technical parameters and their evaluation regarding the specific criteria.

Table 24: Selection table for technical parameters

	TECHNICAL PARAMETER					
	Rut Depth	**Cross-fall**	**Water Height**	**Edge Deformation**	**Rut or Water Area**	**Rut Width**
BASED ON EUROPEAN STANDARD	GOOD	GOOD	GOOD	GOOD	BAD	BAD
STANDARD PRACTICE	GOOD	GOOD	GOOD	GOOD	BAD	BAD
RESEARCH	BAD	BAD	BAD	BAD	GOOD	GOOD
WIDE USE	GOOD	MEDIUM	MEDIUM	MEDIUM	BAD	BAD
DEVICE INDEPENDENT	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM
SAFE TO COLLECT	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
RELIABLE	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
SUSTAINABLE	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD

GOOD
MEDIUM
BAD

Based on previous discussions, the technical parameter Rut Depth is selected as single technical parameter for transverse evenness, since it is used in most of the countries.

Water height provides slightly higher reliability and is less dependent on the algorithm used for data processing. However, its major drawback for now is that it is only used in a few countries.

Two other parameters from the COST 354 database, cross-fall and edge deformation, can be considered as additional parameters to describe transverse profile, but they are not sufficient by themselves to describe transverse evenness and can be hardly recommended as single performance indicators.

Parameters derived from the literature, rut or water area and rut width are primarily used for research purposes at this point.

2.5 PROTOCOLS AND TEST METHODS FOR MEASURING THE PROPOSED INDIVIDUAL INDICATORS

According to prEN 13036-6 (6) ***transverse profile*** is the intersection between the road surface and a reference plane perpendicular to the road surface and to the lane direction

There are several data collection protocols and data processing algorithms for measuring rut depths that are used in European countries and around the world. The results of the survey may be significantly influenced by the type and other parameters of the device, as well as by the calculation algorithms used. Therefore, the introductory part provides some basic information regarding the types of devices, their accuracy and other important characteristics.

2.5.1 Measurement equipment

Devices used for transverse profile surveys can be roughly classified as manual or automated.

Devices for manual surveys include:
- Rod and level
- Straightedge and pin (of various lengths)
- Static and rolling Dipstick, and walking profiler.

Rod and level surveys typically are not accurate enough to be used in PMS applications. Straightedges were mostly used in the past for project level rutting evaluation, while the dipstick or walking profilers are used for defining reference profiles and QC/QA surveys due to their high precision. According to the COST-354 database, straightedge is used in only two countries and no other manual devices are used. However, the straightedge and dipstick methods are defined in many standards.

According to the draft European standard prEN 13036-8 (4), the following equipment can be used for transverse profile surveys:
- Profilometer, according to the standard prEN 13036-6 (6)
- Straightedge, according to the standard EN 13036-7 (7)
- Measuring equipment that have proven to fulfil the required specifications, such as rod and level.

The accuracy classes that can be achieved with this equipment are presented in chapter 2.5.3.

ASTM standard E1703/E1703M-95/2005– *Standard Test Method for Measuring Rut-Depth of Pavement Surfaces Using a Straightedge* (8) describes the procedure for measuring rut-depth at a chosen location with a straightedge. This standard allows use of straightedges from 1.73 m to 3.66 m (5.67 to 12 ft) long. The rut depth is defined as the maximum measured perpendicular distance between the bottom surface of the straightedge and the contact area of the gage with the pavement surface at a specific location. The most frequently used in the US are 4-ft (1.2 m) and 6-ft (1.5m) straightedges.

AASHTO provisional standard PP 32-96/2000 – *Standard Practice for Measuring Pavement Profile Using a Dipstick®* (9) defines procedures for measuring both longitudinal and transverse profiles by measuring elevation differences using a dipstick. For measuring transverse profiles, measurements are recorded at 0.3-m intervals and can be used to calculate rutting using various computational methods.

ASTM standard E2133-03 – *Standard Test Method for Using a Rolling Inclinometer to Measure Longitudinal and Transverse Profiles of a Travelled Surface* (10) describes the measurement of transverse and longitudinal profiles using a rolling inclinometer at walking speeds. Transverse profile is defined as vertical deviations of the pavement surface form a horizontal reference perpendicular to the lane direction, and slope is defined as angular deviation of the travelled surface from the horizontal datum. This method can be used to measure rut depth using a computer simulation in accordance with standard ASTM E 1703/E 1703M (8).

Automated measurements of rut depth can be performed using devices (profilometers) with different systems:
- Ultrasonic
- Laser (point and scanning)
- Optical.

Ultrasonic or point laser sensors are typically mounted on the rut beam in front of survey vehicle. The number of sensors varies between 3 (rarely used in some states in the US) and 132 and the measurement width between 2 and 3.5 m, depending upon the equipment type (11).

Ultrasonic sensors are the lowest cost sensors spaced at approximately 100 mm intervals and measurement width of up to 3 m. Due to the speed of ultrasonic devices, these systems typically sample at every 2.5 – 5 m along the road.

Point lasers give the elevation at a point (12). Since they are much faster than ultrasonic sensors, they can record transverse profile at intervals as close as 10 mm along the road.

Scanning lasers is a relatively new technology that measures almost a continuous profile. For example, the Phoenix Science “Ladar” system samples a 3.5-m pavement width from a single scanning laser mounted 2.3 m above the ground. 950 points are sampled across the transverse profile, every 25 mm along the road (12).

Optical systems use digitized images of the transverse profile which are analyzed to estimate rut depths. These images may be produced using different photographic techniques, often supplemented by lasers to project lines to the pavement and a special camera to measure deformations of the laser line. One type of this device is also used for data collection for LTPP in the US.

The advantage of these automated devices is the high speed of data collection, but the disadvantage is the big variation among the devices, that is highly influenced by the transversal position of the vehicle during the measurement, especially for devices with a low number of sensors.

2.5.2 Calculation algorithms and data processing

The two basic principles used for the rut depth calculation are the straightedge and tensioned wire principles.

Figure 35 presents measuring of rut depth using a straightedge. There are several parameters that impact the value of rut depth calculated using this principle:

- Shape of the profile
- Straightedge length
- If rut depth is calculated as a vertical distance between the transverse profile and the bottom of the straightedge, or as a distance measured perpendicular to the straight edge.

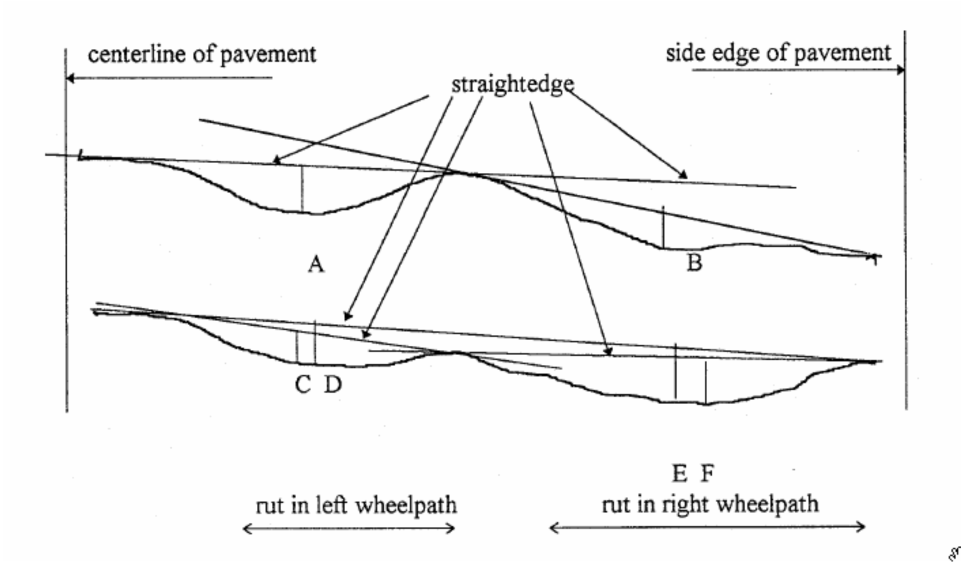

Figure 35: Straightedge method for determining rut depth (11)

The length of the straightedge is a very important parameter when measuring and calculating the rut depth using this principle.

According to the draft European standard prEN 13036-8 (4) the length of a virtual straight reference line should be about 1.5 to 2 m (about half the width of the lane).

The tensioned wire method (Figure 36) relates the transverse profile to the straight line given by an ideal tensioned wire which touches the highest points in the cross profile. With this line as a basis, it is possible to calculate the rutting as the distance between profile and the line. The method removes some of the variables introduced using a straight edge method (11).

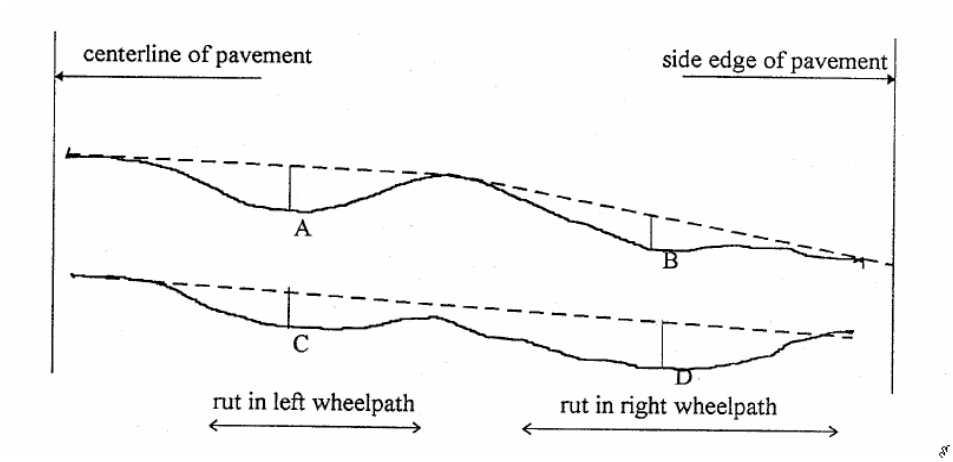

Figure 36: Tensioned wire method for determining rut depth (11)

However, in the report (5) it was concluded that there are no significant differences between 1.8-m straightedge and tensioned wire algorithms for calculation of maximum rut depths.

In Sweden (3), mean cross profile is used as a basis for many of the parameters that describe transverse evenness. It is calculated by setting the outer measurement point to zero and “excluding” the cross-fall. The “zeroed” mean cross profile is then calculated every 0.1 m and expressed as a mean value every 20 m. It is used to calculate the rut depths, but it can also be used in combination with cross-fall to calculate edge deformation, water height, or other parameters.

The Long Term Pavement Performance Program (LTPP) Protocol for collecting rut data (16) uses a photographic technology that results in a series of approximately 30 x-y points that accurately describe the transverse surface of the travel or outer lane of the pavement at a particular location. The transverse profile is measured at intervals over 15.2 m in the 152-m LTPP section. These x-y points are used to determine the rut depth using a tensioned wire-line calculation method. Both wheel-path rut values are stored in the LTPP database. Comparisons of rutting were made using the average of the wheel-path rut depths.

AASHTO provisional standard PP 38-00 – *Standard Practice for Determining Maximum Rut Depth in Asphalt Pavements* (13) describes five-point method and outlines a standard procedure for estimating and summarizing maximum rut depth in asphalt pavement surfaces. The standard also states that five points are the minimum number of points, and that measurement of more points on the transverse profile enhances the likelihood of identifying the maximum rut-depth. Its purpose is to produce consistent estimations for network-level pavement management, based on automated data collection equipment. The interval length used in the standard is 100 m.

2.5.3 Accuracy of measurements

The draft European standard prEN 13036-8 (4) defines the requirements regarding the accuracy for different technical parameters and measurement methods defined in the standard.

There are three accuracy classes that depend on the type of survey equipment and the technical parameter used. Table 25 provides the combination of measurement devices and accuracy classes obtainable for each parameter.

Table 25: Recommended measurement devices and obtainable accuracy classes assuming careful application of devices (4)

Technical Parameter	Profilometer	Straightedge	Rod and Level
Cross-fall	Class 1,2,3	Class 1[1]	Class 1
Irregularity	Class 1,2,3	Class 1	
Rut Depth	Class 1,2,3	Class 1	
Theoretical Water Depth	Class 1,2,3		

Note: [1] with levelling

The accuracy is composed of a combination of a random error from some agreed reference value (precision) and a common systematic error (bias).

Table 26 provides the required maximum values of accuracy, while Table 27 provides maximum values of bias for transversal profile TPs according to the prEN 13036-8 (4).

Table 26: Required maximum values of accuracy (repeatability standard deviation) for transverse evenness parameters for a single transverse profile (4)

Technical Parameter	Class 1	Class 2	Class 3
Cross-fall	0.2 %	0.4 %	0.8 %
Irregularity	0.7 mm	1.5 mm	2.5 mm
Rut Depth	0.7 mm	1.5 mm	2.5 mm
Theoretical Water Depth	0.7 mm	1.5 mm	2.5 mm

Table 27: Required maximum values of bias (repeatability standard deviation) for transverse evenness parameters for a single transversal profile (4)

Technical Parameter	Class 1	Class 2	Class 3
Cross-fall	10 % of a measured value (and a minimum of 0.2 %)	15 % of a measured value (and a minimum of 0.4 %)	20 % of a measured value (and a minimum of 0.8 %)
Irregularity	10 % of a measured value (and a minimum of 0.5 mm)	15 % of a measured value (and a minimum of 1.0 mm)	20 % of a measured value (and a minimum of 2.0 mm)
Rut Depth	10 % of a measured value (and a minimum of 0.5 mm)	15 % of a measured value (and a minimum of 1.0 mm)	20 % of a measured value (and a minimum of 2.0 mm)
Theoretical Water Depth	10 % of a measured value (and a minimum of 0.5 mm)	15 % of a measured value (and a minimum of 1.0 mm)	20 % of a measured value (and a minimum of 2.0 mm)

Table 28 provides the limits for different accuracy classes according to the prEN13036-8 (4) for rut depth and water height on the section level.

Table 28: Required maximum values of accuracy (repeatability standard deviation) for transverse evenness parameters of a section of 100 m (4)

Technical Parameter	Class 1	Class 2	Class 3
Rut Depth	0.5 mm	1.0 mm	2.0 mm
Theoretical Water Depth	0.5 mm	1.0 mm	2.0 mm

The accuracy of the measurements depends on several parameters:

- type of sensors
- number of sensors used for surveys, data processing and sensor positioning
- sampling interval
- measurement width
- lateral placement of the vehicle
- averaging distance.

According to the FILTER experiment (1), the operating speed, initially thought to be of significant influence on the results, did not have a significant impact on rut depth measurements.

2.5.3.1 Sensor Type

Ultrasonic sensors show an average error of 0.3 mm (12), while for laser sensors this error can be expected to be in range of 0.1 mm. However, the number of sensors has more significant impact on measurement error than the sensor type.

2.5.3.2 Number of sensors and their positioning

One feature of profilometer measurements is that they always underestimate the true rut depth. The reason is that sensors are spaced at discrete intervals across the road, and they therefore are unlikely to record the highest and lowest points for each wheel-path. (12)

As previously shown, the number of sensors varies significantly among the equipment used for automated rut depth surveys, ranging from three sensors used at the beginning of the LTPP experiment in the US (and are still used in some states) to more than 30 sensors. AASHTO Provisional standard PP38-00 (13) requires a minimum of five sensors, while some authors (5) recommend use of a minimum of 9 sensors. It is assumed that increasing the number of sensors improves the accuracy of the measurements.

However, according to studies performed in Sweden (2), based on 2342 surveyed profiles, the average rut depth was 14.35 mm. Figure 37 provides the average rut depths obtained with different number of sensors and with three lateral positions of the vehicle. It can be concluded that increasing the number of sensors above 25 results in relatively small improvements of the measurements.

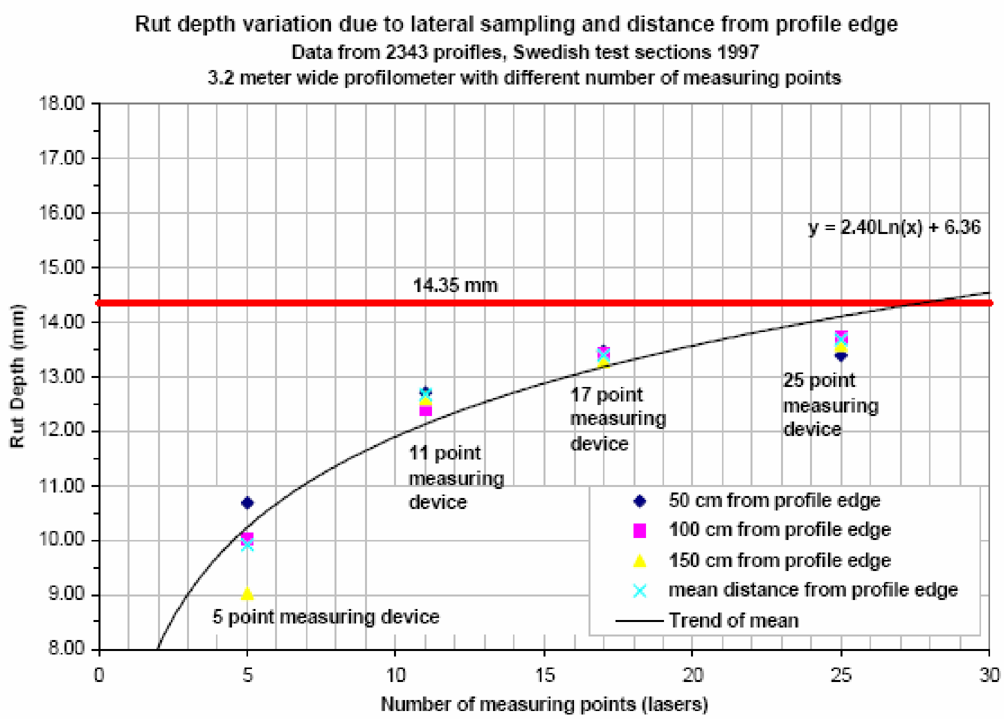

Figure 37: The effect of number of measuring points on the surveyed rut depth (2)

Another study (12) also concluded that bias increases as the number of sensors increases, and therefore, there is a need of compromise regarding the number of sensors versus the accuracy requirements.

2.5.3.3 Measurement width

The measurement width depends on the device used (straightedge with different widths) or profilometers. According to the COST-354 database, the measurement width varies between 1.2 and 4 m.

According to the European standard prEN 13036-8 (4), the width of a reference line can vary from 1.5 to 2 m and should be over approximately one half of the lane width.

The FHWA report (5) recommended use of 1.8-m straightedge instead of 1.2-m straightedge that was used previously.

2.5.3.4 Lateral position of the vehicle

Some experiments that included several survey devices, like the PIARC – EVEN experiment (11), concluded that lateral position of the vehicle during the survey has a significant influence on the measurements, since small movements in the transverse direction caused significant differences in the calculated rut depths. The smaller the width of the measured transverse profile, the more significant is the influence of the lateral position of the vehicle on the calculated rut depths.

A similar trend can be observed regarding the number of sensors, as shown in Figure 37. The lower is the number of sensors; the more dependent the calculated rut depths are on the lateral position of the vehicle.

2.5.3.5 Averaging distance

According to the results of the FILTER experiment (1), the averaging distance has a significant influence on the repeatability of the measurements. Repeatability standard deviation decreases with increasing the averaging distance, by a factor of 2 to 4 when increasing the averaging distance from 50 to 500 m. (1)

2.6 ASSESSMENT OF THE TRANSFORMATION FUNCTIONS

Taking into account that the vast majority of countries do not use transformation functions (they use TP limits directly from the Technical Parameter), the development of the transformation functions are based on the limits of the TP.

As the majority of countries use 5 condition classes a transformation of the database information was performed and all of the limits were distributed into 5 classes (very good, good, fair, poor and very poor). Table 29 presents the distribution of TP by classes for all roads, motorways and primary roads, secondary, and other roads.

Table 29: TP Rut Depth limits (mm) for all road functional classes

Country	Class	Very good		→		Very poor
AUSTRIA (AT)	M	< 2.9	2.9 to 7.6	7.6 to 14.3	14.3 to 20	> 20
AUSTRIA (AT)	P	< 3.6	3.6 to 10.7	10.7 to 17.9	17.9 to 25	> 25
BELGIUM (BE) 1	M, P & S	< 4	4 to 12	12 to 16	16 to 32	> 32
BELGIUM (BE) 2	M, P & S	< 4	4 to 8	8 to 12	12 to 16	> 16
SWITZERLAND (CH)	M	< 4	4 to 6	6 to 9	9 to 12	12 to 16
SWITZERLAND (CH)	P	< 5	5 to 8	8 to 12	12 to 18	18 to 27
SWITZERLAND (CH)	S	< 6	6 to 10	10 to 16	16 to 24	> 24
CZECH REP. (CZ)	M & P	< 6	6 to 11	11 to 16	16 to 22	> 22
CZECH REP. (CZ)	S & O	< 8	8 to 15	15 to 25	25 to 36	> 36
GERMANY (DE)	M	< 4	4 to 10		10 to 20	> 20
GERMANY (DE)	P	< 4	4 to 15		15 to 25	> 25
GERMANY (DE)	S	< 4	4 to 20		20 to 30	> 30
CROATIA (HR)	M & P	< 8	8 to 15		15 to 20	> 20
HUNGARY (HU)	M , P & S	< 5	5 to 8	8 to 12	12 to 18	> 18
SLOVENIA (SI)	M	< 6	6 to 10	10 to 14	14 to 18	> 18
SLOVENIA (SI)	P	< 8	8 to 12	12 to 16	16 to 20	> 20
UNITED KINGDOM (UK)	M & P	< 6	6 to 11		11 to 20	> 20
UNITED STATES (US)	M & P	< 4.4	4.4 to 8.9	8.9 to 13.3	13.3 to 17.8	> 17.8

The results are shown in Figure 38 together with the calculated average transformation function.

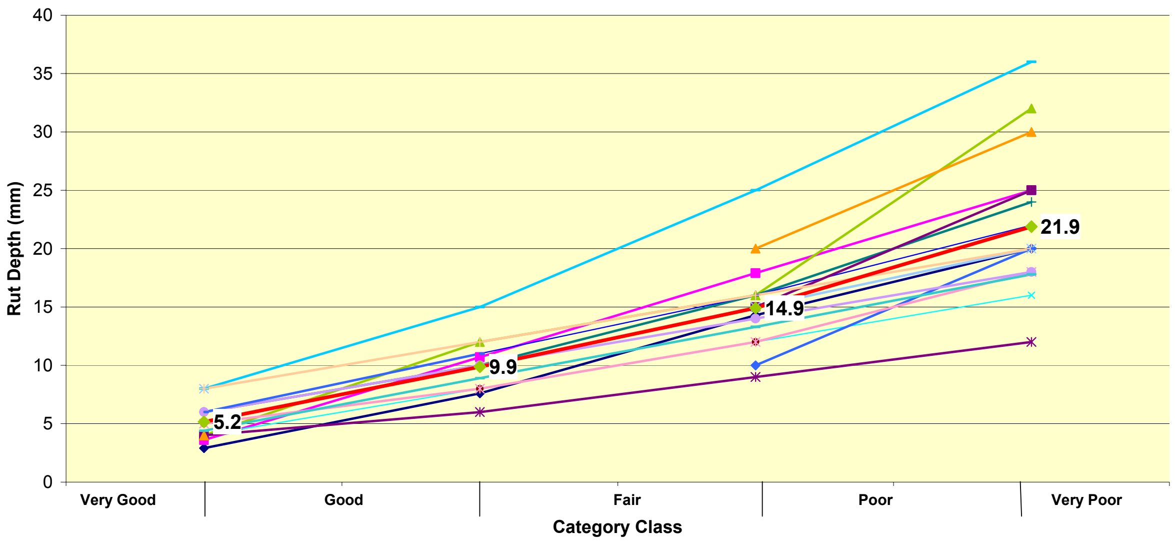

Figure 38: Limits for Technical parameter Rut Depth on Motorways and Other Primary Roads

To be able to propose the unified transformation function from TP Rut Depth to PI Rutting (PI_R), the average TP limits were calculated. These are presented in Table 30, Table 31 and Table 32 for all roads, motorways and primary roads, and secondary roads respectively.

Table 30: Average TP Rut Depth limits and corresponding PI limits for all roads

Condition class name	TP limits (mm, average)	PI_R limits
Very good	0 to 5.0	$0 \leq PI\_R < 1$
	5.0 to 9.4	$1 \leq PI\_R < 2$
↓	9.4 to 13.8	$2 \leq PI\_R < 3$
	13.8 to 20.3	$3 \leq PI\_R < 4$
Very poor	> 20.3	$4 \leq PI\_R < 5$

Table 31: Average TP Rut Depth limits and corresponding PI_R limits for motorways and primary roads

Condition class name	TP limits (mm, average)	PI_R limits
Very good	0 to 5.2	$0 \leq PI\_R < 1$
	5.2 to 9.9	$1 \leq PI\_R < 2$
↓	9.9 to 14.9	$2 \leq PI\_R < 3$
	14.9 to 21.9	$3 \leq PI\_R < 4$
Very poor	> 21.9	$4 \leq PI\_R < 5$

Table 32: Average TP Rut Depth limits and corresponding PI_R limits for secondary roads

Condition class name	TP limits (mm, average)	PI_R limits
Very good	0 to 5.2	$0 \leq PI\_R < 1$
	5.2 to 10.6	$1 \leq PI\_R < 2$
↓	10.6 to 16.8	$2 \leq PI\_R < 3$
	16.8 to 26.0	$3 \leq PI\_R < 4$
Very poor	> 26.0	$4 \leq PI\_R < 5$

The transformation functions were obtained by regression as second order polynomials and are shown graphically in Figure 39:

For all road classes:

$PI\_R = -0.0016 \cdot RD^2 + 0.2187 \cdot RD$ *for RD < 29.0 mm*
$PI\_R = 5$ *for RD ≥ 29.0 mm*

For motorways and primary roads:

$PI\_R = -0.0015 \cdot RD^2 + 0.2291 \cdot RD$ *for RD < 26.4 mm*
$PI\_R = 5$ *for RD ≥ 26.4 mm*

For secondary and local roads:

$PI\_R = -0.0023 \cdot RD^2 + 0.2142 \cdot RD$ *for RD < 46.9 mm*
$PI\_R = 5$ *for RD ≥ 46.9 mm*

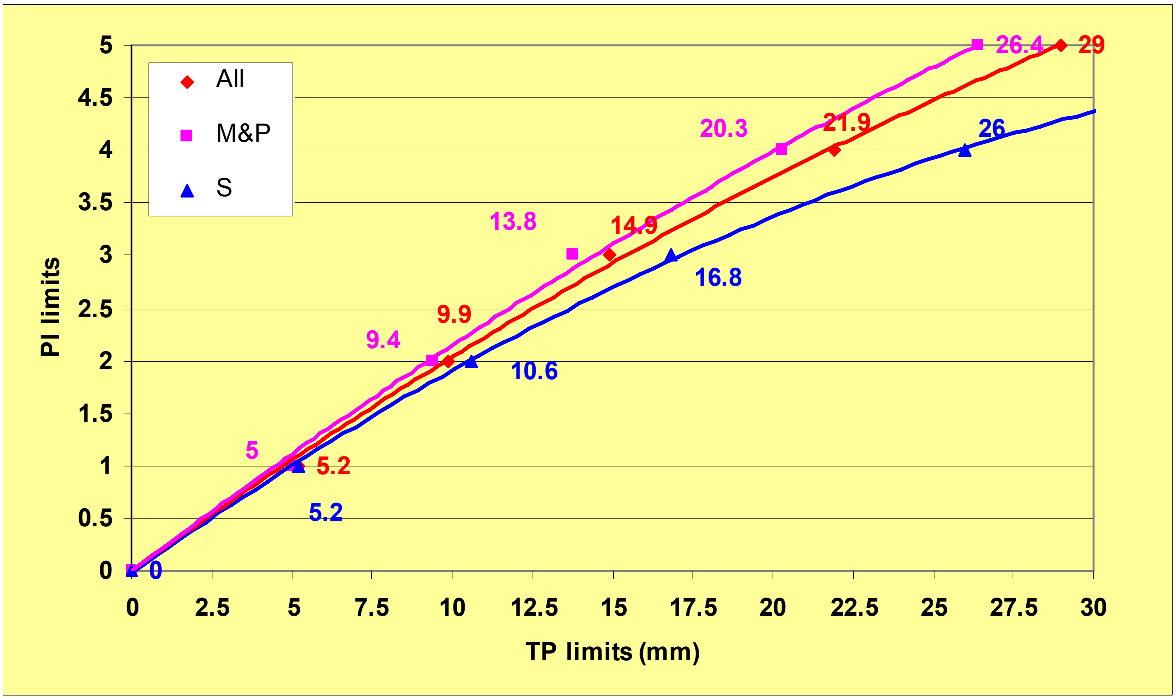

Figure 39: Average transformation function from TP Rut Depth to PI Rutting

However, some issues that may limit the validity of the proposed functions should be mentioned at this point.

First, the sample used for derivation of transformation functions was relatively small (less than 20 records).

Secondly, the analysis was based on technical parameter limits, regardless of the algorithm used for data processing. Some countries use straightedge algorithm with different lengths, and some use wire line algorithm. There is a question of impact of the used algorithm on TP values and its importance on the pavement management level data and corresponding transformation functions.

Finally, the transformation functions were derived from the average values for TP limits between some categories. There was some subjectivity in assigning these values, particularly when there is difference in the number of classes used.

On the other side, comparison with rut depth limits in the AASHTO PP38-00 provisional standard (13) (Table 33) and in ASTM D6433-03 standard (14) shows that used TP limits agree reasonably well with the values used in these two standards.

Table 33: The average rut depth limits for different classifications, according to AASHTO PP 38-00

Level	Number of classes		
	Two classes	**Three classes**	**Four classes**
1	< 12.5 mm	< 12.5 mm	< 5 mm
2	≥ 12.5 mm	≥ 12.5 mm and < 25 mm	≥ 5 mm and < 10 mm
3		≥ 25 mm	≥ 10 mm and < 25 mm
4			≥ 25 mm

ASTM standard D6433-03 – *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys* (14) defines three severity levels according to the mean rut depth (MRD) measured by straightedge:

- Low (MRD equals 6 to 13 mm)
- Medium (MRD equals 13 to 25 mm)
- High (MRD greater than 25 mm)

2.7 CORRELATION BETWEEN THE SELECTED INDICATOR AND OTHER USED INDICATORS

Comparison between different transverse evenness technical parameters is not simple since it includes three types of indices.

This issue is even more complicated since although the COST-354 database contains relatively sufficient data for the TP Rut Depth there is not enough data for the other technical parameters used to describe transverse evenness. Only Germany provided transformation functions for TP Water Height.

Therefore, in this chapter no correlations between the selected indicator (rut depth) and the other indicators are provided.

2.8 REFERENCES

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SECTION 3: MACRO TEXTURE

Surface texture is primarily associated with safety conditions and user comfort but also road deterioration. In terms of safety, texture directly affects how well tyres stick to the pavement in moist or wet conditions, and thereby indirectly affects skid resistance. Texture is also associated with noise emission caused by traffic. From a pavement management perspective, texture depth is important since it can be controlled by maintenance activities and can even trigger maintenance treatments.

Texture depth arises from the angularities in the materials that make up the road surface. Texture can be characterized by measuring a profile in the adequate wavelength band and calculate a proper index, as shown in Figure 40. There are three types of texture, classified according to profile wavelength:

- Microtexture can be described by the roughness of the aggregate itself. It provides the adhesion between the rubber tyres and the road surface. Microtexture is represented by wavelengths of < 0,5 mm wavelength.
- Macrotexture is associated with the coarser element formed by aggregate particles and the particle distribution. It is represented by wavelengths of 0,5 mm – 50 mm.
- Megatexture is associated with deficiencies of the pavement surface, and has a negative impact on safety and comfort. Megatexture is represented by wavelengths of 50 mm-0.5 m.

Surface	Texture profile	Microtexture	Macrotexture
1		Fine	Smooth
2		Coarse	Smooth
3		Fine	Rough
4		Coarse	Rough

Figure 40: Description of texture

At the moment there are no systems capable of measuring microtexture profiles at highway speeds. Therefore, microtexture is evaluated by using pavement friction at low speeds as a surrogate.
As such, this section of the report will only look into the performance indicators which handle the macrotexture (in the rest of the section called “texture”).

3.1 TEXTURE INDICATORS FROM THE COST 354 DATABASE

From the total of 22 countries represented in the questionnaire used by WG2, 10 countries reported that they use texture measurement (45%). 4 of the 10 countries answered 2 questionnaires[1].

[1] As far as Italy is concerned Motorways Authorities run routine texture measurements and a national standard is available but this was not included in the database as it is not used by the respondent Road Authority. To avoid confusions and inconsistency of data this information will not be added in WG2 work.

Table 34: Number of countries and records referred to macrotexture performance indicator

COUNTRY	No. of Texture Records
AUSTRIA	1
CZECH REPUBLIC	2
DENMARK	1
FRANCE	2
HUNGARY	1
SERBIA AND MONTENEGRO	1
SLOVENIA	2
SPAIN	2
SWEDEN	1
UNITED KINGDOM	1
10	14

Total number of records in the database: 14
Total number of countries: 10 out of 22 possible (45%)

3.1.1 General information

According to the database, two general measuring principles are used to indicate the texture. The principles are:

1. Volumetric method (Sand Patch)
2. Laser method

The distribution in use between one method or the other is shown in Table 35.

Table 35: Description of macrotexture technical parameters from the COST-354 database

COUNTRY	Technical Parameter NAME	MEASURING PRINCIPLE
Laser method		
AUSTRIA	Mean profile depth	Laser
CROATIA(*)	Texture depth	Laser
DENMARK	Mean profile depth	Laser
SPAIN 1	Mean profile depth	Laser
SWEDEN	Mean profile depth	Laser
CZECH REPUBLIC 1	Texture depth	Laser
CZECH REPUBLIC 2	Texture depth	Laser
FRANCE	Sand patch value	Laser
SLOVENIA 1	Mean profile depth	Laser
UNITED KINGDOM	Mean profile depth	Laser
Volumetric method		
CROATIA(*)	Mean profile depth	Sand Patch
SLOVENIA 2	Mean profile depth	Sand patch
SPAIN 2	Mean profile depth	Sand patch
SERBIA AND MONTENEGRO	Mean profile depth	Sand patch
Answers which is not usable		
HUNGARY	Mean profile depth	Laser
(*) information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses.		

There are a few answers which need a closer look before being taken into account. The countries which have given these answers are: Hungary, Czech Republic and France.

Hungary: According to Hungary, the levels indicated in the database are based on the sand patch method and not the laser method which is indicated to be the measuring principle. Further on, the levels are not official, but determined by one person based on experience and observations. Due to this, the answers from Hungary will not be taken into account in this analysis.

France: According to France, the two answers are identical. The only difference is that one is by a company on toll motorways and the other is used on national highways. The two answers can therefore be directly combined. The processing of the profile is done so that the result is comparable with the result that would have been obtained at the same location by performing a manual traditional sand patch test. In the following analysis, the two answers from France will count as one.

Czech Republic: The abbreviation for the Czech Republic indicates the use of the sand patch method, but as with France, the method is done by laser.

Name, description, unit and abbreviation were to be stated for each PI, as synthesised in Table 36.

Table 36: Description of macrotexture technical parameters from the COST-354 database

COUNTRY	Technical Parameter NAME	Technical Parameter DESCRIPTION	ABBR.	MEASURING PRINCIPLE	UNIT
Laser method					
AUSTRIA	Mean profile depth	Mean profile depth	MPD	Laser	mm
CROATIA(*)	Texture depth	Mean texture depth	MTD	Laser	mm
CZECH REPUBLIC 1	Texture depth	Mean texture depth	MTD	Laser	mm
CZECH REPUBLIC 2	Texture depth	Mean texture depth	MTD	Laser	mm
DENMARK	Mean profile depth	Texture value	MPD	Laser	mm
FRANCE	Sand patch value	Sand patch	HS/SPV	Laser	-
SLOVENIA 1	Mean profile depth	Sensor Measured Texture Depth	SMTD	Laser	mm
SPAIN 1	Mean profile depth	Macrotexture	MPD	Laser	mm
SWEDEN	Mean profile depth	Macrotexture	MPD	Laser	mm
UNITED KINGDOM	Mean profile depth	Sensor Measured Texture Depth	SMTD	Laser	mm
Volumetric method (Sand Patch)					
CROATIA(*)	Mean profile depth	Texture Depth	TD	Sand patch	mm
SLOVENIA 2	Mean profile depth	Macrotexture	MTD	Sand patch	mm
SPAIN 2	Mean texture depth	Macrotexture	MTD	Sand patch	mm
SERBIA AND MONTENEGRO	Mean profile depth	Texture Depth	DT	Sand patch	mm
(*) information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses.					

As Table 36 shows, 10 of the answers use laser equipment for measuring texture. Only 3 indicate use of the volumetric method[1].

The majority of the responders use the name “Mean Profile Depth” for this technical parameter. One country uses the name texture depth, and one the name sand patch.

[1] Without considering Croatia, added later in the work

As languages have a pronounced influence on the above, it is very important to look at the measuring principle at the same time in the effort to group the PI's. As mentioned earlier, according to the database, 2 measuring principles are used; laser (10 answers) and volumetric methods (3 answers).

3.1.2 Category of performance indicator

Texture is related to skid resistance, which is directly related to road safety. All of the responses agreed with this (Figure 41).
One country states to use the measurement in connection with a pavement structure indicator in addition to Road Safety. Three countries use texture in connection with riding comfort indicator and Road Safety.
There is no special indicator connected with a special category.

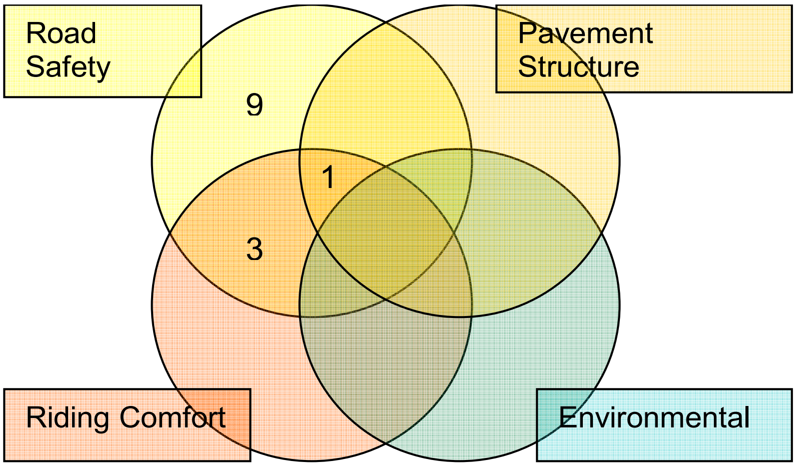

Figure 41: Distribution of macrotexture PI by category

3.1.3 Field of application – distribution by road network

To distinguish between the types of roads that the texture indicator is used on, the roads in the questionnaire are divided into four categories. Namely, motorways, other primary roads, secondary roads and other roads (Figure 42).
12 of the 13 answers indicate that texture measurements are used on motorways and other primary roads. Seven answers state that they use texture measurements on secondary roads and only one country use it on other roads.

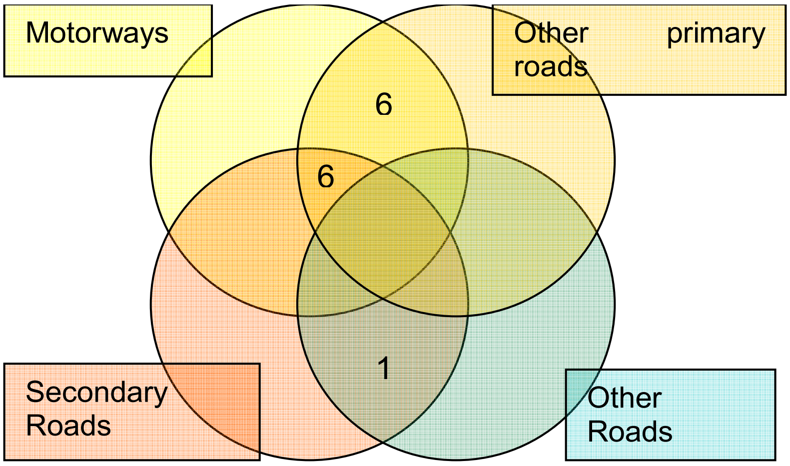

Figure 42: Distribution of macrotexture PI by road network

3.1.4 Distribution by Level of Application

There is a distinct difference between which indicators (and equipment) are used on network and which are used on project levels. From the 13 answers, only three indicators are used on project level (Figure 43). The indicator used for project levels is the volumetric method (sand patch) or MTD.

The 10 remaining answers all use a laser method. 7 answers use their indicators on network level alone, 3 use their indicators on network and project level.

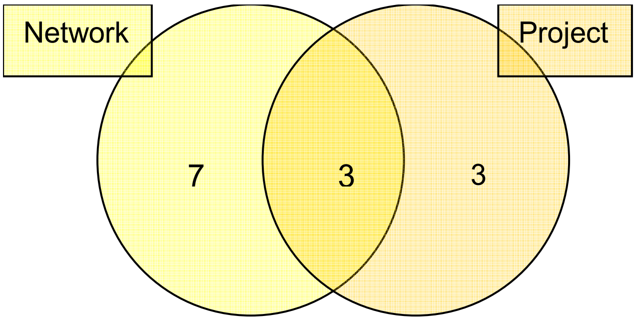

Figure 43: Distribution of macrotexture PI by Level of Application

3.1.5 Distribution by Pavement Type

The answers indicate that texture measurements are applied on both flexible and rigid pavements (bituminous and concrete) with 4 indicators used only for bituminous pavements (Figure 44).

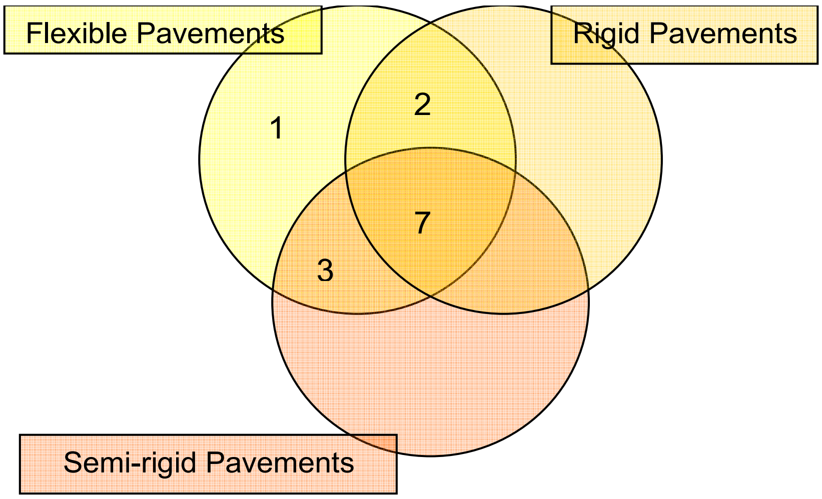

Figure 44: Distribution of macrotexture PI by pavement type

The Sand patch method (3 answers) is only used on bituminous pavements according to the database. However the literature does not suggest that this is because the method is not adequate for other kinds of surfaces. Instead the reason could be that the countries which have provided the answers do not have rigid pavements. The database does say that two of the three countries have rigid pavements within the types of network which are measured. Either the answers are wrong, or the texture measurements are simply not used on rigid pavements.

The Laser methods are used on all pavement types.

3.1.6 Distribution by Type of Application

Only one country hasn't provided the information on the type of application. 11 out of the 12 who did provide this information use texture as a standard application (Figure 45). Only one country uses texture in connection with research.

The country which only uses texture for research purposes, has changed procedures, and is now using texture for both standard and research applications.
There is no special indicator used for a special application.

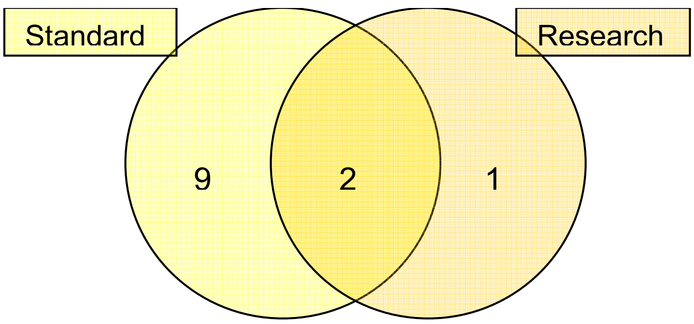

Figure 45: Distribution of macrotexture PI by type of application

3.1.7 Standardization

As it can be seen from Table 37, 7 of the countries (not considering Croatia, added later) have based their technical parameter on a national standard. 3 countries have based their technical parameters on technical specifications, and only 4 countries have based their technical specifications on the ISO standard.

Austria has indicated two standards. The physical measurement is done according to a national standard, but is calculated according to the ISO standard.

Table 37: Standards and specifications used for macrotexture performance indicators

COUNTRY	STANDARD USED TO COLLECT THE TP
AUSTRIA	National Standard/ISO-standard
CROATIA(*)	National Standard/EN Standard
CZECH REPUBLIC 1	National Standard
CZECH REPUBLIC 2	National Standard
DENMARK	ISO-Standard
FRANCE 1	National Standard
FRANCE 2	National Standard
SERBIA AND MONTENEGRO	National Standard
SLOVENIA 1	Technical Specification
SLOVENIA 2	Technical Specification
SPAIN 1	ISO-Standard
SPAIN 2	National Standard
SWEDEN	ISO-Standard
UNITED KINGDOM	Technical Specification

(*) information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses.

3.1.8 Measuring principle

As mentioned earlier, two types of measuring principles are used for the characterization of macrotexture: the volumetric (Sand Patch) and the laser method.

Volumetric (Sand Patch) method:
The Sand Patch method is well known. Traditionally, the Sand Patch Method has been used to estimate performance indicator Mean Texture Depth, or MTD. This method involves applying a determined amount of sand or glass beads onto a textured surface, and spreading the sand outward into a circle, as described by EN standard 13036-1 (1). The more texture a surface contains, the smaller the circle that is created.

Laser method:
Measuring texture using lasers is independent of the operating speed, as it is possible to perform the tests at speeds from a few km/h to traffic speed. Even though there are several different measuring devices which combine texture measurements with either longitudinal evenness or friction (e.g. Aran, RAV, Roadstar, Roar, RST and Rugolaser) the measurements are done in identical ways, but with small differences in the build-up of the equipment. Generally the devices employ lasers pointing at one or more spots on the pavement surface, often in both wheel tracks, to measure texture. The measurements are carried out in individual profiles (parallel profiles can be measured in a single road segment). Each profile consists of a number of levelings which are conducted at a certain interval.
In 2004, in connection with the Hermes project (2), texture measurements with participating devices were carried out. This gave an opportunity to evaluate the reproducibility of the measurement of *MPD* by different devices claimed to comply with EN-ISO 13473-1 (3). The end result showed the standard deviation of reproducibility between pairs of devices to have an overall value of 0,11 mm.

Depending on equipment and software, the measurements are reported in terms of either the “mean profile depth” (MPD) or as the “sensor measured texture depth” (SMTD).

SMTD, or the Sensor Measured Texture Depth is equivalent to the root mean square deviation of the amplitude of the texture about a notional datum. SMTD results cannot be compared directly with the texture depth figures obtained by Sand Patch texture depth or MPD testing.

The mean profile (MPD) depth is a statistic computed by analyzing segments of 100 mm of the collected data, see Figure 46. After dividing each segment in half, the average of the highest profile peaks in each half is computed. The MPD is then computed as the average of all individual segment peak averages. The standard describing calculation and reporting of MPD gives options that can result in different results. This has to be considered. To avoid this, the standard is now under revision. According to the standard, MPD can be used to estimate MTD values (“sand patch”). When MPD is used to predict MTD, the result is referred to as an estimated texture depth (ETD)

3.2 COMPLEMENTARY INFORMATION DERIVED FROM LITERATURE

Another option available is a Circular Texture Meter, or CTM. Like the Sand Patch, this technique involves taking measurements at discrete locations along the pavement. The CTM uses a spot laser mounted on a rotating arm. Once in place, the unit triggers a computer that rotates the arm and measures texture height for one complete revolution. The resulting trace can then be used to estimate the MTD.

3.3 EVALUATION AND SELECTION OF THE MOST USED INDIVIDUAL PERFORMANCE INDICATORS;

The questionnaire clearly states that two types of methods are used; volume metric and laser. From these measuring methods 3 performance indicators can be calculated and used; MTD, MPD and SMTD.
A series of criteria (previously presented in section 1.3) has been listed for the selection of the individual performance to be used. The criteria and comments are as follows:

- The indicator should be described in an European or International standard:
  Two out of three texture performance indicators are described in international standards:
  - MPD: EN-ISO standards 13473 and ASTM E 1845-96.
  - MTD: ISO 10844:1994, EN 13036-1, ASTM E965-96.

The majority of the countries which use MPD or MTD use a national standard or a technical specification.
SMTD is not described in any international standard.

- The indicator must be in standard practice or research:
  All answers in the questionnaire indicate that the texture measurements are used as a standard application. Only two countries (Spain and Serbia and Montenegro) answered that their measurements only are used in connection with research.
  The type of measurements used for research is the Sand Patch method (MTD).

- The indicator must be in wide use:
  Generally texture measurements are widely used. In this case, 8 countries use the MPD method, 3 countries use the MTD method and 2 countries use the SMTD method.

- Device Independent:
  Common for all three methods, they are all device independent.

- Reliable:
  The laser measurements are reliable. The measuring method is fully automated. With calibrated lasers, the difference between the measurements of the lasers will be negligible.
  The sand patch test is a quite simple and well-tried method, which itself makes it reliable.

- Safe to collect:
  MPD and SMTD are measured at traffic speed, which make them very safe to collect on a network level compared to the Sand Patch methods.
  The sand patch method is a slow measurement which demands a closed off area which is then measured.

- Sustainable:
  It is assumed that the MPD and SMTD methods will be used in years to come. The Sand Patch method must be considered as not sustainable, as it is possible to get very well correlated texture numbers by measuring MPD values and applying regressive functions.

Table 38 summarizes the results described above.

Table 38: Selection table for technical parameters

Criteria	**Individual indicator on the list of criteria's**		
	MPD	**MTD**	**SMTD**
European/International standard	[green]	[green]	[red]
Standard practice or research	[green]	[red]	[green]
Wide use	[green]	[green]	[green]
Safe to collect	[green]	[red]	[green]
Reliable	[green]	[green]	[green]
Sustainable	[green]	[red]	[green]

[green]	good
[yellow]	medium
[red]	bad

The criteria are listed according to their importance.

There is no doubt, that the laser methods used for measuring texture are the methods to prefer. These methods can be measured at traffic speed, and are therefore safe to collect. They are widely used as a standard practice and they are both reliable and sustainable.

SMTD does have a range of positive qualities, unfortunately SMTD is not described in any European or International standard.

As the MPD calculation is described in an EN-ISO standard, it was decided that the individual selected performance indicator for macrotexture would be the MPD.

3.4 PROTOCOLS AND TEST METHODS FOR MEASURING THE PROPOSED INDIVIDUAL INDICATOR

As mentioned, the MPD calculation is described in detail in EN-ISO standard 13473-1 (3). Based on measurement done by laser, the MPD can be calculated easily as shown in Figure 46.

The base line is in the EN-ISO standard and has been set to 100 mm.

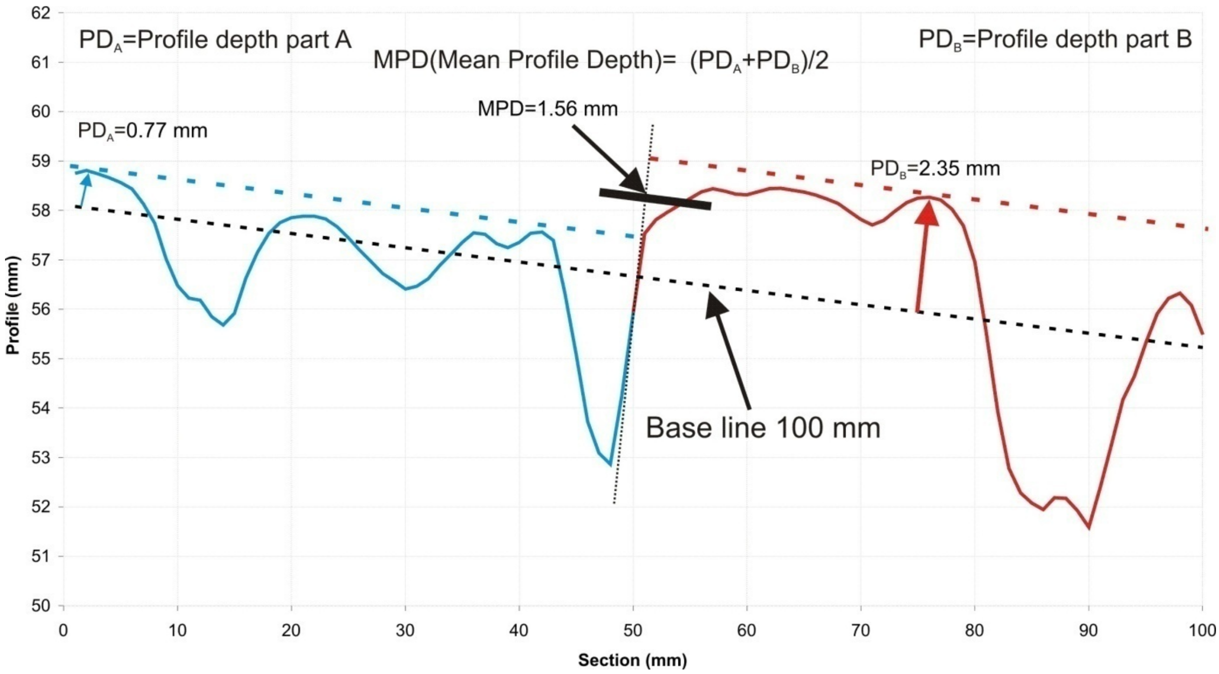

Figure 46: Calculation of the Mean Profile Depth (MPD)

3.5 ASSESSMENT OF THE TRANSFORMATION FUNCTIONS

The aim of this section is to transform the MPD technical parameter (with the units of a length) to a unitless PI on a 0 to 5 scale. To achieve this, the results from both the transformation functions available in the database and the “levels” (thresholds, warning, acceptance and target) proposed by the different responders have been considered.

Levels
The questionnaire provides only a few answers where levels have been indicated by a country[1]. The levels indicated in the database are shown in Table 39:

Table 39: Levels from the database

COUNTRY	NAME	Performance indicator	THRESHOLD		WARNING		ACCEPTANCE		TARGET	
			TP	INDEX	TP	INDEX	TP	INDEX	TP	INDEX
CZECH REPUBLIC 1	Texture depth MPD	MPD	0,54		0,64					
CZECH REPUBLIC 2	Texture depth MPD	MPD	0,44		0,54					
FRANCE 1	Sand patch value MPD	MPD		40		60				

France has indicated that they use 2 levels, 40 as the threshold level and 60 as acceptance level. The processing of the profile is done so that the result is comparable with the result that would have been obtained at the same location by performing a traditional manual sand patch test.
Because it is not known which transformation function is used in the process, it is not possible to take the limits into account when generating the general performance indicator index.

Performance index
Sweden forwarded the levels at a moment where it wasn't possible to put it into the database. The contribution to the database with the conversion to the 5 step performance index is as shown in Table 40.

Table 40: Macrotexture levels adopted by Sweden (not in the database)

MDP interval	**90 - 110 km/h Motorways and other primary roads**	**70 km/h Secondary roads**
0 - 0,3	Not suitable/very poor	Not suitable/very poor
0,31 - 0,5	Not suitable/very poor	Bad/poor
0,51 - 0,7	Bad/poor	Ok/very good
0,71 - 1,0	Ok/very good	Acceptable/good
1,01 - 1,50	Ok/very good	Bad/poor
1,51 - 2,00	Acceptable/good	Bad/poor
2,01 -	Bad/poor	Not suitable/very poor

Sweden has not specified threshold or warning levels. The Swedish intervals/limits are not in use but are under consideration.

As mentioned above, The Czech Republic has specified the limits which they use, shown in Table 41.

[1] Croatia actually has acceptance thresholds but this information was gathered after the analysis was completed and couldn't be considered. It might be included in later revisions of the database.

Table 41: macrotexture limits indicated by Czech Republic

		Czech Rep. Motorways & other primary roads	Czech Rep. Secondary & others roads
1	Very good		
		0,89	0,79
2	Good		
		0,74	0,64
3	Fair		
		0,64	0,54
4	Poor		
		0,54	0,44
5	Very poor		

Correlation

The following diagrams illustrate the result of the analysis of the questionnaires concerning texture. The diagrams have been divided into 2 groups; motorways and Other Primary Roads (Figure 47), and Secondary Roads (Figure 48).

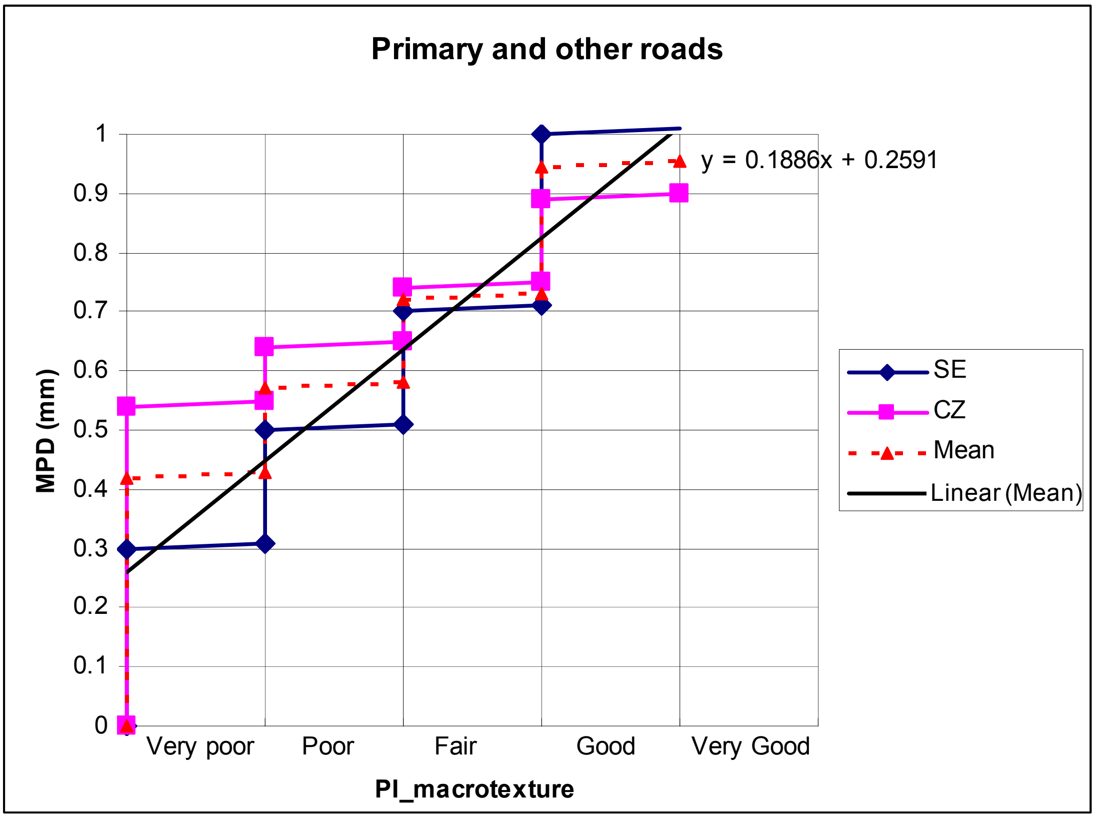

Figure 47: macrotexture levels for motorways and other primary roads

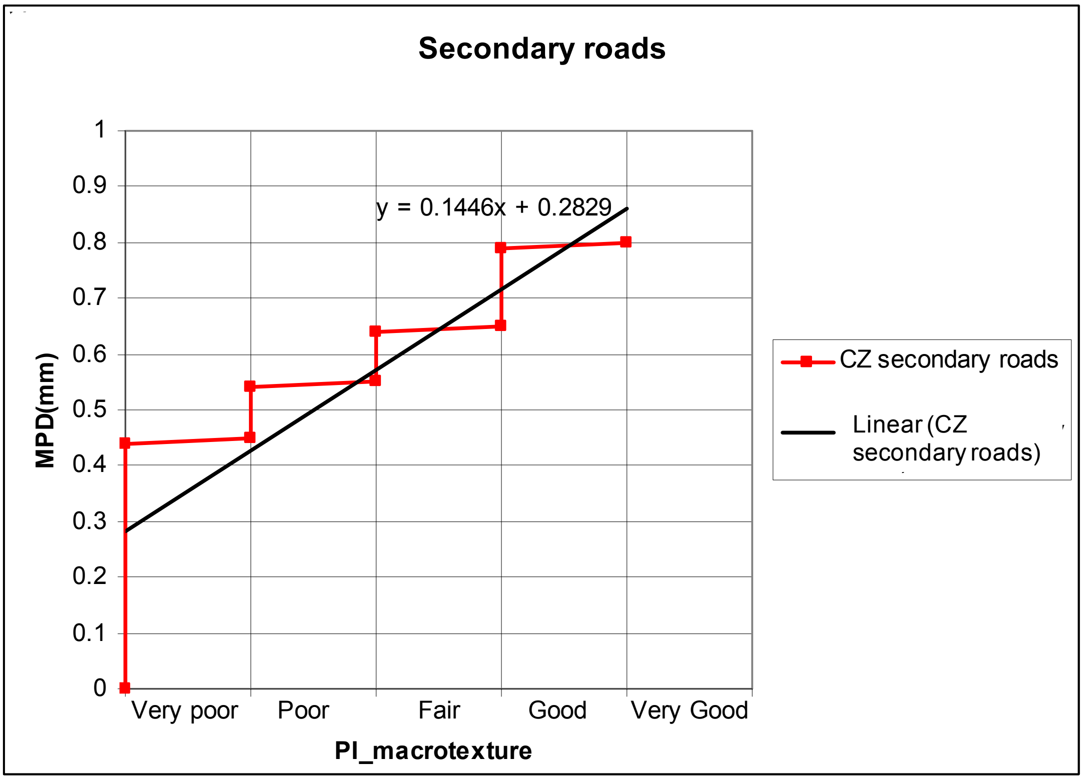

Figure 48: macrotexture levels for secondary roads

It should be noted that, given the very limited amount of data, the information from two countries will be used as a basis for a common expression of the macrotexture PI that will then be used for the following activities in the COST 354 action.

More data concerning levels and limits should be collected to improve the quality of the macrotexture PI definition.

The transformation functions between the MPD measurements (in mm) and the macrotexture performance index (PI_T) that will be used for the COST 354 action are:

For motorways and primary roads **PI_T =6.6-5.3xMPD** (average of SE and CZ data)

For secondary roads **PI_T=7.0-6.9xMPD** (only CZ data used)
with MPD in mm in both equations.

3.6 CORRELATION BETWEEN THE SELECTED INDICATOR AND OTHER USED INDICATORS

Correlation between MPD and other texture PI's from the database
MPD - MTD:
To be able to correlate MPD with a mean texture depth the EN-ISO standard has indicated a conversion equation from MPD to ETD (which is the estimation of he MTD):

ETD=0.2+0.8XMPD

However this is now under consideration and a one to one conversion is being discussed.

Had there been any limits and/or levels given in connection with the MTD indicator, they could have been used to help create a more accurate general performance indicator index (PI). Unfortunately no countries which use MTD have specified any limits and/or levels.

MPD - SMTD:
Because of the difference in calculating MPD and SMTD from the measured profile, a correlation of the two is not possible. The result is that the limits given by U.K and Slovenia are not included in the analysis.

3.7 REFERENCES

1. EN 13036-1 (2002) – *Road and airfield surface characteristics. Test methods. Measurement of pavement surface macrotexture depth using a volumetric patch technique*
2. HERMES – "*Harmonization of European Routine and research Measuring Equipment for Skid Resistance*", FEHRL Project (www.fehrl.org)
3. EN-ISO 13473-1 "*Characterisation of pavement texture by use of surface profiles - Part 1: Determination of Mean Profile Depth*"

SECTION 4: FRICTION

4.1 SKID RESISTANCE INDICATORS FROM THE COST 354 DATABASE

The records included in the COST 354 database regarding skid resistance PI have provided very valuable information as they correspond to almost all of the Countries included in the Action.

The following sections report about the analysis carried out from this information, to try to propose a suitable indicator about skid resistance, and to determine the conclusions that can be reached from the information provided.

Among the 22 countries represented in the database, 20 (90 %), filled in the skid resistance group criteria. But the number of questionnaires analyzed is slightly higher (22) because France and Belgium each reported two.

The last column of Table 42 shows the number of records concerning skid resistance. It doesn't fit with the number of questionnaires. The reason is that Czech Republic gave 4 answers and Croatia reported 2 answers. It means that the total number of records analyzed here is 26.

Table 42: Number of countries, questionnaires and records referred to skid resistance performance indicator

COUNTRY	TOTAL	SKID RESISTANCE	
	Nº QUESTIONNAIRES	Nº QUESTIONNAIRES	Nº RECORDS
AUSTRIA	1	1	1
BELGIUM	2	2	2
CROATIA	1	1	2
CZECH REPUBLIC	1	1	4
DENMARK	1	1	1
FINLAND	1		
FRANCE	2	2	2
GERMANY	1	1	1
GREECE	1	1	1
HUNGARY	1	1	1
ITALY	1	1	1
NETHERLANDS	1	1	1
NORWAY	1	1	1
POLAND	1	1	1
PORTUGAL	1	1	1
SERVIA AND MONTENEGRO	1	1	1
SLOVENIA	1	1	1
SPAIN	1	1	1
SWEDEN	1	**1**	1
SWITZERLAND	1	1	1
UNITED KINGDOM	1	1	1
UNITED STATES OF AMERICA	1		

COUNTRY	TOTAL	SKID RESISTANCE	
22	24	22	26

4.1.1 General information

Some questions about the skid resistance technical parameter are included in the COST 354 database, they are:

- the name,
- the description,
- the abbreviation,
- the unit.

As the abbreviation is not the same in all of the countries (mainly due to both the language and the different words that can describe the same parameter), it hasn't been included in this analysis, which is based on the meaning of the technical parameter. The situation is sometimes the same for the description.

In the case of the skid resistance technical parameters, it is very important to take into account the measuring principle of the device used to collect the data, because it gives very valuable information about the possibility of making groups of the same technical parameter used in different Countries. By doing so, it seems that the terms friction coefficient and sideway force refer to the same technical parameter. Table 43 includes the description of the technical parameters reported in the database.

Table 43: Description of skid resistance technical parameters from the COST-354 database

COUNTRY	NAME	DESCRIPTION	UNIT
AUSTRIA	FRICTION COEFFICIENT	FRICTION VALUE	
BELGIUM 1	SIDEWAY FORCE	SIDEWAY FORCE	
BELGIUM 2	FRICTION COEFFICIENT	TRANSVERSE FRICTION COEFFICIENT	
CROATIA 1	FRICTION COEFFICIENT	SRT	
CROATIA 2	FRICTION COEFFICIENT	GRIP TESTER NUMBER	
CZECH REPUBLIC 1	TEXTURE DEPTH	MEAN TEXTURE DEPTH	mm
CZECH REPUBLIC 2	TEXTURE DEPTH	MEAN TEXTURE DEPTH	mm
CZECH REPUBLIC 3	FRICTION COEFFICIENT	ROUGHNESS	
CZECH REPUBLIC 4	FRICTION COEFFICIENT	ROUGHNESS	
DENMARK	FRICTION COEFFICIENT	FRICTION VALUE	
FRANCE 1	FRICTION COEFFICIENT	TRANSVERSE FRICTION COEFFICIENT	
FRANCE 2	FRICTION COEFFICIENT	TRANSVERSE FRICTION COEFFICIENT	
GERMANY	FRICTION COEFFICIENT	FRICTION VALUE	
GREECE	FRICTION COEFFICIENT	SKID RESISTANCE	
HUNGARY	MICRO ROUGHNESS	MICRO ROUGHNESS INDEX	
ITALY	FRICTION COEFFICIENT	TRANSVERSAL ADHERENCE COEFFICIENT	
NETHERLANDS	FRICTION COEFFICIENT	FRICTION VALUE	
NORWAY	FRICTION COEFFICIENT	FRICTION COEFFICIENT	
POLAND	FRICTION COEFFICIENT	FRICTION COEFFICIENT	
PORTUGAL	FRICTION COEFFICIENT	SKID RESISTANCE	OTHER
SERVIA AND MONTENEGRO	FRICTION COEFFICIENT	SKID RESISTANCE TEST	
SLOVENIA	FRICTION COEFFICIENT	SKID RESISTANCE COEFFICIENT	
SPAIN	FRICTION COEFFICIENT	SIDEWAY FORCE FRICTION	%
SWEDEN	FRICTION COEFFICIENT	FRICTION COEFFICIENT	
SWITZERLAND	FRICTION COEFFICIENT	FRICTION COEFFICIENT	

COUNTRY	NAME	DESCRIPTION	UNIT
UNITED KINGDOM	FRICTION COEFFICIENT	CHARACTERISTIC SCRIM COEFFICIENT	

Some comments can be made from the records that have provided some information:

- In most of the cases with data available, the technical parameter measured is the friction coefficient.

- Macro texture appears only in two records (from the same questionnaire). The fact is that this technical parameter has an influence on skid resistance, mainly as the speed of the vehicle increases. Perhaps only one country has included this technical parameter in the group of skid resistance PI because the database has defined another group of indicators that describes texture.

- One record indicates that the technical parameter measured is micro roughness, and it is obtained from a laser system. Further information was provided by the country, indicating that the system is able to evaluate micro texture, although in an approximate way. It is a random type information, which is expressed as a micro texture index.

As a conclusion, three technical parameters have been identified from the COST 354 database, namely friction coefficient, macro texture and micro roughness (or micro texture). From them, the friction coefficient is the one most commonly used (88.5% of the records). One Country has provided information about macro texture together with the friction coefficient; while one Country has reported information about micro roughness.

4.1.2 Category of performance indicator

All of the responses in the database include the friction performance indicators under the “safety” category.

4.1.3 Field of application – distribution by road network

This issue refers to the type of roads for which the skid resistance indicators are used.

In this section it is important to take into account that many of the answers are restricted to some types of roads. Therefore, the lack of information does not necessarily mean that these indicators are not used in them.

If there are no mistakes, there can be two reasons for which there is no information about the use of indicators on some type of pavement:
- Those pavements are not used in the Country. Therefore it should never appear in any of the responses from that country.
- The indicator is not used for some pavements. In such case, it is probable that these types of roads are mentioned for some other PI in the questionnaire from that Country.

For this reason, to have a clearer idea about this matter, it’s necessary to compare the answers related to the skid resistance indicators, with those provided by each one in the whole questionnaire. Otherwise an incorrect conclusion could be reached.

From the results obtained, the analysis can be divided in three cases:

a) The skid resistance indicators are used in all the categories of roads included in the whole questionnaire of the Country (100% of agreement).
b) The skid resistance indicators are not used in, at least, one of the categories of roads included in the whole questionnaire of the Country.
c) There are data about skid resistance indicators, but there's no information about the category of roads for which they are applied.

From the information analysed, it can be concluded that the skid resistance indicators are used in almost all the types of roads reported in the questionnaires, and they are specially applied to the main categories of roads. This conclusion comes from the results explained in more detail in the following paragraphs.

Case a)

In this case, the skid resistance indicators are used for all the categories of roads that appear in the questionnaire. This is the situation for 21 records from the 26 analysed (80,77%). The distribution of percentages from these 21 records, according to each category or road is included in Figure 49; while Figure 50 shows all the categories of roads covered by each answer.

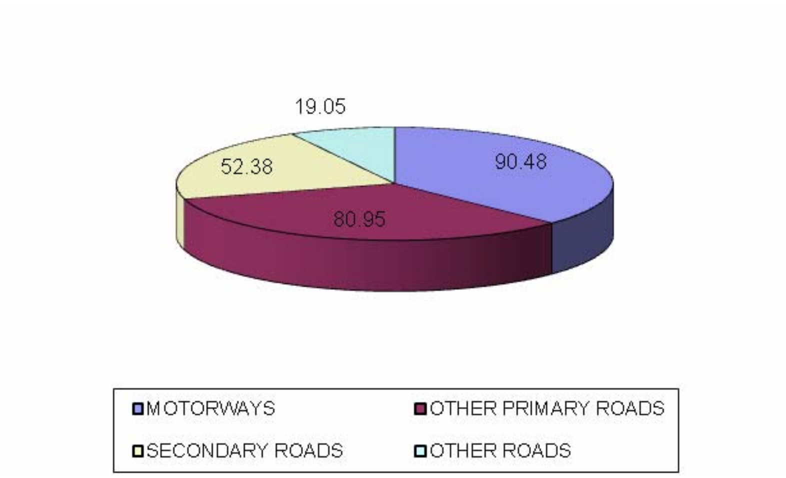

Figure 49: Case a) (100% of agreement). Percentage of affirmative answers for each category of road

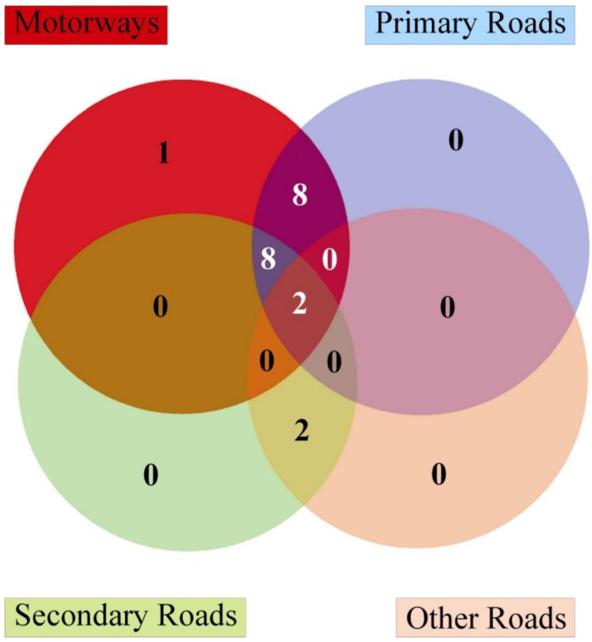

Figure 50: Case a) (100% of agreement). Categories of roads covered by each record

Case b)

From this case, it can be concluded that, if there are no mistakes, the skid resistance indicators are not used for some roads included in the whole questionnaire of the Country. The number of records in this situation is 3:

- One questionnaire provided information about motorways, other primary roads and secondary roads, but skid resistance indicators are not used for secondary roads.
- Two questionnaires provided information about all categories of roads, but skid resistance indicators are not used for “other roads” category.

The distribution of percentages, from the three records already mentioned, according to each category of road is included in Figure 51; while Figure 52 shows the categories of roads covered by each record.

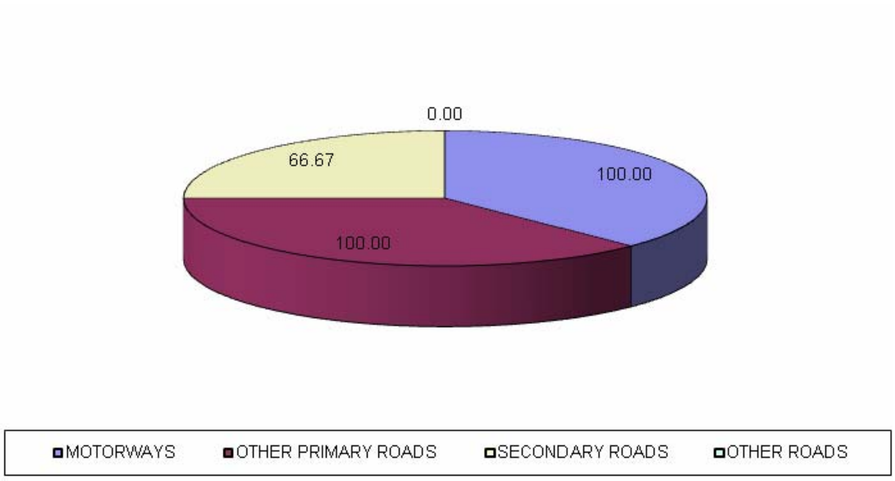

Figure 51: Case b). Percentage of affirmative answers for each category of road

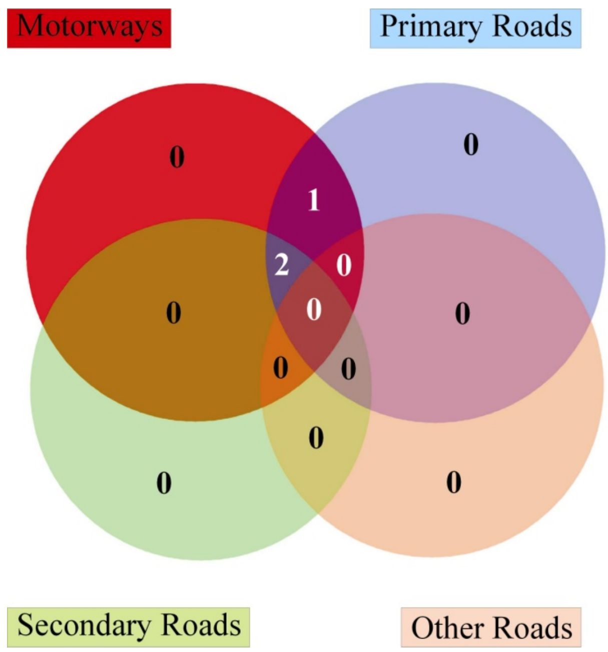

Figure 52: Case b) Categories of roads covered by each record

Case c)

Apart from the two cases mentioned above, one questionnaire does not include information about the category of road for which the skid resistance indicator is applied.

4.1.4 Distribution by level of application

Only two records do not include information about the level of application. The results of the 24 remaining records appear in Figure 53, which shows that in 58,3% of the cases, the skid resistance indicators are used for both network and project level, 29,2% are only used at network level and only 12,5% are applied exclusively at project level.

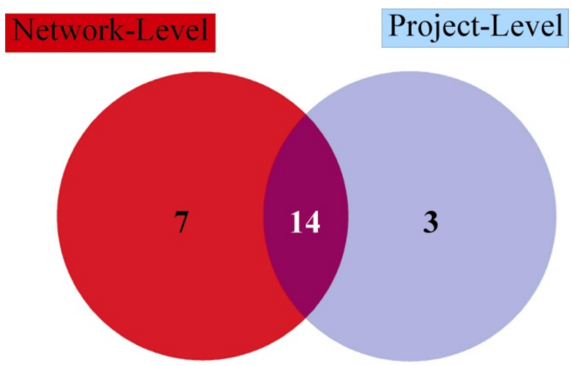

Figure 53: Distribution by level of application

4.1.5 Distribution by Pavement Type

The questionnaire includes the type of pavement for which the skid resistance indicators are used, namely flexible, rigid and semi-rigid pavements. But in the case of PIs related to surface characteristics what is really important is the type of wearing course. As a consequence, they could have been divided in only two categories namely: those with bituminous concrete (including flexible and semi rigid pavements) and those built with cement concrete (for rigid pavements).

In this section, the analysis procedure is the same as for the category of roads (see section 4.1.3), because, again, it's possible that not all the types of pavements exist in one Country. Therefore, the lack of information does not necessary mean that the indicator is not used for a type of pavement, but that those pavements are not found in that Country.

For this reason, to have a clearer idea about this matter, it is necessary to compare the records related to the skid resistance indicators with the answers provided in the whole questionnaire by each Country. Otherwise an incorrect conclusion about the use of this indicator could be reached.

From the results obtained, it can be stated that 100% of the skid resistance PIs are applied to flexible pavements. This means that there is no skid resistance PI which is used exclusively for rigid nor for semi rigid pavements.

In this case, the analysis can be divided in two parts, namely:

a) The skid resistance indicators are used in all the type of pavements included in the complete questionnaire for that Country (100% agreement).
b) The skid resistance indicators are not used in all the types of pavements included in the complete questionnaire for that Country.

Case a)

In the Countries included in this case, the skid resistance indicators are applied for all the pavements included in each questionnaire. This is the situation of 24 records from the 26 analysed (92,3%). The distribution of percentages of the 24 records according to each type of pavement is included in Figure 54, while Figure 55 shows all the pavements covered by each record.

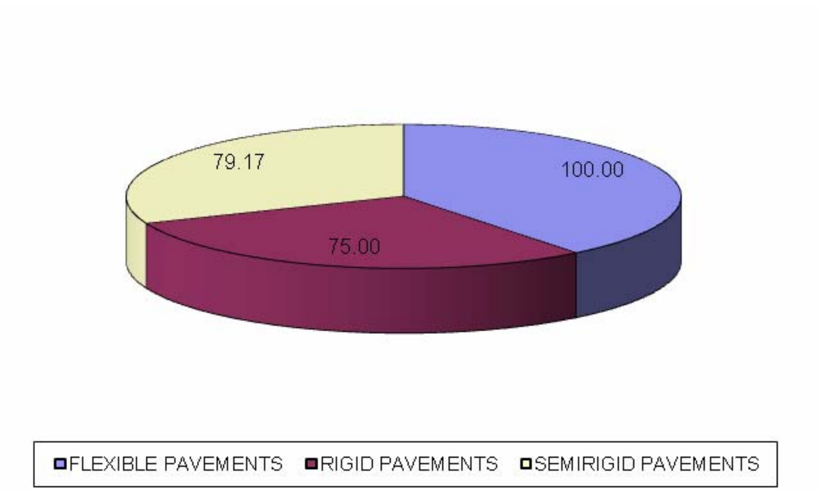

Figure 54: Case a) (100% of agreement) percentage of affirmative answers for each type of pavement

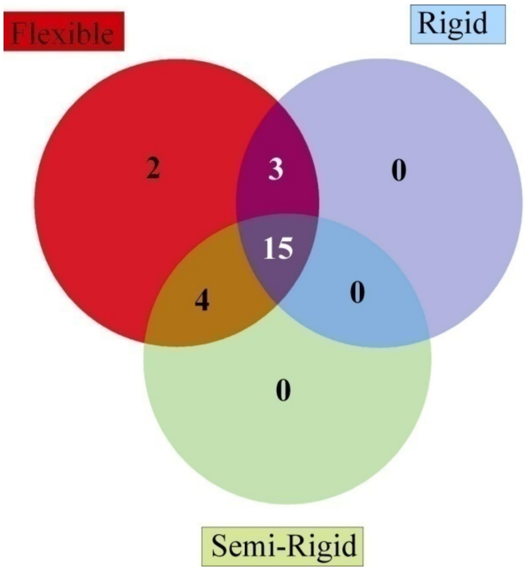

Figure 55: Case a) (100% of agreement) Types of pavements covered by each record

Case b)

From this case, it can be concluded that, if there are no mistakes, the skid resistance PIs are not used for some types of pavements from those provided in the whole questionnaire. Only one record seems to indicate that the skid resistance PI is not applied on semi rigid pavements.

4.1.6 Distribution by Type of Application

Regarding the type of application, the questionnaire distinguishes between standard and research. In this case, as in the previous one, only two records haven't provided this information. The results for the remaining 24 are indicated in Figure 56; which shows that 100% of them are used in standard application and that, at least at the moment, there is no a special skid resistance PI used for research purposes only.

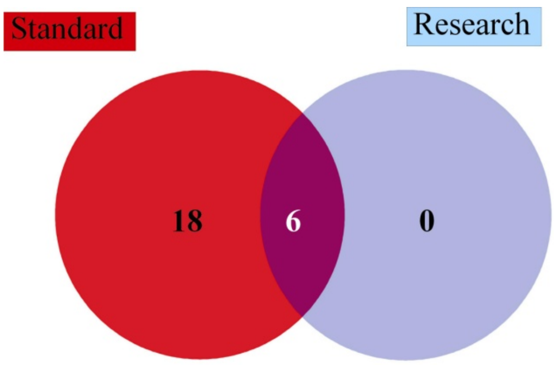

Figure 56: Distribution by type of application

4.1.7 Standardization

The first question included in the chapter of data collection of the COST 354 database, is whether the technical parameter is measured according to a Standard. The answers obtained are shown in Figure 57. It can be concluded that the most common way of collecting data about the technical parameters is following a national standard.

The reason probably is, among others, that the results obtained by devices that do not use a laser system, are influenced by the measuring principle and some other factors (e.g. operating speed, loading on the test wheel, water film thickness, etc) and the efforts carried out so far to harmonize both the measuring method and the data collected have not been satisfactory enough. As a consequence there is no international standard available about this subject.

It can be stated that it is always important to standardize the way of carrying out the measurements of a pavement characteristic in a road network. It is even more important if the results of the measurements are directly influenced by the test method, and, at least at the moment, this is the case for the skid resistance properties of the pavements.

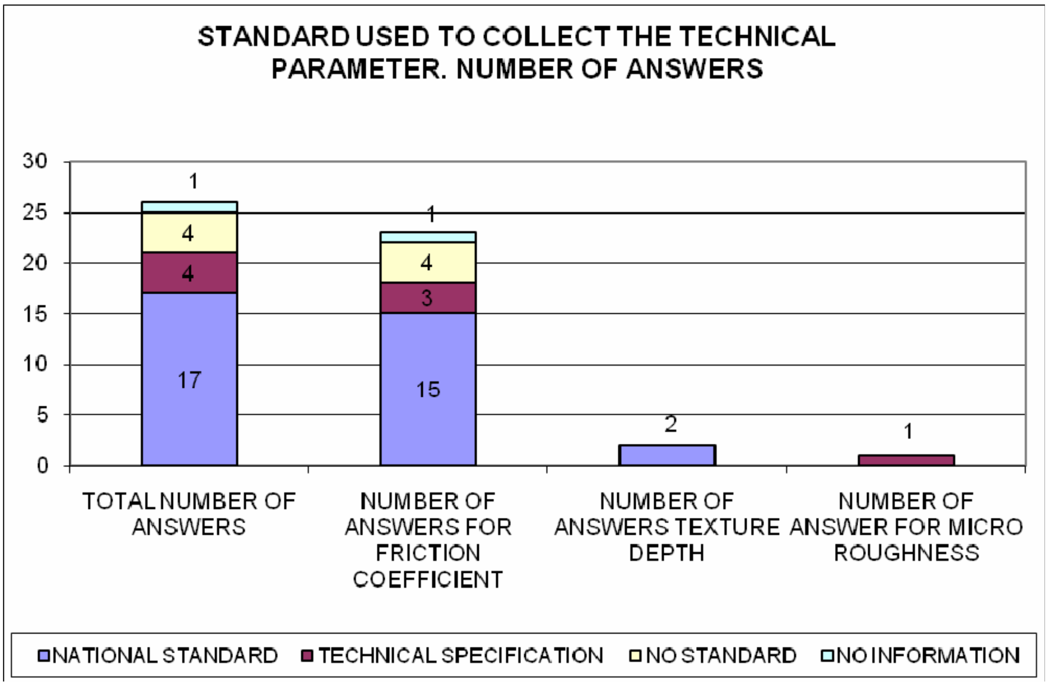

Figure 57: Number of records grouped by the type of standard for TP of skid resistance

4.1.8 Measuring principle

The measuring principle is an essential issue for the skid resistance performance indicators, particularly when the technical parameter measured is the friction coefficient.
Projects carried out at a worldwide level (international PIARC experiment to compare and harmonize texture and skid resistance measurements (1), the HERMES Project (2), etc.) have shown that the measurements obtained to characterize the friction coefficient of the pavements are directly related to both the device and the measuring principle. Therefore, if the measurements of the friction coefficient are different among the Countries, the thresholds and decision values for the PIs related to this parameter could be different as well.

The records included in the COST 354 database about the measuring principle for skid resistance PIs are shown in Table 44. It can be observed that the measuring principles used to obtain the three identified technical parameters are different. For this reason, the following sections are divided into three, one for each technical parameter.

Table 44: Number of records grouped by measuring principle of the technical parameter

MEASURING PRINCIPLE	NUMBER OF ANSWERS
HORIZONTAL FORCE ON MEASURING WHEEL	10
SIDE FORCE ON MEASURING WHEEL	10
LASER	3
PENDULUM DEFLECTION	1
NO INFORMATION	2

4.1.8.1 Micro texture (micro roughness)

The micro texture of the pavement has an essential influence on skid resistance, and the range of wavelength to characterize it is lower than 0.5 mm. Only one record seems to indicate the measurement of this property, and the technical parameter is named as micro roughness. A laser-based device was developed to try to measure in a continuous way. It is known by the users of the measurements that the characterization of micro texture by means of this method is approximate. The data provided are random type information, which is used to obtain an index. This information is collected and applied at network level; therefore it’s possible that the errors created can be acceptable.

The summary of the information included in this record is:

- Technical parameter: Micro roughness.
- Measuring principle: Laser (17).
- Equipment name: RST (Road Survey Tester).
- Collected data: Extension.
- Section length: 100 m.
- Operating speed: 30 – 80
- Interval: 3 years.

4.1.8.2 Macro texture

The macro texture is another characteristic of the pavement that has an influence on skid resistance. It is more important for higher as the speed of the vehicle increases. Two of the records in the questionnaire (both from the same Country) mention this technical parameter and indicate a laser system as the measuring principle. The summary of the information included in these two records is:

- Technical parameter: Mean Texture Depth.
- Measuring principle: Laser.
- Equipment name: ARAN.
- Collected data: Severity.
- Section length: 0.2 m.
- Operating speed: 40 – 90 km/h
- Interval: 5 years.
- Homogenization.
- Quality assurance.

4.1.8.3 Friction coefficient

The friction coefficient tries to characterize the micro texture of the pavement in an indirect way. However when a mechanical device is used, macro texture has a certain influence on the results obtained. This is the reason why one of the parameters that has a direct relationship with the results of friction coefficient is the slip speed of the device. It is related to the operating speed of the vehicle and to both the alignment and the slip ratio of the measuring wheel.

From the answers of the questionnaire, the measuring principles of both “horizontal force on measuring wheel” and “side force on measuring wheel” are focused on characterizing the friction coefficient of the pavement. The main difference between them is the alignment of the test wheel of the device. In the first case (horizontal force), the measuring wheel is longitudinal (in the same direction of the axe of the device) and the result is the longitudinal friction coefficient; while, in the second case (side force), the measuring wheel has an angle with respect to the axle of the device, and the result is the sideways (or lateral) friction coefficient (SFC).
The machines which use the horizontal force principle have differences between them. These differences include the load applied on the test wheel, the tyre of the test wheel and the slip ratio. For this reason the results collected by different devices are not the same.

All the devices that are included in the category of side force measuring wheel are SCRIMs (10 records in the COST 354 database). But this is not a guarantee of obtaining the same measurement; other factors (e.g. operating speed, vertical load, water film thickness, etc.) are often different.

As a consequence, the friction coefficient measured by the devices will probably not be the same. This is one of the reason why:

- in general, calibration exercises are carried out periodically in those Countries that use dynamic devices for measuring friction coefficient,
- the national standards are commonly fulfilled, as it has been stated from the database.

Table 45 shows the summary of the measurement details included in the questionnaire to measure friction coefficient. From Table 45, it can be concluded that the only common devices included in the COST 354 database are Grip Tester, Skid Resistance Tester (SRT), ROAR and SCRIM. It is important to take into account that it is possible that other devices are used in some Countries and they are not included in the database because they are used in other road networks, by other administrations, for other purposes, etc.

The operating speed for ROAR is the same for the two Countries that have included it in the questionnaire, but from the answers it is not possible to know if the data collection procedure is the same as well. Speed is an important factor to harmonize the measurements and therefore in principle some comparisons between them could be made. Unfortunately there is not enough information in the database to carry out this analysis.

Again, there is not enough information in the questionnaire to know if the two Countries that use the Skid Resistance Tester follow the same collecting data method. With regards to the Grip Tester, there is no data at all. Therefore, it is not possible to make any comparison from the COST 354 database.

The data available for SCRIMs states that the operating speed varies from 40 to 80 km/h. As the measurement wheel is free, the slip speed will vary from 13.68 to 27.36 km/h, which means that, if no correction is made, the results will not be harmonized among them. The majority of the data reported about operating speed is in the range of 50 to 60 km/h (17.10 to 20.52 km/h of slip speed).

Table 45: Measuring principle details

COUNTRY	NAME	DEVICE	COLLECTED DATA	SECTION LENGHT (m)	OPERATING SPEED (km/h)	INTERVAL (years)	HOMOG.	QUALITY ASSURANCE
AUSTRIA	FRICTION COEFFICIENT	RodSTAR	SEVERITY	50	60	5	YES	YES
BELGIUM 1	SIDEWAY FORCE	SCRIM	EXTENSION	100	50	2	NO	YES
BELGIUM 2	FRICTION COEFFICIENT	SCRIM	SEVERITY	100		2	YES	YES
CROATIA 1	FRICTION COEFFICIENT		EXTENSION	100(*)	40-100(*)			YES(*)
CROATIA 2	FRICTION COEFFICIENT	GRIP TESTER	EXTENSION					
CZECH REPUBLIC 3	FRICTION COEFFICIENT	TRT	SEVERITY	MIN. 20	40-120	5	YES	YES
CZECH REPUBLIC 4	FRICTION COEFFICIENT	TRT	SEVERITY	MIN. 20	40-120	5	YES	YES
DENMARK	FRICTION COEFFICIENT	ROAR		1000	60	2	YES	YES
FRANCE 1	FRICTION COEFFICIENT	SCRIM	EXTENSION AND SEVERITY	200	65	3		YES
FRANCE 2	FRICTION COEFFICIENT	SCRIM	SEVERITY	10	60	3		YES
GERMANY	FRICTION COEFFICIENT	SCRIM	SEVERITY	100	40-80	4		YES
GREECE	FRICTION COEFFICIENT	GRIP TESTER						
HUNGARY	MICRO ROUGHNESS	RST	EXTENSION	100	30-80	3		
ITALY	FRICTION COEFFICIENT	SCRIM	EXTENSION AND SEVERITY	10	50-60	1	YES	YES
NETHERLANDS	FRICTION COEFFICIENT	DWW- Trailer	SEVERITY	100	50	2		YES
NORWAY	FRICTION COEFFICIENT	ROAR	SEVERITY		60			
POLAND	FRICTION COEFFICIENT	Skid Resistance Tester	SEVERITY	1000/100?	60	1		YES
PORTUGAL	FRICTION COEFFICIENT	SCRIM	SEVERITY		60	2	YES	YES
SERVIA AND MONTENEGRO	FRICTION COEFFICIENT	Skid Resistance Tester	SEVERITY			3		
SLOVENIA	FRICTION COEFFICIENT	SCRIM	SEVERITY	20	80	5	YES	YES
SPAIN	FRICTION COEFFICIENT	SCRIM	SEVERITY	20	50-60	1	YES	YES
SWEDEN	FRICTION COEFFICIENT	SFT, BV 11, BV 14		20	70		YES	YES
SWITZERLAND	FRICTION COEFFICIENT	SKIDDOMETER	SEVERITY	250	40, 60, 80			
UNITED KINGDOM	FRICTION COEFFICIENT	SCRIM	SEVERITY	10	50/80	1	YES	YES

(*) information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses.

4.2 CORRELATIONS BETWEEN TRANSFORMATION FUNCTIONS AND LIMITS IN USE IN THE DIFFERENT COUNTRIES AND FOR THE DIFFERENT PARAMETERS USED

From the 26 records analysed, in 3 cases there was no information available answering the questions about “Classification and Assessment”. From the remaining, 10 records (45%) pointed out that the indicator doesn’t really exist and, as a consequence, the classification system to evaluate the skid resistance properties of a pavement comes directly from the technical parameter. This is the case for the two records about macro -texture, the record about micro roughness and 7 records about friction coefficient. However, most of them state that a homogenization process for the data collection exists. Therefore, it is possible that the individual measurements are somehow homogenized in a longer length; and then, this homogenized value is used to classify the skid resistance properties of the pavement.

13 records have provided some kind of information that seems to indicate that a skid resistance indicator is used. But only 7 of them have provided some information about the transformation function. Moreover, only 4 records include a mathematical expression. They are analysed in the following paragraphs.

4.2.1 Correlations between transformation functions

In the case of macro texture measurements it is impossible to make any correlation because only one Country has reported it. The same is true for micro roughness.

From the records about skid resistance that have mentioned the use of indicators, the correlations can be calculated for only 4 records (those from Austria, Belgium, Germany and Poland). The transformation functions are included in Table 46 and the regressions are shown in the figures from Figure 58 to Figure 61.

Table 46: Information about transformation function for skid resistance indices

COUNTRY	INDICATOR NAME	TRANSFORMATION FUNCT.	COMMENTS
AUSTRIA	SKID RESISTANCE INDEX	9,9286-14,286*TP	CLASSIFICATION ONLY AT NEWORK LEVEL
BELGIUM 1	SKID RESISTANCE INDEX	4*(SFC-0,1)/3	
GERMANY	SKID RESISTANCE INDEX	MAX(1;MIN(5;3,5+(TP-0,36)/(-0,06)))	
POLAND	REPRESENTATIVE FRICTION COEFFICIENT	100-180*TP	

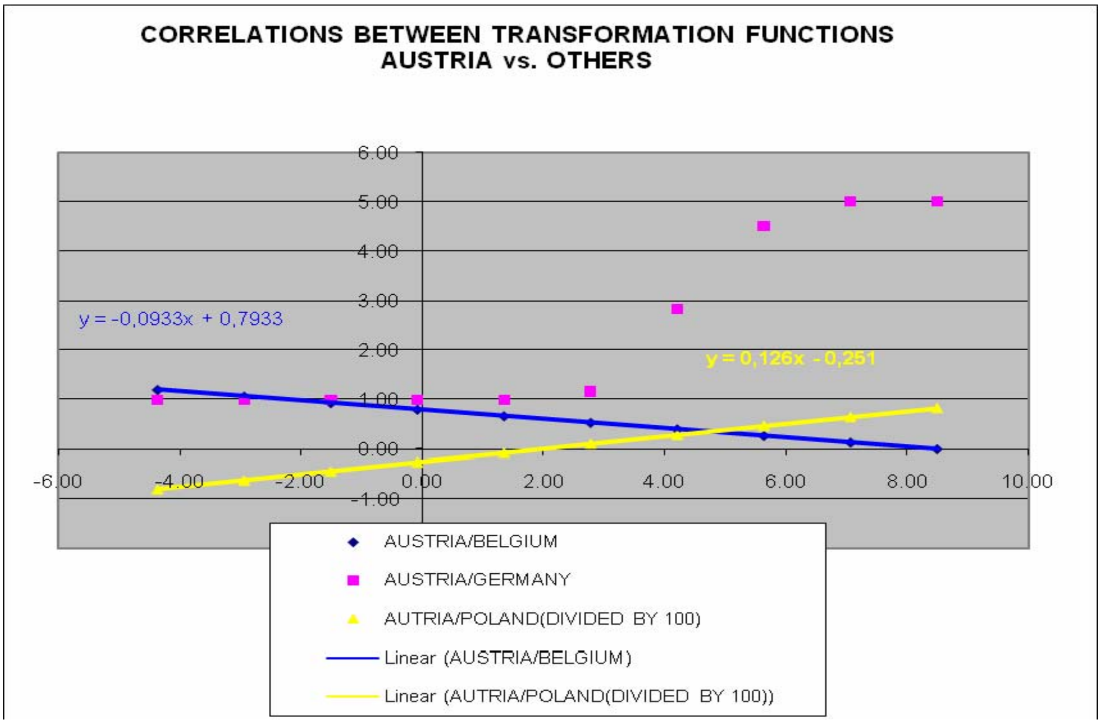

Figure 58: correlation between skid resistance transformation function from Austria and others

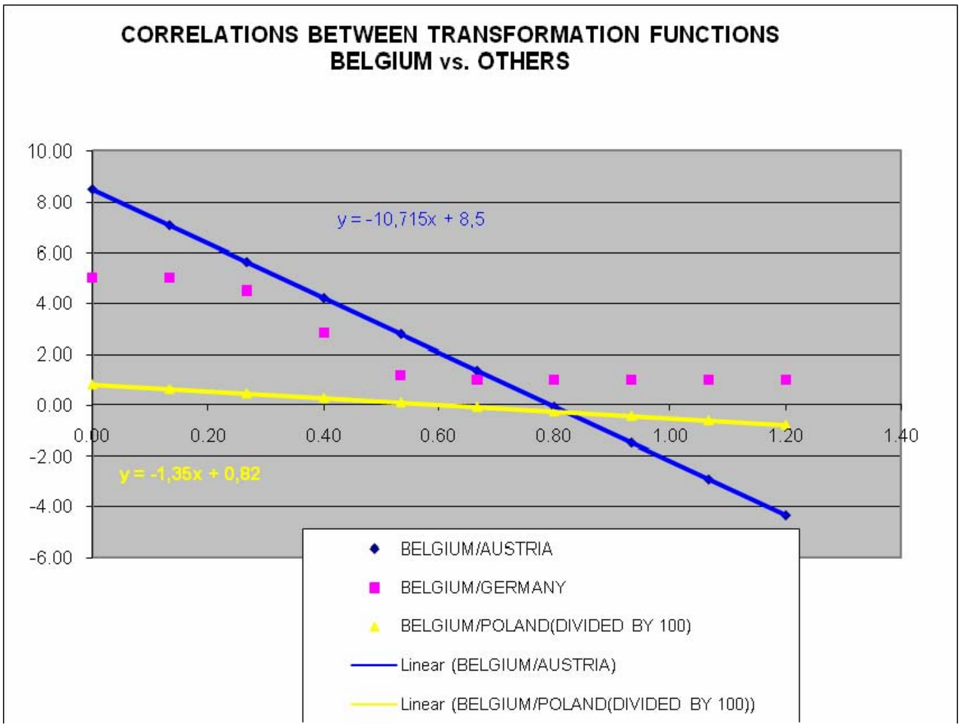

Figure 59: correlation between skid resistance transformation function from Belgium and others

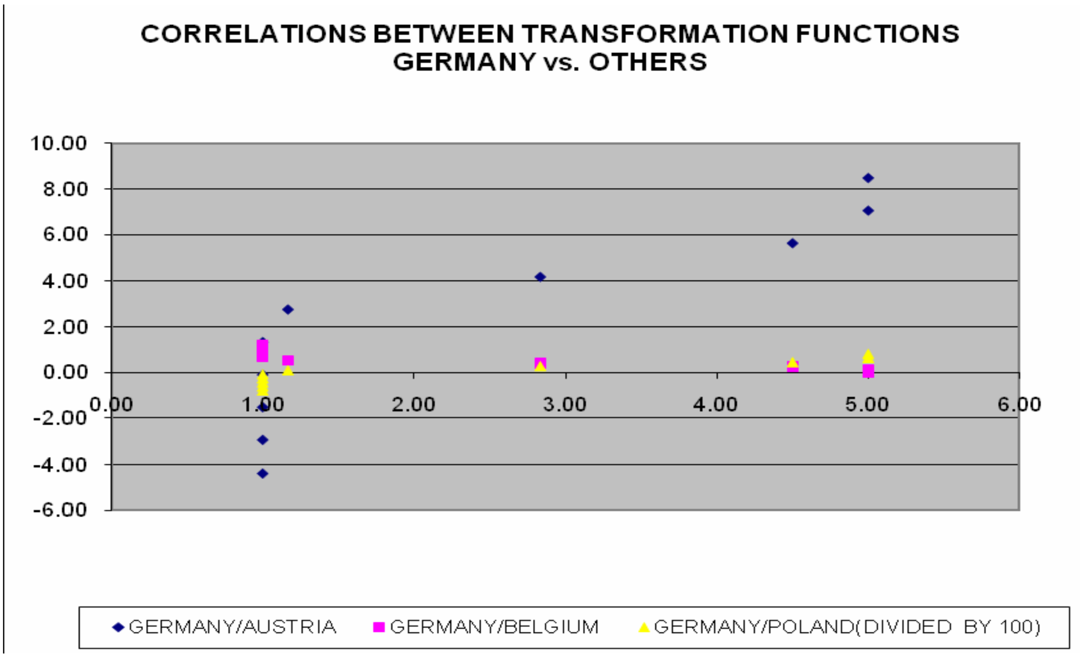

Figure 60: correlation between skid resistance transformation function from Germany and others

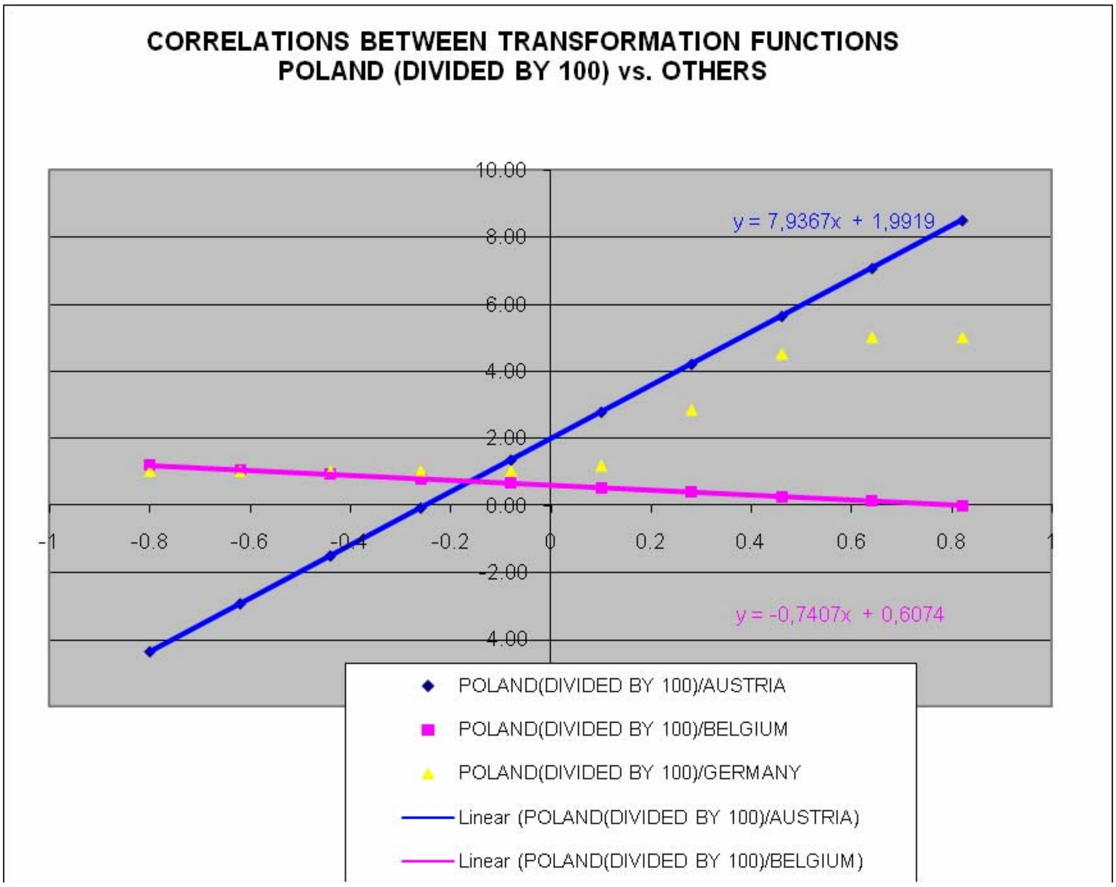

Figure 61: correlation between skid resistance transformation function from Poland and others

As a result it can be concluded that some correlations are possible when the transformation functions are quantitative.

4.2.2 Limits

The summary of the information reported about the limits (threshold, warning, acceptance and target) is included in Table 47.

With regards to macro texture, it’s not possible to make any comparison of limits because there are only two records that correspond to the same Country, but for different types of roads.

In the case of micro roughness, there’s no information about the index or about the limits. Therefore, again, it’s not possible to make any analysis.

As a consequence, comparisons can only be made for the indicators and the technical parameters related to friction coefficient.

Regarding indicators, the correlations are available in the previous section. For those records that provided the transformation function the limit values are included in the COST 354 database by using both the TP and the Index. Taking into account that quite a high number of countries do not seem to use transformation functions (they use limits directly from the Technical Parameter), all of the analysis described in this section has been carried out from the TP limit values.

The friction coefficient is a non-dimensional parameter. In some Countries it is used from a scale from 0 to 1; while, in others, it’s used as a percentage (scale from 0 to 100). Therefore, in order to be able to compare them, the values corresponding to a scale from 0 to 1 have been multiplied by 100.

Table 47: summary of TP limits

COUNTRY	NAME	DEVICE	NAME	TRANSFORMATION FUNCT.	TRESHOLD		WARNING		ACCEPTANCE		TARGET		COMMENTS
					TP	INDEX	TP	INDEX	TP	INDEX	TP	INDEX	
AUSTRIA	FRICTION COEFF.	RodSTAR	SKID RESISTANCE INDEX	9,9286-14,286*TP	0.38	4.5	0.45	3.5					
BELGIUM 1	SIDEWAY FORCE	SCRIM	SKID RESISTANCE NDEX	4*(SFC-0,1)/3	0.4	0.4	0.43	0.44			0.6	0.67	
BELGIUM 2	FRICTION COEFF.	SCRIM	NO INDEX	NO T.F	40		45		48				
CROATIA 1	FRICTION COEFF.		NO INFORMATION	NO INFORMATION									A THRESHOLD VALUE IS GIVEN AS A FUNCTION OF SPEED (*)
CROATIA 2	FRICTION COEFF.	GRIP TESTER	NO INFORMATION	NO INFORMATION									
CZECH REPUBLIC 1	TEXTURE DEPTH	ARAN	NO INDEX	NO T.F	0.54		0.64						
CZECH REPUBLIC 2	TEXTURE DEPTH	ARAN	NO INDEX	NO T.F	0.44		0.54						
CZECH REPUBLIC 3	FRICTION COEFF.	TRT	NO INDEX	NO T.F	0.39		0.5						MEAS. SPEED OF 40. MOTORWAYS AND PRIM. ROADS
					0.34		0.43						MEAS. SPEED OF 60. MOTORWAYS AND PRIM. ROADS
					0.28		0.36						MEAS. SPEED OF 80. MOTORWAYS AND PRIM. ROADS
					0.25		0.3						MEAS. SPEED OF 100. MOTORWAYS AND PRIM. ROADS
					0.21		0.26						MEAS. SPEED OF 120. MOTORWAYS AND PRIM. ROADS
CZECH REPUBLIC 4	FRICTION COEFF.	TRT	NO INDEX	NO T.F	0.35		0.47						MEAS. SPEED OF 40. SECONDARY AND OTHER ROADS
					0.32		0.39						MEAS. SPEED OF 60. SECONDARY AND OTHER ROADS
					0.25		0.33						MEAS. SPEED OF 80. SECONDARYAND OTHER ROADS
					0.22		0.27						MEAS. SPEED OF 100. SECONDARY AND OTHER ROADS

COUNTRY	NAME	DEVICE	NAME	TRANSFORMATION FUNCT.	TRESHOLD		WARNING		ACCEPTANCE		TARGET		COMMENTS
					TP	INDEX	TP	INDEX	TP	INDEX	TP	INDEX	
DENMARK	FRICTION COEFF.	ROAR	NO INDEX	NO T.F					0.4				NEW CONSTRUCTION. SPEED < 80
									0.5				NEW CONSTRUCTION. SPEED ≥ 80
									0.4				IN SERVICE ROADS
FRANCE 1	FRICTION COEFF.	SCRIM	SKID RESISTANCE NDEX	NO AVAILABLE		50		40					
FRANCE 2	FRICTION COEFF.	SCRIM	SKID RESISTANCE INDEX	NO AVAILABLE									
GERMANY	FRICTION COEFF.	SCRIM	SKID RESISTANCE INDEX	MAX(1;MIN(5;3,5+(TP-0,36)/(-0,06)))	0.3	4.5	0.36	3.5			0.48	1.5	MEAS. SPEED OF 80
					0.39	4.5	0.45	3.5			0.57	1.5	MEAS. SPEED OF 60
					0.48	4.5	0.54	3.5			0.66	1.5	MEAS. SPEED OF 40
GREECE	FRICTION COEFF.	GRIP TESTER	GRIP NUMBER	NO INFORMATION									
HUNGARY	MICRO ROUGHNESS	RST	MICRO ROUGHNESS INDEX	NO T.F									
ITALY	FRICTION COEFF.	SCRIM	NO INDEX	NO T.F					60	60			TRADITIONAL CONCRETE
					55	55							RECYCLED CONCRETE
					60	60							POROUS ASPHALT
NETHERLANDS	FRICTION COEFF.	DWW- Trailer	NO INDEX	NO T.F	0.37		0.44						
NORWAY	FRICTION COEFF.	ROAR	NO INFORMATION	NO INFORMATION									
POLAND	FRICTION COEFF.	Skid Resistance Tester	REPRESENTATIV E FRICTION COEFF	100-180*TP	0.29	47.8	0.36	35.2					
PORTUGAL	FRICTION COEFF.	SCRIM	SKID RESISTANCE NDEX	NO INFORMATION	40								
SERVIA AND MONTENEGRO	FRICTION COEFF.	Skid Resistance Tester	NO INDEX	NO T.F	45						55		LIGHT TRAFFIC
					50						60		MEDIUMA ND HEAVY TRAFFIC
					55						65		LONG. SLOPE>6%, CURVE RADIUS <150
SLOVENIA	FRICTION COEFF.	SCRIM	SKID RESISTANCE INDEX	NO INFORMATION	45		51						MEAS. SPEED OF 50
					39		44						MEAS. SPEED OF 70
					33		38						MEAS. SPEED OF 90
SPAIN	FRICTION COEFF.	SCRIM	SKID RESISTANCE NDEX	VALUE OVERCAME BY 95% OF DATA IN AN		35			65				

COUNTRY	NAME	DEVICE	NAME	TRANSFORMATION FUNCT.	TRESHOLD		WARNING		ACCEPTANCE		TARGET		COMMENTS
					TP	INDEX	TP	INDEX	TP	INDEX	TP	INDEX	
				HOMOGENEOUS SECTION									
SWEDEN	FRICTION COEFFF.	SFT, BV1 , BV 14	SKID RESISTANCE NDEX	AVERAGE OF INDIVIDUAL MEASUREMENTS EACH 20 m	50								
SWITZERLAND	FRICTION COEFF.	Skiddometer	SKID RESISTANCE INDEX	NO INFORMATION									
UNITED KINGDOM	FRICTION COEFF.	SCRIM	SKID RESISTANCE INDEX	COMPLICATE CRITERIA. SEE THE LITERATURE									

(*) information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses.

4.2.2.1 *Variation of the limits depending on the speed*

As it has been mentioned, the value of the friction coefficient is directly dependent on the slip speed; and, at the same time, the slip speed is related to the operating speed of the device. In fact, in most of the cases, what is fixed at network level for the different devices is the operating speed. This is the reason why as a first approach, the analysis has been made by only taking into account the operating speed. It was however presumed that the results would not be satisfactory enough as LFC (longitudinal friction coefficient) devices and SFC (sideways friction coefficients) devices have different slip ratios.

Figure 62 shows the values of the TP for the threshold limits depending on the operating speed of the device. It also shows the number of countries that measure at that speed and have provided this information. From the same Figure, it can be stated that 11 countries measure in the range of 40 to 60 km/h, while there are 7 countries that measure at speed higher than 60 km/h and 2 countries did not indicate the operating speed. Moreover the countries that measure at high speed also measure at lower speeds. Therefore, it seems that the common practice is to measure in the range of an operating speed 40 to 60 km/h.

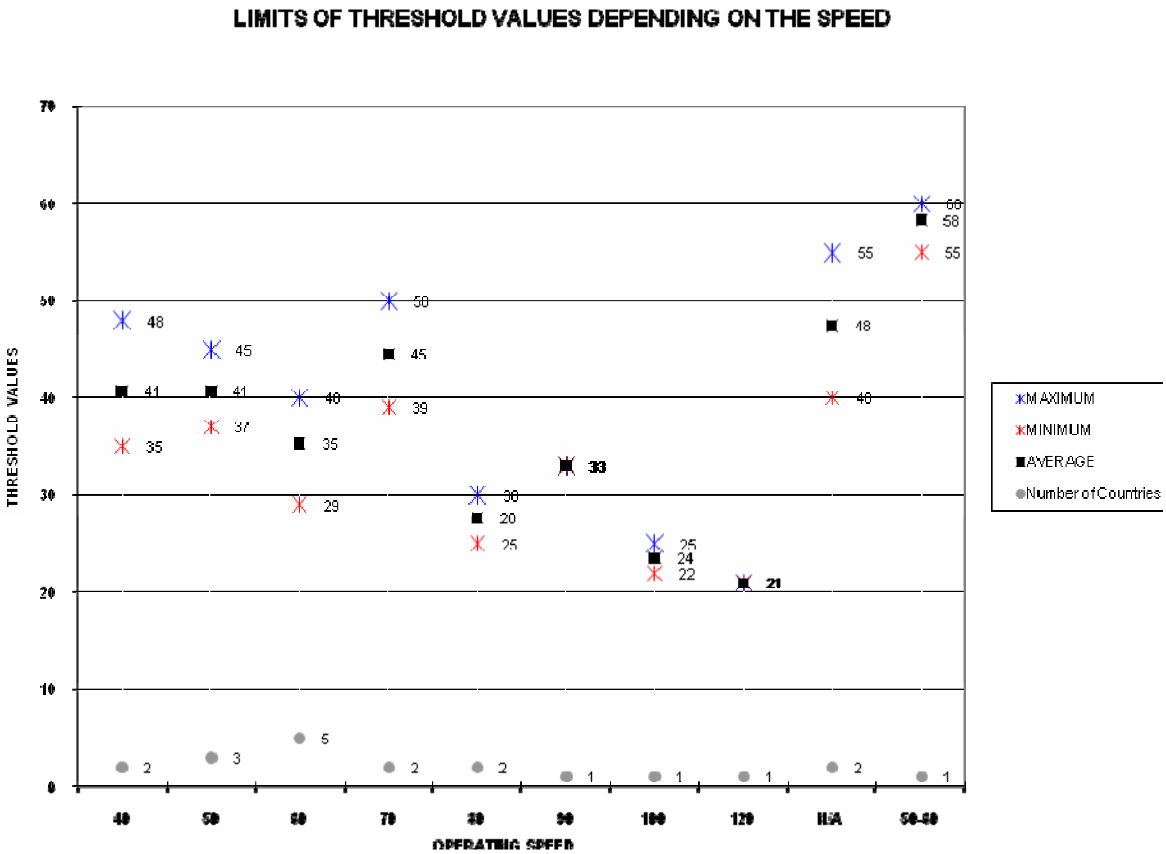

Figure 62: Limits of threshold values of the friction coefficient depending on the speed

The same analysis has been made taking into account the warning limits for the friction coefficient. The results are shown in Figure 63. In this case, it seems that the variation of the values depending on the speed is more homogeneous. But the reason could be that only 3 countries have provided this information.

Regarding the acceptance values for the technical parameter, the answers come from 2 countries. One of them doesn't provide information about the speed and the value is 48. The other gives values depending on the speed and the limits vary from 40 to 50. So they appear to be in the same range.

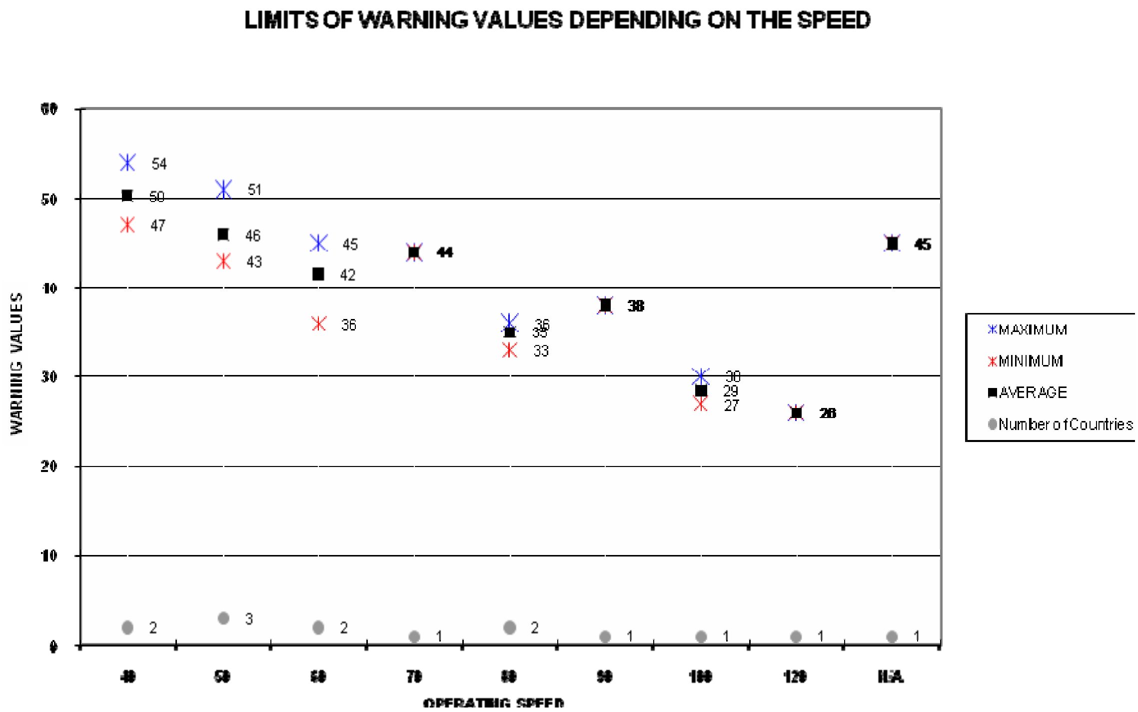

Figure 63: Limits of warning values of the friction coefficient depending on the speed

The target values of friction coefficient have been provided by 3 countries. One of them doesn't give information about the speed but it includes a classification depending on the traffic and the alignment of the road. The values vary from 55 to 65. The second country gives information for 40, 60 and 80 km/h; and the last one has provided information for an operating speed of 50 km/h. Therefore, the comparison does not appear to be possible.

In the following section, the analysis has been repeated separating the SFC devices (all of them have the same slip percentage and, as a consequence, they can be directly compared by using the operating speed) and the LFC devices. For this last type of devices, the slip percentage has been taken into account in order to obtain the variation in the limit values depending on the slip speed.

4.2.2.1.1 SFC devices

As it has been mentioned, SCRIM is the most common device used among the Countries that filled the COST 354 database. This information, together with the fact that:

- there is a high scatter in the limits from the different records in the database considered as a whole,
- there are differences in the slip speed of the devices for a given operating speed,

are the reasons why a separate analysis of the limits of friction coefficient using the SCRIMs has been carried out.

In total, 8 Countries have provided information about the limits from the SCRIM measurements, which means 40% of the Countries included in the COST 354 database. It should be mentioned as well that in the records about skid resistance measured by these devices the limits for primary and secondary roads are the same.

The range of operating speed in this case, varies from 40 to 90 km/h (there are no measurements at 100 or 120 km/h). From all the countries included in this analysis, most of them have reported one operating speed or a range of speeds between 50 and 60 km/h. But, one of them has reported values at 40, 60 and 80 km/h; while another one has reported values at 50, 70 and 90 km/h. For each of these two countries, the differences between the limits at different operating speed are constant.

In the case of the **threshold values**, the Country that measures at 40, 60 and 80 km/h has a difference of 9 between each limit (30, 39, 48); while, the Country that measures at 50, 70 and 90 km/h has a difference of 6 (33, 39, 45) (see Figure 64). Using these rules it is possible to produce limits for additional speeds (shown as “Extra values” on the graph) to allow a better comparison between the two countries. It can be seen that the limit at the lowest operating speed (40 km/h) is the same for both Countries and the differences become higher as the operating speed increases. Therefore, it seems that the main problems are for the limits for higher speeds, which, in practice, are the speeds that would be more useful for monitoring road networks in a safer way for both the users and the operators.

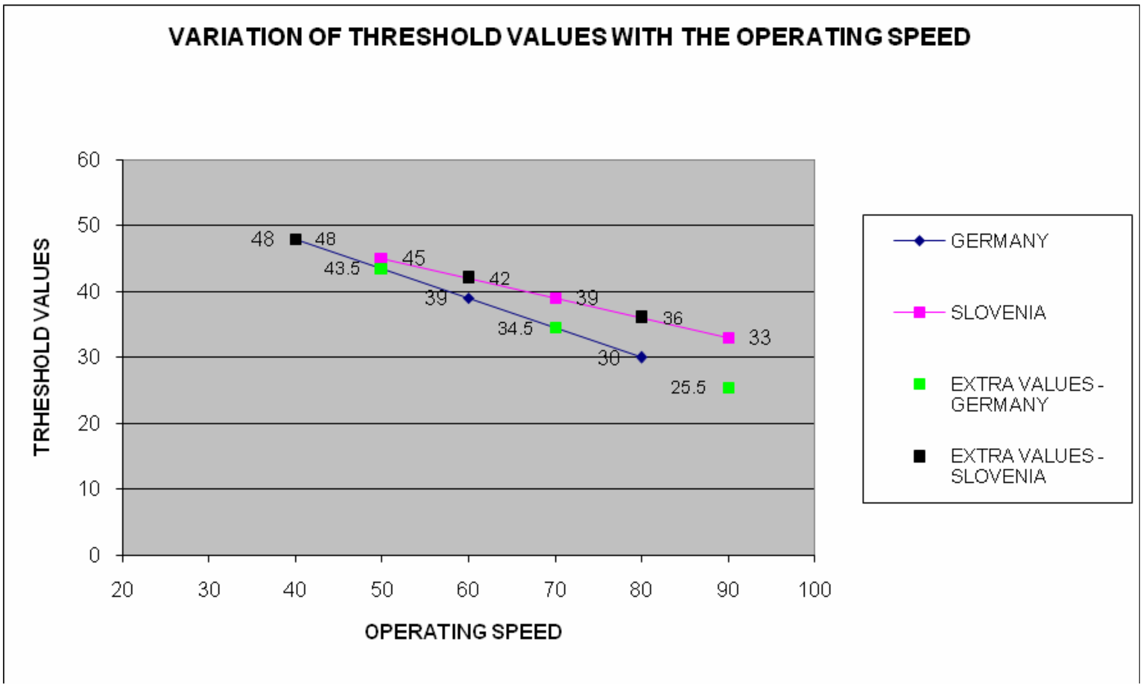

Figure 64: Variation of the threshold values depending on the SFC operating speed

The first conclusion here is that in the two Countries with limits depending on the SCRIM operating speed, the differences between the limits are constant, which means that the variation is considered to be linear.

Taking into account the data available from all the Countries included in the analysis of this section, it can be observed (Figure 65) that it’s possible to obtain a regression line using the threshold values vs. all of the operating speeds. Before selecting linear regressions, other types of functions were checked and the best fit to the data corresponds to a linear expression.

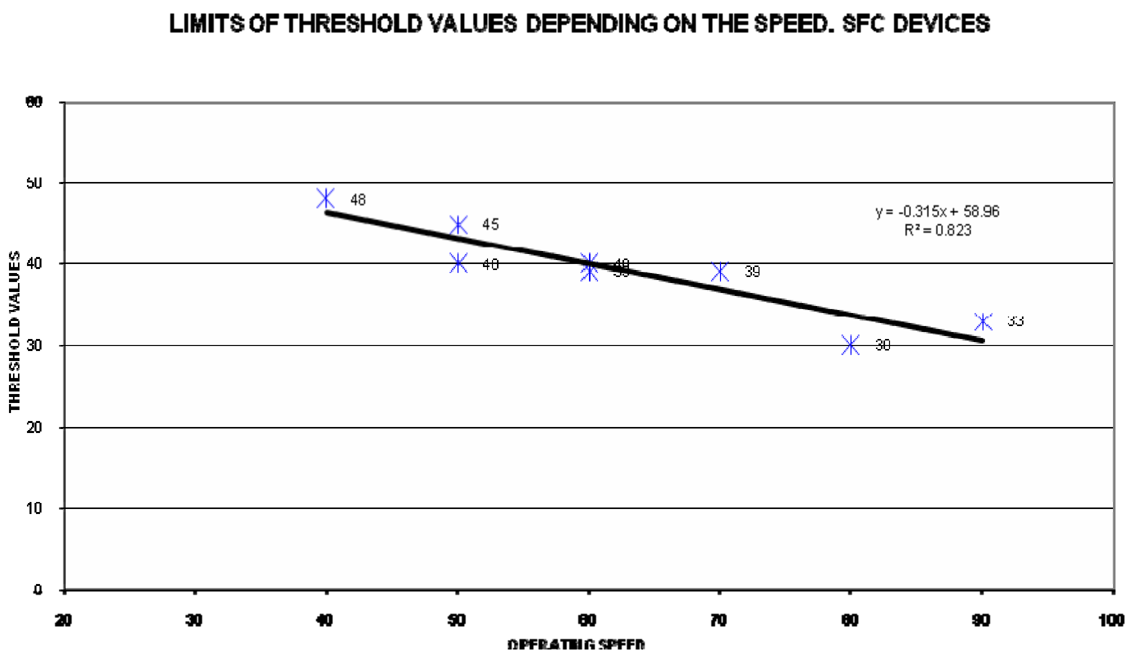

Figure 65: Limits of threshold values of the friction coefficient depending on the speed. SFC devices

Regarding the warning limits, again, the same two Countries have provided information for the different speeds. In this case the analysis is shown in Figure 66 and the conclusions are the same as for the threshold limits.

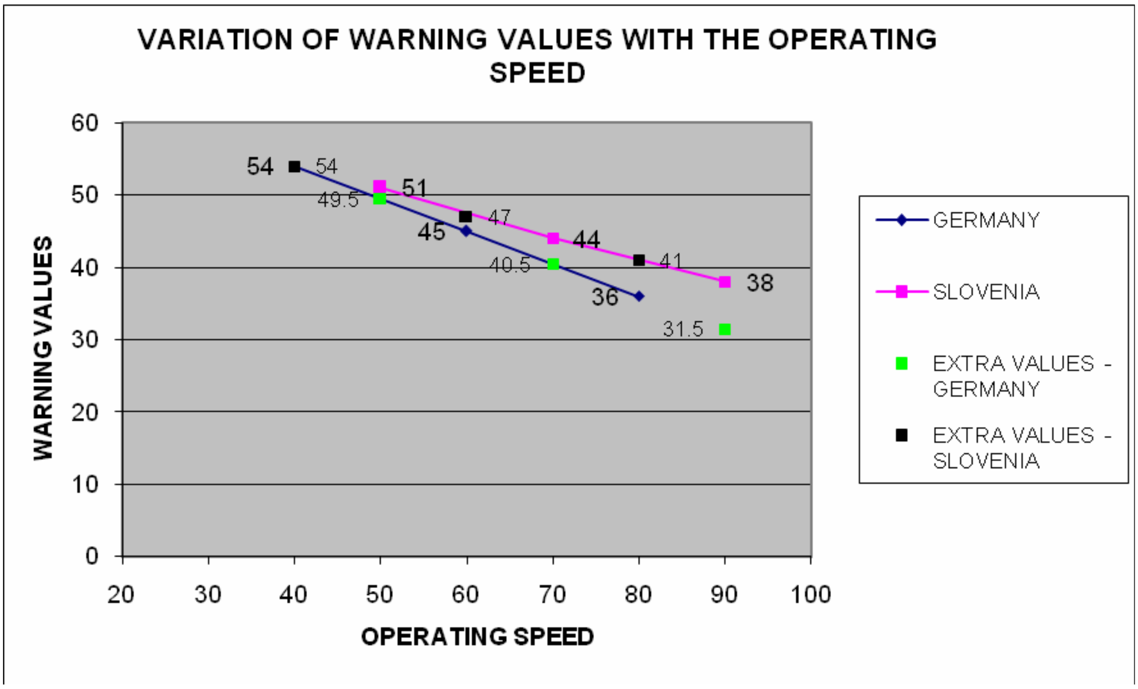

Figure 66: Variation of the warning values depending on the SFC operating speed

The results of the analysis including all the data reported by the different Countries are shown in Figure 67. For the warning limits, there is only information from 3 Countries.

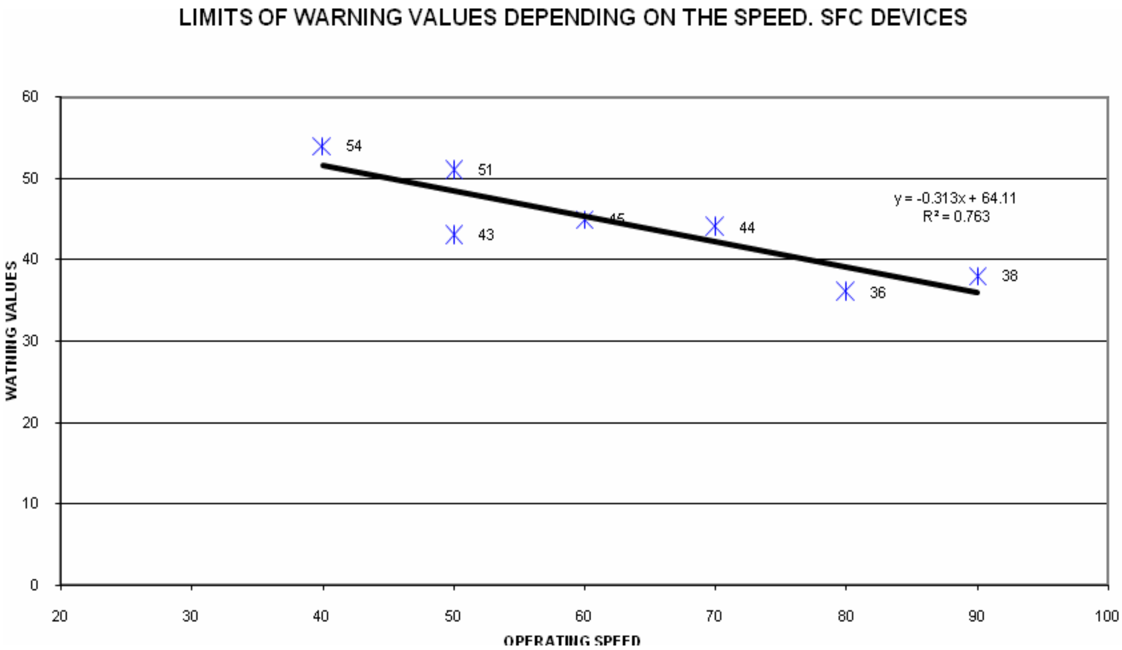

Figure 67: Limits of warning values of the friction coefficient depending on the speed. SFC devices

Only one country has provided information about the acceptance limits. Therefore, it is impossible to make any correlation.

The target limits have been only been provided by two Countries and there is no common operating speed between them, the values reported and the regression line are shown in Figure 68.

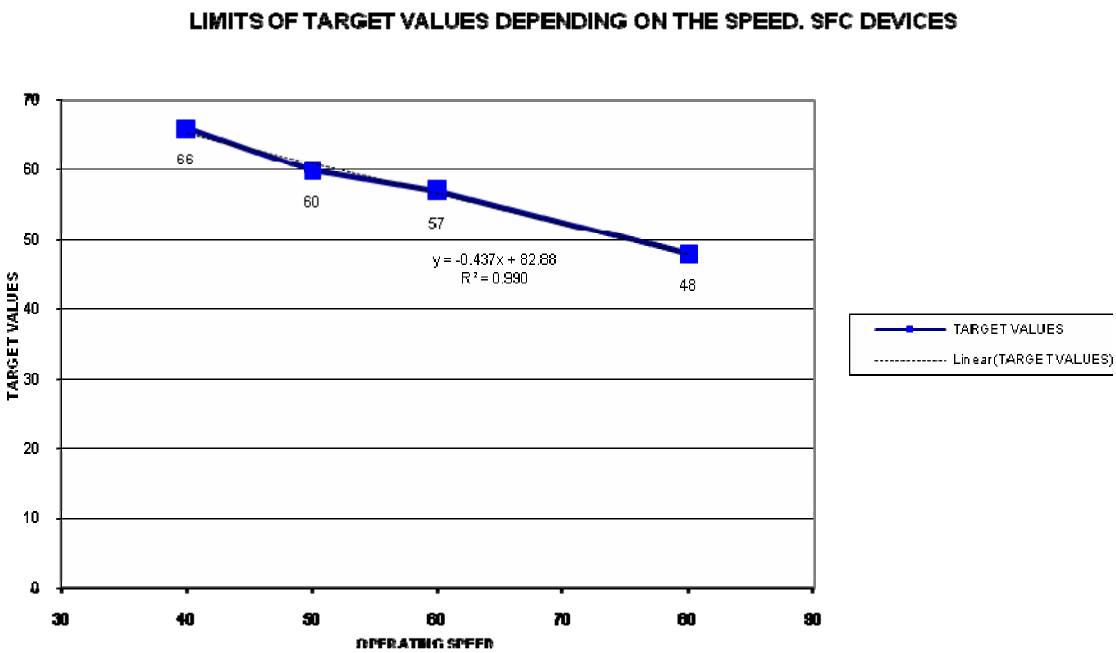

Figure 68: Limits of target values of the friction coefficient depending on the speed. SFC devices

From Figure 65 and Figure 67 it can be observed that the linear regressions are parallel (they have got almost the same gradient). But this is not the case for the target values.

The regression line derived for the target values has been obtained from data from only two countries, while the other two expressions are the results from information provided by many more countries. Therefore it was decided to use the same slope as for the threshold and warning values and to fix the value of the regression line to the one corresponding to 60 km/h (Figure 69) as it is the speed most commonly used by the countries in the COST 354 database. Of course, this is an assumption made to propose a variation of the limits with the operating speed, therefore, each country is free of follow it or not.

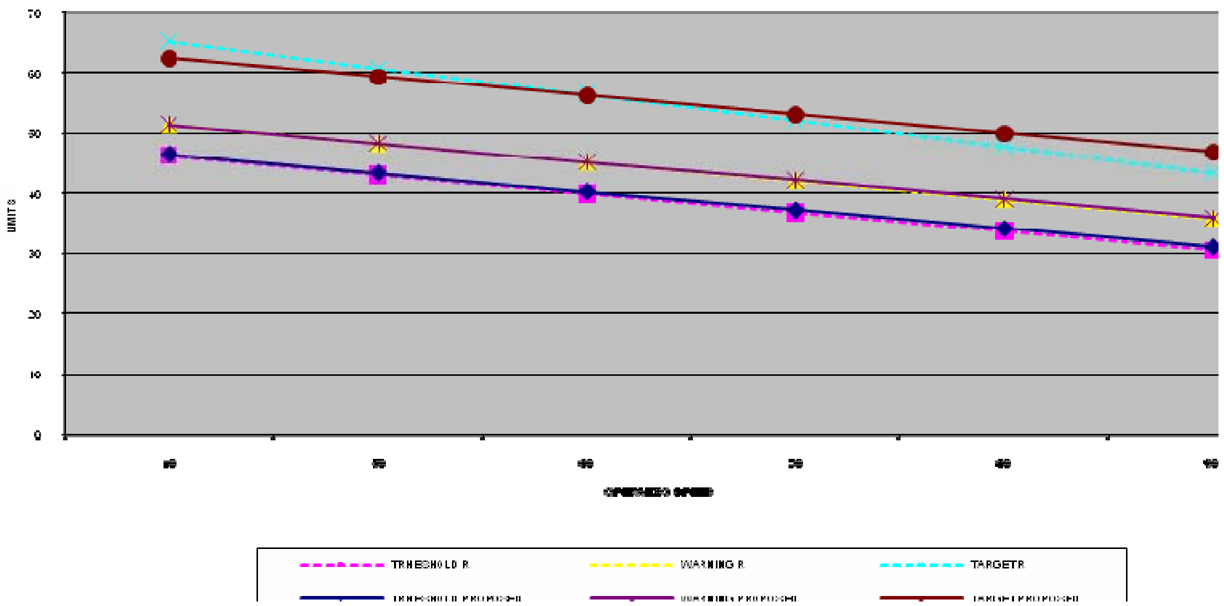

Figure 69: Proposed variation of the threshold, warning and target limits of the friction coefficient depending on the speed. SFC devices

As a consequence, the expressions proposed as variation of the limits depending on the operating speed when measuring with SFC devices are:

- TV = -0,31*OS + 59
- WV = -0,31*OS + 64
- TAV = -0,31*OS + 75

Where:

TV:	threshold value.
WV:	warning value.
TAV:	target value.
OS:	operating speed.

4.2.2.1.2 LFC devices

The number of Countries in the COST 354 database that use longitudinal friction devices is 11. From them, 7 Countries have provided some information about the decision limit values that allow analyses to be performed.

As it has been mentioned previously, there are three LFC devices that are used in more than one Country, but it's not possible to establish comparisons between them, because of the lack of information in the database. Therefore, the only possibility is to make the analysis of all the devices, for which the information is available, together.

From the information provided, it has been noticed that 5 types of longitudinal friction devices are used for measuring friction coefficient. As the IFI model indicates that the slip speed is of major importance, the slip percentage of these devices has been taken into account. These slip percentages vary from 17% to 100%. As a consequence they have been multiplied by the operating speeds in order to obtain the slip speeds.

When the limit values vs. the slip speeds regressions were obtained, the results showed that there is no correlation. However, when the regression is calculated by using the limit values and the operating speed, the correlations do exist. Therefore, it seems that the different limit values in the Countries have been fixed taking into account the operating speed of the device, instead of the slip speed. The reason probably is that the devices and measuring procedures (e.g. slip speed, water depth, wheel load, etc) have been combined in such way that the results can be comparable. As a consequence, all the analysis has been carried out taking into account the operating speed.

From the 7 Countries mentioned before, one of them did not provide information about the speed. Therefore it is not possible to include it in the analysis. From the 6 remaining Countries, only two of them have indicated different limit values depending on the speed. For new roads the first country (Denmark) uses one limit if the speed is greater than or equal to 80 km/h and another one if the operating speed is lower than 80 km/h. The second Country (Czech Republic) indicates different limit values, not only for different speeds but also for different types of roads (see Figure 70). As it can be observed, the limits for secondary roads and other roads are slightly lower (approximately 2 points) than the limits for the main roads. In this case, the differences between the same kinds of limit for different speeds are not constant.

3 of the 4 remaining Countries measure the skid resistance properties at 60 km/h, and the other one measures it at 50 km/h. For 60 km/h, the limits vary from 29 to 38 (average 33 and standard deviation is 3.77), which can be acceptable. The threshold limit for the Country that measures at 50 km/h is 37.

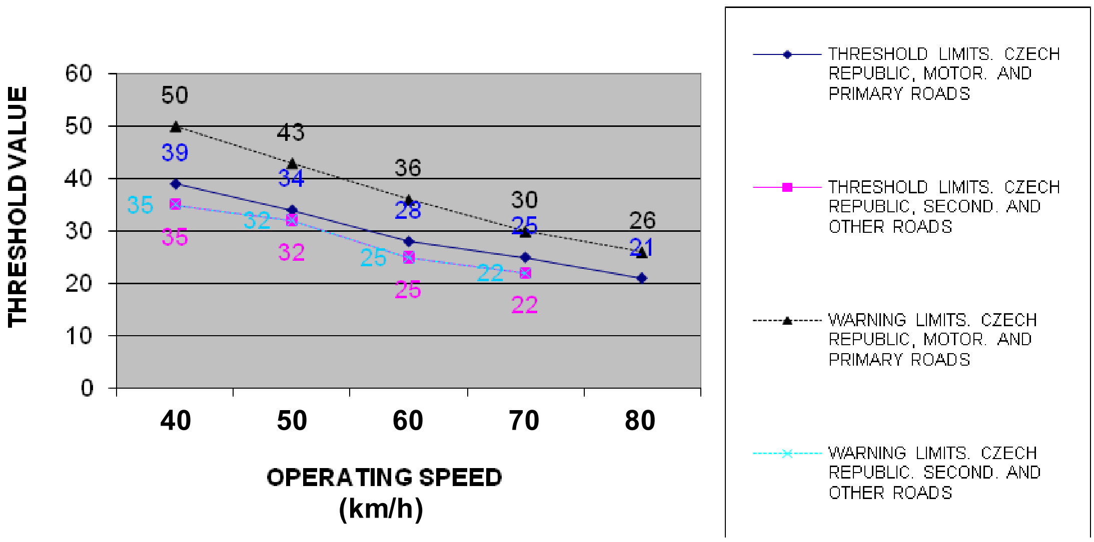

Figure 70: Variation of the threshold values in Czech Republic depending on the operating speed and the category of road

Regarding the warning limits, 4 Countries have reported information. Again, Czech Republic has provided it for different operating speeds and different categories of roads. While 2 Countries provided limits for 60 km/h and one for 50 km/h. For 60 km/h the warning values vary from 36 to 45 (average of 41, and standard deviation of 4). The threshold value is 44 at 50 km/h.

It was not possible to establish consistent comparisons between the acceptance values of different Countries because only one provided this information. The same is true for the target values.

By taking all of the above information into account, the regressions between the operating speed and the threshold and warning limits can been obtained (Figure 71 and Figure 72). It can be seen that the regressions are linear. Other functions had been used to try to determine which one best fits the values with the result that a linear one best fits the data.

In each of the figures the correlations have been obtained for both primary roads and secondary roads.

Regarding the threshold values the linear regressions for both primary and secondary roads have got almost the same slope (-0.23), they only differ in the independent constant i.e. both regressions are parallel.

On examination of Figure 72 (warning limits) it can be seen that the regression for primary roads has a slope quite similar to those obtained for threshold values (-0.28). However, the slope of the linear regression for secondary roads is different (-0.33). At this point two options can be taken:

- To use each expression for each case, which means that the regressions won't be parallel.
- To obtain parallel regressions for threshold and warning limits, taking into account that:
    - There is no physical reason why the variation of the threshold and warning values with the operating speed should have different slope
    - The results for primary roads (which involves more countries), have given quite similar slopes.
    - For the threshold values the slopes are the same and, again, these values have been provided by more countries.
    - The same results but for the limit values using SCRIM devices have reported almost parallel lines.

It has been decided to propose parallel linear functions for the variation of the threshold and warning limits vs. the operating speed (Figure 73).

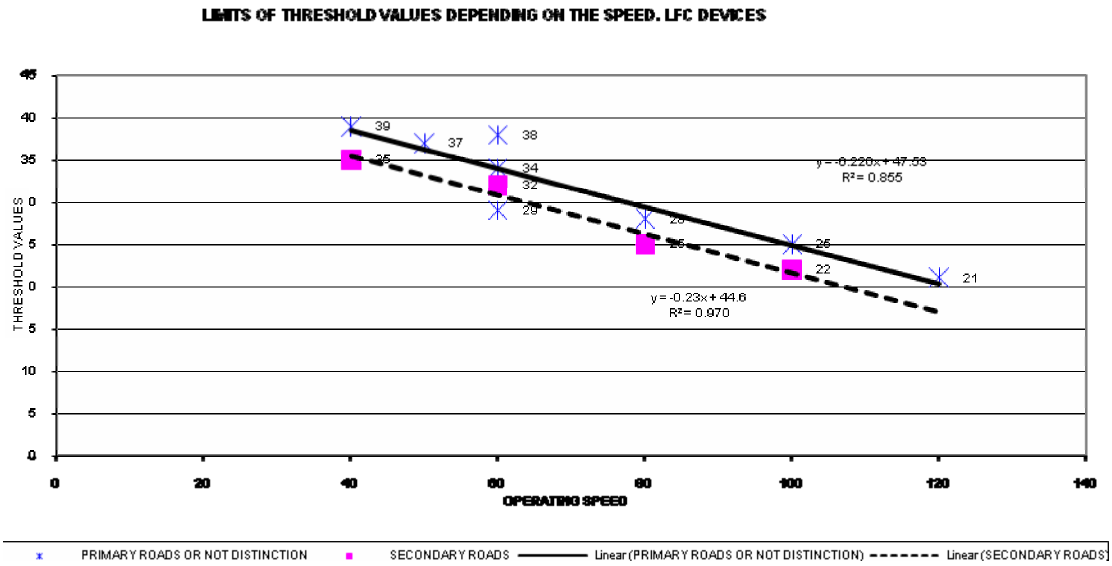

Figure 71: Limits of threshold values of the friction coefficient depending on the speed. LFC devices

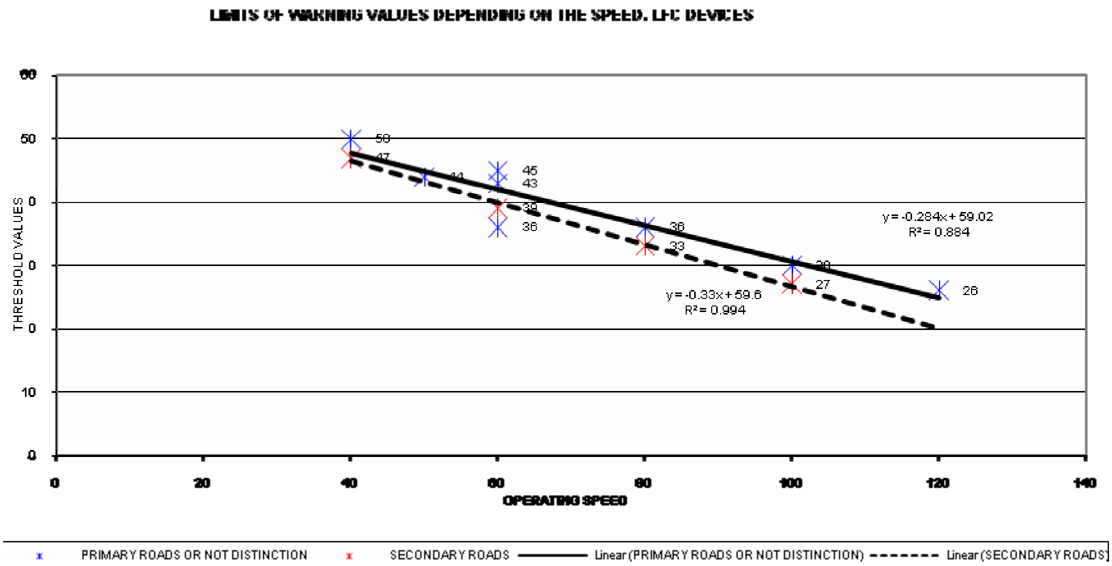

Figure 72: Limits of warning values of the friction coefficient depending on the speed. LFC devices

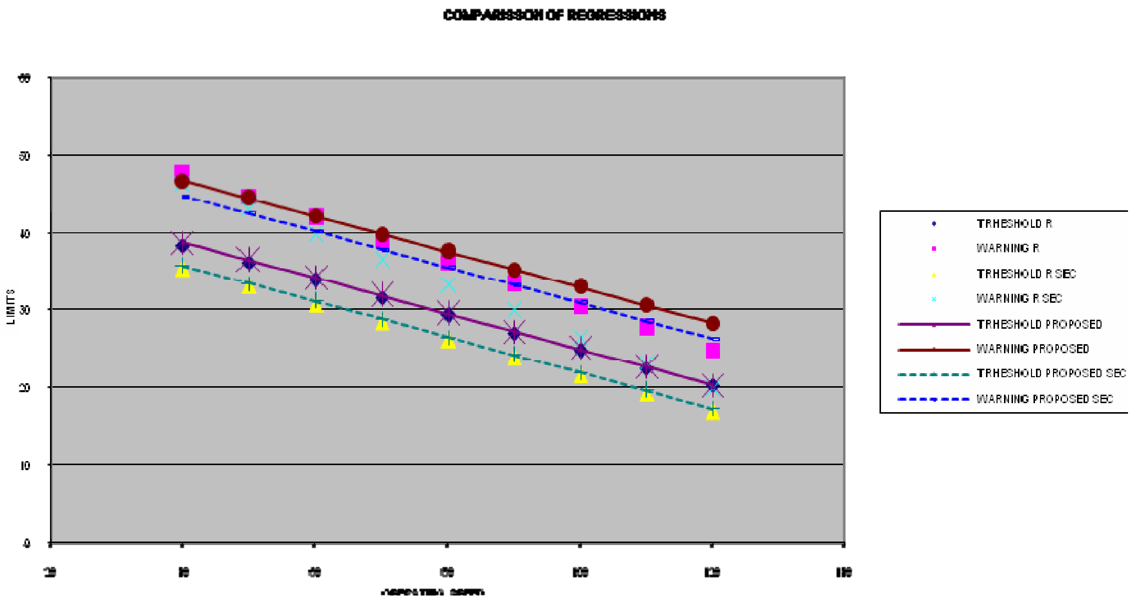

Figure 73: Proposed variation of the threshold and warning values of the friction coefficient depending on the speed. LFC devices

As a result of the linear interpolation the expressions relating the threshold and warning values to the operating speed are as follows:

- Threshold limits:
  - Primary roads: TV = -0,23*OS + 48
  - Secondary roads: TV = -0,23*OS + 45
- Warning limits:
  - Primary roads: WV = -0,23*OS + 56
  - Secondary roads: WV = -0,23*OS + 54

where:

TV: threshold value.
WV: warning value.
OS: operating speed (km/h)

As the PI has to be a single number and not a function of speed it was decided to consider a fixed speed value of 60 km/h for defining the thresholds and warning values.

4.3 EVALUATION OF THE MOST USED INDIVIDUAL PERFORMANCE INDICATORS

The analysis of the COST 354 database has shown that the technical parameters currently defined to determine the skid resistance are friction coefficient, macro texture and micro roughness. From them, the one most used is the friction coefficient, although it is important to state that the majority of Countries did not include macro texture because there is a special group for this characteristic in the database.

The fact is that only one country has provided information about macro texture in this section together with the friction coefficient information. But it is very important to stress that it is clear that both friction and macro texture have an influence on skid resistance, they are complementary and describe different properties of the pavement. However at the moment it's impossible to assess the skid resistance properties by using only macro texture.

Therefore, although there had been more answers about it inside the group of skid resistance, it wouldn't be advisable to choose between friction coefficient and macro texture.

Regarding micro roughness, it seems, from the records in the database, that only one country has been able at the moment, to obtain an index to characterize micro texture with a laser system mounted in a high-speed vehicle. Therefore, although every result obtained in this field is very promising in the development of new techniques to characterize skid resistance, at present from the information provided in the questionnaire, it's not possible to compare the results with those obtained by measuring the friction coefficient.

Although the friction coefficient is measured in almost every country in the COST 354 database, it's not possible to say the same about the performance indicators related to it. In fact, most of the countries do assess the skid resistance properties of the pavements from the friction coefficient data, probably by using a homogenization process such as calculation of averages, or other statistical procedures to obtain a number that characterizes the skid resistance properties of a section of road. The main problem is that there is not enough information in the database to determine those homogenization methods, if they exist, which would be a first step to determine at least the most common uses in this issue.

Only 4 countries provided a transformation function to obtain the indicators, and correlations among them seem to be possible. However the limits fixed from those indicators sometimes had quite large differences

Three other countries have provided some information about the indices, but the method did not fit well in the cells of the questionnaire as they are more complicated and they do not follow mathematical expressions. Therefore it is not possible to analyse them from the information in the database. It is however clear that it should be taken into account that some countries use other methods to assess the skid resistance properties of the pavements.

As the common practice of the Countries, seem to be to use the technical parameter measurements; and as those Countries that use PIs have provided information about the limit values for both the PI and the TP, the analysis has been done using these limit values.

An initial analysis including all of the devices that measure friction coefficient and using all of the information provided about the limits was done. This analysis consisted of determining the variation in the different limit values as a function of the operating speed of the devices.

The results obtained by including all of the devices in the analysis were not consistent (as expected). Therefore the analysis was repeated by investigating the SFC devices (SCRIMs) and the LFC devices separately. From these analyses, it can be stated that better results have been obtained by separating the LFC devices and the SCRIMs, and the most reliable ones are those that referred to threshold limits, as they have been provided by more countries.

Therefore, the common use in this issue could be summarized as follows:

- Three technical parameters have been identified namely micro roughness, macro texture and friction coefficient.
- There is no information about micro roughness index.
- The index used to characterize macro texture is standardized. Therefore, good information is available in the literature.
- Most of the Countries use the technical parameter of friction coefficient to determine the skid resistance properties of the pavements, probably by using some process to obtain a value, which characterizes a longer section of pavement.

- The information provided in the database about indicators obtained by means of a mathematical expression is scarce (only 4), and they are different one another, although in 3 cases it's possible to obtain good correlations.
- The limit values fixed in each Country did not provide useful information for selecting an indicator, because the differences are sometimes high, even for the same type of device, as it is the case of the different SCRIMs. Probably the main reason is that the limit values are usually chosen in the different Countries depending on the maintenance strategy and the policy followed.

When looking at the four indicators provided in the COST 354 database and their transformation function (Table 48), it can be observed that the variation scale for the different indicators is not the same. In three cases the lowest value indicates the best situation of the pavement, while the highest value indicates that the pavement is in bad condition. In the remaining record the situation is the opposite.

When looking at the operating speed of the device (in order to be consistent with the rest of the analysis) most of them correspond to 60 km/h, only one is obtained from data acquired at 50 km/h.

Table 48: Performance indicators for skid resistance

TP	9,9286-14,286*TP	4*(SFC-0,1)/3	MAX(1;MIN(5;3,5+(TP-0,45)/(-0,06)))	100-180*TP
0	9,93	-0,13	5,00	100,00
0,1	8,50	0,00	5,00	82,00
0,2	7,07	0,13	5,00	64,00
0,3	5,64	0,27	5,00	46,00
0,4	4,21	0,40	4,33	28,00
0,5	2,79	0,53	2,67	10,00
0,6	1,36	0,67	1,00	-8,00
0,7	-0,07	0,80	1,00	-26,00
0,8	-1,50	0,93	1,00	-44,00
0,9	-2,93	1,07	1,00	-62,00
1	-4,36	1,20	1,00	-80,00
TP IN SCALE 0-1	SCALE 9.93-(-4,36)	SCALE (-0,13)-1,20	SCALE 5-1	SCALE 100-(-80)
	60 KM/H	50 KM/H	60 KM/H	60 KM/H

As a consequence, it's not possible to define the most used performance indicator, although, what it can be confirmed is that the technical parameter more widely used to determine the skid resistance is the friction coefficient.

4.4 SELECTION OF THE PROPOSED INDIVIDUAL PERFORMANCE INDICATOR

The criteria for selection of the “best” individual performance indicators are described in 1.3.

As 11 records (from 23 with information available) seem to indicate that the technical parameter is used to classify the skid resistance properties of the pavement, the selection criteria have been applied for both the technical parameters and the indicators. The results are shown in tables 8 and 9.

When looking at the indicators and with the criteria established to select the most suitable one, it can be observed that:

- The only indicator based on European standards is the one related to macro texture. That’s the main reason why it seems that it is the most sustainable and reliable indicator from those that have been included in the COST 354 database.
- All of the indicators are used in standard practice, and the data of the technical parameter is safe to collect.
- The only indicator with results that can be almost independent of the device used to collect the data, is the one related to macro texture, which, at the same time makes it more reliable.

Table 49: Selection table for skid resistance indices

	INDEX						
	MTD	9,9286-14,286*TP	4*(SFC-0,1)/3	MAX(1;MIN(5;3,5+(TP-0,36)/(-0,06)))	100-180*TP	ES CRITERIA	UK CRITERIA
BASED ON EUROPEAN STANDARD							
STANDARD PRACTICE							
RESEARCH							
WIDE USE							
DEVICE INDEPENDENT							
SAFE TO COLLECT							
RELIABLE							
SUSTAINABLE							

GOOD
MEDIUM
BAD

As a consequence, from the selection criteria, it seems that the indicator that should be recommended to characterize skid resistance is macro texture. But, from the technical point of view, it is clear that to determine the adherence between the tyre and the pavement it is necessary to measure:

- The friction coefficient that depends mainly from the micro texture, which is not easy to measure in a direct way.
- The macro texture which is directly related with the capability of the surface drainage and has an influence on the skid resistance reduction as the speed of the vehicles increases.

Therefore, the recommendation is to obtain a performance indicator for macro texture as described in section 3 of this report in combination with a friction coefficient with the procedure that will be described in this section.

The problem is that, at least at the moment and from the data included in the questionnaire, it is not possible to choose one of the indicators included in the database for measuring friction coefficient.

However, from the answers of the COST 354 database, it can be concluded that the most commonly used approach is to determine friction by means of the technical parameter therefore, it is a solution that should be taken into account. That is the reason why Table 50 shows the selection criteria results obtained from the three technical parameters identified in the database.

As the characterization of micro texture from the laser system is only used in one country and, from the data available, it's impossible to evaluate it and make any correlations with the friction coefficient of the pavements, the conclusions are the same after analysing the technical parameters.

Table 50: Selection table for skid resistance technical parameters

	TECHNICAL PARAMETER		
	MACRO TEXTURE (LASER)	**MICRO ROUGHNESS**	**FRICTION COEFFICIENT**
BASED ON EUROPEAN STANDARD	CEN	NO STANDARD	NATIONAL STANDARDS
STANDARD PRACTICE	ALL THE ANSWERS	ALL THE ANSWERS	ALL THE ANSWERS
RESEARCH	NONE OF THE ANSWERS	NONE OF THE ANSWERS	26% OF THE ANSWERS
WIDE USE	1 COUNTRY	1 COUNTRY	22 RECORDS
DEVICE INDEPENDENT	QUITE GOOD CORRELATIONS (HERMES PROJECT (2))	N/A	
SAFE TO COLLECT	HIGH SPEED DEVICE	HIGH SPEED DEVICE	HIGH SPEED DEVICE
RELIABLE			
SUSTAINABLE			

(green)	GOOD
(yellow)	MEDIUM
(red)	BAD

4.5 PROTOCOLS AND TEST METHODS FOR MEASURING THE PROPOSED INDIVIDUAL INDICATORS

As it has been mentioned previously, the results obtained by using dynamic friction devices for measuring skid resistance are directly related with the device itself (its characteristics and maintenance), and with the test method used to collect the data (operating speed, water thickness, etc.). But, even when fixing this last method, the international experiences carried out till now haven't been encouraging.

All the researches carried out up to now to harmonize the data collected by different devices by following the same test method, to try to obtain a harmonized indicator, haven't been successful enough. Nevertheless the use of this common test method is essential to go further in the harmonization process in the coming years.

At present, it is quite clear that to try to compare different devices by fixing only the test method provides very rough results. That is the reason why the following harmonization process will be devoted to attempt to improve the results by comparing the same types of devices and by using a common test method.

But, from the information available in the COST 354 database it's not possible to give any proposal about the protocols and the test method for measuring friction coefficient to determine harmonized skid resistance indicators.

4.6 ASSESSMENT OF THE TRANSFORMATION FUNCTIONS

As it has been discussed in previous chapters, it is not possible, at this moment, to decide which one is the best transformation function from those included in the COST 354 database. As a consequence, it's probable that each country keeps its knowledge and continues working with its own transformation functions and indicators if they exist. But, in case some administrations or countries decide to implement a new approach, the analysis included in this section has been carried out.

The following analysis has been made to produce a transformation function that takes into account all of the information provided in the database, giving the same weight to all the records included in the database.

After the analysis conducted for comparing the different transformation functions and limits (cfr. Chapter 4.2 in this section) it was noticed that the transformation functions from Austria and from Germany provided very similar values when the technical parameter varies from 0.4 to 0.6 (Figure 74). These two transformation functions are based in measurements taken at an operating speed of 60 km/h.

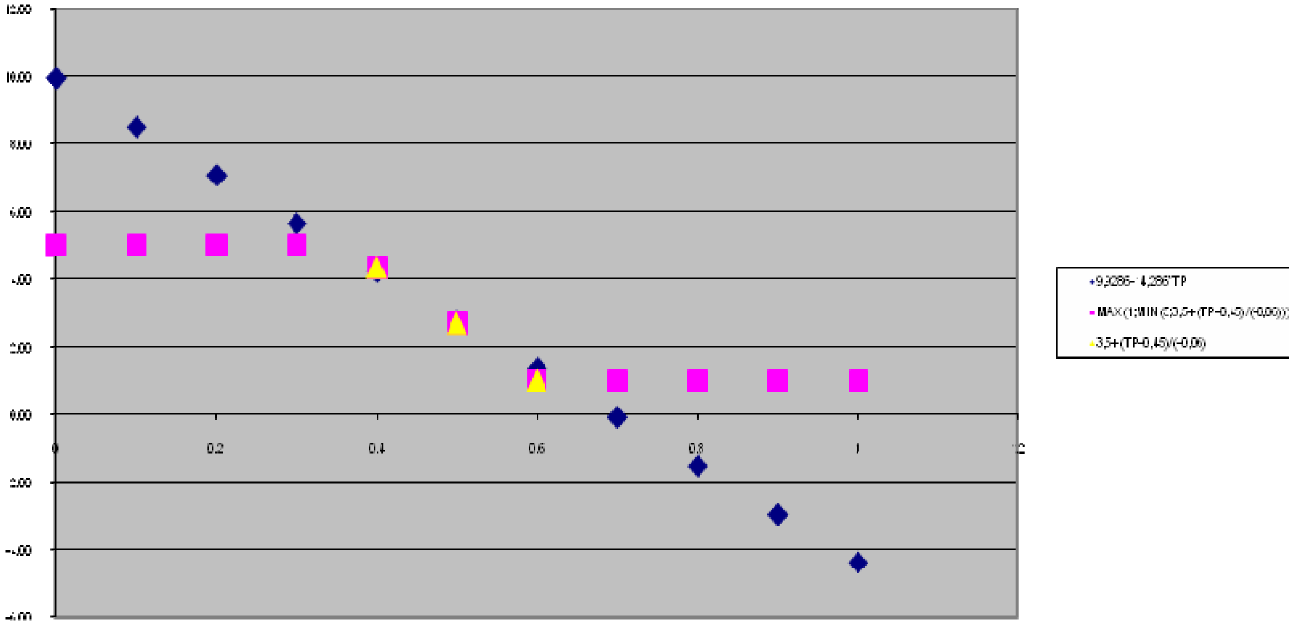

Figure 74: Transformation functions from Austria to Germany (at 60 km/h)

But, as it has been noticed in chapter 4.2.1 (correlations between transformation functions), when the function has an “S” shape (as occurred for the function provided by Germany) there is no correlation with the other ones. Therefore, for the remaining analysis, it was decided that for the transformation function provided by Germany only the part where the TP ranges from 0.4 to 0.6 will be considered.

The other transformation function that uses data obtained at 60 km/h is the one provided by Poland (100-180*TP). But, in this case the scale for the indicator varies from –80 (best case) to 100 (worst case). Therefore, the next step was to divide the whole expression by 10 in order to obtain a similar scale than the other two Transformation Functions.

Finally, the transformation function provided Belgium by (4*(TP-0.1)/3) has been analysed as well, although the data in the country is collected at 50 km/h the difference seems to be small. In this case it has been necessary not only to adapt the scale by multiplying by 10, but to reverse the function to allow for a decrease in the Transformed Value when the TP increases. This was needed to make the function consistent with the other three functions analysed before. The resulting expression is 10-40*(SFC-0.1)/3.

In Table 51 the 4 original transformation functions provided are indicated in columns 2 (Austria), 3 (Belgium), 5 (Germany) and 7 (Poland) with a list of the values assumed by the transformed value for each given value of the TP (form 0 to 1). These columns are coloured in yellow for ease of reading. In the same Table the modified or limited functions are listed in columns 4 (for Belgium), 6 (for Germany) and 8 (for Poland). These modifications are the ones described above.

Table 51: Original transformation functions (yellow cells) and transformed transformation functions (green cells)

TP	9.9286-14.286*TP	4*(TP-0.1)/3	10-40*(TP-0.1)/3	MAX(1;MIN(5;3.5+(TP-0.45)/(-0.06)))	3.5+(TP-0.45)/(-0.06)	100-180*TP	10-18*TP
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	AUSTRIA	BELGIUM	BELGIUM modified	GERMANY	GERMANY (0.4-0.6)	POLAND	
0	9.93	-0.13	11.33	5.00		100.00	10

TP	9.9286-14.286*TP	4*(TP-0.1)/3	10-40*(TP-0.1)/3	MAX(1;MIN(5;3.5+(TP-0.45)/(-0.06)))	3.5+(TP-0.45)/(-0.06)	100-180*TP	10-18*TP
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	AUSTRIA	BELGIUM	BELGIUM modified	GERMANY	GERMANY (0.4-0.6)	POLAND	
0.1	8.50	0.00	10.00	5.00		82.00	8.2
0.2	7.07	0.13	8.67	5.00		64.00	6.4
0.3	5.64	0.27	7.33	5.00		46.00	4.6
0.4	4.21	0.40	6.00	4.33	4.33	28.00	2.8
0.5	2.79	0.53	4.67	2.67	2.67	10.00	1
0.6	1.36	0.67	3.33	1.00	1.00	-8.00	-0.8
0.7	-0.07	0.80	2.00	1.00		-26.00	-2.6
0.8	-1.50	0.93	0.67	1.00		-44.00	-4.4
0.9	-2.93	1.07	-0.67	1.00		-62.00	-6.2
1	-4.36	1.20	-2.00	1.00		-80.00	-8
SCALE 0-1	SCALE 9.93-(-4.36)	SCALE (-0.13)-1.20	SCALE 11.33-(-2)	SCALE 5-1	SCALE 11-(-5.67)	SCALE 100-(-80)	SCALE 10-(-8)
	60 KM/H	50 KM/H	50 KM/H	60 KM/H	60 KM/H	60 KM/H	60 KM/H

When combining the different transformation functions the following results are obtained:

- The linear regression obtained by combining the two functions is listed in columns 4 and 5 of Table 51 (9.9286-14.286*TP and 3.5+(TP-0.45)/(-0.06)) a linear correlation between the Transformed Value and the TP can still be derived with a very high determination coefficient of 0.999, as shown in Figure 75;
- Combining the three functions listed in columns 4, 5 and 8 of Table 51 (all related to a 60 km/h measurement), the diagram shown in Figure 76 is obtained. There is more scatter than before but a linear correlation can still be obtained with a determination coefficient is still very high (0.955);
- The linear regression obtained using all the 4 transfer functions available (columns 3, 4, 5 and 8 of Table 51) is characterised by a lower determination coefficient (0.8979) as shown in Figure 77.

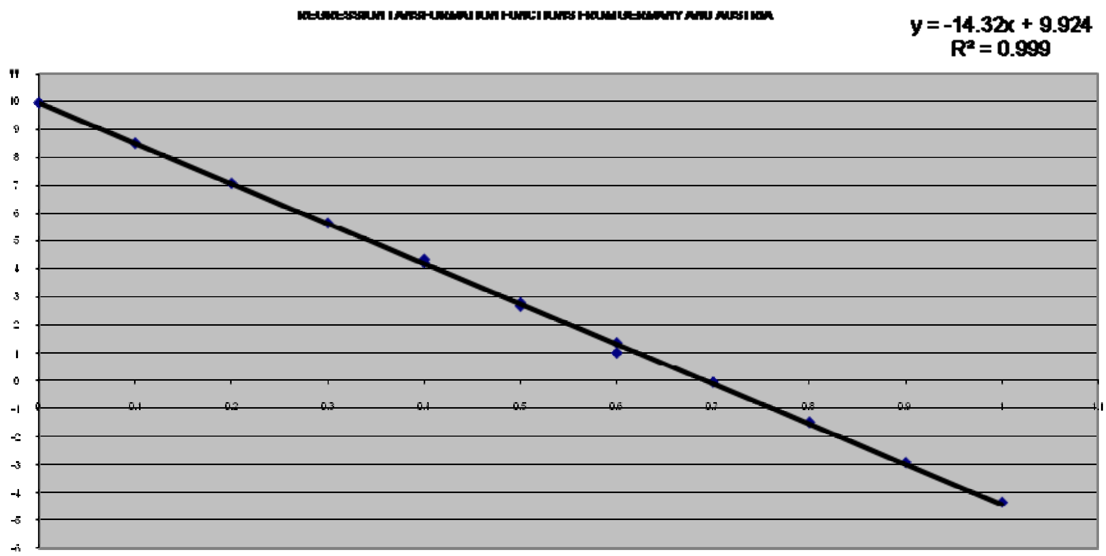

Figure 75: Correlation between the transformation functions: 9.9286-14.286*TP and 3.5+(TP-0.45)/(-0.06)

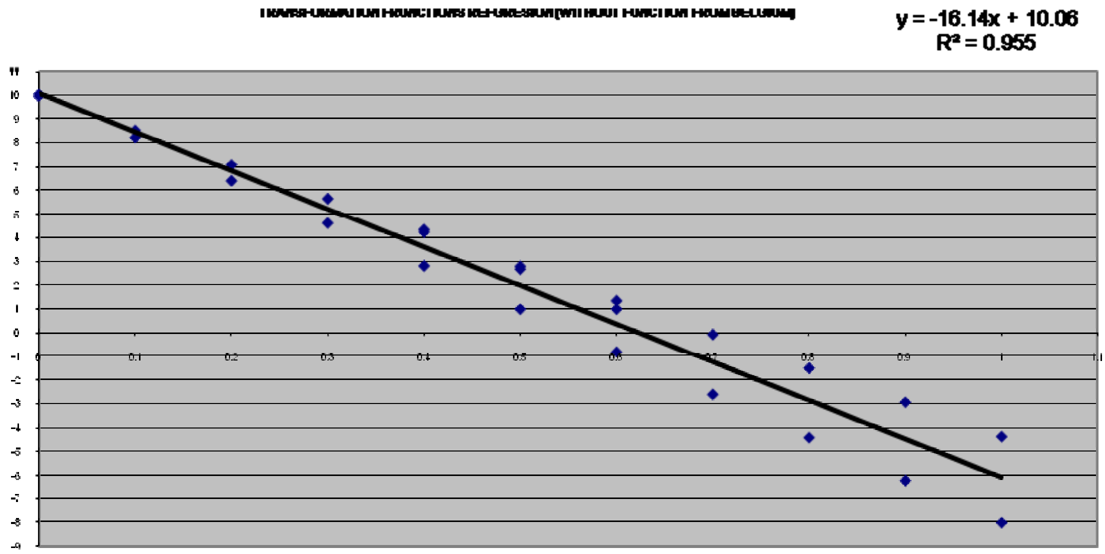

Figure 76: Correlation between the transformation functions: 9.9286-14.286*TP. 3.5+(TP-0.45)/(-0.06) and 10-18*TP

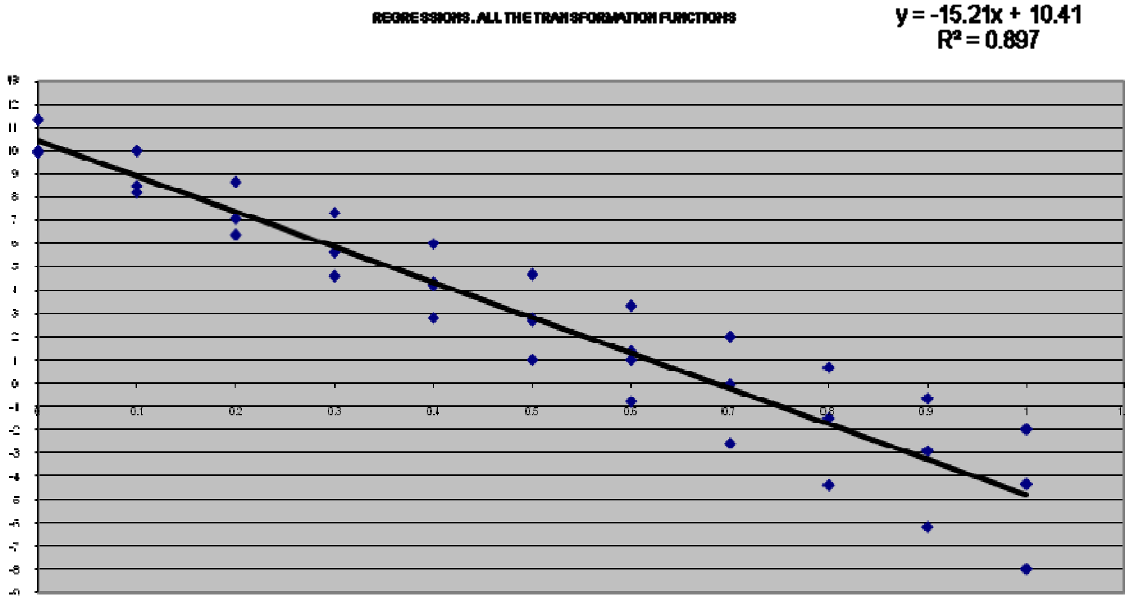

Figure 77: Correlation between the transformation functions: 9.9286-14.286*TP. 3.5+(TP-0.45)/(-0.06). 10-18*TP and 10-40*(SFC-0.1)/3

As it can be seen the accuracy of the transformation function decreases as the number of functions averaged is increased but there is still a very good determination coefficient when all 4 of the available functions (modified as described earlier) are considered. For this reason it was decided to consider this function as the proposed transfer function.

Given the fact that the Transformed Value ranges from 10.41 (when TP is 0) to -4.8 (when TP is 1) while the unitless Performance Index for friction (PI_F) has to range from 5 (very poor) to 0 (very good) the transfer function had been modified accordingly. It should be noted that the minimum and maximum value of the Transformed Values do not necessarily match the minimum and maximum values of the PI_F.

To relate these two indices the same assumptions already discussed in section 1 were made (see chapter 1.5.2) these were:
- The threshold level is assumed to represent the limit between poor and very poor conditions (PI_F=4);
- The warning level is assumed to represent the limit between fair and poor conditions (PI_F=3).

For this analysis the limits derived for primary roads for SFC and LFC devices have been considered. The details on these limits are described in chapters 4.2.2.1.1 and 4.2.2.1.2 of this report.

In Table 52 the values of PI_F obtained through these assumptions and the Transformed Values (Y) obtained by means of the transformation function defined earlier are shown. As it can be seen they can differ considerably (form 4 to 5.24 in the case of the LFC transfer function). It was therefore decided to average the two figures to obtain an overall transfer function, limited between PI_F=0 and PI_F=5 as shown in Figure 78.

The proposed transfer functions are therefore:
- When measuring with SFC devices (or other side force coefficient devices) at an operating speed of 60 km/h:
  PI_F = MAX(0;MIN(5;-17.600*SFC+11.205)) being SFC in a 0 to 1 scale.
- When measuring with LFC devices at an operating speed of 50 km/h:
  PI_F = MAX(0;MIN(5;-13.875*LFC+9.338)) being LFC in a 0 to 1 scale.

Table 52: Indices obtained by using the three transformation functions

	LIMIT VALUES in a [0 to 1] scale	PI_F	Y=-15.215X+10.412
THRESHOLD SFC (at 60 km/h)	0.40	4	4.33
WARNING SFC (at 60 km/h)	0.45	3	3.57
THRESHOLD LFC (at 50 km/h)	0.34	4	5.24
WARNING LFC (at 50 km/h)	0.42	3	4.02

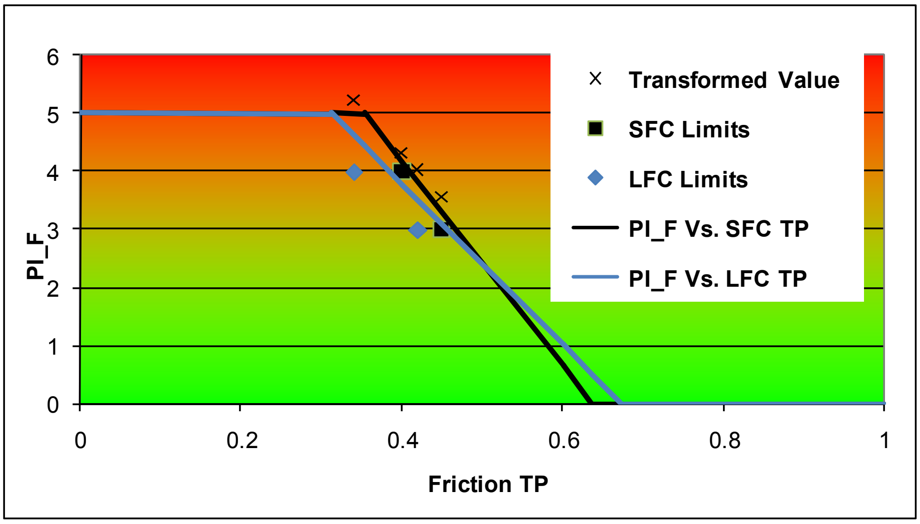

Figure 78: comparison between thresholds and warning limits and Transformed Values and proposed PI_F functions.

4.7 CORRELATION BETWEEN THE SELECTED INDICATOR AND THE USED INDICATORS

The results included in this chapter are those obtained by correlating the indicators used by the four countries that provided transformation functions versus the indicators calculated from the proposed transformation functions. The device used by each of these four countries has been taken into account in order to select the adequate proposed transformation function.

The regression obtained by taking into account the indicators used in Austria is included in Figure 79. Austria reports in the database 5 classification classes (very good, good, fair, poor and very poor) with the indicators varying from 1 to 5. Such scale is the one that has been taken into account to obtain the results in Figure 79.

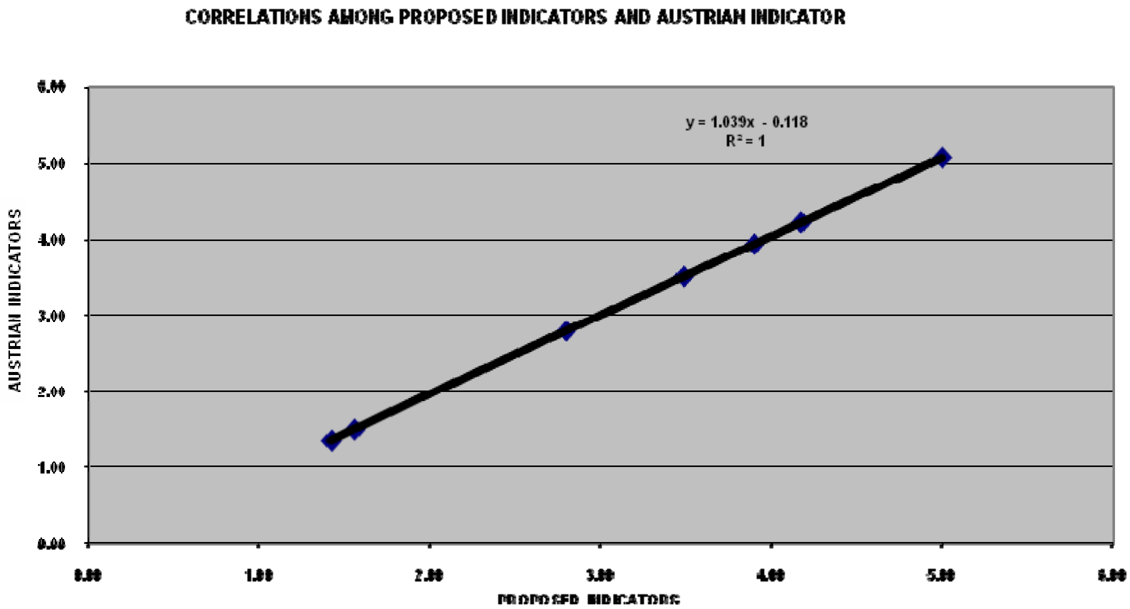

Figure 79: Proposed indicator vs. Austrian indicator

Again, 5 classes have been reported for the indicator used in Belgium, with a scale from 1 (very good) to 0 (very poor). The results of the correlation are shown in Figure 80. Although these results seem to be good, statistically it is not acceptable to create a correlation like the one shown by using the whole range. That is the reason why in the same figure the linear regression in the range 0.8 to 0.2 has been obtained as well (pink colour). In this case the correlation is acceptable and the difference between it and the other regression in the same figure is that the cases classified as very poor and very good are not included.

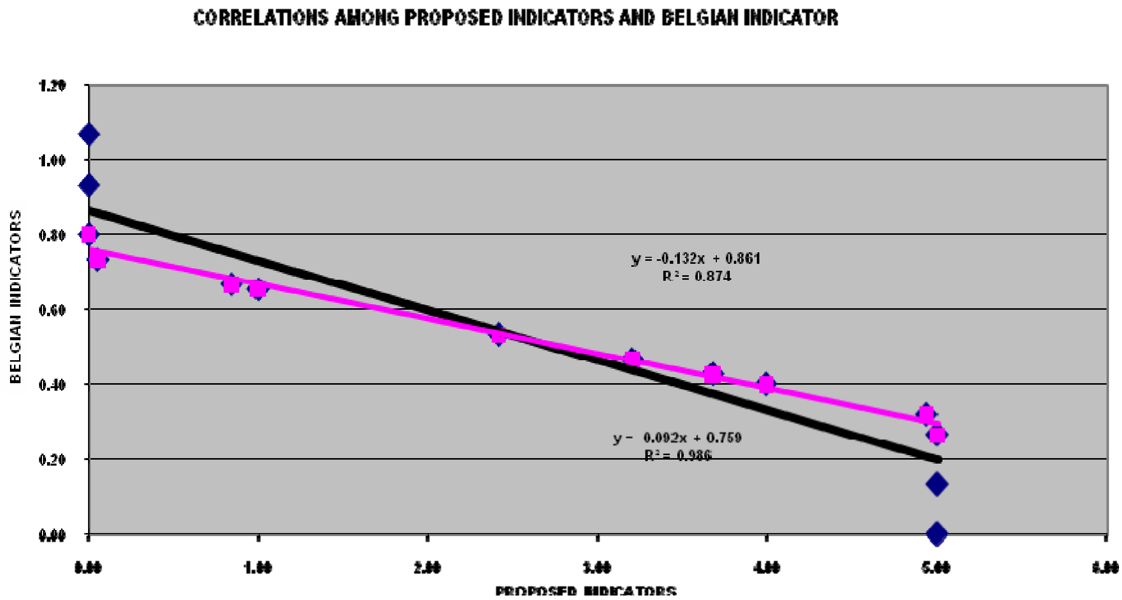

Figure 80: Proposed indicator vs. Belgian indicator

The results obtained from the indicators used in Germany are shown in Figure 81. Four classes have been reported in the database (very poor, poor, fair and good) with a scale from 1 to 5 which is shown in the figure.

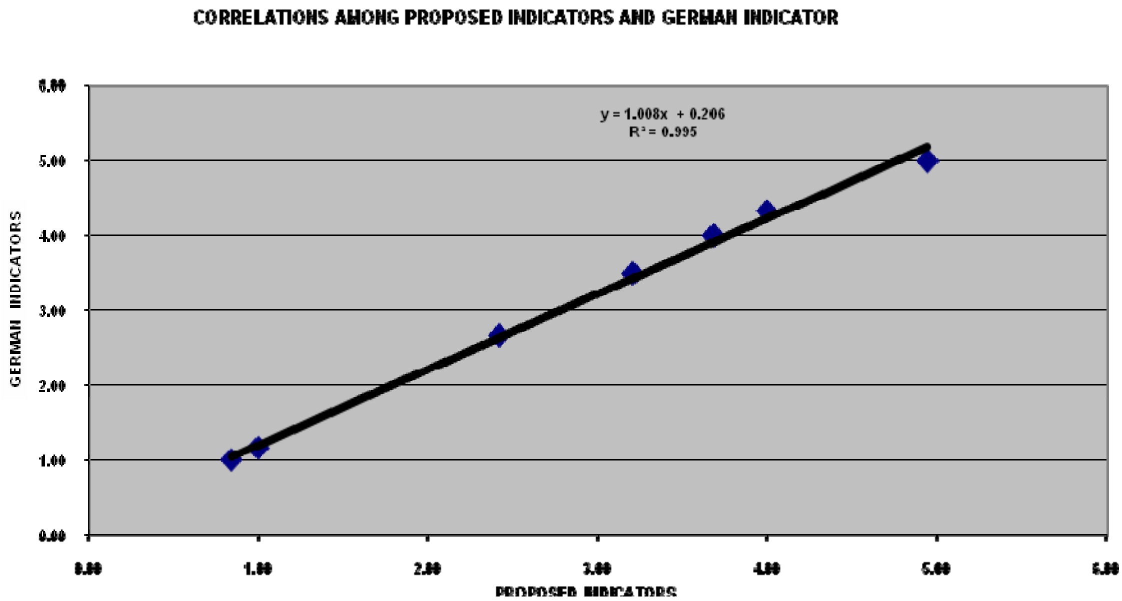

Figure 81: Proposed indicator vs. German indicator

Finally, the correlation obtained by analysing the Polish indicators is shown in Figure 82. Four classes are defined in Poland (good, fair, poor and bad) in a scale 8.2 to 47.8, which is the range showed in the figure.

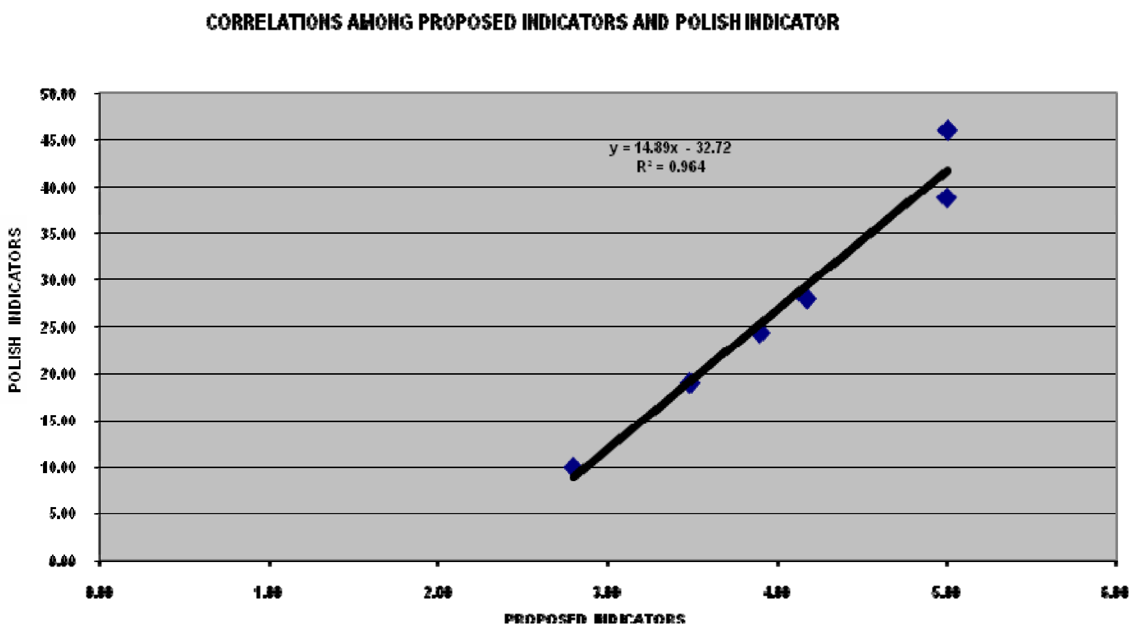

Figure 82: Proposed indicator vs. Polish indicator

From the results obtained in this chapter, it can be concluded that the correlations between the national indicators analysed here and the proposed indicators seems to be acceptable in the range used in each country.

4.8 REFERENCES

1. PIARC "*International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements*" Doc. AIPCR 01.04.T-1995
2. HERMES – "*Harmonization of European Routine and research Measuring Equipment for Skid Resistance*", FEHRL Project (www.fehrl.org)

SECTION 5: NOISE

5.1 NOISE POLLUTION INDICATORS FROM THE COST 354 DATABASE

Only 4 of the involved 22 countries represented in the database have provided information about noise pollution.

Analyzing the database it was found that several answers from one country mean that, as a matter of fact, different measuring devices or different technical parameters are used and therefore it is correct that they are included in further analyses. Table 53 shows that 7 records are analyzed.

Table 53: Number of countries, questionnaires and records referred to noise performance indicator

COUNTRY	TOTAL	Noise
	Nº QUESTIONNAIRES	Nº RECORDS
AUSTRIA (AT)	1	2
NETHERLANDS (NL)	1	3
SPAIN(ES)	1	1
UNITED KINGDOM (UK)	1	1
	4	**7**

5.1.1 General information

For the noise pollution performance indicator different technical parameters are used in individual countries.

TP are in the database described with:
- the name,
- the TP description,
- the abbreviation,
- the unit
- the measuring equipment and measuring principle.

WG 1 unified the information because some fields contained different information for the same equipment or measuring principle.
In the database there are 4 unified types of technical parameters describing noise pollution:
- CPX: A-weighted sound pressure level measured by microphones located close to the tyre-road interface.
- SPB: Maximum A-weighted sound pressure level measured by road side microphones
- N: Laser
- L_{den}: Noise predictive model calculation and/or sound level meter measurements

Table 54 gives an overview of the relevant information. The column *Name Ind (unified)* is partly empty in the COST-354 database and completed in Table 54. The identified TPs are then summarized in Table 55.

Table 54: Description of noise technical parameters from the COST-354 Database

Code-Country	Name	Name TP (unified)	TP description	Measuring Principle (unified)	Name Ind (unified)
AT	Rolling noise	Tyre/road sound level	Rolling noise level	A-weighted sound pressure level measured by microphones located close to the tyre-road interface	CPX
AT	Pass-by noise	Tyre/road maximum sound pressure level	Statistical pass-by index	Maximum A-weighted sound pressure level measured by road side microphones	SPB
ES	Rolling noise	Tyre/road sound level	Rolling Noise	A-weighted sound pressure level measured by microphones located close to the tyre-road interface	CPX
UK	Noise	Noise	Noise	Laser	N
NL	Noise charact eristic	Tyre/road maximum sound pressure level	effect road surface on noise emission	Maximum A-weighted sound pressure level measured by road side microphones	SPB
NL	Noise charact eristic	Tyre/road sound level	noise emission	A-weighted sound pressure level measured by microphones located close to the tyre-road interface	CPX
NL	Environ mental noise	A-weighted long term average sound level	Long term average soundlevel	Noise predictive model calculation and/or sound level meter measurements	L_{den}

Table 55: Summary of technical parameters specified for noise

Name of the index	No. records	No. Countries	Countries
SPB	2	2	A, NL
CPX	3	3	A, E, NL
L_{den}	1	1	NL
N	1	1	GB

5.1.2 Category of the PI

All indicators are (only) related to Environment.

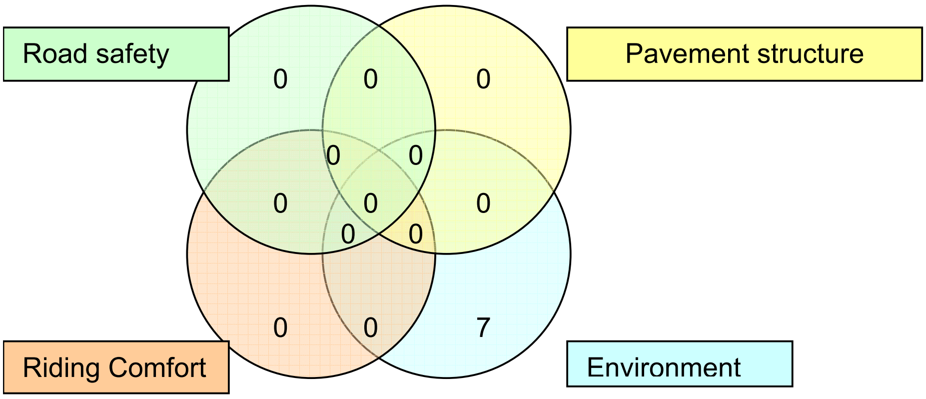

Figure 83: Distribution of noise PI by category

5.1.3 Field of application – distribution by road network

All indicators are applicable on Motorways and Primary Roads, the main issues for this COST-action.

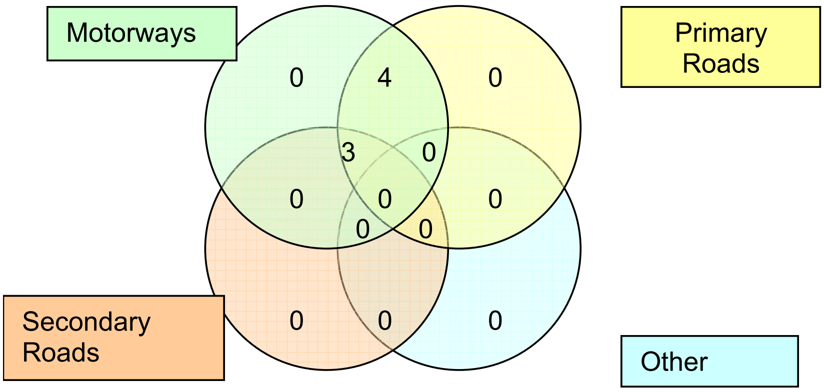

Figure 84: Distribution of noise PI by road network

5.1.4 Distribution by Level of Application

Based on the data contained in the COST 354 database the following conclusions on the use of noise PIs can be drawn:

- CPX can only be used on project level (1 country didn't answer the question).
- SPB can either be used on only network (NL) or only project (AT) level.
- L_{den} and Noise can be used on both network and project level.

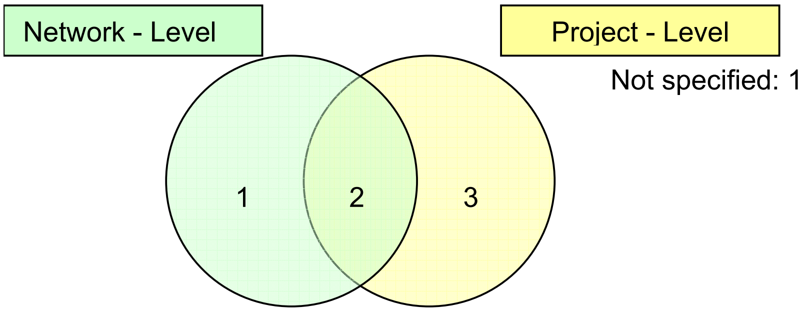

Figure 85: Distribution of noise PI by level of application

5.1.5 Distribution by Pavement Type

All methods can be used on the 3 pavement types.

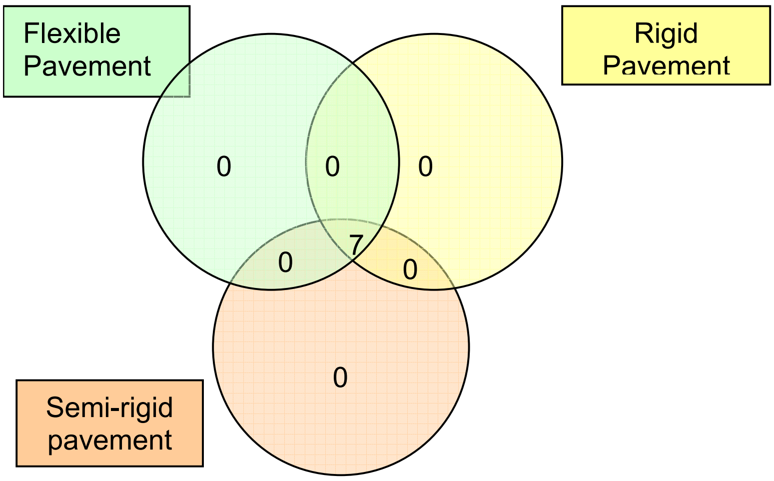

Figure 86: Distribution by pavement type

5.1.6 Type of application

Only L_{den} refers to both standard and research (name of the standard is Directive 2002/49/EC d.d. 25 June 2002).

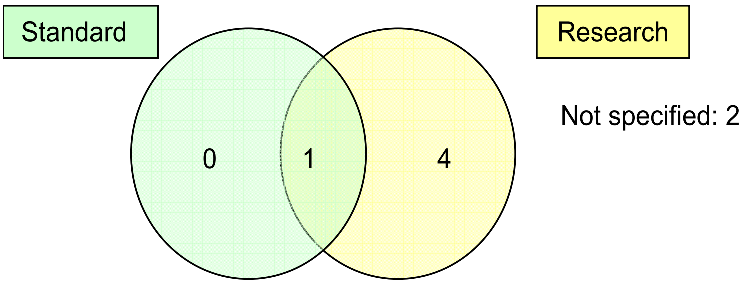

Figure 87: Distribution by type of application

5.1.7 Standardization

Table 56 shows the standards in use for noise measurement. As it can be seen SPB is the only TP that refers to an international standard; an international standard for CPX is under development.

Table 56: Standards and specifications used for noise performance indicators

Code-Country	Name Ind (unified)	Standard	Name of Standard	Equipment Name
AT	CPX	National Standard	RVS 11.066 - Teil IV, Rollgeraeuschmessung	Rolling noise trailer
AT	SPB	ISO-Standard	ISO 11819-1 Acoustics - Measurement of the influence of road surfaces on traffic noise, part I: Statistical pass-by method	Microphone
ES	CPX	ISO-Standard	ISO/CD 11819-2 Acoustics - Method for measuring the influence of road surfaces on traffic noise. Part 2: The close-proximity method	
UK	N	Technical Specification	IAN 42/05 - Traffic-Speed Condition Surveys (TRACS): Revised Assessment Criteria	Road Assessment Vehicle (RAV)
NL	SPB	ISO-Standard	ISO 11819-1 Acoustics - Measurement of the influence of road surfaces on traffic noise, part I: Statistical pass-by method	
NL	CPX	Technical Specification	ISO/CD 11819-2 Acoustics - Method for measuring the influence of road surfaces on traffic noise. Part 2: The close-proximity method	CPX trailer
NL	L_{den}	EC-Standard	Directive 2002/49/EC d.d 25 June 2002	VenW wegen geluid model/Silence

5.1.8 Measuring principle

The details of the different measuring principles used for noise PIs are shown in Table 57.

Table 57: measuring principle details

Code-Country	Name Ind (unified)	Details of Data Collection (as given in the database)
AT	CPX	2 microphones in defined distances to the tyre (PIARC tyre)
AT	SPB	maximum A-weighted sound pressure level (SPL),vehicle speed
ES	CPX	Number of measurements depend on speed. Averaged each 20 m. Data are processed to obtain homogeneous section with hypotheses of normal distribution and 95% confidence. Measurements are corrected depending on actual speed and pavement temperature
UK	N	Noise calculated using algorithm based on surface type and texture profile.
NL	SPB	SPL measurement alongside the road on regular vehicles passing by, combined with speed measurement. Regression analysis gives a normalised SPL at specified speeds for 3 vehicle categories, passenger cars / dual axle and multi axle heavy vehicles.
NL	CPX	SPL measurement with 2 microphones at short distance from car tires. SPL data is measured over 20m segments. Result is the average over 4 different specified tires.
NL	L_{den}	Using parameters for the road (location, elevation, traffic, volume & speed) sound levels from the traffic on the road are generated. Based on this and the characteristics of the surroundings the sound level on a certain distance can be calculated.

5.2 COMPLEMENTARY INFORMATION DERIVED FROM LITERATURE

5.2.1 HARMONOISE

The HARMONOISE project (Aug 2001- Jan 2006) produced methods for the prediction of environmental noise levels by road and railway traffic (3). These methods are intended to become the harmonized methods for noise mapping in all EU Member States.

The methods are developed to predict the noise levels in terms of L_{den} and L_{night} , which are the harmonized noise indicators according to the Environmental Noise Directive 2002/49/EC.
Reports can be found on: http://www.imagine-project.org

5.2.2 Silvia

The EU Fifth Framework Project "SILVIA – Sustainable Road Surfaces for Traffic Noise Control" provided a "*Guidance manual for the implementation of low-noise road surfaces*" (4), published as a FEHRL Report.

The manual gives the following measurement procedure[1]:

"9.3 Labelling procedures in the classification system
The classification system identifies specific measurement procedures necessary for labelling the acoustic performance of a road surface. These measurement procedures are described in Appendix A. There are two possible labelling procedures:

- *LABEL1 (preferred): Assessment based on SPB and CPX measurements;*
- *LABEL2: Assessment based on SPB measurements and measurements of intrinsic properties of the road surface, e.g. texture and sound absorption.*

[1] The literature references in square brackets are referred to the Silvia report reference list. With reference to the current report the following correspondence can be established: [26] is ref (1) of this report while [113] is reference (2). More details on SILVIA references can be found in (4).

Both noise labels are based on SPB measurements [26]. However, due to the limitations of the SPB method in assessing only a small section of a test surface, additional measurements to assess the acoustic performance over the full length of the trial section is required. LABEL1 includes a direct assessment of noise over the entire length of the trial surface using the CPX method [113] and is the preferred method. LABEL2 allows for an indirect assessment based on measurements of the intrinsic properties of the surface which can be related to the generation and propagation of noise e.g. texture and sound absorption."

CPX is used by at least:
- U.K., Norway, Sweden/Poland, Germany, Spain, USA, Netherlands, France, Austria, Denmark, Finland

5.2.3 Environmental Noise Directive 2002/49/EC

The Environmental Noise Directive is a direct result of the European Union's Noise Policy Green Paper from 1996. It covers transportation and industrial noise in the environment. The directive requires that noise maps and action plans (noise policy) be made for:

- Agglomerations with populations greater than 100 000
- Major roads with more than 3 000 000 vehicles a year (approximately 8 000 a day)
- Major railways with more than 30 000 trains a year
- Major civil airports with more than 50 000 operations per year (approximately 135 day)

Noise maps show the L_{DEN} (the L_{Aeq} where evening and night time levels are given a penalty of 5 and 10 dB, respectively) and L_{night} (the night time L_{Aeq}) of each type of source (road, rail, industry, etc.) at a height of 4m over the ground. Aggregation of levels from different sources can be performed with a stated method. The European Union requires the making of maps of transportation and industrial noise using current models that comply with certain demands. The following methods are recommended:

- Industrial sites: ISO 9613
- Roads: NMPB-96 (the French method)
- Railways: RLM2 (the Dutch method)
- Airports: ECAC 29

Later, noise maps are made using harmonized techniques.
The general public must be informed and consulted during the process, and the European Environment Agency in Copenhagen will collate the result in a central European database. The first maps for major areas are required by mid 2007, and action plans required one year later. These activities are repeated at five yearly intervals and all defined areas are incorporated in the following round of deadlines starting in 2012. The above are minimum requirements and some countries are expected to go further and faster.
The text of the directive in English can be found on http://europa.eu.int/.

5.3 SELECTION OF THE PROPOSED INDIVIDUAL PERFORMANCE INDICATOR

The criteria for selection of the "best" individual performance indicators are described in 1.3.

These criteria have been applied to the noise performance indicators and the results are shown in Table 58. It should be noted that:

- SPB is a static measurement and therefore not suitable for network-measurement
- L_{den}: the EC is working on a harmonized method for predicting noise levels. HARMONOISE will hopefully be operational in 5 years (see paragraph 5.2). This is more or less a static measurement (computer model).

Table 58: selection table for technical parameters

	SPB	*CPX*	*L_{den}*	*Noise*
European/Int. standard	ISO 11819-1	AT refers to a national standard. NL to ISO TC43. ES to ISO/CD 11819-2. It will take some years before we have ISO 11819-2.	EC-standard: Directive 2002/49/EC dd 25 June 2002	No
Standard practice or research	Standard practice	Research (EU-programme Silenda Via / SILVIA)	Both	Research
Wide use	Only 2 answers but widely spread.	Participation of around12 EU-countries	?	Probably not (only in GB?)
Device independent	Yes	Probably yes	Yes	No (RAV/laser)
Safe to collect	Yes	Probably yes	Yes	Yes
Reliable	Yes	Probably yes	Yes	Unknown
Sustainable	Yes	Probably yes	Yes	Unknown

We do not have the elements to provide a PI for noise pollution at the moment:
- SPB is the only standardized method but it cannot be used for monitoring (it has very strict constraints for the selection of the measurement site and is not suitable for network-measurement);
- CPX is the only real solution but the ISO EN standard is still under development.

The proposal could be: within a couple of years the method to be used is CPX, the index is the one defined by the EN ISO standard and the procedure will be that.

It is worth noting that a PI for noise is not for the interest of road users and road operators, but for the environment of the road. Therefore we need computer models that combine characteristics of the pavement (like SBP or CPX), traffic (amount and speed), surrounding etc.

5.4 REFERENCES

1. ISO 11819-1 "*Acoustics - Measurement of the influence of road surfaces on traffic noise, part I: Statistical pass-by method*"
2. ISO/CD 11819-2 "*Acoustics - Method for measuring the influence of road surfaces on traffic noise. Part 2: The close-proximity method*"
3. HARMONOISE "*Harmonised Accurate and Reliable Methods for the EU Directive on the Assessment and Management Of Environmental Noise*" Final Reports (http://www.imagine-project.org)
4. SILVIA "*Guidance Manual For The Implementation of Low-Noise Road Surfaces*", FEHRL Report 2006/02

SECTION 6: AIR POLLUTION

6.1 AIR POLLUTION INDICATORS FROM THE COST 354 DATABASE

According to the information in the database only 1 of the 24 countries involved gave information about air pollution.

The 2 records deal with different technical parameters.

Table 59: Number of countries, questionnaires and records referred to air pollution performance indicator

COUNTRY	TOTAL	Noise
	Nº QUESTIONNAIRES	Nº RECORDS
NETHERLANDS (NL)	1	2
	1	**2**

Afterwards Sweden added some information; this information is used as far as possible in this overview.

6.1.1 General information

For the air pollution performance indicator different technical parameters are used.

TP are in the database described with:
- the name,
- the TP description,
- the abbreviation,
- the unit
- the measuring equipment and measuring principle.

WG 1 unified some information. In the database there is 1 unified type of technical parameters describing air pollution: Pollution density. Table 60 gives an overview of the relevant information which are then synthesised in Table 61. The column *Name Ind (unified)* is empty in the database and completed in Table 60.

Table 60: Description of air pollution technical parameters for COST-354 database

Code-Country	Name	Name TP (unified)	TP description	Measuring Principle (unified)	Unit TP	Name Ind (unified)
NL	NO_2 concentration	Pollution density	NO_2 concentration	Prefiltering and reactive impregnation	μg/ m^3	NO_2
NL	PM_{10} concentration	Pollution density	PM_{10} concentration	Total amount of filterable particulate	μg/ m^3	PM_{10}
SE		Pollution density	PM_{10} concentration		μg/m^3	PM_{10}

Code-Country	Name	Name TP (unified)	TP description	Measuring Principle (unified)	Unit TP	Name Ind (unified)
SE	Road surface PM_{10} load	Pollution density	PM_{10} mass per m^2 road surface		mg/ m^2	

Table 61. Summary of technical parameters specified for air pollution

Name of the index	No. records	No. Countries	Countries
PM_{10}	2	2	NL, SE
NO_2	1	1	NL
Road surface PM_{10} load	1	1	SE

6.1.2 Category of performance indicator

In this sub-section and in the following paragraphs of this chapter only the data coming from the COST-354 database are used.

Both indicators are related only to environmental issues.

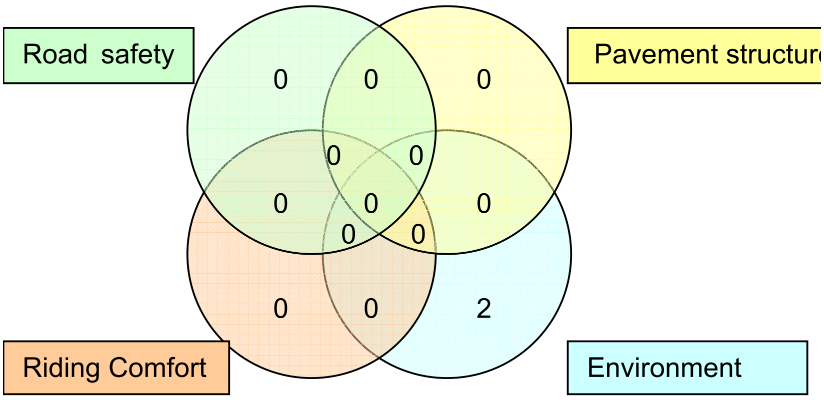

Figure 88: Distribution of air pollution PI by category

6.1.3 Field of application – distribution by road network

Both indicators are applied only on Motorways and Primary Roads.

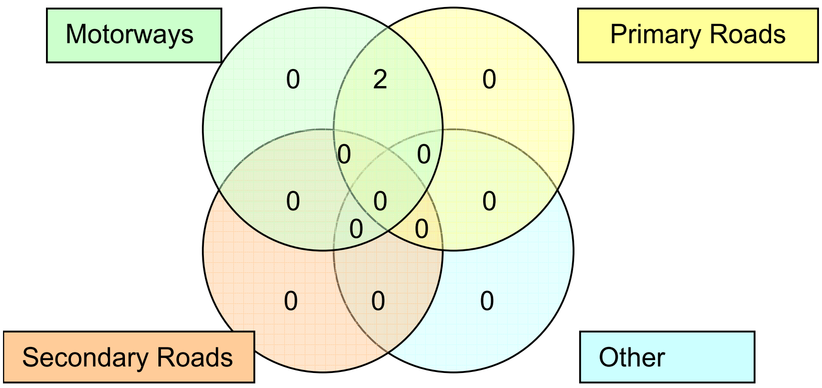

Figure 89: Distribution of air pollution PI by road network

6.1.4 Distribution by Level of Application

Both indicators are applied only at network level.

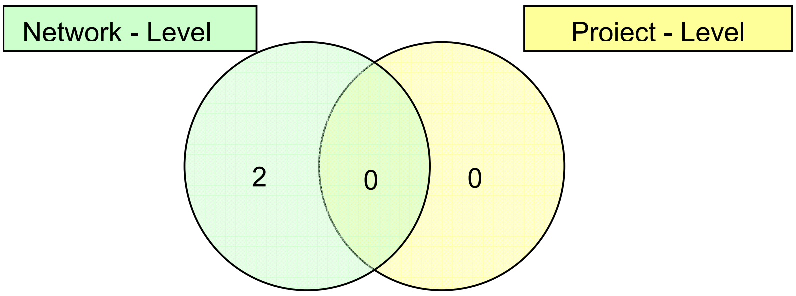

Figure 90: Distribution of air pollution PI by Level of Application

6.1.5 Distribution by Pavement type

Both indicators are applicable for flexible and rigid pavements.

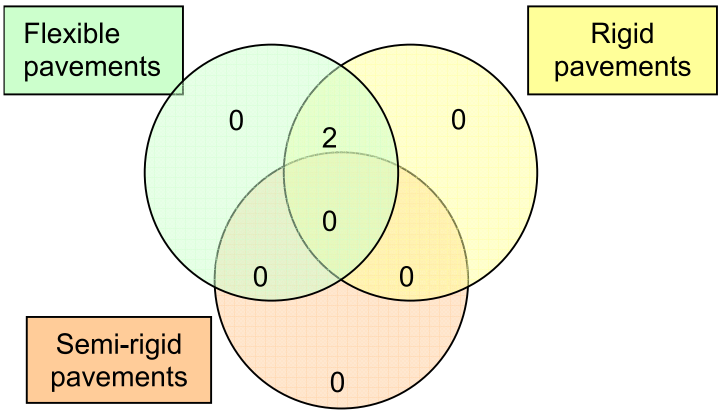

Figure 91: Distribution of air pollution PI by pavement type

6.1.6 Type of application

Both indicators are considered standard practices.

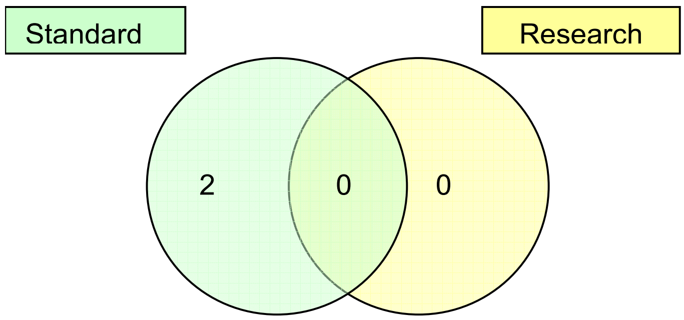

Figure 92: Distribution of air pollution PI by type of application

6.1.7 Standardization

Table 62 shows that there is no international standard to measure air pollution. This table also includes data from Sweden not included in the COST-354 database.

Sweden mentioned TEOM as a European standard, but there is not enough information.

Table 62: Standards and specifications used for air pollution performance indicators

Code-Country	Name Ind (unified)	Standard	Name of Standard
NL	NO_2	No Standard	VLW air quality model
NL	PM_{10}	No Standard	VLW air quality model
SE	PM_{10}	?	TEOM
SE		?	TEOM

6.1.8 Measuring principle

Table 63 details the measuring principles adopted by the Netherlands (as described in the COST-354 database) and Sweden (not in the database) for air pollution characterization.

Table 63: Measuring principle details

Code-Country	Name Ind (unified)	Measuring principle (unified)	Description of measuring principle
NL	NO_2	Total amount of filterable particulate	Model calculation. Transfers profile till 1 km from middle of road, measurement on 10, 20, 30, 40, 50, 75, 100, 200, 300, 400, 500, 750, 1000 m from middle of road, input, traffic intensities, % heavy trucks, meteorology, characteristics of road, roughness surrounding
NL	PM_{10}	Prefiltering and reactive impregnation	Model calculation. Transfers profile till 1 km from middle of road, measurement on 10, 20, 30, 40, 50, 75, 100, 200, 300, 400, 500, 750, 1000 m from middle of road, input, traffic intensities, % heavy trucks, meteorology, characteristics of road, roughness surrounding
SE	PM_{10}	TEOM	Gravimetric method with detection of mass induced frequency changes of oscillating glass rod.
SE	N	WDS (Wet Dust Sampler)	High-pressure water cleans the surface and the cleaning water is sampled and analyzed for particle sizes.

6.2 EVALUATION OF THE MOST SUITABLE PERFORMANCE INDICATORS

6.2.1 Name of the indices and transformation function

Name of the indices:
- PM_{10} concentration
- NO_2 concentration

There are no transformation functions.

6.2.2 Limits

There is legislation from EU: Council Directive 1999/30/EC (limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air).

PM_{10} concentration

	Averaging Period	Limit Value (threshold)	Date by which limit value is to be met
1. 24-hour limit value	24 hours	50 µg/m³ PM_{10} not to be exceed more than 35 times a calendar year	1st January 2005
2. Annual limit value	Calendar year	40 µg/m³ PM_{10}	1st January 2005

NO_2 concentration

	Averaging Period	Limit Value (threshold)	Date by which limit value is to be met
1. Daily limit value	Calendar year	40 µg/m3 NO_2	1st January 2010

6.3 SELECTION OF THE PROPOSED INDIVIDUAL PERFORMANCE INDICATOR

The criteria for selection of the “best” individual performance indicators are described in 1.3. The results for these criteria when applied to air pollution are shown in Table 64.

Table 64: Selection table for technical parameters

		PM_{10} concentration	PM_{10} concentration (TEOM)	NO_2 concentration	Road surface PM_{10} load
1	European/Int. standard	No	Yes ?	No	No
2	Standard practice or research	Standard	Standard	Standard	Research
3	Wide use	?	Yes	?	No
4	Device	Yes	Yes	Yes	?

	independent				
5	Safe to collect	Yes	Yes	Yes	Yes
6	Reliable	Yes	Yes	Yes	?
7	Sustainable	Yes	Yes	Yes	Yes

Proposal for the selection of the best PI

a. There is no international standard to measure air pollution. There is however legislation from the EU.
b. There are Council Directives (e.g. 96/62/EC http//europa.eu.int/ and 1999/30/EC http//europa.eu.int/) that form a framework in the way EU-countries inform Brussels about air-pollution. The EU-countries are obliged to do static measurements. The use of additional information from computer models is allowed and there are some rough restrictions on quality, reliability etc.

Because there is legislation from the EU, the following PI's are recommended:

- PM_{10} concentration
- NO_2 concentration

6.4 PROTOCOLS AND TEST METHODS FOR MEASURING THE PROPOSED INDIVIDUAL INDICATORS.

There are no strict protocols; the following should be used:

a. NO_2: Annex IX of Council Directive 1999/30/EC refers to ISO 7996: *Ambient air -- Determination of the mass concentration of nitrogen oxides -- Chemiluminescence method*.
b. PM_{10} : Annex IX of Council Directive 1999/30/EC refers to pr EN 12341: *Air Quality – Field Test Procedure to Demonstrate Reference Equivalence of Sampling Methods for the* PM_{10} *fraction of particulate matter*.

6.5 ASSESSMENT OF THE TRANSFORMATION FUNCTIONS

There is no data to define a 0 to 5 scale. According to the existing data only 2 classes for both NO_2 and PM_{10} can be defined:

Limits January 1st 2005

Class	NO_2	PM_{10}
1	< 60 - x µg/m^3	< 40 µg/m^3
2	>=60 - x µg/m^3	>=40 µg/m^3

x= 20/9 for each year between 2001 and 2010

Limits January 1st 2010

Class	NO_2	PM_{10}
1	< 40 µg/m3	< 20 µg/m3
2	>= 40 µg/m3	>= 20 µg/m3

SECTION 7: BEARING CAPACITY

7.1 BEARING CAPACITY INDICATORS FROM THE COST 354 DATABASE

Out of the 22 countries represented in the COST354 Database used for the analysis, 12 submitted responses about bearing capacity (55%). The majority of them reported one questionnaire per country. However, UK, Greece, Denmark and Spain submitted two questionnaires each, leading to a total of 16. The list of countries that submitted questionnaires, together with number of records is presented in Table 65.

Table 65: Numbers of countries, questionnaires and records referred to the bearing capacity performance indicator

Country	Total
	Nº Questionnaires
Austria	1
Denmark	2
France	1
Greece	2
Hungary	1
Italy	1
Portugal	1
Serbia and Montenegro	1
Slovenia	1
Spain	2
Switzerland	1
United kingdom	2
TOTAL	**16**

7.1.1 General information

In the COST 354 database there are 5 different technical parameters (TP) identified as bearing capacity performance indicators:

- Deflection;
- Structural number;
- Residual life;
- E-modulus;
- Deflection velocity.

The majority of the countries use deflection as a technical parameter for bearing capacity (12 out of 16 responses representing 10 out of 12 countries). Slovenia only uses residual life while Hungary only uses E-modulus as the TP for bearing capacity. Greece uses structural number as a TP in addition to Deflection and Denmark uses deflection velocity in addition to Deflection.

Figure 93 and Table 66 provide a summary of the analysed technical parameters and corresponding countries where they are used.

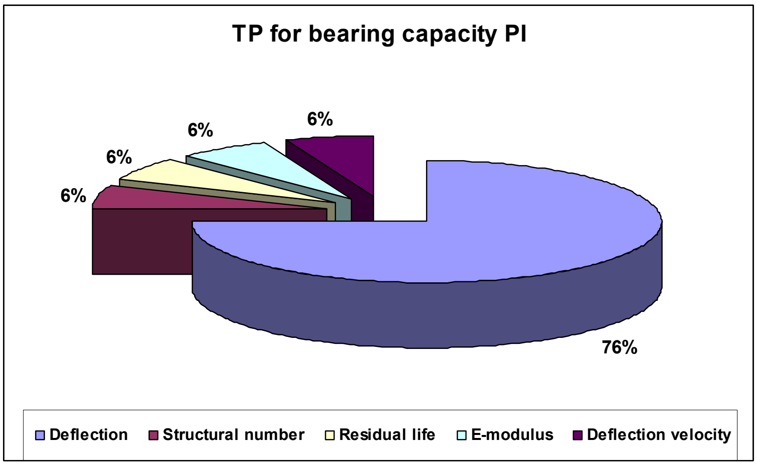

Figure 93: Technical parameters for bearing capacity performance indicator

Table 66: Summary of technical parameters specified for bearing capacity

Technical Parameter	No. Records	No. Countries	Countries
Deflection	12	10	UK[2], AT, EL, IT, FR, CH, DK, PT, ES[2], CS, HR(*)
Structural number	1	1**	EL
Residual life	1	1	SI
E-modulus	1	1	HU
Deflection velocity	1	1**	DK
* information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses. ** these countries use also deflection as a TP for bearing capacity			

7.1.2 Category of performance indicator

In terms of distribution by PI categories the bearing capacity indices are, as expected, always used as pavement structural indicators. As shown in Figure 94 no responders indicated that bearing capacity indices are used also for safety or riding comfort indicators.

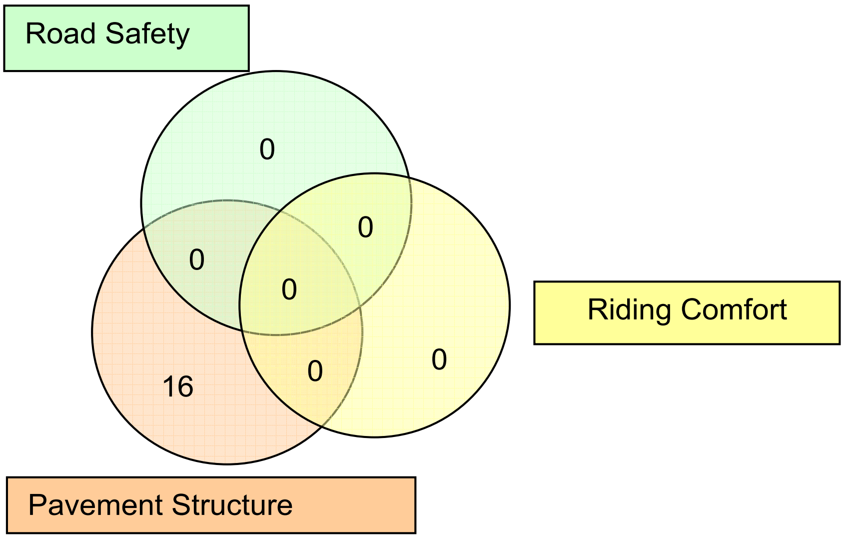

Figure 94: distribution of bearing capacity PI by category

7.1.3 Field of application – distribution by road network

According to the database responses, bearing capacity indices are essentially used in motorways and primary roads with few countries indicating that this type of indicator is also used in secondary roads, as shown in Figure 95. Specifically Slovenia indicated that bearing capacity indices are used only for primary and secondary roads, Hungary, Denmark - only for deflection - and Serbia-Montenegro indicated that these performance indicators are used for motorways, primary roads and secondary roads and only Italy and Switzerland have indicated that these indicators refer to all types of roads.

In a general sense it can be stated that, in the majority of the countries represented in the bearing capacity section of the COST 354 database, the bearing capacity indicators are essentially used for highly trafficked roads.

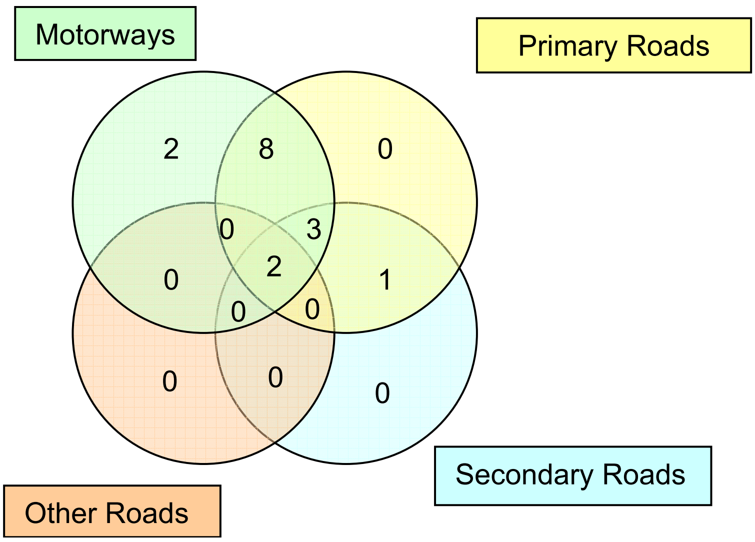

Figure 95: distribution of bearing capacity PI by road network

7.1.4 Distribution by Level of Application

It was extremely interesting to observe that 5 out of the 16 (31%) responses (Denmark – only for the deflection velocity, Italy, Portugal, Slovenia and Switzerland) indicated that the bearing capacity PI is used only at a network level while 4 (25%) responses indicated that the bearing capacity indicators are used both at network and project level. Only 7 responses indicated the bearing capacity index as a project level indicator only.

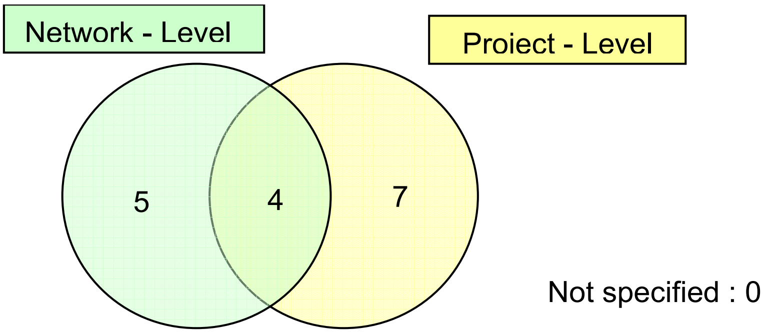

Figure 96: Distribution of bearing capacity PI by level of application

7.1.5 Distribution by Pavement Type

In terms of application of the different indicators to different pavement types most of the responders (9 out of 16) indicated that these are used for both flexible and semi-rigid pavements, while 4 indicated that these are used for all pavement types (Figure 97). It could seem strange that 3 responders (Serbia-Montenegro, Slovenia and Switzerland) indicated that the bearing capacity PI is used for flexible pavements but not for semi-rigid ones. It should be noted however that these countries did not provide any response at all which referred to semi-rigid pavements throughout the database. This indicates that is likely these countries do not use semi-rigid pavements. In the same manner it should be noted that rigid pavements are only used by a minority of countries among the responders to the questionnaire.

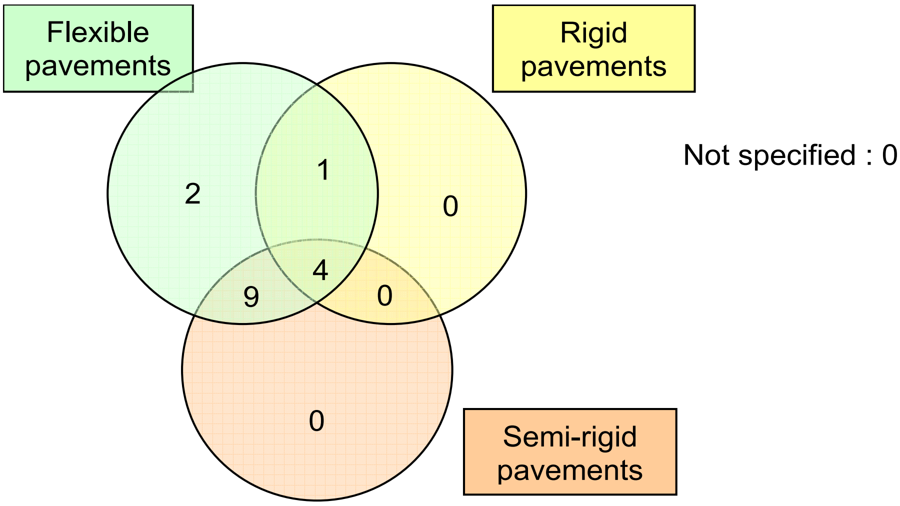

Figure 97: Distribution of bearing capacity PI by pavement type

7.1.6 Distribution by Type of Application

In terms of distribution by type of application (standard or research) it is quite interesting to observe that 6 out of 16 (37.5%) did not specify to which type of application the PI could be referred (Figure 98). Most of the others indicated that is a standard practice (7 out of 16) or both a standard practice and a research activity (2 out of 16). Only the Deflection Velocity index used in Denmark is applied only at a research level.

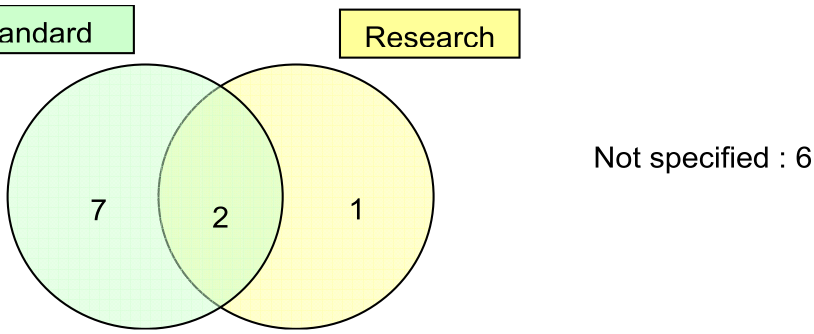

Figure 98: Distribution of bearing capacity PI by type of application

7.1.7 Standardisation

One of the questions in the COST 354 questionnaire was whether the technical parameter is measured according to a national or international standard or if a technical specification was used instead. From the results of the questionnaire synthesised in Table 67 it can be seen that no country refers to an international standard while most of them (excluding only Portugal, UK and Denmark for the deflection velocity) refer either to a national standard or to a technical specification.

Table 67: Standards and specifications used for bearing capacity performance indicators

Country	Standard [NS = national standard; IS = international standard; TS = technical specification]	Technical Parameter
Austria	NS: Evaluation according to RVS 11.066-Teil III, Deflektionsmessung Benkelmanbalken, optische Methode und Deflectorgraf Lacroix	Deflection
Croatia(*)	NS: HRN U.E4.016: Equipment and methods of deflection measurements HRN U.E4.018: Determination of relevant elastic deflection for flexible pavements	Deflection
Denmark		Deflection velocity
	NS: Konstruktion og vedligehold af veje og stier, Hæfte 4, Vedligehold af færdselsarealet, Juni 2004.	Deflection
France	NS: Méthode LPC n° 39	Deflection
Greece	TS: FWD measurements and evaluation: Draft report of NTUA for the Greek Public Ministry	Deflection
		Structural number
Hungary	TS: ÚT 2-2.121/2000 Dinamikus behajlásmérés méretezéshez (KUAB) (Dynamic bearing capacity meassurement by KUAB apparatus)	E-Modulus
Italy	TS: ASTM D 4694-96; ASTM D 4595-96; ASTM D 5858-96	Deflection
Portugal		Deflection
Serbia and Montenegro	NS: JUS U.E8.016 (1981), JUS U.E8.018 (1981)	Deflection
Slovenia	NS: TSC 06.630 Pavement surface properties, Deflections	Residual life
Spain	NS: NLT 338/98 Medida de las deflexiones de firmes con deflectómetro de impacto. 6.3 I.C. Instrucción para la rehabilitación de firmes	Deflection
		Deflection
Switzerland	NS: SN 670 362a "Poutre de Benkelman"	Deflection
United Kingdom		Deflection
		Deflection
* information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses.		

A grouping of the responses in terms of type of standards used for the different Technical Parameters is shown in Figure 99. It can be seen that most of the applications based on deflections are supported by either a technical specification or a standard, however 4 responses (Portugal, Spain [1 out of 2] and UK [2]) indicate that no standard or technical specification is available for that specific application. Out of the other 4 PIs 2 (residual life in Slovenia and E-modulus in Hungary) are based on either a national standard or a technical specification while Structural Number in Greece and Deflection Velocity in Denmark have no specification.

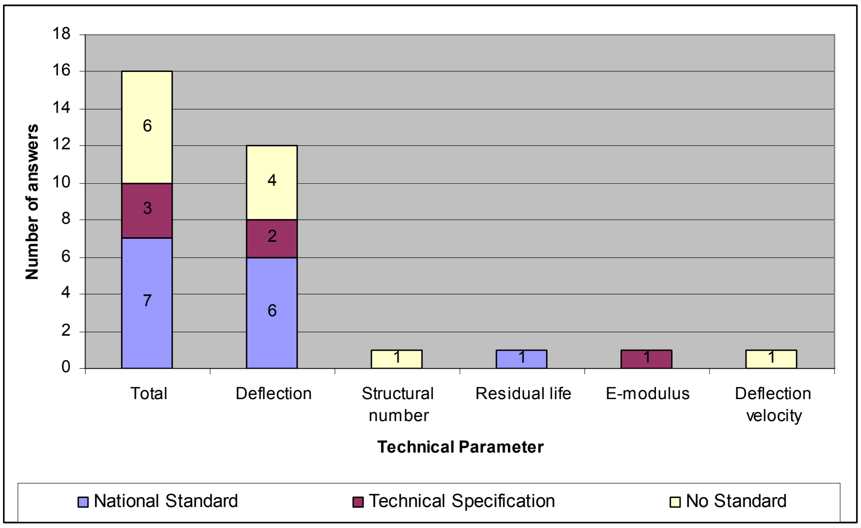

Figure 99: Number of answers grouped by the type of standard for bearing capacity PIs

7.1.8 Measuring principle

In terms of measuring principle Figure 100 clearly shows that the wide majority of responders use a dynamic deflection measurement (11 out of 16) with only Denmark measuring Deflection Velocity with a laser system and 5 responders indicating that a static device is used.

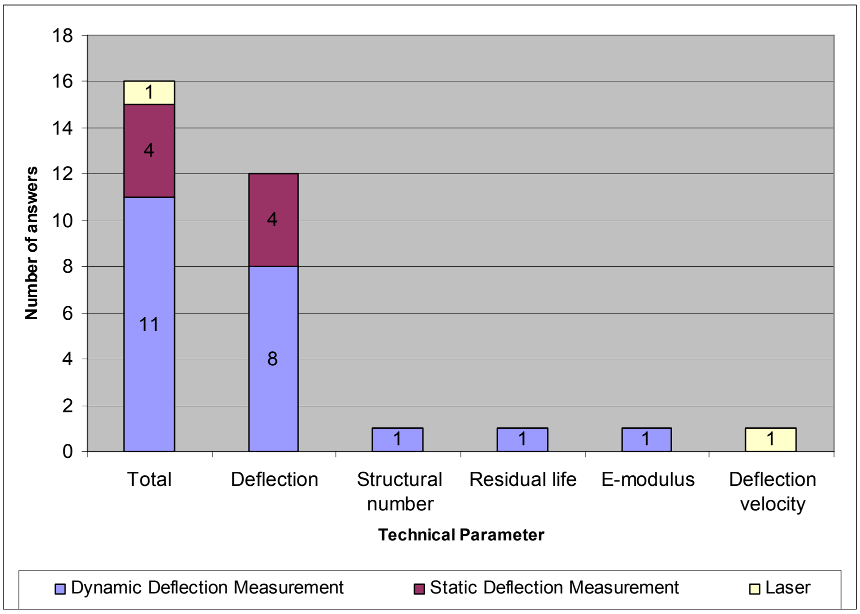

Figure 100: Number of records grouped by measuring principle for bearing capacity

7.2 COMPLEMENTARY INFORMATION DERIVED FROM LITERATURE

Most of the studies aimed at defining a structural performance indicator for bearing capacity agree on the fact that the most suitable one is the residual life of the pavement calculated based on the actual condition and on the expected traffic volume (see, among the others, (1), (2)).

As a matter of fact this is not a true performance indicator but the final result of the analysis of the expected performance of the structure that requires:

- the definition of the actual structure analysed (for instance by means of the layers thicknesses and elastic moduli);
- the definition of the expected traffic loading during its future lifetime;
- the definition of the operating conditions (including environmental conditions);
- the definition of a damage law to allow for the calculation of the residual life of the pavement.

It should be noted, that most of the above aspects are not standardized and commonly agreed among the different authors. In particular the damage law can generally be different from agency to agency. In addition to this, the huge amount of data and calculations required to define the residual life of the pavement does not enable it to have a direct link between a measured Technical Parameter and a Performance Index.

There are in the literature bearing capacity technical parameters that could be used as an easier to use indicator of bearing capacity when a full residual life calculation cannot be performed.

The COST Action 336 “Falling Weight Deflectometer” (3) has conducted an extensive background study, out of which a number of different technical parameters have been identified as suitable for project level analyses (Table 68) or for network level analyses (Table 69).

For network level different types of TP are recommended according to the accuracy required according to the following structure:

- Level 1 is the absolute minimum to have any satisfaction (Budgeting);
- Level 2 is anything in between (Selection and Allocation);
- Level 3 is for the most detailed level, equal or close to Project level (Prioritisation).

Table 68: TP possible TPs for bearing capacity at project level according to COST 336 Action (3)

DEFLECTION BOWL PARAMETER			
NAME	EQUATION	UNIT	PURPOSE
Centre deflection	d_0	µm	Determine overall pavement condition
Non-central deflection	d_r	µm	Determine condition of layer at equivalent depth r
Surface Curvature Index, SCI	$d_0 - d_r$	µm	Determine fatigue of bound layers
Base Damage Index, BDI	$d_1 - d_r$	µm	Determine condition of base layer(s)
Base Curvature Index, BCI	$d_{n-1} - d_n$	µm	Determine condition of subbase layer(s)
Curvature Basin Factor, CBF	$(d_0 - d_r) / d_0$	-	Determine condition of layer at equivalent depth r
Deflection Ratio, DR	d_0 / d_r	-	Determine condition of layer at equivalent depth r

Table 69: possible TPs for bearing capacity at network level according to COST 336 Action (3)

Output data	
Level 1	Centre deflection
Level 2	SN - SCI or similar indices
Level 3	Deflection bowl

Several other studies ((4), (5), (6), (7), (8) and (9)) refer to the SCI as a possible TP for the definition of bearing capacity of a pavement's structure. When FWD testing is performed and in most cases SCI_{300} (D_0-D_{300mm}) is used.

It should be noted that the SCI index, which seems to be the TP most used for FWD testing, is a "deflection" index and not a residual life or structural number representation.

7.3 SELECTION OF THE PROPOSED INDIVIDUAL PERFORMANCE INDICATOR

As noted earlier the most appropriate indicator for bearing capacity would be the assessment of residual life but this is not a Performance indicator that can be assessed directly from a measured Technical Parameter as it requires a complete damage analysis after bearing capacity measurements are conducted. In the section on transformation functions the user will be allowed to produce a Bearing Capacity Performance Index directly from the results of a residual life evaluation but, in order to allow all users to apply the procedures developed in COST 354 action a simpler procedure will also be considered based only on a Performance Indicator that can be related to a measured TP.

The analysis of the COST 354 database as well as the literature review highlighted that both at project and at network level "deflection" is the most used performance indicator of bearing capacity of a road pavement.

For the definition of a Technical Parameter to be associated to the deflection indicator the COST 354 database doesn't provide any indicator common to more than one country, as shown in Table 70.

Literature review highlighted that the most suitable TP to represent is:
$SCI_{300} = D_0 – D_{300}$

where:
SCI_{300} is the surface curvature index, generally in μm
D_0 is the deflection under the load plate, generally in μm
D_{300} is the deflection measured in the geophone located at 300 mm distance from the load plate in μm.

The results of the PARIS Project (9) have shown that this indicator is very well correlated with the crack propagation mechanism in a flexible pavement.

This TP will therefore be selected in this section as the most suitable for the definition of the Performance Indicator “deflection”.

7.4 PROTOCOLS AND TEST METHODS FOR MEASURING THE PROPOSED INDIVIDUAL INDICATOR

As indicated above the PI is actually the deflection and therefore any of the data collection procedures described in COST354 database referred to this PI can be used. These are synthesised in Table 70.

Table 70: TP used in the cost 354 database to quantify the “deflection” PI

Country	Abbr TP	Unit TP	Details of Data Collection
UK	Df	mm	The FWD produces a dynamic impulse load that simulates a moving wheel load. This information can in turn be used in a structural analysis to determine the bearing capacity, estimate expected life, and calculate an overlay requirement
AT	DEF	mm	loading plate 30cm diameter, load 70kN, loading impact time 25 milliseconds
EL	DI	μ	Based on COST 336
IT	PD	μ	
FR	dc	μ	
CH	d	mm	
DK		other	A weight system is dropped onto a set of springs creating a transient load pulse. The magnitude of the load plus surface deflections at different distances from the load centre are monitored
UK	Def	mm	Measurement every 4m
PT	D0	μ	7 deflection sensors; Peak load 78 kN; Flexible loading plate diameter 300 mm
ES	D	μ	The values are corrected by some coefficients depending on the measurement equipment, the humidity of the subgrade and the temperature
ES	D	μ	The values are corrected by some coefficients depending on the measurement equipment, the humidity of the subgrade and the temperature
CS	D0	mm	2 B. beams for both wheel paths; pavement deflection under the heavy wheel load; FWD - 7 geophones

7.5 ASSESSMENT OF THE TRANSFORMATION FUNCTIONS

The final output of the procedure described in this section of the document is the definition of a Performance Index for bearing capacity (PI_B) in a 0 to 5 scale where 0 represents a very good condition and 5 a very bad one.

If the user can provide a residual life for the specific section or network segment analysed the ratio of this residual life to the design life can be used to assess the bearing capacity index according to the graph in Figure 101.

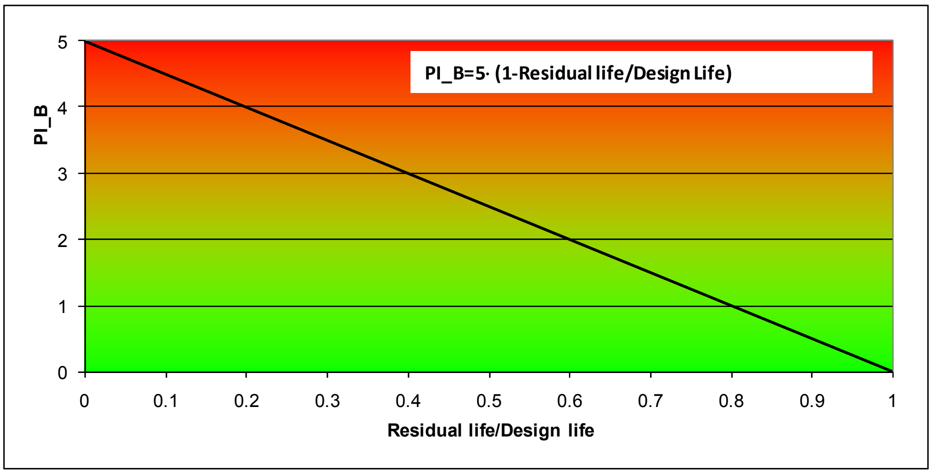

Figure 101: transfer function for Bearing Capacity Performance Index based on residual life

If the SCI_{300} or another deflection indicator is used the user can either:
- provide a Bearing Capacity Index value in a 0 to 5 scale based on their own transfer functions;
- derive the Bearing Capacity Index value from a SCI_{300} value based on the transfer function described below.

The results of the STSM1 (Short Term Scientific Mission No. 1) of COST Action 354 (10) have shown that the two approaches are consistent in determining the structural condition of the pavement, both for flexible and semirigid structures. As a matter of fact the PARIS crack initiation model (9), based on the SCI_{300}, value is extremely well correlated with the Belgian CRR indicator which rates the surface deterioration.

According to Molenaar et al. (6) the vertical compressive strain at the top of the base layer (ε_b) that can be allowed to sustain 10^6 load repetitions is in the order of 630 to 1122 μm/m depending on the structural characteristics of the base material.

This can then be transformed in a limiting value for SCI_{300} based on the equation:

$$\log \varepsilon_b = 0.9962 + 0.8548 \cdot \log SCI_{300}$$

provided in the same paper.

This leads us to consider a limiting value of SCI_{300} between 129 μm (for weak base materials) and 253 μm (for strong base materials).

Assuming a linear relationship between the PI_B and the SCI_{300} limits, a transfer function can be drawn for weak and strong base materials, as shown in Figure 102.

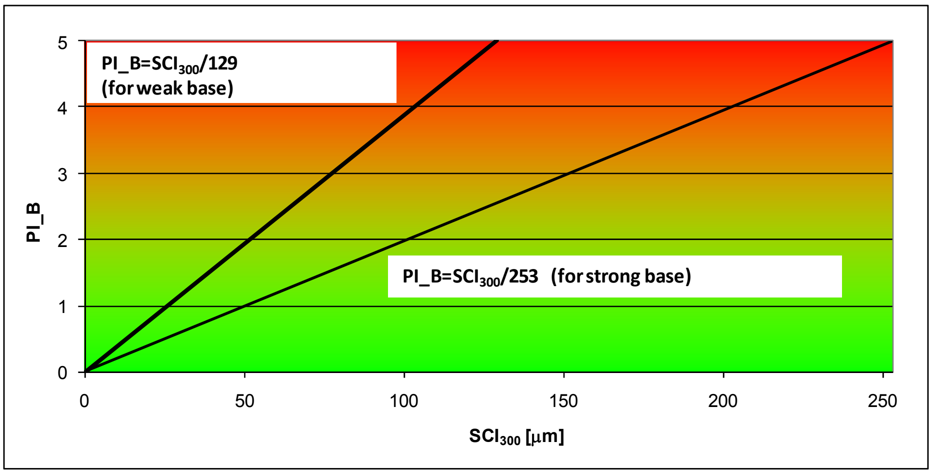

Figure 102: transfer function for bearing capacity index based on SCI_{300} for weak and strong base materials

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SECTION 8: SUMMARY AND CONCLUSIONS

8.1 SYNTHESIS OF SELECTED TP, PERFORMANCE INDICES AND TRANSFER FUNCTIONS

Based on the analysis of each single PI described above a set of “selected” PIs have been identified and are summarized in Table 71. For each of the selected PIs the transfer function that leads from the Technical Parameters (TP) to the unitless PI is also included in Table 71. As it can be seen in some cases there is not a single transfer function as this can depend on the type of road network, on the type of TP used or on the strength of the structure. For longitudinal evenness a “more restrictive” and a “less restrictive” function have been provided to give the user an idea of the range of different solutions adopted in practice.

It is important to note, that it is not mandatory to use the proposed TP as the basis for calculating the Performance Index. If the user is able to provide a transformation function for a different TP, providing a PI on the 0 to 5 scale (0 being good and 5 poor), this can be used in the general indices that will be developed in WP 4 of COST 354 Action instead of the proposed index and transfer function. In the same manner the user can adopt the proposed TP but a different transfer function as compared to those listed in Table 71.

Table 71: synthesis of the selected indicators

PERFORMANCE INDICATOR	TP	PI_index	TRANSFER FUNCTION
Longitudinal evenness	IRI (mm/m)	PI_evenness (PI_E)	PI_E = MAX(0; MIN (5; (0.1733·IRI^2+0.7142·IRI-0.0316))) (more restrictive) PI_E = MAX(0; MIN (5; 0.816·IRI)) (less restrictive)
Transverse evenness	Rut depth [RD] (mm)	PI_rutting (PI_R)	For all road classes: PI_R = MAX(0; MIN (5; (-0.0016·RD^2 + 0.2187·RD))) For motorways and primary roads: PI_R = MAX(0; MIN (5; (-0.0015·RD^2 + 0.2291·RD))) For secondary and local roads: PI_R = MAX(0; MIN (5; (-0.0023·RD^2 + 0.2142·RD)))
Skid resistance	SFC (0 to 1) at 60 km/h LFC (0 to 1) at 50 km/h	PI_friction (PI_F)	PI_F = MAX(0; MIN (5;(-17.600*SFC+11.205))) PI_F = MAX(0; MIN (5;(-13.875*LFC+9.338)))
Macrotexture	MPD (mm)	PI_macrotexture (PI_T)	For motorways and primary roads: PI_T = MAX(0; MIN (5;(6.6 – 5.3·MPD))) For secondary roads: PI_T = MAX(0; MIN (5;(7.0 – 6.9·MPD)))
Bearing capacity	• Residual life/ Design life	PI_bearing capacity (PI_B)	PI_B = MAX(0; MIN (5;(5·(1- R/D))))

	[R/D] (if available) • SCI_{300} (µm)		PI_B = MAX(0; MIN (5;(SCI_{300}/129))) *for weak bases* PI_B = MAX(0; MIN (5;(SCI_{300}/253))) *for strong bases*
Noise	-	-	-
Air pollution	-	-	-

8.2 FUTURE PERSPECTIVES AND RESEARCH NEEDS

The evaluation of the data contained in the COST 354 database has highlighted some basic problems that could be addressed by additional research or that can lead to a change in the selection of the PIs in a close future.

The key issues that arose during the work can be summarized as follows:

- in most cases the most used indicators are "conventional" ones (such as IRI and MPD) but this does not mean that these are the best ones to represent the given performance indicator. Most of the "new" indicators are still in a research stage or used only by a limited number of countries and this lead to the decision that it was not possible to select them as the "proposed PI". The use of these indicators should be encouraged in order to move to these PIs in the near future;
- the use of 0 to 5 Indices are quite uncommon for most PIs and this lead to the need to define a transfer function based on very limited data (as for the macrotexture indicator) or none (as for the bearing capacity indicator);
- some PIs have very limited data (noise and environmental issues) and this, at this stage, doesn't allow to define a 0 to 5 scale Performance Index. In this area there is probably a specific research need.

SECTION 9: GLOSSARY OF TERMS

Performance indicator	A superior term of a technical road pavement characteristic (distress), that indicates the condition of it (e.g. transverse evenness, skid resistance, etc). It can be expressed in the form of a **technical parameter** (dimensional) and/or in the form of an **index** (dimensionless,)[cost 354]
Single performance indicator	A dimensional or dimensionless number related with only one technical characteristic of the road pavement, indicating the condition of that characteristic (e.g. roughness)
Combined performance indicator	A dimensional or dimensionless number related with two or more characteristics of the road pavement that indicates the condition of all the characteristics involved (e.g. PCI-Pavement Condition Index)
Technical Parameter (TP)	A physical characteristic of the road pavement condition derived from various measurements or collected by other forms of investigation (e.g. rut depth, friction value, etc).
Performance Index	An assessed technical parameter of the road pavement, a **dimensionless** number or letter on a scale that evaluates the technical parameter involved (e.g. rutting index, skid resistance index, etc) in a 0 to 5 scale 0 being a very good condition and 5 a very poor one.