PAVEMENT SURFACE CONDITION INDICATORS

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IN MEMORIAM

The C1 Committee members were shocked by the sudden death of Mr. Gilbert Caroff in January 2001.
As director of Scetauroute company Gilbert made a huge contribution to the development of the working Group C activities, and was well known as a very efficient and hard-working individual who was also a friend to all the Committee members.
It is with warm feelings of remembrance and great respect that the working group members dedicate this report to the memory of Gilbert Caroff.

ABSTRACT

The objective of this CI contribution is to outline the growing use of global pavement surface condition (combined characteristics) indices, as compared to the use of individual unit surface condition (individual characteristics) indicators. The role of surface characteristics in pavement management systems (PMS) is described, and then the technical needs of a wide range of potential users is outlined in order to identify the potential to combine surface condition indicators into one index. On this basis, it is possible to define and develop a level of service (pavement surface performance) for road users, operators and administrators for a life-cycle performance and cost approach, and to provide recommendations on the appropriate use of pavement surface condition indicators.

Functional classification, including classifications with the use of two index families (single and combined indices) and two levels per family, taking into account the complexity and the level of aggregation, are explained with typical examples giving a clear explanation of: how special indexes characterising the pavement condition permit an assessment of the effectiveness of different approaches, from technical and macroeconomic viewpoints; and how to support pavement maintenance planning goals with the use of a structural and

service index rating. A comprehensive body of information about indices is not presented, but rather practical examples of the different types of indices to illustrate the concepts involved.

The major problem encountered with the creation of combined indices, from an international perspective, is that the individual performance indicators used by various agencies, countries and world regions are generally not, or only to some extent, comparable (use of different factors, rating systems and measuring procedures for instance). For this reason, some harmonisation approaches are discussed in order to initiate future wider international activities to specify pavement characteristics in more uniform terms. Harmonised condition, or performance, indicators could thus be used as a more objective and effective tool in road construction and maintenance activities at various administrative levels, from local roads to international highways, including asset management.

KEY WORDS

PAVEMENT / INDICATORS / SURFACE / MANAGEMENT / GLOBAL

1. INTRODUCTION

Since the 1950^{s}, with the Present Serviceability Index (PSI) defined to characterize pavement condition within the AASHTO Road Test, global pavement condition (combined characteristics) indices have been used in many countries for different purposes (PSI, PSR for various highway performance monitoring systems in the United States, IQRN for national roads in France, MSI in Japan, etc.). The objective of this CI contribution is to outline the growing use of these global indices, as compared to the use of individual unit (individual) surface indicators.

As a starting point, the type of use of surface condition indicators, which will be termed more generally ‘indicators’ throughout, can be defined as:

- Qualifying and quantifying the pavement quality for road users;
- Qualifying and quantifying the pavement quality for maintenance (pavement preservation and rehabilitation) work programming, within pavement management systems;
- Setting specification requirements in performance-related pavement construction, maintenance and rehabilitation contracts, within pavement management and subset pavement maintenance systems; and.
- Providing pavement condition-related information to overall transportation infrastructure asset management systems (the subject of a separate CI contribution).

In this regard, a clear distinction is made between:

- Unit indices - for instance roughness, skid resistance, cracks and rutting; and
- Global indices – combining (aggregating) unit indices, with a possible weighting (gradation) in the combination (globalization), for instance surface/structural or overall pavement quality indices.

The overview inventory of unit and global indices provided is not based on an international state practice survey, but rather on CI activities, expert opinion and international organization (PIARC, World Bank, OECD for instance) current publications.

2. TERMINOLOGY

For the comprehension of the present report and also as a contribution to the general task given by PIARC to all Committees to co-operate in the establishment of an internationally unified terminology for the road sector the following list of terms has been adopted by Working Group C and is proposed for general use. Terms and if possible their definitions have been copied/taken from the following sources:

- PIARC Terminology Dictionary, updated March 2002
- PIARC Terminology Lexicon, updated June 2002
- ISO 13473-2 Characterization of pavement texture by use of surface profiles Part 2: Terminology and basic requirements related to pavement texture profile analysis

Additional references are included in Annex A to this report.

TABLE 1 TERMINOLOGY (general terms describing surface condition indicators)

Unit/Single index (surface condition indicator):	a number representing directly or indirectly the result of the measurement or assessment of unique feature of the surface of a pavement, such as roughness, rutting, cracking, deformation, etc.
Global/Derived index (combined, composite index):	a number representing the aggregated contributions of different single condition index features.
Transverse profile:	The vertical deviations of the road surface from a horizontal reference perpendicular to the lane direction.
Longitudinal profile:	The perpendicular deviations of the road surface from an established reference parallel to the lane direction, usually measured in the wheel tracks.
Longitudinal index:	index describing the longitudinal unevenness/roughness calculated from the longitudinal profile
Transverse index:	index describing the transverse unevenness/roughness calculated from the transverse profile
Texture:	deviation of a pavement surface from a true planar surface, with a texture wavelength less than 500 mm, divided into micro-, macro- and megatexture
Unevenness (Roughness):	surface irregularities of a road pavement with horizontal dimensions greater than 500 mm parallel to the lane direction and vertical dimensions exceeding the tolerance of the design specifications.
Rutting:	the depression in the wheel tracks, which is caused by the traffic

A more detailed list of terms, abbreviations and definitions is presented as annex B to this report.

3. FUNCTIONAL CLASSIFICATION

A road agency's aim is to design, construct and maintain a pavement, such that it provides an acceptable level of serviceability to the road users, at a life-cycle performance and cost that represents the best value and optimizes available technical and financial resources. The level of serviceability is defined in terms of the potential impact the pavement condition has upon its users. A pavement can impact upon its users in different ways - ride quality (smoothness), safety (frictional characteristics for instance), vehicle operating cost, delay and increased travel time costs, and environmental impact. The term 'road user' includes, but is not limited to, vehicle (passenger, bus and commercial) users, pedestrians, people that live or work near the road, and indeed the road owner themselves (agency on behalf of tax and/or toll payers).

To achieve their user satisfaction objective, the agency requires information that meaningfully describes the serviceability of a pavement; in other words, they require knowledge of the potential impact the current road condition has upon the users. (It is assumed that the agency has systematic maintenance procedures in place.) However, this information will only determine whether the agency is providing an acceptable level of serviceability to the users. If the agency is not providing an acceptable level of serviceability, then the pavement needs more extensive pavement preservation (maintenance) or rehabilitation. That is, the owner must improve the physical condition of the pavement, because deficiencies in the physical condition have caused an unacceptable reduction in the level of its serviceability. Therefore, the agency also requires information (surface distress types, severity and extent for instance) that meaningfully describes the current physical condition of a pavement and allows prediction of pavement deterioration with time.

From the above discussion, it is clear that two distinct types of indices are desirable. Firstly, indices that meaningfully describe the overall impact of the road upon the road user, and secondly, indices that meaningfully describe the physical condition of the road. This information both allows road agencies to determine when a pavement is not providing an acceptable level of serviceability, and to determine which physical qualities of the pavement are deficient. However, if the relationship between the physical condition of the pavement and the level of serviceability the pavement provides is known, then one of these types of indices is redundant, i.e. it is readily derivable as required, in pavement management systems for instance. The components of a pavement's physical condition that influence the different aspects of its serviceability are generally known; however, the precise relationship between the two is either generally not known or standardized from agency to agency.

In general, it is much easier to measure the physical condition of a pavement (distresses or roughness for instance), rather than the impact that it has upon road users. Therefore, the aim of an index is to quantify the physical condition of a pavement, such that:

- The road agency can determine if the pavement is providing an acceptable level of serviceability; and
- If the pavement is not providing an acceptable level of serviceability, the agency can then identify the pavement's physical deficiencies and schedule the necessary intervention.

These objectives define, in general terms, what is ideally required from an index.

Functional analysis has shown that an agency can work with two index families, single and combined (composite). Each of these families can be further split into more levels, depending on the specific requirements of the user.

A broad overview of the current pavement management systems practice in a large number of countries shows that basically two types of index are being used to characterise the surface condition of pavements. In the following, the terms single (unit) index and composite index will be used for these two types:

- A single (unit) index is a number representing directly or indirectly the result of the measurement or assessment of a unique feature of the surface of a pavement, such as roughness, rutting, longitudinal cracking and ravelling; and

- A composite index is a number representing the aggregated (combined) contributions of different single condition features. The number of composite indices used is not limited, and while a number of countries only use one composite index, other countries use different composite indices. Frequently the composite index (or one of different composite indices) is termed a 'global index'. Different formulas can be applied for the aggregation of the different single indices into a composite index.

Figure 1 shows an example of the application of single and composite indices with five single indices (surface defects, cracking, roughness, skid resistance and rutting) and three composite indices (PDI - pavement and distress index, CSI - comfort and safety index and TCI - total condition index). In this example from Austria, it can be seen that even other data may be used for the calculation of a composite index.

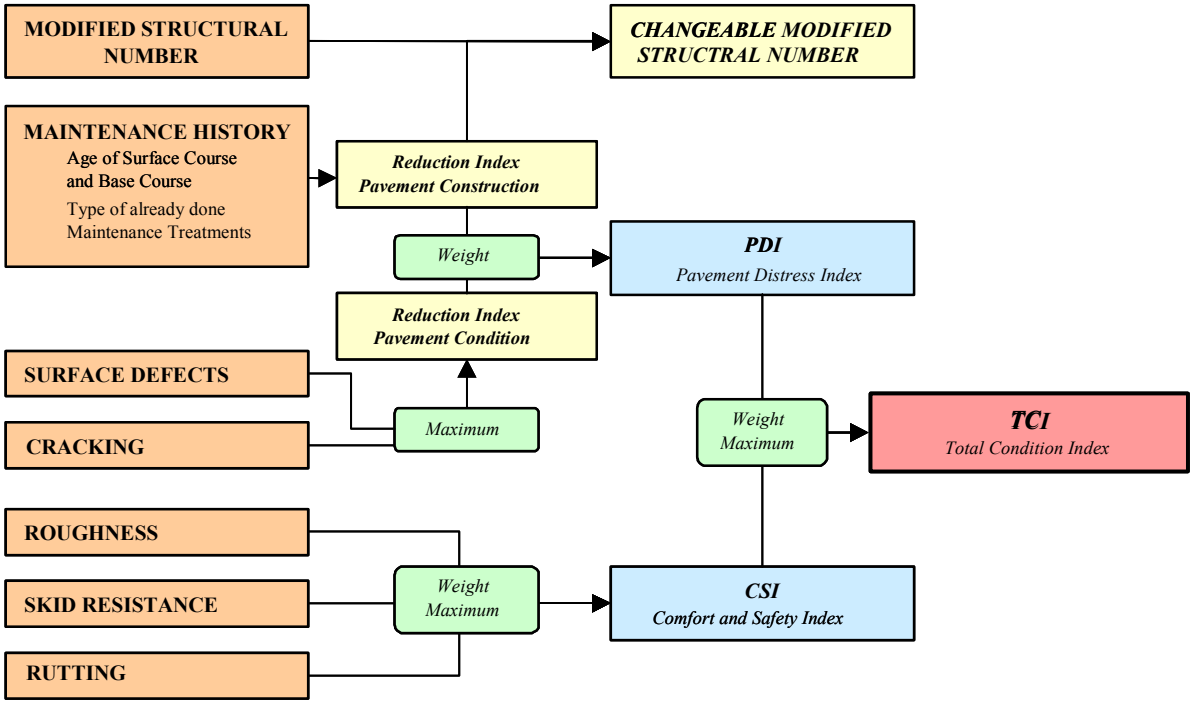

Figure 1 - Method of Assessing the Condition of Asphalt Pavements in Austria [Vycudil, 2000]

Two types of indices can be presented with the following families of indices:

- Two families: single and combined indices; and
- Two levels per family, taking into account the complexity and the level of aggregation.

Table 2 - Two Families of Indices

	LEVEL	DEFINITION	EXAMPLES
First Family A "Single"	A1	Directly or Indirectly Measured	IRI Rut Depth Texture
	A2	Derived From at least Two Measurements	Water Depth
Second Family B "Combined"	B1	Combined for Functional Characteristics: Surface, Safety, Winter, Environment and/or Structure	Surface Index Safety Index
	B2	Combined for Overall Quality of the Pavement	HPMS (US) MCI (J) IQRN (F)

The first family is used for technical decisions, with the second one used for definition of strategies. The use of four levels is dependent on the specific pavement management system used.

3.1 The Role of Pavement Condition Indicators in the Pavement Management Process

The specific role of pavement condition indicators in pavement management system depends upon the specific criteria and the general approach on which the pavement management process is based. In some cases only some sort of ranking method is used for fixing maintenance priorities, while more advanced systems elaborate a list of maintenance proposals on the basis of a multi-year optimisation analysis. In the latter case the optimisations can address the issues of:

- Minimising agency costs (maximise the benefits of the agency);
- Minimising user costs; and/or
- Minimising total transport costs.

The evaluation of the role of condition indicators could start with an answer to the following questions:

- Why do pavements deteriorate?; and
- How can we restore a deteriorated pavement?

The answer to these questions may be found through an understanding of the mechanism of the deterioration process and the recognition of those 'symptoms' which finally determine the decision to apply a maintenance or rehabilitation treatment. The understanding of these elements is the first step in the process of the definition, or selection, of condition indicators needed for pavement management systems. There are at

least four major reasons why condition indicators are needed in a pavement management system:

- Selection and assignment of pavement preservation treatments;
- Calculation of costs;
- Evaluation of the network condition; and
- Comparison of single sections, roads and networks.

In a more detailed view of the possible use of condition indicators, within a pavement management system, the following specific functionalities are associated with condition indicators:

- Representation of the condition of a section or road network;
- Definition of different quality classes;
- Selection of the appropriate treatment(s);
- Indication of the quality level (trigger) at which a particular treatment should be applied;
- Performance curves or models;
- Indication of the improvement of condition after the application of a maintenance treatment (benefit of the treatment); and
- Use of the same evaluation scheme for the comparison of different sections of roads or networks.

3.2 Fields of Application of Single Indices

3.2.1 Treatment Selection

The selection of the appropriate maintenance treatment(s) (from a technical and financial point of view) depends upon a number of factors, but should primarily represent the result of a detailed pavement distress survey and analysis, and the recognition of the cause(s) of the specific distresses. Such a cause is generally associated with a specific type and severity of distress which can, in turn, be described by condition indicators. In pavement management systems, single condition indicators or indices are used within decision trees of defined conditions (severity ranges) to identify a specific state of distress and the related cause of the damage. From this, it is thus possible to select the appropriate treatment(s) for the pavement preservation.

3.2.2 Trigger Limits

In the same way as single indices are used for the selection of a pavement preservation treatment, they also can be used to specify the trigger limits. This is basically a similar approach to the use of quality levels for new construction or limit values for safety reasons. In addition to the restrictive aspect of the term 'trigger limit' which suggests some action at a specific point (level), single condition indicators can also define broader 'trigger zones' within which the application of a specific treatment remains a technically and economically adequate solution.

3.2.3 Calculation of Costs

The use of single condition indicators for the calculation of costs is an indirect one. Costs are determined, and optimized, on the basis of the selection of the most appropriate treatment(s), their corresponding costs and the quantity of each treatment required. The

selection of optimal appropriate (technical and cost) treatments(s) based on single condition indicators requires a systematic approach, and practical experience, on how the condition indicators interact and proven treatment effectiveness. With a reduced degree of accuracy, costs can also be roughly estimated on the basis of a composite index and its distribution within the network (how many kilometres of the network are in a 'poor' or 'very poor' condition for instance), by associating unit rehabilitation costs to each condition class.

3.2.4 Performance Models

Performance models are used in pavement management systems as a tool for forecasting the potential future pavement condition, enabling multi-year pavement preservation optimization analysis to be completed. Single condition indicators must generally be used as the input value in pavement performance models. The value of composite indices may depend on a wide range of factors, and hence a performance model cannot generally be built upon these indices (i.e. theoretically possible, but with very questionable results).

3.3 Fields of application of Composite Indices

3.3.1 Comparison of Sections, Roads and Networks and Condition Evaluation of Networks

The use of standardised scales for quantifying the description of the pavement condition, with respect to different parameters, is necessary for the objective comparison of a section with a given distress with another section with a similar distress, and also for comparing sections with completely different distress situations. Composite or 'global' indices are specifically suited for the comparison of sections with different distress appearances and to represent in a certain way a general pavement 'state of health'. Therefore, global indices are also particularly suited for the evaluation of networks and are frequently used in pavement management applications as optimisation criterion, in order to show and to quantify the 'benefit' of applying a given choice of maintenance treatments.

Comparisons and evaluations of pavement condition can be done for different purposes:

- Selection of candidate sections for maintenance projects;
- Priority ranking of different sections;
- Evaluation of the condition distribution within a network (what percentage of the network can be considered as excellent, good, fair, poor or very poor?);
- Deforming deterioration of the average condition for different subdivisions of an agency. This type of information can be used as a weighting element for budget distribution;
- Following-up the average condition over time. This type of comparison allows evaluation of the adequacy of the budget level in the corresponding period; and
- Comparison of the condition of networks of different agencies.

4. SELECTED PRACTICAL EXAMPLES

The use of different types of indices is well accepted throughout the world. One example of a common index is the IRI (International Roughness Index), that is calculated from a detailed road profile measurement. The purpose of using indices could be expressed as a way to make a rather complex functional performance measurement much simpler. It is a way to fill the gap between advanced technology and practical use. Obviously, the need and level of simplification depends on the specific use of the index. The users of different indices can be divided into:

- Technical – Researchers, Engineers, and Practitioners; and
- Non-technical – Economists, Managers, Politicians, Road Users and the Public.

For an engineer, an index is a simplified way to present rather complex and detailed information without overwhelming the user. For a user (infrastructure manager for instance), an index provides a better understanding of a component of the overall system and associated problems and fosters practical use of pavement performance information.

Surface condition indicators can also be divided into:

- Road engineering indices that describes the technical performance of a road. Road engineering indices are obviously indirectly related to road user effects because the technical performance of a road sooner or later results in an impact on road users; and
- Road user indices that describe the serviceability of the road. Road user indices (parameters) are related to the demonstrated road user effects such as accidents, vehicle operating costs, speed, noise, emissions, etc.

Table 3 - Examples of Indices

INDEX	**ADDRESSING**	**MEASUREMENT METHOD**	**DESCRIPTION**
Measurement Indices			
IRI	Longitudinal Unevenness	Automatic Profilometers or Response Meters or by Straight Edge	International Roughness Index
Evaluated Indices			
IRI Change	Longitudinal Unevenness		Analysis Based on Time-Series of Measurements
Combined indices			
Surface Distress		Visual Some Distresses may be Evaluated from Texture Measurements	Surface Distress Index Index Combining Factors such as Raveling, Bleeding, Potholes etc.
KPI			Key Performance Indicator. A Combination of all Factors – Safety, Serviceability, Reporting, Quality Assurance, Asset Value. Surface Condition Affects Safety and Serviceability. (see 'Performance Driven Pavement Management System (PD-PMS)' for instance, see Figure 2 and [Maarabani, 2000])
TDI			Total Condition Index. Based on PDI and CSI, for instance.

It is important to recognize that the benefit of measuring road surface characteristics gets a 'boost' when positive use is made at a practical decision level. No matter how sophisticated the measurements and analyses, it is still necessary for this information to clearly indicate the consequences of the results to the decision makers and road users. This gap between technology and practical, applied use has to be closed. This also means there is a need to systematically advance from the technical approach of surface characteristics measurements into a more management-based approach - how to get surface characteristics to be a significant factor considered at pavement investment decision levels?

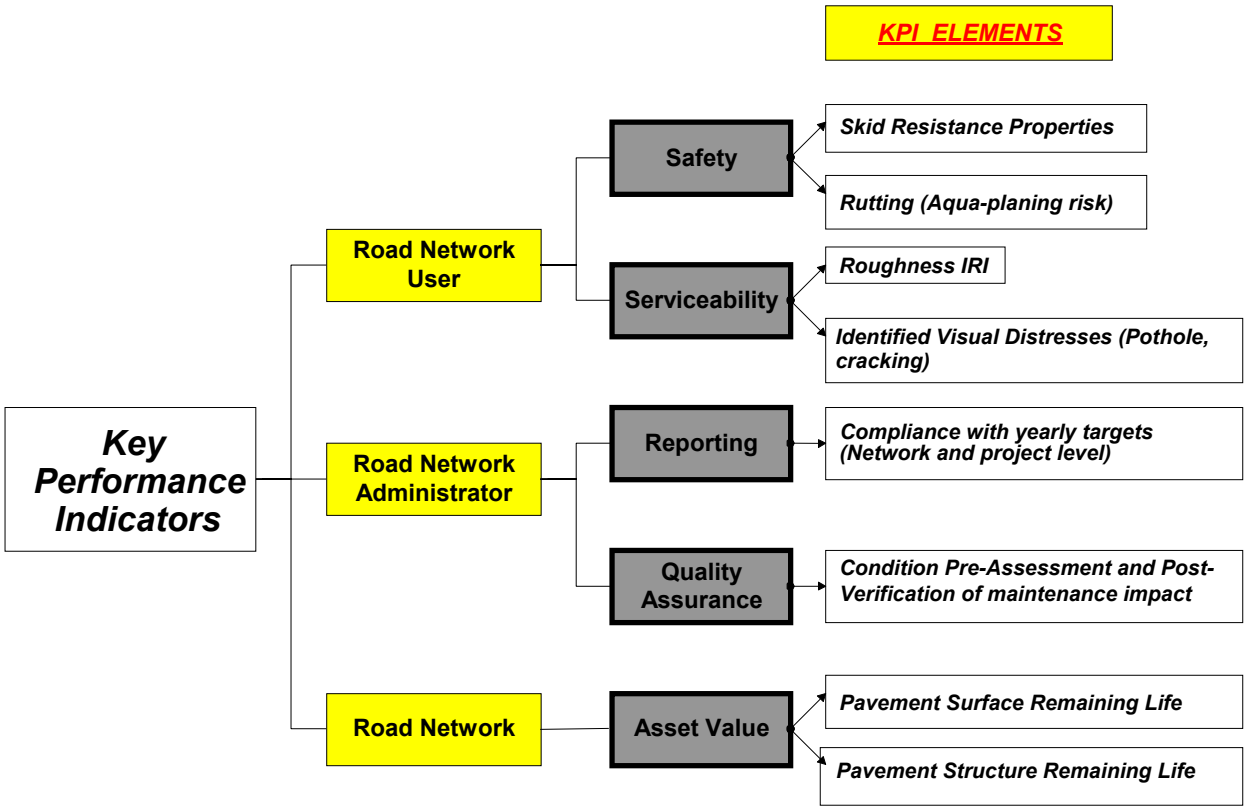

Figure 2 - Key Performance Indicator

5. SUMMARY AND RECOMMENDATIONS

A road agency's aim is to design, construct and maintain a pavement such that it provides an acceptable level of serviceability to road users, and at an investment that represents the best life-cycle performance and cost. To meet this objective, the agency requires information that meaningfully describes the serviceability of a pavement. The aim of an index is to provide this information by quantifying the physical condition of the pavements.

A broad overview of current practice in a large number of agencies shows that basically two types of indices are being used to characterise the surface condition of pavements – single (unit) and composite (combined) indices. First family indices are mostly used for technical decisions while composite or (global) indices are specifically suited for the

comparison of sections with different distresses and for the definition of pavement preservation strategies for road sections.

Recommendations:

- Data and information must be presented in such a way to make it understandable to non-technical decision makers and road users in order to provide maximum benefit to society as a whole;
- General guidelines should be developed to aggregate pavement condition data to make it suitable for various applications, from project level decision-making through to a component of asset management;
- Intervention levels, or standards, for different road types should be established; and
- Pavement condition information use needs and judgment process must be recognized.

ANNEX A

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ISO 13473-2, Characterization of pavement texture by use of surface profiles - Part 2: Terminology and basic requirements related to pavement texture profile analysis

ISO 13473-3, Characterization of pavement texture by use of surface profiles - Part 3:

ISO 1879, Instruments for the measurement of surface roughness by the profile method - Vocabulary

ANNEX B

TERMS, ABBREVIATIONS AND DEFINITIONS

UNIT/SINGLE INDICES; Longitudinal indices

International Roughness Index/IRI: *index describing the longitudinal unevenness/roughness based on a computational procedure defined by the World Bank.*

Mean Profile Depth/MPD: surface texture index; the average value of the profile depth over a 100 mm long baseline

UNIT/SINGLE INDICES; Transverse indices

Rut depth: The maximum perpendicular distance between the bottom surface of a straightedge and the contact area of the gauge with the road surface at a specified location, usually measured in the wheel tracks. PTCD

GLOBAL/COMBINED INDICES

Network Condition Index/CI: Network Condition Index (UK), a weighed sum roughness, rut depth and skid resistance.

Comfort and Safety Index/CSI: index based on roughness, skid resistance and rutting.

Evenness Coefficient/EC: index for different wavelength (Belgium)

Network pavement performance/IQRN: monitoring system used annually by Road Directorate (SETRA)

Key Performance Indicator/KPI: index combining all factors – safety, serviceability, reporting, quality assurance, asset value.

Maintenance Control Index/MCI: index for pavement surface conditions performance (Japan)

Present Serviceability Index/PSI: index defined to characterize pavement condition within the AASHO Road Test (1950+).

Present Serviceability Rating/PSR: index for Highway Performance Monitoring System in the United States.

Road Condition Index/RCI: Road Condition Index (Ontario)

Rut condition index/RUTCON: Rut condition index that converts rutdepth into a scale 0-100 (IMS, USA)

Surface Condition index /SCI: a combination of RUTCON, ROUGHCON and CRACKCON (IMS, USA)

Total Condition Index/TCI: index based on PDI and CSI