COST Action 354 - Performance indicators for Road Pavements

European cooperation in the field of scientific and technical research

The way forward for pavement performance indicators across Europe

Final Report

COST Action 354 Performance Indicators for Road Pavements

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COST Overview

COST- the acronym for European **CO**operation in the field of **S**cientific and **T**echnical Research- is the oldest and widest European intergovernmental network for cooperation in research. Established by the Ministerial Conference in November 1971, COST is presently used by the scientific communities of 35 European countries to cooperate in common research projects supported by national funds.

The funds provided by COST - less than 1% of the total value of the projects - support the COST cooperation networks (COST Actions) through which, with EUR 30 million per year, more than 30.000 European scientists are involved in research having a total value which exceeds EUR 2 billion per year. This is the financial worth of the European added value which COST achieves.

A "bottom up approach" (the initiative of launching a COST Action comes from the European scientists themselves), "à la carte participation" (only countries interested in the Action participate), "equality of access" (participation is open also to the scientific communities of countries not belonging to the European Union) and "flexible structure" (easy implementation and light management of the research initiatives) are the main characteristics of COST.

As precursor of advanced multidisciplinary research COST has a very important role for the realisation of the European Research Area (ERA) anticipating and complementing the activities of the Framework Programmes, constituting a "bridge" towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of "Networks of Excellence" in many key scientific domains such as: Biomedicine and Molecular Biosciences; Food and Agriculture; Forests, their Products and Services; Materials, Physical and Nanosciences; Chemistry and Molecular Sciences and Technologies; Earth System Science and Environmental Management; Information and Communication Technologies; Transport and Urban Development; Individuals, Societies, Cultures and Health. It covers basic and more applied research and also addresses issues of pre-normative nature or of societal importance.

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The way forward for pavement performance indicators across Europe

COST Action 354

Performance Indicators for Road Pavements

Final Report

This COST Action was initiated by

FEHRL

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ABSTRACT

The main objective of the COST Action 354 “Performance Indicators for Road Pavements” was the definition of uniform European performance indicators for road pavements taking the needs of road users and road operators into account. A quantitative assessment of performance indicators provides guidance regarding present and future needs in road pavement design and maintenance at both the national and the European levels.

Performance indicators are defined for different types of pavement structures and road categories. In a first step several single performance indicators describing the characteristic of the road pavement condition are assessed. The next step is the grouping of these single performance indicators or indices into representative combined performance indices as

- Functional performance indices (demands made on road pavements by road users);
- Structural performance indices (structural demands to be met by the road pavement);
- Environmental performance indices (demands made on road pavements from an environmental perspective).

Finally, based on the combined performance indices a global (general) performance index is defined for describing the overall condition of the road pavements, which can be used for general optimization procedures.

Recommendations for the application of the indices developed are given taking into account the various random conditions given at the users. A spreadsheet toll was developed as well, which supports the decisions made by the road administrations.

This final report summarises the results of the action. It also contains also a CD-ROM with all the detailed reports of the working groups and the other deliverables.

EXECUTIVE SUMMARY

The main objective of the COST Action 354 “Performance Indicators for Road Pavements” was the definition of uniform European performance indicators for road pavements taking the needs of road users and road operators into account. A quantitative assessment of different aspects of pavement performance, through the implementation of performance indicators, can provide guidance regarding present and future needs in road pavement design and maintenance, at both national and European levels. In total, 23 European countries and the FHWA/USA have sent their delegates to the Management Committee; this breadth of interest reflects the importance attached to the objective of the Action.

Within the Action a “Performance Indicator” for a road pavement was taken to be a value derived to represent 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 (dimensional) and/or dimensionless indices. The focus of the Action was to develop “Performance Indices”, defined as dimensionless figures on a common 0 to 5 scale, with 0 representing a pavement in very good condition and 5 a very poor one, with respect to a specific pavement condition property.

Given the wide variety of potential users of the COST 354 final approach, it was deemed necessary to develop a procedure that could be applied in different ways, depending on the type of measurements available and the analysis approach already in place in a given road authority. As a result of this approach, a flexible system of single, combined, and general performance indices was developed. This report provides details of these indices, as well as guidance on their practical application and a spreadsheet tool to assist in their implementation.

A set of single (individual) performance indicators was identified, for which the Action sought to define corresponding “Performance Indices” (PI) for the assessment of key properties of road pavements:

- Longitudinal evenness;
- Transverse evenness;
- Macro-texture;
- Friction;
- Bearing Capacity;
- Noise;
- Air Pollution;
- Cracking;
- Surface defects.

Each single PI is related to one technical characteristic of the road pavement and can be derived from a “Technical Parameter” (TP) obtained from measurements by a device or collected by other forms of investigation (e.g. rut depth, friction value, etc.). However, since cracking and surface defects both encompass a range of different individual defects it was necessary to develop “pre-combined performance indicators” that combine the different forms of distress into a single value for each type.

The definition of Noise and Air Pollution indicators was considered but, despite their recognised importance, there was insufficient data concerning the influence of road pavements on these environmental impacts for their use in this COST Action. Due to this situation only a textual description for the use of environmental indicators was given.

A further objective was the development of four combined performance indices, derived from the single PIs and pre-combined PIs, that represent important aspects of pavement performance, relevant to road users and road operators:

- Safety Index;
- Comfort Index;
- Structural Index;
- Environmental Index.

The objective of each “Combined Performance Index” (CPI) is to characterise the contribution of the pavement structure and condition to the performance of the road asset. It should be noted that it was not the intention to derive overall indices of road safety, user comfort and environmental impact, which are influenced by many factors outside the scope of this Action, which is dealing with the pavement only.

At the highest level in the assessment of pavement condition is the calculation of a “General Performance Indicator” (GPI). The GPI is a mathematical combination of single and/or combined indicators which gives a first impression of the overall pavement condition at network level, and enables badly performing sections to be identified. By using this information a general maintenance strategy can be derived. Consequently the general indicator is a useful tool for decision-makers to assess the general condition of the network and to evaluate future strategies and consequent funding requirements.

For the practical application of the single, combined and general performance indicators, detailed descriptions are given concerning the method for deriving each PI, including:

- Selection of input parameter(s);
- Transfer functions and/or combination procedures;
- List of weighting factors for the different CPIs and GPI.

As part of the Action, a spreadsheet tool was developed to facilitate the calculation of single, combined and general performance indicators. This was used to conduct a comprehensive sensitivity analysis to show the effects of changing on the one hand the weights of the input parameters and on the other hand the influence of modifications in the recommended combination procedures.

The spreadsheet tool is provided on the accompanying CD-ROM and can also be used to implement examples of the calculation of PIs, CPIs, and GPI, using actual data available to a road administration, following the procedures developed within the work in COST Action 354.

Performance Indicators for Road Pavements

Final Report

1 INTRODUCTION

1.1 BACKGROUND

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 call 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.).

Efforts to describe certain road pavement characteristics by means of indices were initiated more than one decade ago. These indices, which as a rule are composed of several information components (such as road condition, pavement data, road geometry data, etc.) are a measure of the effects perceived by the road users, as well as a measure reflecting the structural condition of a road pavement. The Pavement Management Guide published by the American Association of State Highway and Transportation Officials (AASHTO) in 2001 [1] uses the “Present Serviceability Index” (PSI) as a measure of riding comfort along with information about structural indices - specifically the “Pavement Condition Index (PCI)” and the “Road Condition Index (RCI)” - and their use as part of pavement management systems. The “Highway Development & Management Tool HDM 4” developed by the World Bank [2,3] in co-operation with PIARC (the World Road Association) likewise uses special indicators (such as the PSR – the Present Serviceability Rating) as measures of pavement characteristics. In 1995 a research project entitled “Performance Indicators for the Road Sector” was established by the OECD (Organisation for Economic Co-operation and Development) and aimed at the investigation of existing road indicators (with only little relation to road pavements) in the member countries. This project was finished in 1997 [4].

During the period 2003-2007, PIARC TC 4.1 „Management of Road Infrastructure Assets” also dealt with the combination of performance indicators in a work group. Their report [5] is based on the use of „drawer”-concept. A “drawer” means an area where one or more of the stakeholders are interested. The following drawers were selected for the presentation of technical and non-technical performance indicators: environmental, financial, human resources, travelling time, traffic safety, sustainability and social ones. Some of the drawers were divided into sub-drawers (e.g. traffic noise, air quality and landscape sub-drawers in the environmental drawers). The work group proposes a holistic approach applying multidisciplinary methodology and the co-operation of all stakeholders. The world-wide harmonisation of performance indicators was initiated since the main challenges (environmental, safety, economic etc.) are basically the same.

In Europe, a number of studies have been conducted at the national level, on the basis of which specifications have been developed that define pavement characteristics in relation to the requirements of road users, road operators and road administration authorities. Modelled on clearly defined maintenance planning goals, the RPE-Stra 01 guideline (guidelines for planning road pavement maintenance measures) published in Germany in 2001 [6] uses a structural index rating the structural condition of road pavements, as well as a service index rating riding safety and comfort. In the United Kingdom the Highways Agency has been using a performance indicator for the effective maintenance of the national road network for many years. Similar systems and procedures are in use in the Scandinavian countries, as well as in France, Switzerland, Italy and Austria (cf. articles at the 1st European Pavement Management Systems Conference 2000 in Budapest, Hungary, the 2nd European Asset Management Conference 2004 in Berlin, Germany, the 5th International Pavement Management Systems Conference 2001 in Seattle, USA and the 6th International Conference on Managing Pavements 2004 in Brisbane, Australia). It was found that, with minor exceptions, the individual performance indicators used by the various European countries are hardly or only to some extent comparable (use of different factors, rating systems, measuring procedures, etc.).

1.2 ENVISAGED SOLUTIONS AND BENEFITS TO DIFFERENT TYPES OF USERS

The development of uniform performance indicators and indices for road pavements is the key to performance evaluation and assessment, and thus to the future planning of European road networks. Considerations towards this objective have already been undertaken by CEDR (Conference of European Directors of Roads) and the European Union within the framework of TERN (Trans European Road Networks). Within the Strategic European Road Research Program (SERRP) drafted by FEHRL (formerly Forum of National European Highway Research Laboratories), this theme has been assigned high priority.

It is only the Europe-wide harmonization of specific road pavement performance indicators that permits international comparisons of existing road pavements from the perspectives of both the road users and the road operators. Uniform performance indicators could constitute a key prerequisite for future investments in road infrastructure projects at the European level.

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.

Results from previous COST-Actions and European research projects were forming a valuable basis for the work within this project. COST 324 (Long-Term Performance of Road Pavements) and the PARIS-project were dealing with the evaluation of road condition and the development of performance prediction models. COST 325 (New Pavement Monitoring Equipment and Methods) and COST 336 (Use of Falling Weight Deflectometers in Pavement Evaluation) were focused on condition monitoring of road pavements, which is also treated within COST 343 and the EU-project FORMAT.

The potential benefits arising from the action are substantial for road operators and road users as well. The primary use of such indicators is for the comparison of different road networks and the identification of investment requirements where relevant minimum standards have been defined taking into account the requirements of road users.

For the development of international standards regarding to road pavement condition harmonized performance indicators are an essential prerequisite. In this context they can be used on the one hand for international and national road audit, but also on the other hand, for widening the market for supervision and construction within Europe, and thus strengthen the competition.

Performance indicators can be used in particular as target criteria in life cycle analyses within the context of pavement design and/or systematic road maintenance at the national and the European levels. Uniform performance indicators permit an evaluation of the effects of different design and maintenance strategies, but they can also be a basis for predicting road performance and for improving and developing new prediction models. Performance indicators are thus an objective tool for use in road construction and maintenance at various administrative levels, from local roads to international highways.

A further benefit arises for the road construction industry. In connection with increasing privatization of road construction and maintenance in Europe, the objective assessment of condition or performance indicators is gaining special importance. Such indicators may be used in awarding maintenance contracts to private enterprises and, in particular, within the framework of the new awarding procedures being contemplated in many European countries (public-private partnership contracts PPP, build-operate-transfer contracts BOT). Clearly defined harmonized performance indicators are an important precondition for the successful application of these new types of contracts.

2 OBJECTIVES AND WORK PROGRAM OF COST ACTION 354

2.1 GENERAL

The preparation of the COST-Action 354 was supported by FEHRL in close cooperation with the Institute for Road Construction and Maintenance of the Vienna University of Technology and started after formal approval of the COST-office at 17th March 2004, with a scheduled duration of 4 years. Upon request of the Management Committee the official end of the action was extended to end of July 2008 to allow for the organisation of a final seminar closely linked to the 3rd European Conference on Pavement and Asset Management in Coimbra/Portugal which took place on 7th of July 2008. This was a unique possibility to reach a big number of colleagues working in this field.

The interest for participation in the action was quite high from the very beginning. Finally a total of 23 European countries and the FHWA/USA (see Figure 1) have sent their delegates to the Working Group meetings and to the Management Committee (details can be seen under the COST 354 website http://cost354.zag.si and www.cost.org as well).

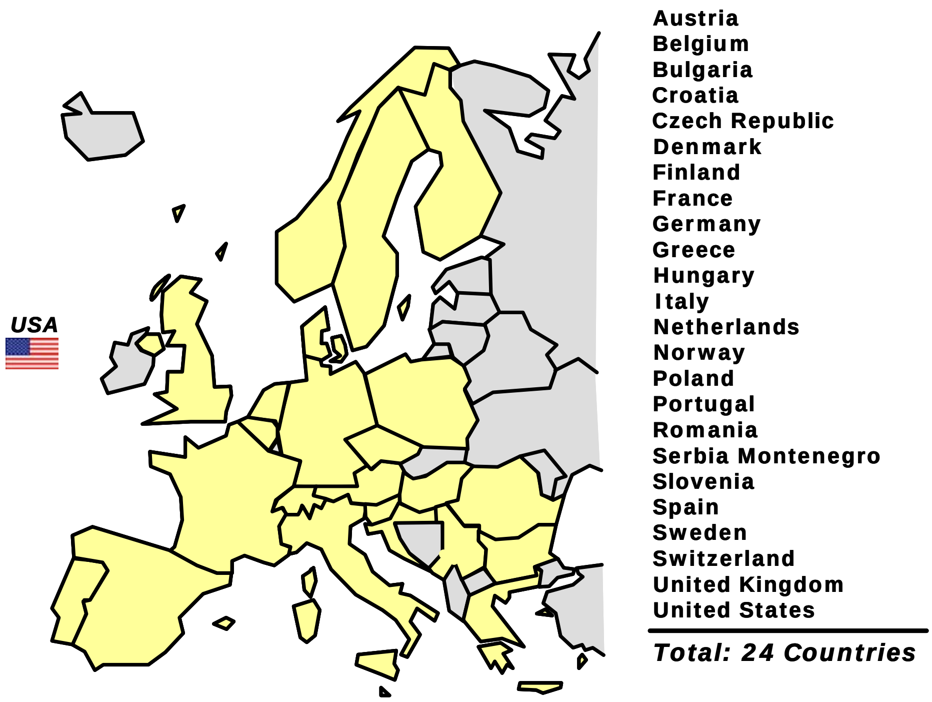


Figure 1: COST 354, participating countries

2.2 OBJECTIVES

The main objective of the Action was 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 (e.g. target values, alert values, threshold values, etc.) for individual (single) performance indicators, minimum standards can be laid down for both projected and existing road pavements. Performance indicators are defined for different types of pavement structures and road categories.

A further objective is the grouping of these individual performance indicators or indices into representative combined performance indices as:

- Functional performance indices (demands made on road pavements by road users);
- Structural performance indices (structural demands to be met by the road pavement);
- Environmental performance indices (demands made on road pavements from an environmental perspective).

Finally, based on the combined performance indices, a general (global) performance index is defined for describing the overall condition of the road pavements, which can be used for general optimization procedures.

2.3 SCIENTIFIC WORK PROGRAMME

The Action aimed at producing the following deliverables:

- Data base on individual pavement performance indicators used throughout Europe, including limit values, classification systems and measurement and data collection procedures;
- Review of existing methods and practical guides for choice and application of individual (single) pavement performance indicators, including measurement and data collection procedures;
- Practical procedure for developing combined performance indices and proposed areas of application;
- Practical procedure for developing a general performance index and proposal for application;
- Final report of the action.

The work programme to be carried out under this COST Action was subdivided into five work packages (WP) set up to deal with the tasks outlined above, each producing one of the five deliverables. Each work package was in turn broken down into a number of tasks, which are listed in Table 1 below.

Work package	***Contents***	***Research Task No.***	***Contents***
WP 1	Collection of existing basic information	1.1	Inventory
		1.2	Database
WP 2	Selection and assessment of individual (single) performance indicators	2.1	Selection of suitable performance indicators
		2.2	Definition of target values and limits
		2.3	Development of transfer functions
		2.4	Practical guide
WP 3	Combination of individual performance indicators	3.1	Development of combination-procedure
		3.2	Report on practical procedure
WP 4	Development of a general performance indicator	4.1	Development of combination-procedure
		4.2	Report on practical procedure
WP 5	Final report	5.1	Draft
		5.2	Final version

Table 1: Working programme with working areas and research tasks

Work Package 1 involved an inventory on performance indicators for road pavements used across Europe, taking into account different road categories and pavement types. The inventory covers also information on each individual performance indicator about the target values and limits, as well as applied transfer functions, classification systems and methods of measurement and data collection.

The technical approach to the work in this Work Package was working through questionnaires and subsequent discussion by the technical experts of the Action. The final deliverable of this Work Package is the database with the information on the individual pavement performance indicators, which are described above.

Work Package 2 started with the selection of suitable individual pavement performance indicators based on the information, which are stored in the data base. After the selection of individual performance indicators, the target values and limits of each single indicator were developed based on statistical and empirical studies, as well as on analytical evaluations. For the comparison of the different individual performance indicators transfer functions were defined in a next step. To calculate dimensionless performance indices a special classification system was set up.

The deliverable of this Work Package is a practical guide for the selection and application of individual performance indicators including limit values, classification systems and measurement and data collection procedures (see chapter 4).

Work Package 3 started with the comparison of the existing combination procedures to form combined indices from several individual performance indices. Consequently, a harmonized procedure with unified weighting factors was developed, which is described in detail in a report on the practical procedure and the application of combined indices (see chapter 5).

Work Package 4 had the same structure as work package 3, this time dealing with the unification of several combined performance indices to one general performance index. The deliverable of this Work Package is a practical procedure for the development of a general performance index and its application (see chapter 6).

The deliverables of Work packages 1 to 4 are compiled in this Final Report of the Action (Work Package 5).

All reports from the several work packages (deliverables) are included in the CD-ROM which is attached to this final report. In these detailed reports also comprehensive lists of references are added.

2.4 DEFINITIONS

Throughout the whole action the following terms and definitions were used:

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).
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.).
Transfer Function	A mathematical function used to transform a technical parameter into a dimensionless performance index.
Performance Index (PI)	An assessed Technical Parameter of the road pavement, **dimensionless** number or letter on a scale that evaluates the Technical Parameter involved (e.g. rutting index, skid resistance index, etc.) on a 0 to 5 scale, 0 being a very good condition and 5 a very poor one.
Single Performance Indicator	A dimensional or dimensionless number related to only one technical characteristic of the road pavement, indicating the condition of that characteristic (e.g. roughness) (also called Individual Performance Indicator).
Pre-combined Performance Indicator	A dimensional or dimensionless number related to two or more similar (related) characteristics of the road pavement, combined into one characteristic (e.g. linear cracking and alligator cracking combined into cracking) for further application or combination.
Combined Performance Indicator	A dimensional or dimensionless number related to two or more different characteristics of the road pavement, that indicates the condition of all the characteristics involved (e.g. PCI- Pavement Condition Index).
General Performance Indicator (GPI)	A mathematical combination of single and/or combined indicators which describe the pavement condition concerning different aspects like safety, structure, riding comfort and environment (also called Global Performance Indicator).

Table 2: Glossary of terms in COST354

The relationship between technical parameters (TP), single indices (PI), combined indices (CPI), and general index (GPI) can be seen in the following Figure 2.

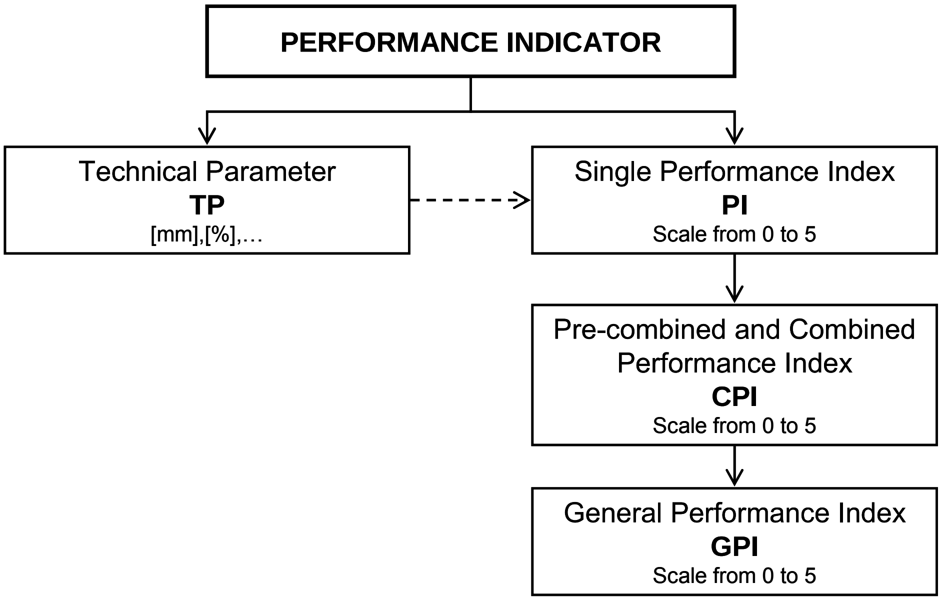


Figure 2: Overview of the development of performance indicators in the COST 354 action

2.5 SHORT TERM SCIENTIFIC MISSIONS

In addition to the work performed by each Work Package team, several Short Term Scientific Missions (STSM) were conducted during the Action to support the activities of the Working Groups and also to enable young researchers from the contributing countries to visit other institutions abroad for a limited time in order to exchange knowledge and experiences.

The following STSMs took place:

STSM 1, Structural Performance Indicators based on GPR- and Bearing Capacity Measurements
Host: BRRC, Belgium
Applicant: Dr. Simona Fontul, LNEC, Portugal

STSM 2, Detection of Structural Damages based on GPR measurements
Host: Roadscanners, Finland
Applicant: Dipl.-Ing. Gudrun Golkowski, BASt, Germany

STSM 3, part 1: Bearing Capacity Measurements for PMS Purpose based on Comparative Measurements
Host: BASt, Germany
Applicant: Dr. Gregers Hildebrand, DRI, Denmark

STSM 3, part 2: Bearing Capacity Data Evaluation for PMS Purposes based on comparative Measurements
Host: BASt, Germany
Applicant: Dr. Carl van Geem, BRRC, Belgium

STSM 4, Practical Application of Single Performance Indicators and Development of a practical Guide
Host: Univ. of Florence, Italy
Applicant: Stuart Brittain, TRL, United Kingdom

STSM 5, Practical Application of Combined and General Performance Indicators
Host: Technical University of Vienna
Applicant: Darko Kokot, ZAG, Slovenia

All the reports from these short term scientific missions are included in the CD-ROM which is attached to this final report.

3 COLLECTION OF EXISTING BASIC INFORMATION

3.1 GENERAL

The work described in this chapter was carried out in Work Package 1. The aim of this Work Package was to produce an inventory on performance indicators for road pavements used across Europe and USA, taking into account different road categories and pavement types. The inventory covers also information of each single performance indicator about the target values and limits, as well as applied transfer functions, classification systems and methods of measurement and data collection.

In order to obtain the data, the technical approach to the work in this Work Package was to produce a questionnaire and to make subsequent discussion by the technical experts of the Action. This chapter describes the questionnaire and the database and gives a brief overview of the responses received.

3.2 QUESTIONNAIRE ON PERFORMANCE INDICATORS

The questionnaire was designed to enable data to be collected from the countries participating in COST Action 354 in a structured manner in order to input into a database with the information on the individual pavement performance indicators. The output of the questionnaire can be distributed to all participating experts and non-experts, policy makers, research institutes, etc. The purpose of this database was also to provide the input for the subsequent Work Packages, in particular Work Package 2.

3.2.1 Process of preparing the questionnaire

The primary aim of this questionnaire was the collection of existing available information about performance indicators and indices for road pavements, which are applied in practice (routine) or for research purposes, as well as indicators and indices, which are in "development" at the moment.

The content and the structure of the questionnaire was based on the constraints of the technical annex of this COST-action, as well as on the framework conditions for a comprehensive processing of the different tasks by the different working groups. The questionnaire deals exclusively with performance indicators and indices, which are related to the structural and surface maintenance of road pavements and not to operational maintenance (e.g. winter maintenance).

The complexity of the formulation of the different questions cast the use of a conventional questionnaire (paper form) into inexpedient and demanded the use of an electronic questionnaire (“spreadsheet file”). The basis for the decision to use the “spreadsheet file” was on the one hand, the availability of the related software in almost every road administration authority and, on the other hand, the easy application.

The structure of the questionnaire was designed for an easy and clear input of the information about performance indicators for road pavements. To make the filling in as easy as possible, the questionnaire was annotated and provided with "push buttons" and "red arrows", which helped to find the right way through the different tables. The experts who completed the questionnaire were guided almost automatically through the different levels and tables of the questionnaire. Special marked data fields contain comments with additional explanations.

Furthermore, the questionnaire was provided with "Further Comment" fields to add additional comments, references, and information, which could not be written in the provided fields (due to specific format of field, length of field, etc.). In the first row of each table an example was added how to fill in the information.

3.2.2 Structure of the questionnaire

As already mentioned, the content of the questionnaire is based on the objectives of this COST-action. From this it follows that the questionnaire is divided into two different main parts:

- Information about single performance indicators;
- Information about combined performance indicators.

Beside these main elements, further information about the expert(s), who completed the questionnaire, about the related road networks, and about references and literature were added into the structure. Figure 3 gives an overview of the structure of the questionnaire. The questionnaire was exclusively designed as electronic version.

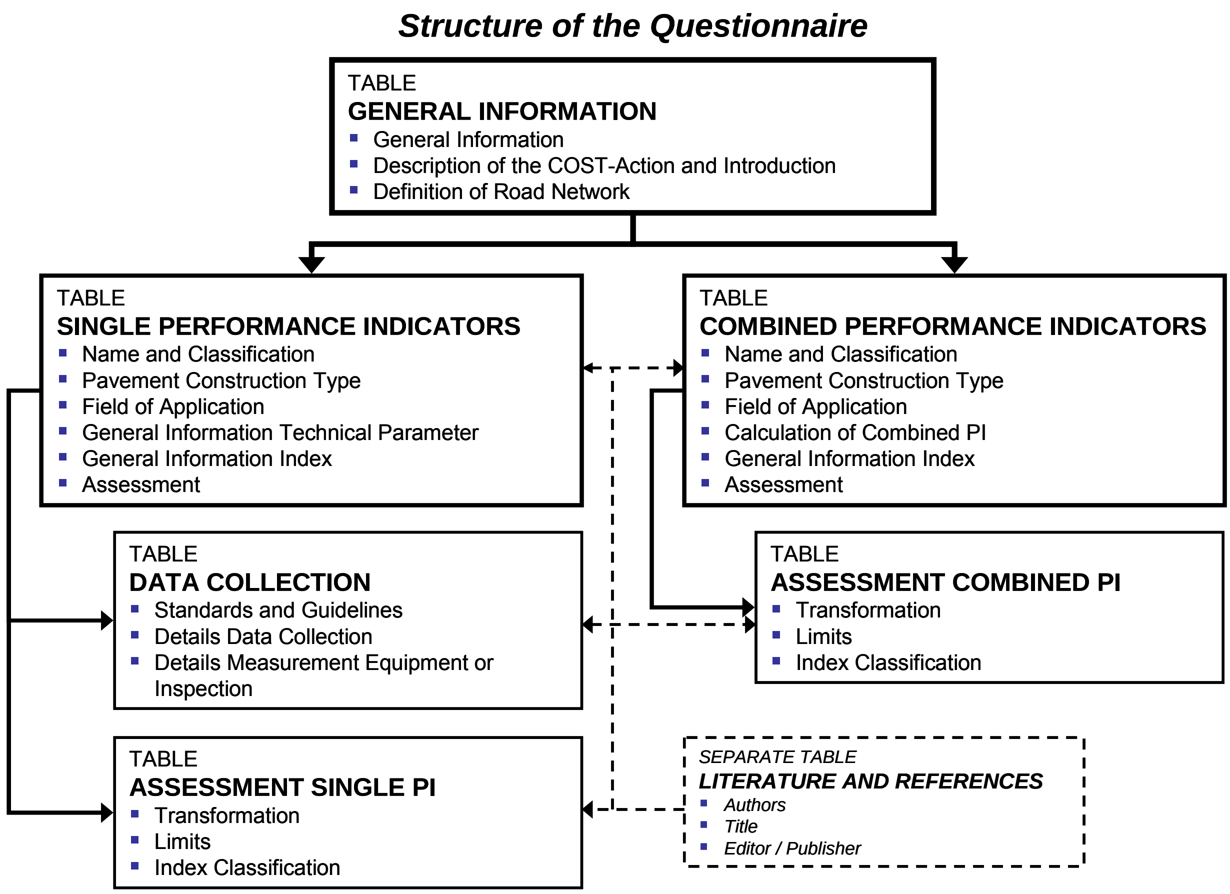


Figure 3: Structure of the questionnaire

The contents of the different tables are described in detail in the report of WP 1, which is included in the CD-ROM attached to this final report.

3.3 DATABASE

3.3.1 Objective

For the evaluation of the collected information from the electronic questionnaire, the data were implemented into an electronic database, which was to be used for the subsequent work of working groups 2 to 4. Furthermore, the database can be distributed to all members of the COST Action, participating experts and non-experts, policy makers, research institutes, etc. and can be the basis for their decision in the context of implementing and using new performance indicators for road pavements.

3.3.2 Structure

The structure of the database consists of a number of different data tables, in which the information is stored in form of data sets. In principle, one data set is related to one single or combined performance indicator.

Beside tables of single and combined performance indicators separate tables for literature, traffic data, queries, etc. are used in the COST354 database.

For the practical application of the database, special data forms (for data view) and reports (for data view and printout) were implemented into the database.

Beside these data forms, individually defined reports allow printing the information and querying results of the database:

- Report single PI: report of query results about single performance indicators;
- Report Combined PI: report of query results about combined performance indicators;
- Literature: report of literature and references.

The following Figure 4 shows the Front Page and a Data Sheet of COST354 data base.

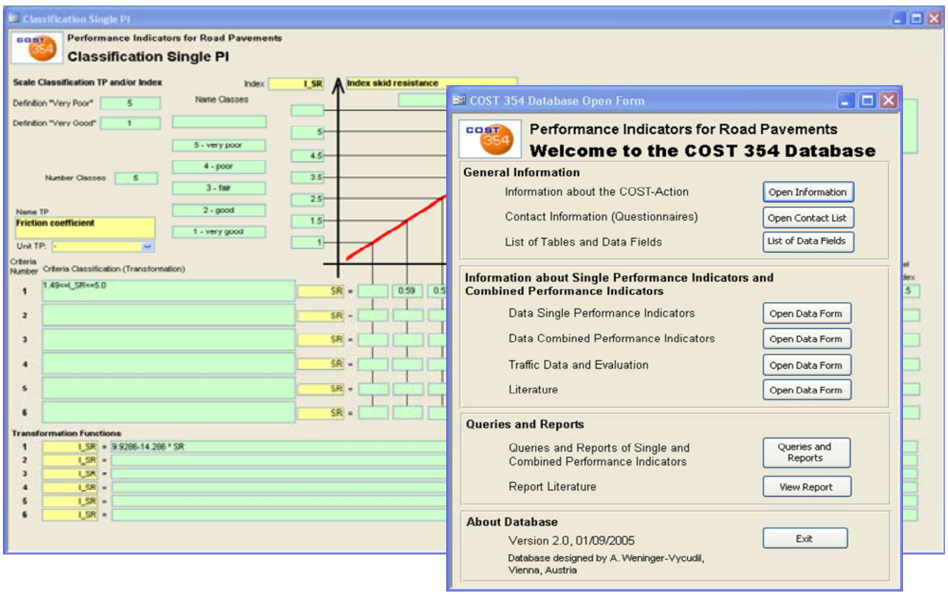


Figure 4: Front page and data sheet example of the COST 354 data base

An overview about the functionality of the database is described in detail in the report of WP 1, which is included in the CD-ROM attached to this final report.

3.4 DATA AND INFORMATION IN THE COST354 DATA BASE

The COST354 data base was used as a basis for the selection and definition of single, combined and general performance indicators.

In total, the output of 25 questionnaires were implemented into the data base including detailed information about single and combined indicators, different assessment methods, data collection, as well as references to the adequate literature.

The following Table 3 gives an overview of the existing information in the COST354 data base.

COST354 data base	
Number of questionnaires included	25
Number of countries providing information	24
Number of single performance indicators	209
Number of combined / general performance indicators	46
Number of referenced literature	98

Table 3: Overview of information in COST354 data base

The electronic version of the database is included in the CD-ROM attached to this final report for public use. However, it has to be stated that the data are related to the year 2005 (final year of data-input) and no update has been made later. Also, the member of the action can take no responsibility in the quality and accuracy of single data, although they were reported with best knowledge.

4 SELECTION AND ASSESSMENT OF SINGLE PERFORMANCE INDICATORS

4.1 GENERAL

The assessment and selection of single (individual) performance indicators was the aim of WP2. The planned activities were:

- Select suitable performance indicators;
- Define target values and limits (for interventions);
- Develop transfer functions from technical parameters to performance indices;
- Provide a practical guide for the calculation of the performance index.

The task was to identify a set of performance indices to represent in a dimensionless scale the following performance indicators:

- Longitudinal evenness;
- Transverse evenness;
- Macro-texture;
- Friction;
- Bearing Capacity;
- Cracking;
- Noise;
- Air Pollution.

Cracking was initially considered as a single performance indicator, but it was later on decided to consider it as a pre-combined performance indicator, and it was therefore tackled by WP3 (see chapter 5).

Noise and Pollution were also considered for use as indicators; however there was insufficient data at the moment for their use in this COST action. These indices may be added at a later date, once more research has been carried out.

These activities have been performed mostly based on the results of the work of WP1 using the data in the COST354 data base. 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 and further into a “General Performance Index” in WP4.

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 available and analysis approach already in place in a given road authority (user).

The different levels can be summarized as follows:

- The user provides the value for the technical parameter identified as the “most suitable” by WP2 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 WP2, 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. 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.

The following chapter is the practical guide to the output from work package 2 “Selection and assessment of individual performance indicators”. The full report of this work package is included in the CD-ROM attached to this final report.

4.2 PERFORMANCE INDICES AND TRANSFER FUNCTIONS DEVELOPED

As discussed previously, five performance indicators have been studied to develop individual performance indices and the related transfer functions. Details of these indicators, including proposed technical parameters and transfer functions can be found on the following sheet:

- Sheet 1 - Longitudinal Evenness (Figure 6);
- Sheet 2 - Transverse Evenness (Figure 7);
- Sheet 3 - Macro-texture (Figure 8);
- Sheet 4 - Skid Resistance (Figure 9);
- Sheet 5 - Bearing Capacity (Figure 10).

To obtain a Performance Index (PI) for a given indicator the following process should be applied:

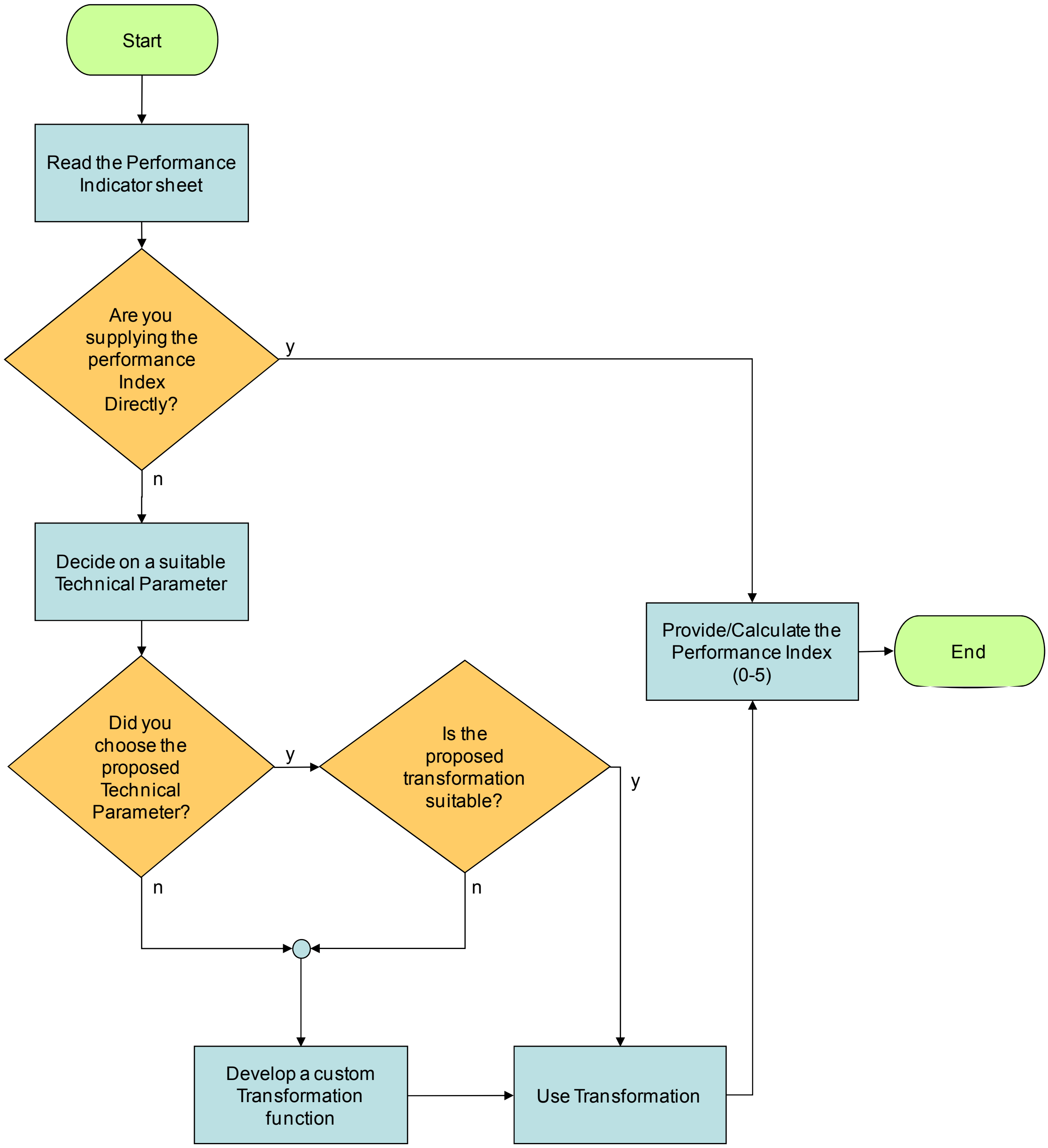


Figure 5: Flow chart to obtain a Performance Index (PI) for a given indicator

The process for developing custom transfer functions is detailed later in this section.

1. Performance Indicator details			Sheet 1
Indicator Name:	Longitudinal Evenness, PI_E		
Description of Index:	Longitudinal Evenness is the deviation of the longitudinal profile from a straight reference line in a wavelength range of 0.5 m-50 m. The reference line is usually the intersection of the profile plane and the horizontal plane.		
Possible TPs:	International Roughness Index, Evenness, Wavelength, Spectral Density, Longitudinal Profile Variance and others.		
2. Proposed Technical Parameter(s)			
Technical Parameter(s):	International Roughness Index, IRI	Units:	mm/m
3. Proposed Transfer function(s), usage and Limitations			
Proposed Transfer Function(s):	$PI\_E = Max\left(0; Min\left(5; (0.1733 \cdot IRI^2 + 0.7142 \cdot IRI - 0.0316)\right)\right)$ [1] $PI\_E = Max\left(0; Min\left(5; 0.816 \cdot IRI\right)\right)$ [2]		
Usage of Transfer Functions(s):	Transformation [1] was developed to create a more restrictive range than transformation [2] (see range and sensitivity below). The choice of transfer function should be based on which range best suits the user's network.		
Limitations of Proposed Transfer Function(s):	Transformations [1] and [2] are both suitable for all pavement types (flexible, semi-rigid and rigid). Transformations [1] and [2] are both suitable for motorways and primary roads.		

4. Range and Sensitivity of Transfer functions					
	Very Good		→		Very Poor
Longitudinal Evenness, PI_E	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5
IRI (mm/m) - Transformation [1]	0.0 – 1.1	1.1 – 1.9	1.9 – 2.6	2.6 – 3.2	3.2 – 3.7
IRI (mm/m) - Transformation [2]	0.0 – 1.2	1.2 – 2.5	2.5 – 3.7	3.7 – 4.9	4.9 – 6.1

Figure 6: Sheet 1 - Longitudinal Evenness

1. **Performance Indicator details**	Sheet 2		
Indicator Name:	Transverse Evenness, PI_R		
Description of Index:	Transverse Evenness is a measure of unevenness of the road across the full survey width as described in EN 13036-8 (2008).		
Possible TPs:	Rut Depth, Water Depth, cross-fall, edge deformation and others.		
2. Proposed Technical Parameter(s)			
Technical Parameter(s):	Rut Depth, RD	Units:	mm
3. Proposed Transfer function(s), usage and Limitations			
Proposed Transfer Function(s):	$PI\_R = Max\left(0; Min\left(5; (-0.0016 \cdot RD^2 + 0.2187 \cdot RD)\right)\right)$ [1] $PI\_R = Max\left(0; Min\left(5; (-0.0015 \cdot RD^2 + 0.2291 \cdot RD)\right)\right)$ [2] $PI\_R = Max\left(0; Min\left(5; (-0.0023 \cdot RD^2 + 0.2142 \cdot RD)\right)\right)$ [3]		
Usage of Transfer Functions(s):	Transformation [1] can be used for all road classes. Transformation [2] should only be used for motorways and primary roads. Transformation [3] should only be used secondary and local roads.		
Limitations of Proposed Transfer Function(s):	Transformations [1], [2] and [3] are all suitable for flexible and semi-rigid pavement types (not rigid). Transformation [1] is suitable for all road categories (Motorway, Primary and Secondary). Transformation [2] is suitable for Motorway and Primary roads. Transformation [3] is suitable for Secondary roads.		
4. Range and Sensitivity of Transfer functions			

	Very Good		→		Very Poor
Transverse Evenness, PI_R	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5
RD (mm) - Transformation [1]	0.0 – 4.7	4.7 – 9.9	9.9 – 15.5	15.5 – 21.8	21.8 – 29.0
RD (mm) - Transformation [2]	0.0 – 4.5	4.5 – 9.3	9.3 – 14.5	14.5 – 20.1	20.1 – 26.4
RD (mm) - Transformation [3]	0.0 – 4.9	4.9 – 10.5	10.5 – 17.2	17.2 – 25.8	25.8 – 46.6

Figure 7: Sheet 2 - Transverse Evenness

1. Performance Indicator details			Sheet 3
Indicator Name:	Macro-texture, PI_T		
Description of Index:	The Macro-texture of surface is formed from the aggregate particles and is represented by wavelengths of 0.5 mm to 50 mm.		
Possible TPs:	Mean Profile Depth, Sensor Measured Texture Depth, Sand patch value and others.		
2. Proposed Technical Parameter(s)			
Technical Parameter(s):	Mean Profile Depth, MPD	Units:	mm
3. Proposed Transfer function(s), usage and Limitations			
Proposed Transfer Function(s):	$PI\_T = Max(0; Min(5; (6.6 - 5.3 \cdot MPD)))$ [1] $PI\_T = Max(0; Min(5; (7.0 - 6.9 \cdot MPD)))$ [2]		
Usage of Transfer Functions(s):	Transformation [1] should only be used for motorways and primary roads. Transformation [2] should only be used secondary and local roads.		
Limitations of Proposed Transfer Function(s):	Transformations [1] and [2] are both suitable for all pavement types (flexible, semi-rigid and rigid). Transformation [1] is suitable for Motorway and Primary roads. Transformation [2] is suitable for Secondary roads.		

4. Range and Sensitivity of Transfer functions

	Very Good		→		Very Poor
Macro-texture, PI_T	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5
MPD (mm) - Transformation [1]	1.25 – 1.06	1.06 – 0.87	0.87 – 0.68	0.68 – 0.49	0.49 – 0.30
MPD (mm) - Transformation [2]	1.01 – 0.87	0.87 – 0.72	0.72 – 0.58	0.58 – 0.43	0.43 – 0.29

Figure 8: Sheet 3 - Macro-texture

1. Performance Indicator details	Sheet 4
Indicator Name:	Skid Resistance, PI_F
Description of Index:	Skid Resistance is a measure of the Frictional properties of the pavement surface.
Possible TPs:	Sideways Force Coefficient, Longitudinal Force Coefficient, Grip Number, Friction, Transverse Adherence Coefficient, Skid Resistance and others.

2. Proposed Technical Parameter(s)			
Technical Parameter(s):	Sideways Friction Coefficient, SFC (60km/h) Longitudinal Friction Coefficient, LFC (50km/h)	Units:	none none

3. Proposed Transfer function(s), usage and Limitations	
Proposed Transfer Function(s):	$PI\_F = Max\left(0; Min\left(5; (-17.600 \cdot SFC + 11.205)\right)\right)$ [1] $PI\_F = Max\left(0; Min\left(5; (-13.875 \cdot LFC + 9.338)\right)\right)$ [2]
Usage of Transfer Functions(s):	Transformation [1] should only be used for SFC devices running at 60km/h. Transformation [2] should only be used for LFC devices running at 50km/h.
Limitations of Proposed Transfer Function(s):	Transformations [1] and [2] are both suitable for all pavement types (flexible, semi-rigid and rigid). Transformations [1] and [2] are both suitable for motorways and primary roads.

4. Range and Sensitivity of Transfer functions

	Very Good		→		Very Poor
Skid Resistance, PI_F	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5
SFC (60km/h)-Transformation [1]	0.64 – 0.58	0.58 – 0.52	0.52 – 0.47	0.47 – 0.41	0.41 – 0.35
LFC (50km/h)-Transformation [2]	0.67 – 0.60	0.60 – 0.53	0.53 – 0.46	0.46 – 0.38	0.38 – 0.31

Figure 9: Sheet 4 - Skid Resistance

1. Performance Indicator details	Sheet 5
Indicator Name:	Bearing Capacity, PI_B
Description of Index:	A measure of the structural performance of the pavement.
Possible TPs:	Residual life, Surface Curvature Index, Deflection, Structural number, E-modulus, Deflection velocity and others.

2. Proposed Technical Parameter(s)			
Technical Parameter(s):	Residual life / Design life, R/D Surface Curvature Index, SCI_{300}	Units:	none µm

3. Proposed Transfer function(s), usage and Limitations	
Proposed Transfer Function(s):	$PI\_B = Max(0; Min(5; 5 \cdot (1 - R/D)))$ [1] $PI\_B = Max(0; Min(5; (SCI_{300}/129)))$ [2] $PI\_B = Max(0; Min(5; (SCI_{300}/253)))$ [3]
Usage of Transfer Functions(s):	Either transformation [1] or [2]/[3] can be used depending on data availability. Transformation [2] should only be used for pavements with Weak bases. Transformation [3] should only be used for pavements with Strong bases.
Limitations of Proposed Transfer Function(s):	Transformation [1] is all suitable for all pavements (flexible, semi-rigid and rigid). Transformations [2] and [3] are all suitable for flexible and semi-rigid pavements. Transformations [1], [2] and [3] are all suitable for motorways and primary roads.

4. Range and Sensitivity of Transfer functions					
	Very Good		→		Very Poor
Bearing Capacity, PI_B	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5
R/D - Transformation [1]	1.0 – 0.8	0.8 – 0.6	0.6 – 0.4	0.4 – 0.2	0.2 – 0.0
SCI_{300} (µm) - Transformation [1]	0 – 129	129 – 258	258 – 387	387 – 516	516 – 645
SCI_{300} (µm) - Transformation [2]	0 – 253	253 – 506	506 – 759	759 – 1012	1012 – 1265

Figure 10: Sheet 5 - Bearing Capacity

4.3 EXAMPLES OF THE PROCESS TO CALCULATE A PERFORMANCE INDEX

4.3.1 Example of using the proposed Technical Parameter with the proposed transfer function

For this example we will look at the Skid Resistance index and assume that the user in question uses SFC (Sideways Friction Coefficient) obtained by means of a SCRIM measurement at 60 km/h.

The measured value of SFC is 0.6.

The transfer function 1 of sheet 4 is used for transforming the technical parameter (SFC) in the performance index (PI_F):

$$PI\_F = Max(0; Min(5; (-17.600 \cdot 0.6 + 11.205))) = 0.65$$

4.3.2 Example of using the proposed Technical Parameter with a custom transformation

In this example we will look at the Skid Resistance index again. As before the user uses SFC (Sideways Friction Coefficient). However this time the user will not apply the transfer function shown in sheet 4 but his own transfer function. As an example a simple linear function as the one shown in Figure 11 could be applied.

The first step in developing a custom transformation is to define at least two TP, PI pairs (in the example below SCF, PI_F pairs) as shown in Figure 11.

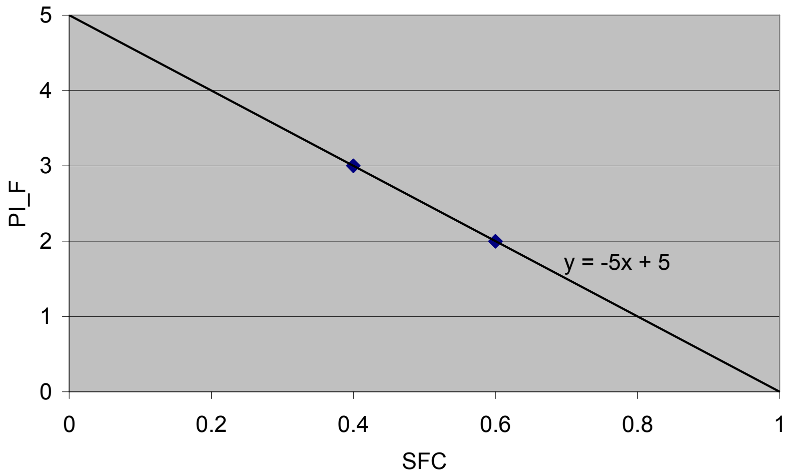


Figure 11: Example graph for developing custom transformation

The transfer function in the example above would be:

$$PI\_F = Max(0; Min(5; (-5.0 \cdot SFC + 5.0)))$$

and for the same value of 0.6 in terms of SFC the PI_F would now result in 2.00

4.3.3 Example of using a different Technical Parameter with a custom transformation

The user is still measuring SFC values but at a speed of 50 km/h and the transfer function 1 in sheet 4 cannot be used (it is referred to a speed of 60 km/h). In this case the user will have to provide her/his own transfer function, boundaries and limitations as indicated above.

4.3.4 Example of supplying the Index directly

In this application the user is not measuring skid resistance at traffic speed, but a PI_F is directly provided based on the results of an inspection, on a low speed measurement (e.g. a British Pendulum) or other surrogate measures for defining the skid resistance of the surface. Based on his own scale the user provides directly the PI_F in a 0 to 5 scale.

4.4 DEVELOPING CUSTOM MADE TRANSFER FUNCTIONS

If the proposed transformation is unsuitable or the technical parameter used is different from the proposed one then it will be necessary to develop a custom transformation. The process for developing a custom transformation is shown in Figure 12 and then explained in the text below.

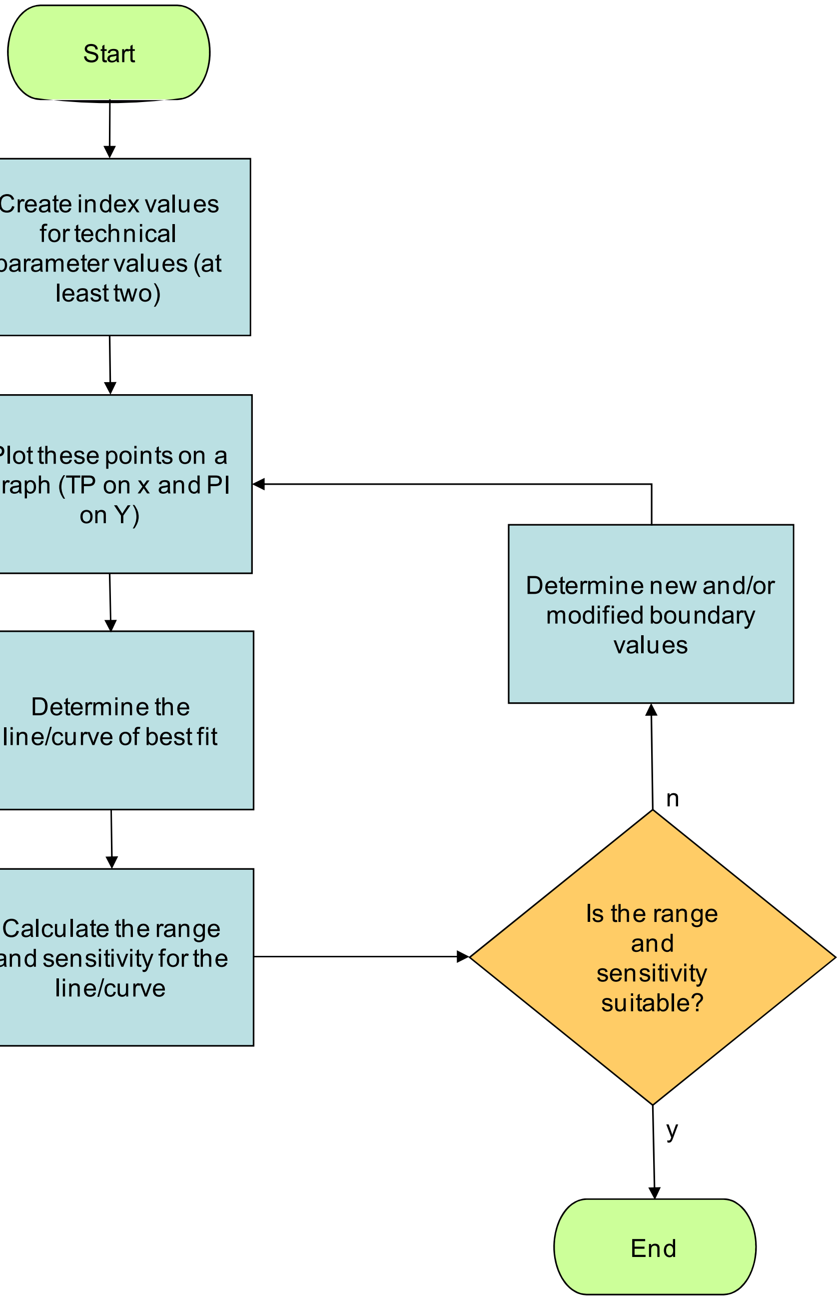


Figure 12: Flow chart for developing custom transformation

There are four steps in producing a custom transformation:

1. Decide on TP values with corresponding Index values. It is necessary to define at least two values for the technical parameter with corresponding Index values. These points can be at any point in the Index scale.
2. Plot points on graph. This allows the relationship between the technical parameter and the Index to be seen. The graph must be plotted with the technical parameter on the x-axis and the Performance Index on the y-axis.
3. Determine the line/curve of best fit. Choose a graph which best fits the points you have chosen. The graph can be of any type, however most cases will use either a linear ($y=mx+c$) or quadratic ($y=ax^2+bx+c$) equation.
4. Calculate and check the range and sensitivity. This can be done by reproducing a table like the ones in part 3 of the Performance Indicator Information sheets. If the transformation is unsuitable return to step one with additional and/or modified index values.

5 COMBINED PERFORMANCE INDICATORS

5.1 GENERAL

Based on the specification given in the Technical Annex of the Action, the objective of WP3 was the development of four combined performance indices that represent important aspects of pavement performance, relevant to road users and road operators:

- Safety Index;
- Comfort Index;
- Structural Index;
- Environmental Index.

The objective of each Combined Performance Index (CPI) is to characterise the contribution of the pavement structure and condition to the performance of the road asset; it is not the intention to derive overall indices of road safety, user comfort and environmental impact, which are influenced by many factors outside the scope of this Action. It is anticipated that the CPI will be implemented within road administrations to support high level decisions by:

- Allowing different aspects of pavement performance to be quantified;
- Enabling reporting of pavement performance at a network level;
- Facilitating comparison with other road administrations;
- Identifying potential improvement schemes.

In addition to the four CPI listed above, procedures have also been developed to produce pre-combined performance indices for surface defects and cracking, which combine the different distress types and different units.

5.2 APPROACH

Each CPI uses different input variables in form of single performance indices and/or other pre-combined performance indices (e.g. the cracking index as an input for the structural index). To provide a consistent basis for quantitative analysis, each CPI is expressed by a dimensionless index on a scale 0 (good condition) to 5 (poor condition). The approach for the definition of CPIs can be summarized as follows:

- Selection of single / pre-combined performance indices as input variables for each CPI;
- Development of a combination procedure;
- Validation of the formula including proposals for the weights of the various input variables;
- Sensitivity analysis;
- Practical application guide.

5.3 INDICES FOR CRACKING AND SURFACE DEFECTS

To meet the requirements for the definition of combined performance indices (CPI) it was necessary to look at missing input parameters in a first step.

Indices for cracking and for surface defects were not defined in the context of WP2, because both indicators are usually composed from different input variables. Due to this situation both Indices were categorized as “Pre-combined Performance Indicators” and it was decided in accordance with WP2 to define an index for cracking and an index for surface defects as first objective. The resulting Indices can be used similarly to other single performance indices as input information for the calculation of CPIs.

Based on the results of WP2 a method was developed which combines on the one hand different appearance forms or types of cracking (linear, alligator, reflective, etc.) into one single cracking parameter (TP_{cr}) and on the other hand, different types of surface defects (potholes, bleeding, ravelling, etc.) also into one single surface defects parameter (TP_{sd}). By using a transfer function, the technical parameters can be transformed into Indices finally. Furthermore the combination procedures take into account the significance of each single variable (single performance indicator) in form of different weights. The results are summarized in the following two sections.

5.3.1 Technical Parameter Cracking

The technical parameter for cracking (TP_{cr}) is defined as a weighted sum of different types and dimensions (area, linear, numbers) of cracking in reference to the investigated area. The different dimensions are converted into equivalent areas. The result is a cracking rate, which can be calculated through the use of the following equations. To simplify the calculation procedure the mathematical function for the cracking rate is split into 3 partial expressions (area, length, and cracked elements (e.g. concrete slabs)) which can be summarized as follows:

$$TP_{cr} = Min\left(100; TP_{cr,A} + TP_{cr,L} + TP_{cr,E}\right)$$

Area:

$$TP_{cr,A} = Min\left(100; \frac{1}{A_{ref}} \cdot \sum_m \left[W_m \cdot \sum_i \left(S_{cr,a,i} \cdot A_i\right)\right] \cdot 100\right)$$

where

$TP_{cr,A}$ .... cracking rate area [%]
A_{ref} .... reference-area
W_m .... weight of cracked areas
$S_{cr,a,i}$ .... severity of crack type i
A_i .... cracked area of crack type i

Length:

$$TP_{cr,L} = Min\left(100; \frac{1}{A_{ref}} \cdot \sum_n \left[W_n \cdot l_{width,l} \cdot \sum_j \left(S_{cr,l,j} \cdot L_j\right)\right] \cdot 100\right)$$

where

$TP_{cr,L}$ .... cracking rate length [%]
A_{ref} .... reference-area
W_n .... weight of cracked length
$l_{width,l}$ .... standard influence width of linear cracks (e.g. 0.5 m)
$S_{cr,l,j}$ .... severity of crack type j
L_j .... cracking length of crack type j

Element:

$$TP_{cr,E} = Min\left(100; \frac{1}{A_{ref}} \cdot \sum_{o}\left[W_o \cdot I_{area,k} \cdot \sum_{k}\left(S_{cr,E,k} \cdot E_k\right)\right] \cdot 100\right)$$

where

$TP_{cr,E}$ .... cracking rate element [%]
A_{ref}.............. reference-area
W_o .... weight of cracked elements
$I_{area,k}$ .... standard area of elements with cracks (e.g. area of concrete slab)
E_{ref}.............. total number of referred elements (e.g. number of concrete slabs)
$S_{cr,E,k}$ .... severity of cracks on an element of crack type k
E_k .... number of elements with cracks of type k

For the calculation of the cracking rate it is necessary to apply different weights for different types of cracking. Based on a statistical evaluation of collected information from the experts within WP3 about different weights the following proposal was drawn up.

This proposal can be used as first specification in the context of computing the cracking rate. If there are weights already available, the function can be adapted individually by the user.

The following tables (Table 4 to Table 6) present the mean, median, and a proposed range (minimum and maximum) of weights for different types of cracking subject to the type of the pavement construction (flexible, rigid, and semi rigid). The range is defined by the second largest and second lowest value of the analyzed data volume.

Cracking type	Weight W' [0-1] (0 = lowest importance, 1 = highest importance)			
	Flexible pavements			
	min*)	max*)	median	mean
alligator cracking	0.9	1.0	1.0	0.9
longitudinal cracking	0.7	0.8	0.7	0.7
transverse cracking	0.6	0.8	0.8	0.7
block cracking	0.6	1.0	1.0	0.8
thermal cracking	0.6	0.9	0.7	0.7
reflective cracking	0.8	0.9	0.8	0.8

*) second largest and second lowest value of statistical evaluation

Table 4: Weights for cracking types for flexible pavements

Cracking type	Weight W' [0-1] (0 = lowest importance, 1 = highest importance)			
	Semi rigid pavements			
	min*)	max*)	median	mean
alligator cracking	1.0	1.0	1.0	1.0
longitudinal cracking	0.7	0.8	0.7	0.7
transverse cracking	0.6	0.9	0.8	0.7
block cracking	0.6	1.0	1.0	0.8
thermal cracking	0.6	0.9	0.7	0.7
reflective cracking	0.9	1.0	0.9	0.9

*) second largest and second lowest value of statistical evaluation

Table 5: Weights for cracking types for semi rigid pavements

Cracking type	Weight W’ [0-1] (0 = lowest importance, 1 = highest importance)			
	Rigid pavements			
	min*)	**max*)**	**median**	**mean**
cracked concrete slabs	0.9	1.0	1.0	0.9
edge cracking	0.7	0.8	0.8	0.7

*) second largest and second lowest value of statistical evaluation

Table 6: Weights for cracking types for rigid pavements

The weights represent the influence of the different cracking types on a relative basis.

The maximum weight in use has to be always equal to 1.0. If this is not the case all the weights have to be multiplied by a scaling factor x

$$x = \frac{1}{\max\left(W_1^{'}; W_2^{'}; \ldots; W_n^{'}\right)}$$

$$W_1 = x \cdot W_1^{'};\ W_2 = x \cdot W_2^{'}; \ldots.; W_n = x \cdot W_n^{'}$$

The transformation of the weights is not a section or area based commitment. It is a general commitment of the investigated road network subject to the collected cracking types. If a certain cracking type will not be found on one or more investigated sections – but it is still in the list of the collected cracking types – the selected and transformed weights may not be changed.

Beside the definition of different weights subject to the cracking type and the type of pavement, a standard influence width must be used in the equation. This standard influence width converts linear cracks into a representative cracked area. For the standard influence width a value of 0.5 m is proposed by WP3 referenced to „OECD Full-scale Pavement Test“ [7].

Beside the standard influence width for linear cracking types also a standard area of elements with cracks can be used for the calculation of the cracking rate. This area should be referred to the area of the affected element (e.g. area of one single concrete slab).

For the practical application the calculation procedure should be carried out individually for flexible, rigid and semi-rigid pavements. A mixture of cracking rates on different types of pavement construction can cause implausible results.

5.3.2 Technical Parameter Surface Defects

The technical parameter for surface defects (TP_{sd}) is defined as weighted sum of different types and dimensions (area, linear, numbers) of surface defects in reference to the investigated area. The different dimensions are converted into equivalent areas. The result is a distress rate, which can be calculated through the use of the following equation. To simplify the calculation procedure, the mathematical function for the cracking rate is split into 3 partial expressions (area, length, and distressed elements (e.g. concrete slabs)) which can be summarized as follows:

$$TP_{sd} = Min\left(100; TP_{sd,A} + TP_{sd,L} + TP_{sd,E}\right)$$

Area:

$$TP_{sd,A} = Min\left(100; \frac{1}{A_{ref}} \cdot \sum_m \left[W_m \cdot \sum_i \left(S_{sd,a,i} \cdot A_i\right)\right] \cdot 100\right)$$

where

$TP_{sd,A}$.......... surface defect rate area [%]
A_{ref}.............. reference-area
W_m .... weight of distressed areas
$S_{sd,a,i}$........... severity of distress type i
A_i................ distressed area of distress type i

Length:

$$TP_{sd,L} = Min\left(100; \frac{1}{A_{ref}} \cdot \sum_n \left[W_n \cdot I_{width,l} \cdot \sum_j \left(S_{sd,l,j} \cdot L_j\right)\right] \cdot 100\right)$$

where

$TP_{sd,L}$........... surface defect rate length [%]
A_{ref}.............. reference-area
W_n .... weight of distressed length
$I_{width,l}$ .... standard influence width of linear distresses
$S_{sd,l,j}$............ severity of distress type j
L_j .... distressed length of distress type j

Element:

$$TP_{sd,E} = Min\left(100; \frac{1}{A_{ref}} \cdot \sum_o \left[W_o \cdot I_{area,k} \cdot \sum_k \left(S_{sd,E,k} \cdot E_k\right)\right] \cdot 100\right)$$

where

$TP_{sd,E}$.......... surface defect rate element [%]
A_{ref}.............. reference-area
W_o .... weight of distressed elements
$I_{area,k}$ .... standard area of elements with distresses (e.g. area of concrete slab)
E_{ref}.............. total number of referred elements (e.g. number of concrete slabs)
$S_{sd,E,k}$ .... severity of distress type k
E_k .... number of distressed elements of type k

The combination procedure enables to combine different surface defects to one single TP. The user of this procedure should take into consideration that not all different distress types can be summarized into one single value. It is strongly dependent on the characteristics and their importance in the context of the assessment (transfer function with limits). E.g. the combination of potholes with ravelling can cause implausible results because the affected area of ravelling can be very large in comparison to potholes with a very small affected area. A compensation of this effect can be carried out through the use of different standard areas, however this example would cause an unrealistic standard area of potholes (> 50 m^2 for one single pothole). Due to this situation the different surface defects are categorized subject to the type of the pavement construction as follows. A combination of surface defects from different categories should be avoided.

Surface defects category 1 – Flexible pavements and semi rigid pavements

- Bleeding;
- Ravelling;
- Patching;
- Spalling.

Surface defects category 2 – Flexible pavements and semi rigid pavements

- Potholes;
- Subsidence and bulge.

Surface defects category 3 – Rigid pavements

- Spalling;
- Joint spalling.

For the calculation of the distress rate it is necessary to apply different weights for different types of surface defects (distresses). Based on a statistical evaluation of collected information from the experts within WP3 about different weights, the following proposal was drawn up. This proposal can be used as first specification in the context of computing the distress rate for surface defects. If there are weights already available the function can be adapted individually by the user.

Only surface defects which refer to category 1 and 3 (see section 5.3.2) were used in the analysis as there were no useful data available for category 2 surface defects.

The following tables (Table 7 to Table 8) contain the mean, median, and a proposed range (minimum and maximum) of weights for different types of surface defects subject to the type of the pavement construction (flexible, rigid, and semi rigid). The range is defined by the second highest and second lowest value of the analyzed data volume.

Surface defect type (category 1)	**Weight W' [0-1]** (0 = lowest importance, 1 = highest importance)			
	Flexible and semi rigid pavements			
	min*)	**max*)**	**median**	**mean**
Bleeding	0.6	0.8	0.7	0.7
Ravelling and fretting	0.6	0.9	0.7	0.7
Patching	0.2	0.7	0.5	0.5
Spalling	0.5	1.0	1.0	0.8

*) second largest and second lowest value of statistical evaluation

Table 7: Weights for surface defect types category 1 for flexible and semi rigid pavements

Surface defect type (category 3)	**Weight W' [0-1]** (0 = lowest importance, 1 = highest importance)			
	Rigid pavements			
	min*)	**max*)**	**median**	**mean**
Spalling	0.8	1.0	1.0	0.9
Joint spalling	0.8	1.0	0.8	0.9

*) second largest and second lowest value of statistical evaluation

Table 8: Weights for surface defect types for rigid pavements

The use of the different weights in the context of the calculation of a surface defect rate is similar to the cracking procedure. The weights represent the influence of the different distress types again on a relative basis and must be transformed if the maximum weight in use is lower than 1.0. The equations to define the weight transformation are equal to the expressions which are used for cracking (see chapter 5.3.1).

5.3.3 Proposal for Cracking Index and Surface Defect Index

The last step in the calculation process is the transformation of the technical parameter into the dimensionless Index. The approach is similar to the process for other single performance indicators, which was defined in the context of WP2 (see chapter 4.1).

Based on the data in the COST354 database, a statistical evaluation of threshold values for cracking rates and surface defects rates was carried out in the context of defining the "most suitable" transfer function.

Because of the low number of European countries which are using a cracking rate or a distress rate for the calculation of indices, only a restricted data volume could be used in the context of this statistical evaluation.

Table 9 shows the recommended transfer function for the TP cracking rate and TP surface defect rate based on the basics described above.

Performance Indicator	TP	Index	Transfer Function
Cracking	Cracking rate [CR] (%)	PI_cracking (PI_CR)	For motorways: PI_CR = Max(0; Min(5; 0.16·CR)) For other primary roads: PI_CR = Max(0; Min(5; 0.1333·CR))
Surface defects (category 1 and 3)	Surface defect rate [SD] (%)	PI_surface defects (PI_SD)	PI_SD = Max(0; Min(5;0.1333·SD))

Table 9: Transfer function cracking and surface defects

5.4 DEVELOPMENT OF COMBINED PERFORMANCE INDICATORS

5.4.1 Combination Function

The combination of single PIs into CPIs is based on the advanced maximum criteria. It takes into account the maximum weighted PI value affected by biased values of other weighted PIs. By using this method it is possible to combine different indices under different preconditions.

This method was selected in order to ensure that the final result of the CPI is strongly influenced by the maximum weighted PI. For the practical application of the combination procedure two alternatives were developed. The alternatives give the user the possibility to consider the influence of the other weighted PIs as follows:

- Alternative 1 considers the mean value of the weighted single performance indices other than the maximum weighted single performance index influenced by a factor *p*.

$$CPI_i = \min\left[5; I_1 + \frac{p}{100} \cdot \overline{(I_2, I_3, \ldots, I_n)}\right]$$

where

$$I_1 \geq I_2 \geq I_3 \geq \ldots \geq I_n$$

and

$$I_1 = W_1 \cdot PI_1; I_2 = W_2 \cdot PI_2; \ldots; I_n = W_n \cdot PI_n .$$

- Alternative 2 considers the second largest weighted single performance index influenced by a factor *p*. All other PIs which are less than the second largest weighted single performance index are not taken into consideration.

$$CPI_i = \min\left[5; I_1 + \frac{p}{100} \cdot I_2\right]$$

where

$$I_1 \geq I_2 \geq I_3 \geq ... \geq I_n$$

and

$$I_1 = W_1 \cdot PI_1; I_2 = W_2 \cdot PI_2; ...; I_n = W_n \cdot PI_n.$$

Alternative 1 is the preferred combination procedure for the calculation of CPIs because it takes all relevant input values into consideration. However, alternative 2 can be useful for specific applications.

The influence factor *p* enables to control the total influence of the weighted single performance indices according to their relevance. Based on investigations and analysis done in Germany, the influence factor for the calculation of combined performance indices should be between 10 and 20% (see Oertelt et al, 2007 [8]). A high *p* factor increases the influence of the other weighted single performance indices than the maximum one.

The reason for the application of the advanced maximum criteria can be given by the following example. If only the maximum value will be used for the combination procedure and no influence of the other weighted single performance indices is given, than a section with rutting in "poor" condition and friction in "very good" condition will be similar to a section with rutting and friction in "poor" condition. There will be no difference in the value of the Combined Performance Index.

In order to avoid this situation, the indices other than the maximum single performance index must be taken into consideration in the combination procedure. The two alternatives described above define the method of influence and the p factor defines the degree of influence. With regard to the given example a section with rutting in "poor" condition and friction in "very good" condition will not be similar to a section with rutting and friction in "poor" condition anymore. Subject to the method and the degree of influence, the second section will be possibly in "very poor" condition from the Combined Performance Index point of view.

The weights W_i represent the influence of the different single performance indices or pre-combined performance indices on a relative basis as well. The maximum weight of all used single performance indices or pre-combined performance indices should be always 1.0.

If the maximum weight is less than 1.0 and no transformation of the weights has been applied, the Combined Performance Index will never reach the maximum value. E.g., if the maximum weight for the calculation of the Safety Index is 0.8 for friction and no transformation took place, the value of the Safety Index will be 4 as maximum, although the friction holds an index of 5. The correct answer of this example should hold a Safety Index of 5 as well. Therefore it is necessary to guarantee, that the maximum weight in use is always equal to 1.0. In practice the weights of all used single performance indices or pre-combined performance indices will be transformed through the use of a linear transfer function if the maximum weight is less than 1.0.

Furthermore, the transformation of the weights is not a section or area based commitment. It is a general commitment subject to the single performance indices or pre-combined performance indices in use. The equations to define the weight transformation are equal to the expressions which are used for cracking and surface defects and can be taken from chapter 5.3.1.

5.4.2 Input Parameters and Weights for Combined Performance Indices

As already described in chapter 5.1, the combined performance indices are categorised in four groups representing different areas of application. The significance of the input parameters (single performance indices and pre-combined performance indices) is given on the one hand by the indicator itself, and on the other hand by their weights. One single performance index can be used for the calculation of one or more combined performance indices. Table 10 shows the single performance indices recommended for the calculation of the four combined performance indices, subject to the level of application:

Level	**Comfort Index**	**Safety Index**
Minimum	PI_E	PI_F
Standard	PI_E, PI_SD, PI_R	PI_F, PI_R, PI_T
Optimum	PI_E, PI_SD, PI_R, PI_T, PI_CR	PI_F, PI_R, PI_T, PI_SD$_{cat1}$ *), PI_SD$_{cat2}$
Level	**Structural Index**	**Environmental Index**
Minimum	PI_B	-
Standard	PI_B, PI_CR	-
Optimum	PI_B, PI_CR, PI_R, PI_E	PI_E or air pollution, PI_T or noise labelling; PI_SD$_{cat2}$

PI_E…PI evenness
PI_F…PI friction
PI_CR…PI cracking
PI_SD…PI surface defects (all categories)
PI_SD$_{cat2}$…PI surface defects category 2
PI_R…PI rutting
PI_T…PI macro-texture
PI_B…PI bearing capacity
PI_SD$_{cat1}$…PI surface defects category 1

*) including bleeding only

Table 10: Input parameters for combined performance indices

The missing element is the Environmental Index. Based on the results of WP2 no single performance indices for noise and air pollution could be found. Due to this situation and to avoid a spurious accuracy, only a textual description about possible approaches is given in the next chapter 5.4.3.

The influence of the input parameters (single and pre-combined performance indices) on the CPI value is given on the one hand by the value of indicator itself and on the other hand by the weight assigned to the indicator. For the calculation of the combined performance indices in practice it is necessary to determine different weights for different single performance indices.

Based on a statistical evaluation of collected information from the experts within WP3 about different weights, the following proposal was drawn up. Table 11 to Table 13 contain the mean, median, and a proposed range (minimum and maximum) of weights for the calculation of the Safety Index, the Comfort Index, and the Structural Index. The range is defined by the second largest and second lowest value of the analyzed data volume.

Single Performance Index	Weight W' [0-1] (0 = lowest importance, 1 = highest importance)			
	Comfort Index			
	min*)	max*)	median	mean
PI evenness (PI_E)	1.0	1.0	1.0	1.0
PI rutting (PI_R)	0.6	0.8	0.8	0.7
PI texture (PI_T)	0.3	0.5	0.5	0.4
PI surface defects (PI_SD)	0.3	0.8	0.8	0.6
PI cracking (PI_CR)	0.3	0.8	0.6	0.5

*) second largest and second lowest value of statistical evaluation

Table 11: Weights for input parameters for the Comfort Index

Single Performance Index	Weight W' [0-1] (0 = lowest importance, 1 = highest importance)			
	Safety Index			
	min*)	max*)	median	mean
PI rutting (PI_R)	0.8	1.0	1.0	0.9
PI friction (PI_F)	0.4	1.0	1.0	0.9
PI texture (PI_T)	0.4	0.9	0.5	0.6
PI surface defects (PI_SD)	0.2	0.8	0.7	0.6

*) second largest and second lowest value of statistical evaluation

Table 12: Weights for input parameters for the Safety Index

Single Performance Index	Weight W' [0-1] (0 = lowest importance, 1 = highest importance)			
	Structural Index			
	min*)	max*)	median	mean
PI evenness (PI_E)	0.5	0.8	0.7	0.6
PI rutting (PI_R)	0.4	0.8	0.5	0.5
PI cracking (PI_CR)	0.8	1.0	0.9	0.9
PI bearing capacity (PI_B)	1.0	1.0	1.0	1.0

*) second largest and second lowest value of statistical evaluation

Table 13: Weights for input parameters for the Structural Index

This proposal can be used as first recommendation in the context of computing the combined performance indices. If there are weights already available, the function can be adapted individually by the user.

The following Figure 13 shows the effects of changing the weights in the context of the combination of 2 Single Indices (PI1 and PI2) into a Combined Index through the use of the advanced maximum criteria (alternative1) as a general example.

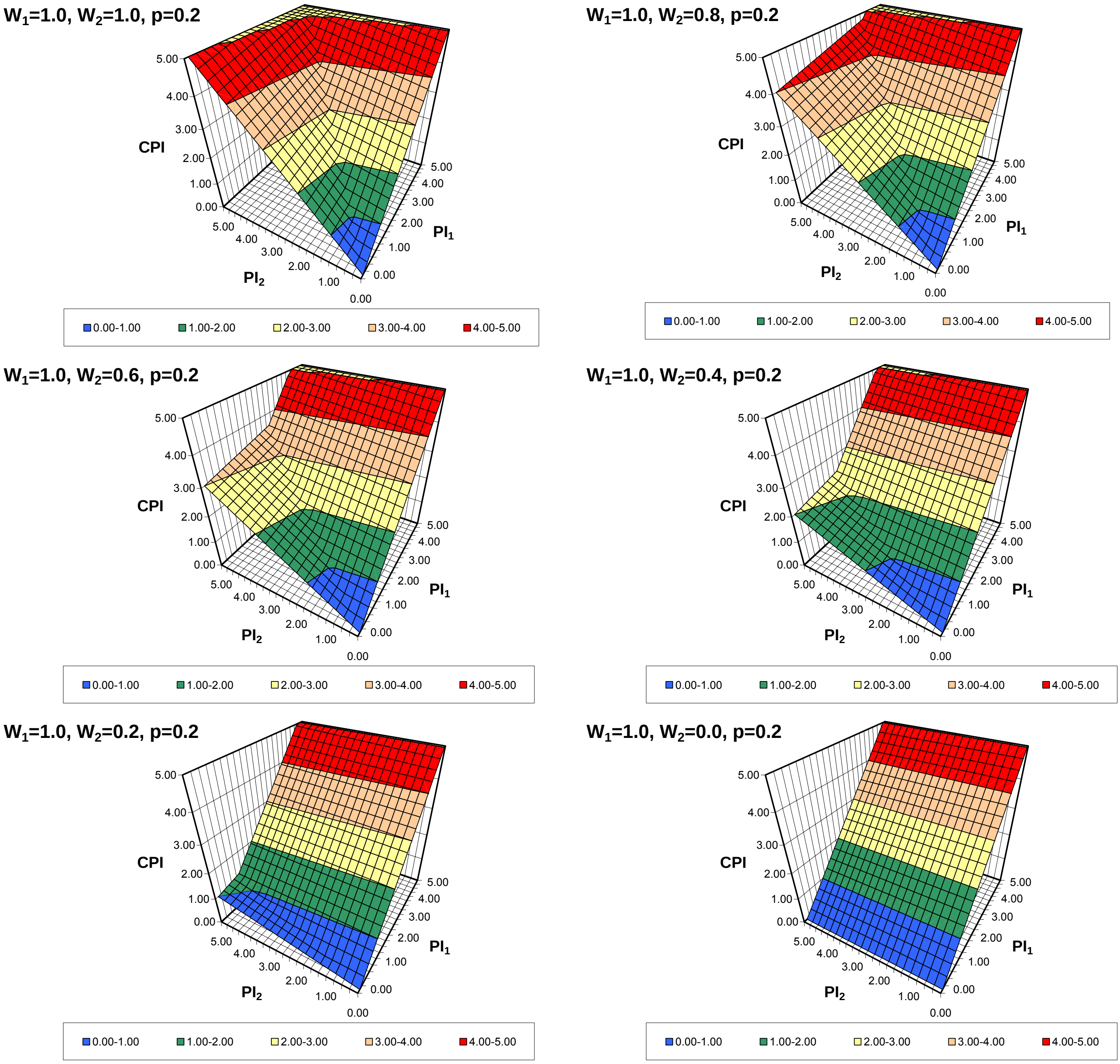


Figure 13: Example on changing weights in the combination procedure

5.4.3 Combined Environmental Indicator

The assessment of pavement construction taking into account the environmental point of view becomes more and more important in the future. It is assumed that certain environmental indicators will play a decisive rule in the decision procedures of road administration authorities, private concessionaires, and finally policy makers.

As already mentioned in chapter 4, some basic problems during the evaluation of the data contained in the COST354 database were highlighted especially on the environmental sector. From today's point of view two single performance indicators could be used to describe the environmental status - however it is defined - of a pavement construction in the close future.

These indicators are

- Noise and
- Air pollution.

No adequate technical parameters and thus no single performance indices could be defined. Both indicators are seen as important for the assessment of environmental impacts of road pavements. However at present there are not sufficient data concerning the influence of road pavements on these environmental impacts available to derive appropriate indices.

In the context of the evaluation of COST354 database four Combined Environmental Indicators could be found in total. All four environmental indicators are coming from USA and show a different way of defining environmental indicators as mentioned above. These indicators describe indirectly the effects on the environment through the use of a correlation between a poor pavement condition and high vehicle operating costs (e.g. increase of vehicle operating costs by bad pavement condition) and/or user costs (time loss in connection with higher CO_2-emmissions). Similar definitions or correlations can be also taken from the environmental assessment procedures which are used in HDM III and HDM 4 [2,3].

These examples could be a practical approach for the definition of the Environmental Index as well. As first recommendation, the following single performance indices can be used in a combination procedure for the definition of the Environmental Index:

- Longitudinal evenness as indirect indicator for air pollution and vibrations;
- Texture as indirect indicator for noise emission;
- Surface defects (category 2) as indirect indicator for vibrations.

The practical application of certain single performance indices is strongly dependent on the field of application and the significance of each single performance index. For example, noise and vibrations will have a high significance in urban but not in uninhabited areas, emissions of CO_2 and fine particles will have a high significance in general. Thus different weights should be used as well.

At the moment it is not possible to give a proposal of weights related to the indicators listed above. However, the combination procedures are available and weights can be defined individually by the user, subject to the road network, the field of application, and other preconditions.

6 GENERAL (GLOBAL) PERFORMANCE INDICATORS

6.1 DEFINITION OF GENERAL PERFORMANCE INDICATOR

A general indicator is a mathematical combination of single and/or combined indicators which describe the pavement condition concerning different aspects like safety, structure, riding comfort and environment.

The general indicator gives a first impression of the overall pavement condition at network level, and points out weak sections. By using this information, a general maintenance strategy can be derived. Consequently, the general indicator is a useful tool for superior decisions-makers to assess the general condition of the network and to evaluate future general strategies and the funding.

As a general indicator does not reflect the cause of the lack of quality in detail, a more detailed analysis based on the single performance indicator has to be performed to assess the maintenance work itself and the necessary financial budget.

6.2 CURRENT PRACTICES FOR ESTABLISHING GENERAL PERFORMANCE INDICATORS

General performance indicators are provided in the COST 354 database as part of the combined performance indicators. These and other indicators presented in the literature were analysed in order to help in the definition of a GPI (see WP4 report on the CD-ROM enclosed).

The information analysed shows that there are not many indices reported in the COST 354 database that can be defined as global or general indices. The most appropriate approach seems to be the definition of a general performance index using a simple function to combine safety, comfort, structural adequacy and environment indices.

However, the use of a simple linear relationship will not be enough for that purpose, since the selected function should be able to provide adequate information if the pavement is totally inadequate with respect to one of the combined indicators, even if the others have low values. A combination procedure based on advanced maximum criteria was considered the most adequate.

6.3 DEVELOPMENT OF A GENERAL PERFORMANCE INDICATOR

This section concerns the development of a general performance indicator (GPI) for road pavements, using the following combined performance indicators (CPI) presented in the previous chapter:

- Safety Index;
- Comfort Index;
- Structural Index;
- Environmental Index.

As already referred in Work Packages 2 and 3 reports, it may be difficult to get appropriate input data for the calculation of a Combined Environmental Index. Nevertheless the following combination procedure can be used without a Combined Environmental Index.

6.3.1 Selection of a function

The combination of combined performance indices (CPIs) into a general performance index (GPI) is based on the advanced maximum criteria already presented in the context of calculation of CPIs. It takes into account the maximum weighted CPI value affected by biased values of other weighted CPIs. By using this method it is possible to combine different indices under different preconditions.

This method was selected in order to ensure that the final result of the GPI is strongly influenced by the maximum weighted CPI. For the practical application of the combination procedure the two alternatives presented in chapter 5.4.1 were considered.

The following equations show both alternatives for the calculation of the GPI:

- Alternative 1:

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot \overline{(I_2, \ldots, I_n)}\right]$$

where

$$I_1 \geq I_2 \geq \ldots \geq I_n$$

and

$$I_1 = W_1 \cdot CPI_1; I_2 = W_2 \cdot CPI_2; \ldots; I_n = W_n \cdot CPI_n.$$

- Alternative 2:

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot I_2\right]$$

where

$$I_1 \geq I_2 \geq \ldots \geq I_n$$

and

$$I_1 = W_1 \cdot CPI_1; I_2 = W_2 \cdot CPI_2; \ldots; I_n = W_n \cdot CPI_n.$$

Alternative 1 is the preferred combination procedure for the calculation of GPI because it takes all relevant input values into consideration. However, alternative 2 can be useful for specific applications.

The influence factor *p* enables to control the total influence of the weighted combined performance indices in subject to their relevance. Based on investigations and analyses done in Germany, the influence factor for the calculation of Combined Indicators should be between 10 and 20% [8]. A high *p* factor increases the influence of the other than the maximum one weighted combined performance indices.

The weights W_i represent the influence of the different combined performance indices on a relative basis. The CPIs with the highest weight should always have a weighting factor of 1.0. For example, if the maximum weight for the calculation of the general performance index is 0.8 for safety and no transformation took place, the value of the general performance index may be 4, although the Safety Index holds a value of 5. The correct answer of this example should hold a general performance index of 5 as well. Therefore it is necessary to guarantee, that the maximum weight in use is always equal to 1.0. In practice the weights of all used combined performance indices will be transformed through the use of a linear transfer function if the maximum weight is less than 1.0.

Furthermore the transformation of the weights is not a section or area based commitment. It is a general commitment subject to the CPIs in use.

The following equations define the weight transformation when the maximum weighting factor is lower than 1.

$$x = \frac{1}{\max\left(W_1^{'}; W_2^{'}; \ldots; W_n^{'}\right)}$$

$$W_1 = x \cdot W_1^{'};\ W_2 = x \cdot W_2^{'}; \ldots ; W_n = x \cdot W_n^{'}$$

6.3.2 Weighting factors for combined indices

For the calculation of a general performance indicator using the function presented in the previous section, it will be necessary to assign appropriate weighing factors to each of the combined performance indicators adopted. Each user will be able to choose a set of weighting factors that reflect his / her priorities. These priorities may also be different for different types of networks.

In order to provide additional information for the choice of weighing factors, WP4 implemented a survey within the countries represented in COST 354, with the purpose of collecting opinions from different groups of stakeholders concerning the relative importance of each type of combined performance indicator. Each member of the Management Committee was asked to collect opinions from the following categories of respondents:

- Road Authorities;
- Road Operators;
- Researchers;
- Road Users.

Each respondent was asked to provide a relative influence factor (from 0 to 1) for each of the above combined pavement performance indices, taking into account the type of road network. In order to have a common scale, it was requested that the sum of influence factors for a given network type should be equal to 1. The information gathered is presented in WP4 report (see CD-ROM). Figure 14 shows the average relative influence factors per type of road and type of respondent.

In many cases it was difficult to differentiate whether a respondent to the questionnaire belonged to the group of “Road Administrators” or “Road Operators”, since very often a single organisation is in the two groups. Therefore, in the final analysis of the questionnaire, these two groups were combined into one group for the analysis taking into consideration all answers together.

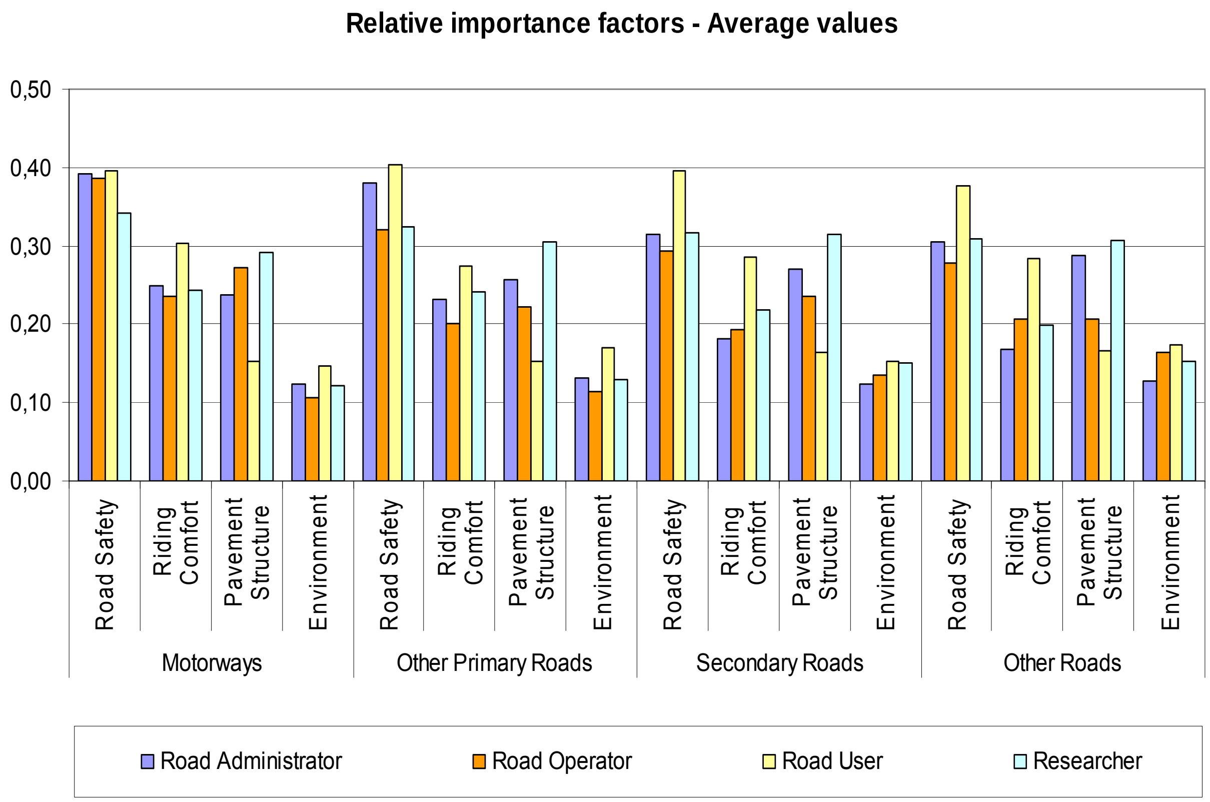


Figure 14: Average replies per type of respondent and road category

Figure 15 to Figure 17 present the distribution of replies from Road Administrators and Operators, Road Users and Researchers, respectively.

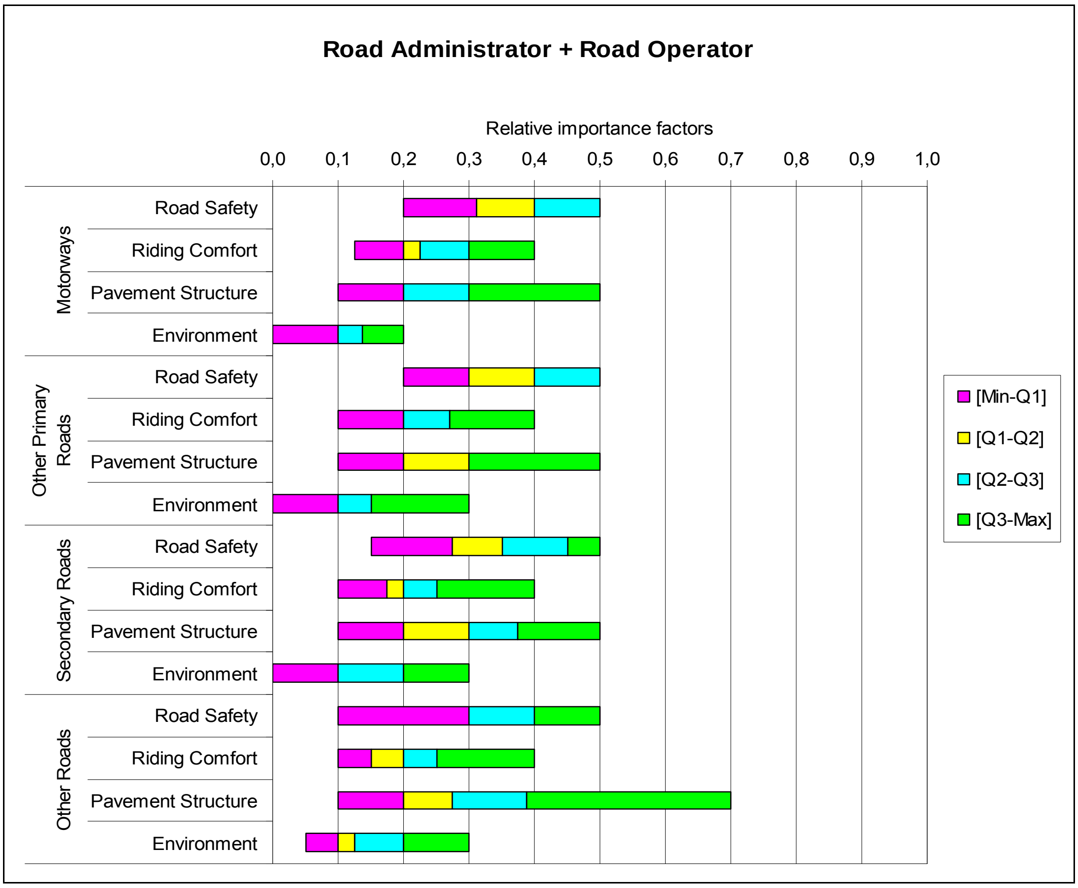


Figure 15: Distribution of relative importance factors by quartiles - Road Administrators and Operators

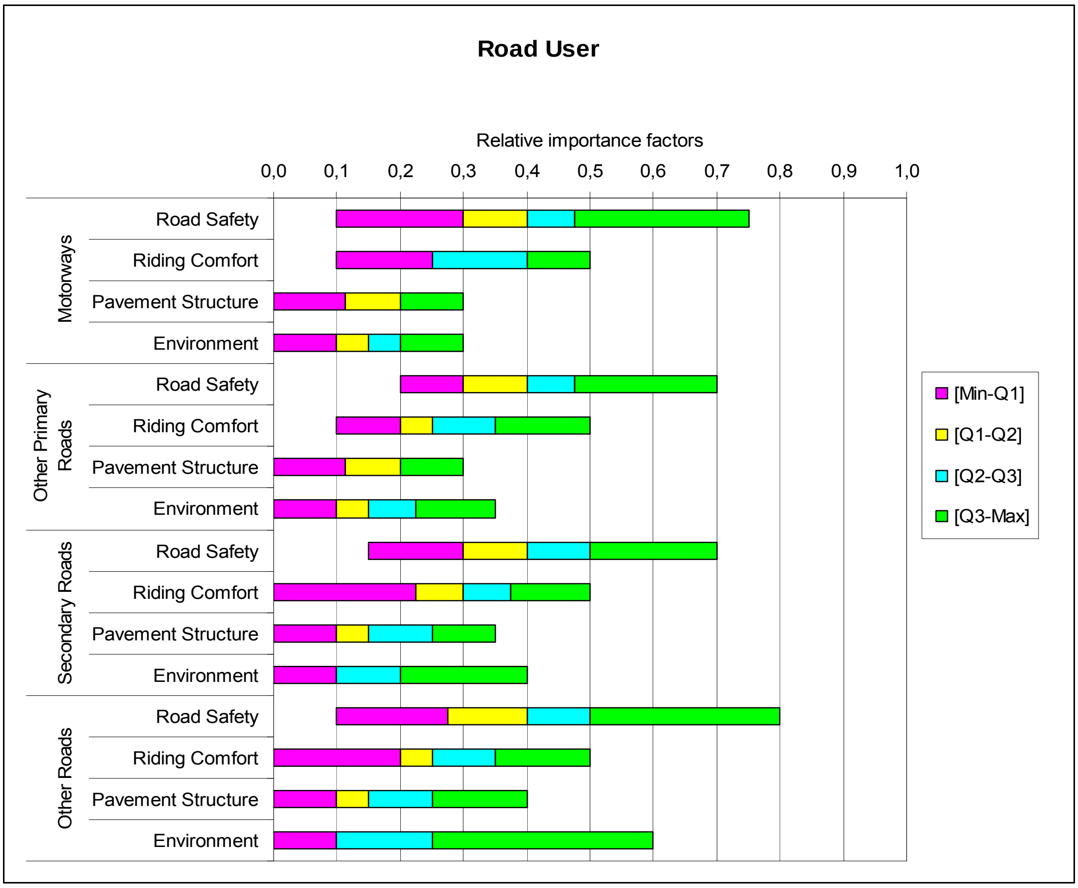


Figure 16: Distribution of relative importance factors by quartiles - Road Users

Figure 17 - Distribution of relative importance factors by quartiles - Researchers

In order to apply the advanced maximum criteria presented in chapter 6.3.1, the weighing factors (W1 to W4) to be used in the combination procedure will be given in a different scale, where the highest value(s) must be equal to 1.0. For this purpose, the weights had to be transformed by a linear transfer function (see chapter 6.3.1).

Despite of having received replies concerning the relative importance of CPI for "Other Roads", there was no specific information in the database regarding Single or combined performance indicators for this category of roads. Therefore, subsequent analysis was performed with a combination of elements collected for Secondary Roads and Other Roads.

Using the data gathered through the questionnaire and summarised in the previous Tables, the following weighting factors are recommended by COST 354. Before applying these weights in practice, they should be checked for plausibility subject to the field of application, their objectives and other preconditions.

Motorways			
Road Safety	**Riding Comfort**	**Pavement Structure**	**Environment**
1.00	0.70	0.65	0.25
Primary Roads			
Road Safety	**Riding Comfort**	**Pavement Structure**	**Environment**
1.00	0.70	0.80	0.30
Secondary and Other Roads			
Road Safety	**Riding Comfort**	**Pavement Structure**	**Environment**
1.00	0.65	1.00	0.35

Table 14: Proposed weighting factors

The WP4 report (see CD-ROM) presents two examples of application of the proposed procedure where alternatives 1 and 2 are compared, using the weighting factors recommended above.

7 TOOL FOR PRACTICAL APPLICATION AND SENSITIVITY ANALYSIS

7.1 SPREADSHEET TOOL

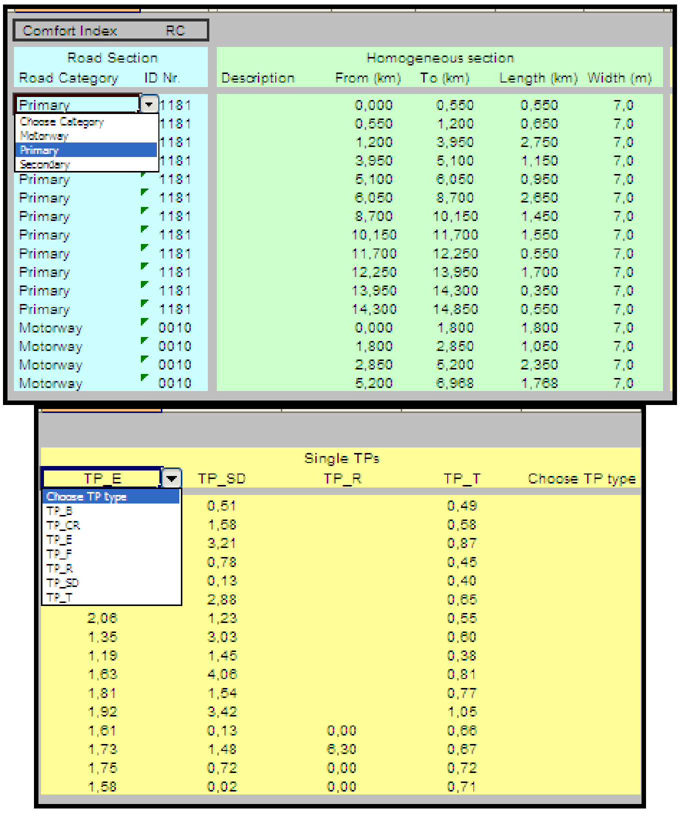
Within this COST Action a spreadsheet tool was developed for the practical application of the recommended procedure. The tool itself allows for calculating combined performance indices (CPIs) from technical parameters (TPs) that the user has collected. Based on these CPIs, a general performance index (GPI) is calculated. This spreadsheet is described in more detail in WP3 report (see CD-ROM). The spreadsheet tool can be used to:

- transform technical parameters into single performance indices,
- calculate combined performance indices, and
- calculate a general performance index,

following the procedures developed and proposed in the various work packages (see chapters 4, 5, and 6). This spreadsheet tool is also included in the CD-ROM.

In general, the calculation can be performed for the three different road categories: motorways, primary roads and secondary roads. Based on the users needs, calculation is done for single measured sections or for homogeneous sections. Basic road sections data is entered into the table on four spreadsheets named: “Comfort Index”, “Safety Index”, “Structural Index” and “Environmental Index”.

As can be seen from Figure 18, the road category can be chosen from a drop-down list and some other road specific data can be also entered directly (section length is calculated and does not need to be entered).



Comfort Index RC

Road Section		Homogeneous section				
Road Category	ID Nr.	Description	From (km)	To (km)	Length (km)	Width (m)
Primary	1181		0,000	0,550	0,550	7,0
	1181		0,550	1,200	0,650	7,0
	1181		1,200	3,950	2,750	7,0
	1181		3,950	5,100	1,150	7,0
Primary	1181		5,100	6,050	0,950	7,0
Primary	1181		6,050	8,700	2,650	7,0
Primary	1181		8,700	10,150	1,450	7,0
Primary	1181		10,150	11,700	1,550	7,0
Primary	1181		11,700	12,250	0,550	7,0
Primary	1181		12,250	13,950	1,700	7,0
Primary	1181		13,950	14,300	0,350	7,0
Primary	1181		14,300	14,850	0,550	7,0
Motorway	0010		0,000	1,800	1,800	7,0
Motorway	0010		1,800	2,850	1,050	7,0
Motorway	0010		2,850	5,200	2,350	7,0
Motorway	0010		5,200	6,968	1,768	7,0

Single TPs				
TP_E	TP_SD	TP_R	TP_T	Choose TP type
	0,51		0,49	
	1,58		0,58	
	3,21		0,87	
	0,78		0,45	
	0,13		0,40	
	2,88		0,65	
2,06	1,23		0,55	
1,35	3,03		0,60	
1,19	1,45		0,38	
1,63	4,06		0,81	
1,81	1,54		0,77	
1,92	3,42		1,05	
1,61	0,13	0,00	0,66	
1,73	1,48	6,30	0,67	
1,75	0,72	0,00	0,72	
1,58	0,02	0,00	0,71	

Figure 18: Road sections specific data in the spreadsheet tool

For each of the CPIs (Comfort Index, Safety Index or Structural Index) the user needs to enter the TP data into the tables. Each CPI can be calculated from up to 5 TPs. The TP type can be selected from a drop-down list with 7 TP types (bearing capacity, cracking, evenness, friction, rutting, surface defects and texture).

Based on the road category, TP type and data, single PIs are calculated for each single road section using the transfer functions. Transfer functions can be found on the “Transfer functions” spreadsheet.

Depending on the availability of user criteria, the user can enter their own TP values for single PIs condition limit value, or use the default ones (that form the default transfer functions).

Once single PIs are calculated, the user should choose and enter the weighting factors, which are used for calculating Combined PIs, as described in chapter 5. In this regard, next to the “weights” section there is a “proposed weights” section. As assistance for defining proper weighting factors, the user can have a look to minimal, maximal, mean and median factors, as a result of factors gathered during the work in COST Action. The weighting factors can be found also on “Weights” spreadsheet, where there is a statistical evaluation of factors gathered from several European countries’ experts. Beside the four previously mentioned, there are more weighting factors available (e.g. mean minus standard deviation, mean plus standard deviation, etc.). When deciding about weighting factors, the user has to bear in mind, that, as suggested from the COST Action group, the highest one should always be equal to 1.0. In some cases, when the user is calculating CPIs from just a few PIs and depending on combination of these few PIs, it might happen, that the highest suggested weight is not 1.0. Nevertheless, the user should enter weights with the highest one equal to 1.0.

After the weighting factors are defined, the weighted single PIs are calculated by the spreadsheet. For information, the weighted PIs are ranked and shown in descending order. The final result (CPI) is strongly influenced by the maximum weighted PI.

The GPI is calculated using the advanced maximum criteria for combination of CPIs. To this aim, the user should define her/his own CPI weighting factors. Like in the case of single PIs, as guidance for the definition of weighting factors, the user can have a look at different sets of CPI weighting factors. From a drop-down list, the user can choose and look at sets of factors (mean and median) attributed to the “Administrator and Operator”, “User” and “Researcher”. These factors were gathered through the questionnaire presented in chapter 6.3.2, and can be found on the “Weights CPIs” spreadsheet. This spreadsheet also contains the suggested factors (“Proposed”) presented in Table 14. An example can be seen in Figure 19 .

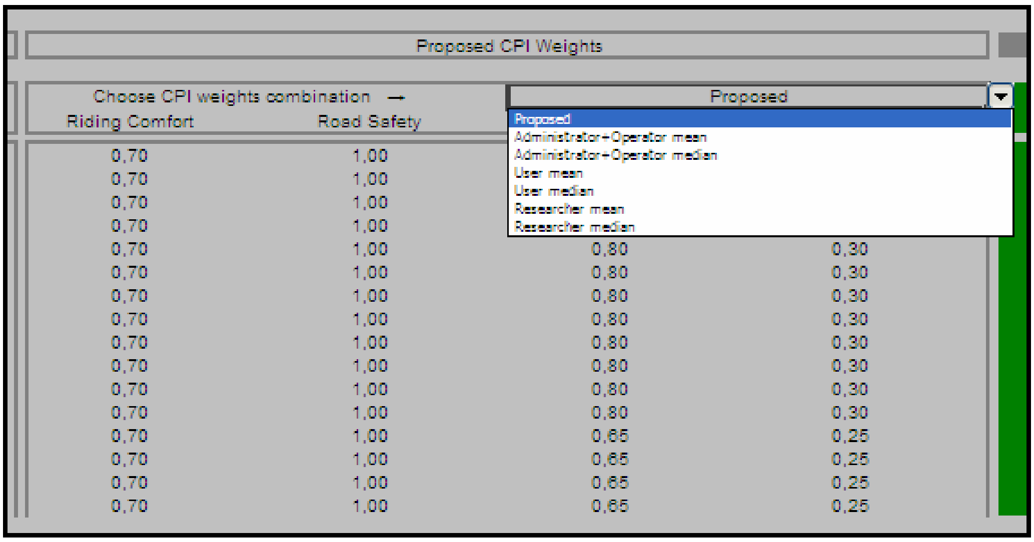


Figure 19 - Weighting factors for GPIs

7.2 SENSITIVITY ANALYSIS

After the spreadsheet tool was developed, it has been used for performing a short sensitivity analysis in the context of a Short Term Scientific Mission (STSM 5, see CD-ROM). The idea was to gather some data from real road sections, from different European countries, and use it for calculation of CPIs and finally general PIs. The sensitivity analysis was done firstly with changing the proposed sets of weighting factors for single PIs, and secondly changing the influence factor p – thus increasing the influence of other than the maximal weighting factors towards the maximal one.

For performing the sensitivity analysis, data from Slovenia, Austria and UK were gathered. The data sets from Slovenia and Austria refer to homogeneous sections with different representative condition values, whereas the data sets from the UK refer to different data points in one specific section.

For calculating the single PIs from TPs, the countries' own transfer functions were used (most of them were available), and for calculating weighted single PIs, the weighting factors gathered from experts from respective countries, were used.

At first step, for testing the difference in single PIs calculated with different weighting factors, two sets of factors were taken into account. For each country the weighted single PIs were calculated using mean and median values sets. These were calculated from gathered weighting factors from a number of European countries, respective to the CPIs and PI group.

The analysis showed expected results. In case of Structural Index, the gathered weighting factors within the same single PIs differ less from each other than in case of the two other CPIs. This results in more homogeneous group of factors, thus also to mean and median sets of factors that are very close to each other. Using similar factors returns very similar calculated CPI values.

In case of higher level of calculated CPI values, the difference between mean and median sets of factors results in larger discrepancy between CPI values compared to lower levels of calculated CPI values.

One dominant weighted single PI in group of others with relatively low weight, results in higher discrepancy between CPI values (Slovenian case) compared to group of weighting factors, relatively closer to each other (UK case).

The next step was to test the difference in results when increasing the influence factor p. For this test, the weighting factors gathered from experts from respective countries were used. The influence factors that affect the influence of the other weighted single PIs in relation to the maximal one were changed from 0.1 to 0.5, by steps of 0.1. The results are shown in the following figures.

The effect of changing the influence factors depends on the level of other weighted single PIs compared to the highest one. If the highest weighted single PI is predominant, than there will be a low influence of increased influence factor p and vice versa. Where there is a more homogeneous group of weighted single PIs, the increase in influence factor p will show in higher discrepancy between CPI values. It should be noted that not only the predominance of the highest weighted PI, but also the absolute level of the CPI values has an influence on the differences.

For testing the difference in calculated GPI values with different CPI weighting factors, seven sets of factors were taken into account. For each country the GPIs were calculated using "Administrators and Operators", "Users" and "Researchers" sets of average and median CPI weighting factors for the respective road categories. In addition to these six sets of factors, the calculation was done using the weighting factors suggested by WP4. For each set of factors, the influence factor p was varied between 0.1 and 0.5.

Figure 20 illustrates the results obtained using alternative 1 and the COST 354 proposed weighting factors (Table 14) for calculation of general performance indices considering the influence factors varying between 0.1 and 0.5. From these calculations, it was concluded that in general, where weighted Combined PIs levels are low, like in the UK example, changing of influence factor p has very limited impact. When the level of weighted Combined PIs with exception of the highest one, is high, like in the Austrian case, the influence factor has more impact on the GPI.

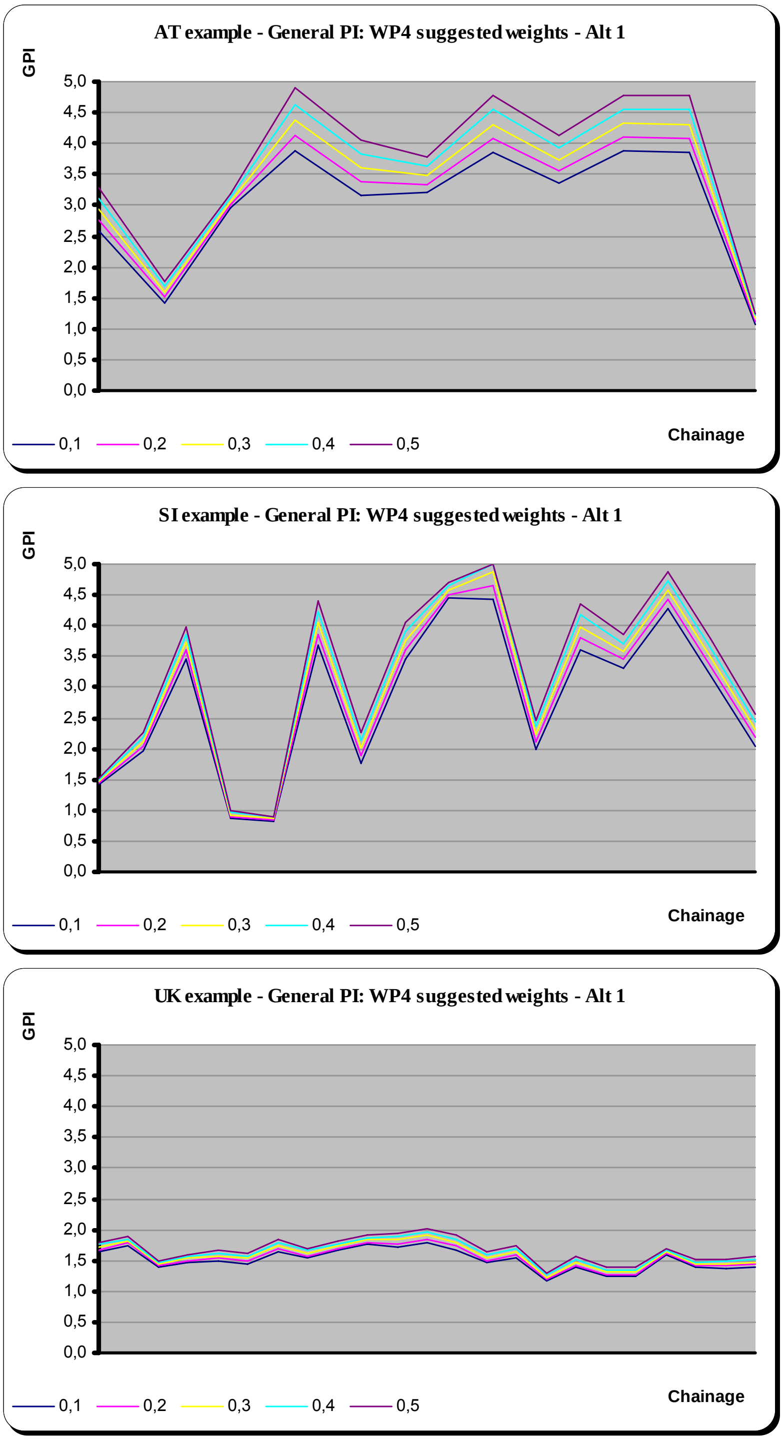


Figure 20: Changes in GPIs due to changes in influence factor p

As part of the sensitivity analysis, a comparison was made between GPIs, calculated by using all seven sets of weighting factors and a constant influence factor of 0.1 and by applying alternatives 1 and 2. The results for all three countries are presented with data points along the road sections and shown in Figure 21. The results are identified as follows:

- WP4 – factors suggested by WP4 members;
- A+O – Administrators and Operators set of factors;
- U – Users set of factors;
- R – Researchers set of factors.

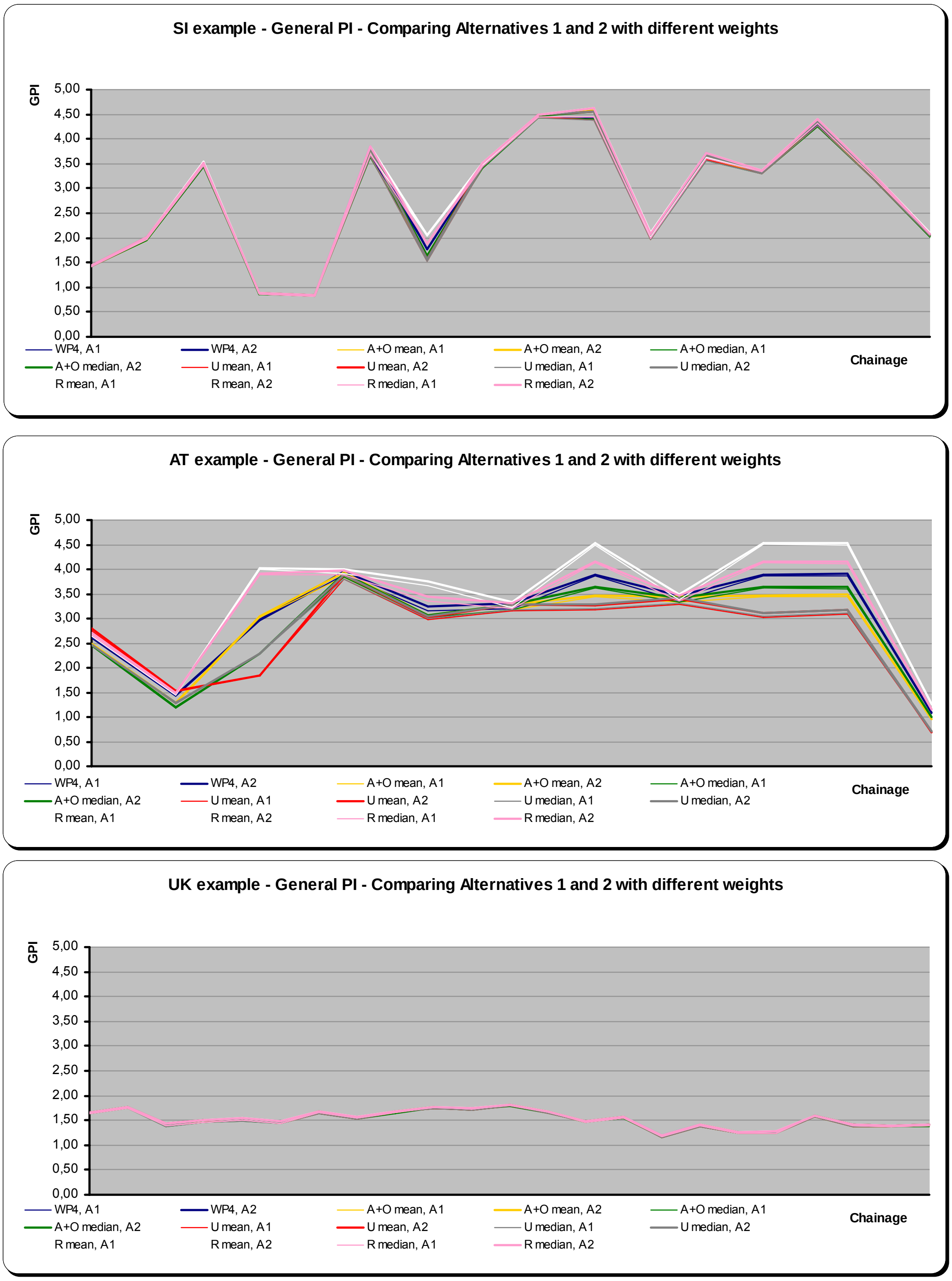


Figure 21 - GPIs calculated using alternatives 1 or 2 for advanced maximum criteria, and with all sets of weighting factors, UK case

When we compare results from the three sets of data, we can conclude that, when the different Combined PIs have higher values, the results become much more sensitive to the specific sets of weighting factors used, as well as to the choice of calculation alternatives or to the influence factor. This is the case for the Austrian data, where the rest of Combined PIs are relatively high compared to the highest one, and therefore, the variation in GPIs when the weighting factors change, is high.

7.3 RECOMMENDATIONS FOR PRACTICAL APPLICATION

The spreadsheet tool used in the sensitivity analysis can be used informatively for the calculation of general performance indicator following the procedures developed within the work in this COST Action. This should be done with great care, since the tool was tested only to a minor extent, and it might include some unintentional or misleading fault.

The tool was prepared in a way, to be as useful as possible for the user, not making him input or define the non-needed or duplicate information. Many options in drop-down lists are given to the user, for easier decisions there are also shown proposed sets for weighting factors. When the CPIs and GPIs are calculated, it is done for technical parameters, derived from various measurements or collected by other forms of investigation, alongside the road sections. Calculations can be done for other road sections simply by copying the last row and pasting it to next ones, as many times as needed.

The transfer functions in the tool are based on:

- WP2 and WP3 suggestions, or
- sectional linear regression lines.

In case of suggested transfer functions, they can be linear or quadratic ones. They take the following forms:

- $PI = B \cdot TP + C$;
- $PI = A \cdot TP^2 + B \cdot TP + C$.

For both cases, coefficients A, B and C are entered in appropriate tables, and if selected from drop-down list, also shown in chosen functions table. If the user prefers to use her/his own linear or quadratic transfer functions, they can be used by entering appropriate coefficients A, B and C.

When the user chooses only the limit values for evaluating the road pavement condition, then the transfer functions can take the form of linear functions. For each TP there is a table indicating TP values for the Single PIs condition limit values (0 to 5 scale, very good to very poor or vice versa). Parameters A, B and C for the best fit straight lines are calculated and shown near the tables and are used for calculating the Single PIs from TP data. Depending on the availability of user criteria, the user can enter her/his own TP values for Single PIs condition limit value, or use the default ones.

The recommended weights are based on the analysis of the answers given by a certain number of people all over Europe. Before applying these weights in practice they should be checked for plausibility subject to the field of application, their objectives and other preconditions.
To ensure that reliable results are achieved, the users should make a sensitivity analysis of their own local performance data and define their own relative weighting factors.

8 EXAMPLE ON CALCULATION OF SINGLE, COMBINED AND GENERAL PERFORMANCE INDICES

The following section provides an example of the calculation of single, combined, and general performance indices, according to the methodology presented in previous chapters and based on an actual road section condition.

Step 1 – Current Pavement Condition

The results of the survey of a section of a primary road, 5-km long and with an average width of 7.5 m are provided in Table 15. Pavement structure is composed of asphalt layers on surface and in base course and unbound base.

Technical Parameter	Abbr. / Unit	Severity	Value
Longitudinal Evenness	IRI (m/km)		3.0
Transverse Evenness	RD (mm)		12.5
Skid resistance	SFC		0.5
Texture	MPD (mm)		0.5
Bearing Capacity	SCI_{300} (µm)		325
Cracking			
- longitudinal cracking	LC (m)	1	550
		2	200
- transverse cracking	TC (m)	2	200
- alligator cracking	AC (m^2)	1	2000
		2	1500
- block cracking	BC (m^2)	1	1500
Surface defects			
- bleeding	BL (m^2)		2000
- patching	PTCH (m^2)	1	800
		2	200

Table 15: Input data

Step 2 – Calculation of Single Performance Indices

The calculation of single performance indices (SPI) is presented in Table 16, including the equation of the used transfer functions.

Technical Parameter (TP)	Single Performance Index (SPI)	Value of the TP	Equation Transfer Function	Value of the SPI
Longitudinal Evenness	PI_E	3.0	PI_E = MIN(5;0.1733·IRI^2+0.7142·IRI-0.0316)	3.67
Transverse Evenness	PI_R	12.5	PI_R = MIN(5;-0.0015·RD^2 + 0.2291·RD)[1]	2.63
Skid resistance	PI_F	0.5	PI_F = MIN(5;-17.600*SFC+11.205)	2.41
Texture	PI_T	0.5	PI_T = MIN(5;6.6 - 5.3 MPD)[1]	3.95
Bearing Capacity	PI_B	325	PI_B = MIN(5;SCI$_{300}$/129)[2]	2.52

Notes: [1]Primary road
[2]Unbound (weak) base

Table 16: Single performance indices

Step 3 – Calculation of Pre-combined Performance Indices

Two pre-combined performance indices need to be calculated (cracking and surface defects).

The "Cracking" technical parameter needs to be calculated first. It consists of two parts: $TP_{cr,A}$ for areal cracking (alligator and block cracking) and $TP_{cr,L}$ for linear cracking (longitudinal and transverse cracking).

The input data for calculation of TP_{cr} are presented in Table 17.

Type of Cracking	Unit	Weight W	Transformed Weight W'	Severity	Extent (m^2)	Section area (m^2)
Alligator cracking	m^2	0.9	1.0	1	2000	37500
				2	1500	
Block cracking	m^2	0.8	0.89	-	1500	
Longitudinal cracking	m	0.7	0.78	1	550	
				2	200	
Transverse cracking	m	0.7	0.78	2	200	

Table 17: Input data for cracking

The technical parameter cracking due to the areal cracking distresses (alligator and block cracking) is obtained from the following equation:

$$TP_{cr,A} = Min\left(100; \frac{1}{37500} \cdot \left(1.0 \cdot \left(1 \cdot 2000 + 2 \cdot 1500\right) + 0.89 \cdot 1500\right) \cdot 100\right) = 16.89\%$$

The technical parameter cracking due to the linear cracking distresses (longitudinal and transverse cracking) is obtained from the following equation:

$$TP_{cr,L} = Min\left(100; \frac{1}{37500} \cdot \left(0.78 \cdot (1 \cdot 550 + 2 \cdot 200) + 0.78 \cdot 200\right) \cdot 0.5 \cdot 100\right) = 1.20\%$$

The technical parameter cracking is sum of previous two:

$$TP_{cr} = Min(100; 16.89 + 1.20) = 18.09\%$$

The pre-combined performance index "Cracking" can be calculated from the following equation:

$$PI\_CR = Min(5; 0.1333 \cdot TP_{CR}) = 2.41$$

Additionally, the "Surface defects" technical parameter has to be calculated.

Surface defects are divided into two categories. The first category includes bleeding, ravelling and patching, while the second category includes potholes.

The input data for calculation of surface distress TP are presented in Table 18.

Surface Defect	Unit	Weight W	Transformed Weight W'	Severity	Extent	Section area (m^2)
Category 1						37500
Bleeding	m^2	0.7	1.0	1	2000	
Patching	m^2	0.5	0.71	1	800	
				2	200	

Table 18: Input data for surface defects

The technical parameter for surface defects due to category 1 surface defects is obtained from the following equation:

$$TP_{sd,cat1} = Min\left(100; \frac{1}{37500} \cdot \left(1.0 \cdot 2000 + 0.71 \cdot (1.0 \cdot 800 + 2 \cdot 200)\right) \cdot 100\right) = 7.61\%$$

If only bleeding is included, than $TP_{SD,cat\,1}$ has the following value:

$$TP_{sd,cat1,bleeding} = Min\left(100; \frac{1}{37500} \cdot 1.0 \cdot 2000 \cdot 100\right) = 5.33\%$$

The pre-combined performance index "Surface Defects" can be calculated from the following equation:

$$PI\_SD_{cat1} = Min(5; 0.1333 \cdot TP_{SD}) = 1.01$$

$$PI\_SD_{cat1,bleeding} = Min(5; 0.1333 \cdot 5.33) = 0.71$$

Step 4 – Calculation of Combined Performance Indices

The four combined performance indices will be calculated next. Since all necessary single performance indices are available, the "optimum" level will be used for calculation of CPI. Calculation is based on Advanced Maximum Criteria. The "Alternative 1" which takes into account the average values of all SPI other than maximum is used. The "p" value is selected to be 20 %.

Comfort Index

The following single PIs are available:

- Longitudinal Evenness PI_E = 3.67
- Surface Defects PI_SD = 1.01
- Transverse Evenness PI_R = 2.63
- Texture PI_T = 3.95
- Cracking PI_CR = 2.41

The values of individual performance indices and corresponding transformed weights are presented in Table 19.

SPI Abbreviation	SPI Value	Weight	Transformed Weight W_i	I_i=W_i SPI_i	SPI Order
PI_E	3.67	1.0	1.0	3.67	1
PI_SD	1.01	0.6	0.6	0.61	5
PI_R	2.63	0.7	0.7	1.84	2
PI_T	3.95	0.4	0.4	1.58	3
PI_C	2.41	0.5	0.5	1.21	4

Table 19: Weights for the calculation of Comfort Index

The value of the influence factor is p = 20 %.

In the first alternative for calculation of CPI the average value for I2 to I5 (PI_R, PI_T, PI_C, and PI_SD) is used:

$$\frac{I_2 + I_3 + I_4 + I_5}{4} = \frac{1.84 + 1.58 + 1.21 + 0.61}{4} = 1.31$$

The combined performance index for comfort is:

$$CPI_{comfort} = \min\left[5; I_1 + \frac{p}{100} \cdot \overline{(I_2, I_3, ..., I_n)}\right] = \min\left[5; 3.67 + \frac{20}{100} \cdot 1.31\right] = 3.93$$

Safety Index

The following single PIs are available:

- Friction PI_F = 2.41
- Rutting PI_R = 2.63

- Texture PI_T = 3.95
- Surface Defects (bleeding) $PI\_SD_{cat1,bleeding} = 0.71$

The values of individual performance indices and corresponding transformed weights are presented in Table 20.

SPI Abbreviation	SPI Value	Weight	Transformed weight W_i	I_i=W_i SPI_i	SPI Order
PI_F	2.41	0.9	1.0	2.41	3
PI_R	2.63	0.9	1.0	2.63	1,2
PI_T	3.95	0.6	0.67	2.63	1,2
$PI\_SD_{cat1,bleeding}$	0.71	0.6	0.67	0.48	4

Table 20: Weights for the calculation of Safety Index

The value of the influence factor is p = 20%. In this case indices for rutting and texture have highest values and one of them should be taken as maximum value. For the remaining indices average values should be calculated:

$$\frac{I_2 + I_3 + I_4}{3} = \frac{2.63 + 2.41 + 0.48}{3} = 1.84$$

The combined performance index for safety is:

$$CPI_{safety} = \min\left[5; I_1 + \frac{p}{100} \cdot \overline{(I_2, I_3, ..., I_n)}\right] = \min\left[5; 2.63 + \frac{20}{100} \cdot 1.84\right] = 3.00$$

<u>Structural Index</u>

The following SPIs are available:

- Bearing Capacity PI_B = 2.52
- Cracking PI_CR = 2.41
- Rutting PI_R = 2.63
- Longitudinal Evenness PI_E = 3.67

The values of single performance indices and corresponding transformed weights are presented in Table 21.

SPI Abbreviation	SPI Value	Weight	Transformed weight W_i	I_i=W_i SPI_i	SPI Order
PI_B	2.52	1.0	1.0	2.52	1
PI_CR	2.41	0.9	0.9	2.17	3
PI_R	2.63	0.5	0.5	1.32	4
PI_E	3.67	0.6	0.6	2.20	2

Table 21: Weights for the calculation of Structural Index

The value of the influence factor is p = 20 %. In this case indices for rutting and texture have highest values and one of them should be taken as maximum value. For the remaining indices average values should be calculated:

$$\frac{I_2 + I_3 + I_4}{3} = \frac{2.20 + 2.17 + 1.32}{3} = 1.90$$

The combined structural performance index is:

$$CPI_{structural} = \min\left[5; I_1 + \frac{p}{100} \cdot \overline{(I_2, I_3, ..., I_n)}\right] = \min\left[5; 2.52 + \frac{20}{100} \cdot 1.90\right] = 2.90$$

No environmental index will be calculated at this time, since no data are available on SPI related to environmental impacts.

Step 5 – Calculation of General Performance Index

The general performance index (GPI) is calculated from combined performance indices:

- Safety Index $CPI_{safety} = 3.00$
- Comfort Index $CPI_{comfort} = 3.93$
- Structural Index $CPI_{structural} = 2.90$

The values of individual performance indices and corresponding transformed weights are presented in Table 22.

CPI Name	CPI_i	Transformed weight W_i	I_i=W_i CPI_i	Order
Safety	3.00	1.00	3.00	1
Comfort	3.93	0.70	2.75	2
Structural	2.90	0.65	1.89	3

Table 22: Weights for the calculation of Structural Index

The value of the influence factor is p = 20 %.

In the first alternative for calculation of GPI the average value of I_2 and I_3 is used:

$$\frac{I_2 + I_3}{2} = \frac{2.75 + 1.89}{2} = 2.32$$

The general performance index is:

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot \overline{(I_2, I_3, ..., I_n)}\right] = \min\left[5; 3.00 + \frac{20}{100} \cdot 2.32\right] = 3.46$$

9 CONCLUSIONS AND RECOMMENDATIONS

The main objective of the COST Action 354 “Performance Indicators for Road Pavements” was the definition of uniform European performance indicators for road pavements taking the needs of road users and road operators into account. A quantitative assessment of performance indicators provides guidance regarding present and future needs in road pavement design and maintenance at both the national and the European levels.

The Action was based on a comprehensive investigation of performance indicators for road pavements used across Europe and USA, taking into account different road categories and pavement types (flexible, semi-rigid, and rigid pavements). The investigations covered also information of each single performance indicator about the target values and limits as well as applied transfer functions, classification systems and methods of measurement and data collection.

In total, the output of 25 completed questionnaires from 24 countries including more than 260 indicators were used as basis for the selection of adequate single performance indicators, the definition of combined performance indicators and finally the recommendation of a general performance indicator. The collected information about different indicators refers to different types of pavements and road categories. Only road category “other roads” showed insufficient data and was not treated separately in the context of this Action.

The collected information were implemented into a specially prepared data base and provided to the members of this Action in the different Working Groups.

Within the Action a “Performance Index” (PI) 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” (TP) 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 (dimensional) and/or in form of dimensionless indices.

The selection of single (individual) performance indicators was carried out to identify a set of “Performance Indices” (PI) as recommendation for the assessment of the properties of road pavements and to provide a basis for the calculation of combined performance indicators and finally a general performance indicator. It includes the indicators as follows:

- Longitudinal evenness;
- Transverse evenness;
- Macro-texture;
- Friction;
- Bearing Capacity;
- (Cracking);
- (Surface defects);
- (Noise);
- (Air Pollution).

Cracking and surface defects were initially considered as single performance indicators, but it was then decided to consider this as a pre-combined performance indicator combining different forms of appearance of cracking and surface defects.

However it has to be stated that all single performance indices which were dealt with in this action are all using existing, “old” assessments and indicators. Thus no real innovation could be put forward in this sector but the proposals are relying on widely available measurement methods. Nevertheless the recommended procedures can be easily applied to new indicators and methods as soon as they are widely available.

Noise and Pollution were also considered for use as indicators; however there is insufficient data at the moment for their use in this COST Action. Due to this situation only a textual description for the use of environmental indicators (single as well as combined indicators) was given in this Action referring to current European projects (e.g. SILVIA). These indices may be added at a later date once more research has been carried out. Nevertheless it has to be mentioned that the road pavement itself can have only limited influence on the environmentally related issues.

Given the wide variety of potential users of the COST 354 final procedure it was deemed necessary 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” 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”, 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).

The selection of the “most suitable technical parameter” for a specific performance indicator was made by means of a set of criteria defined by the COST 354 Management Committee (e.g. based on European standard, standard practice or used only for research, device independent).

Contrary to the original ideas no target values or limit values (intervention levels) were 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. But the spreadsheet tool which was developed within this action (described below) enables the user to quickly assess the consequences in changing the various input factors and weights as a basis for his/her decision.

Based on the specification given in the Technical Annex of the Action, a further objective was the development of four combined performance indices that represent important aspects of pavement performance, relevant to road users and road operators:

- Safety Index;
- Comfort Index;
- Structural Index;
- Environmental Index.

The objective of each “Combined Performance Index” (CPI) is to characterise the contribution of the pavement structure and condition to the performance of the road asset; it is not the intention to derive overall indices of road safety, user comfort and environmental impact, which are influenced by many factors outside the scope of this Action. It is anticipated that the combined performance indicator will be implemented within road administrations to support high level decisions by:

- Allowing different aspects of pavement performance to be quantified;
- Enabling reporting of pavement performance at a network level;
- Facilitating comparison with other road administrations;
- Identifying potential improvement schemes.

In addition to the four combined performance indicators listed above, procedures have also been developed to produce pre-combined performance indicators for surface defects and cracking, which combine the different distress types and different units.

Based on the investigations of available data, the appropriate literature, the recommendations on single performance indices (PIs), and the technical discussions, a practical procedure was developed including the following method statements:

- Combination procedures in form of two alternatives;
- List of input parameters (single performance indicators, pre-combined performance indicators) for the calculation of combined indices for three different levels of application;
- List of weighting factors for the use of input parameters (single performance indicators, pre-combined performance indicators).

The last step in the assessment process of pavement condition is the calculation of a “General Performance Indicator” (GPI). The general performance indicator is a mathematical combination of single and/or combined indicators which describe the pavement condition concerning different aspects like safety, structure, riding comfort and environment.

The general indicator gives a first impression of the overall pavement condition at network level, and points out weak sections. By using this information a general maintenance strategy can be derived. Consequently the general indicator is a useful tool for superior decisions-makers to assess the general condition of the network and to evaluate future general strategies and the funding.

As a general indicator does not reflect the cause of the lack of quality in detail, a more detailed analysis based on the single performance indicator has to be performed to assess the maintenance work itself and the necessary financial budget.

The calculation of a general performance indicator was based on data analysis, the recommendations of previous work packages and an additional survey within the countries represented in COST 354, with the purpose of collecting opinions from different groups of stakeholders (operators, authorities, researchers, and users) concerning the relative importance of each type of combined performance indicator as well. For this reason also general weighting factors have been recommended.

For the practical application of the general performance indicator a detailed description was given concerning the following method statements:

- Combination procedures in form of two alternatives;
- List of weighting factors for different CPIs.

For the calculation of single, combined and general performance indicators a spreadsheet tool was developed. This also was used to conduct a comprehensive sensitivity analysis to show the effects of changing on the one hand the weights of the input parameters and on the other hand the influence of modifications in the recommended combination procedures.

This spreadsheet tool used in the sensitivity analysis can also be used informatively for the calculation of PIs, CPIs, and GPI following the procedures developed within the work in COST Action 354. This could also help Road Administrations to implement the results of this Action taking into account their existing experience and data availability.

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