TU1406

COST ACTION

Quality specifications for roadway bridges, standardization at a European level

WG1

Technical Report

Performance Indicators for Roadway Bridges of Cost Action TU1406

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CONTENT

FOREWORD

Lifecycle analyses methods are used for the assessment of new and existing bridges, as well as for the evaluation of maintenance strategies. Management systems, capturing different degradation processes, are very often used in relation to such lifecycle analyses methods. Such systems, developed for a structural condition assessment, are usually based on deterministic performance prediction models which describe the future condition by a functional correlation between structural condition attributes, such as the structural age, and the mechanical, chemical and thermal loading processes.

Each construction, during its life cycle, will face with deterioration depending on several factors such as the environmental condition, the natural aging, the quality of the material, the execution of works and the planned maintenance. Therefore, several design procedures based on the prediction of deterioration that will likely act on the structure will be developed in the framework of the international research. The target of Work Group 1 (*WG1*) is among others the characterisation and definition of performance indicators for the present and future structural conditions on deterministic and probabilistic level. It is known that management systems are supported in Quality Controls (*QC*) plans which in turn are supported by performance indicators.

Therefore, it is extremely important to analyse such indicators in terms of used assessment frameworks (e.g. what kind of equipment and software is being used), and in terms of the quantification procedure itself. In this particular report, the objectives are to show the collected and analysed practical and research based performance indicators.

Viena, Austria, July 2016,

(Alfred Strauss, *WG*1 Leader)

The goal of *WG*1 is to explore those bridge performance indicators, in the course of international research cooperation, which capture their main technical, social and environmental performance along their service-life and can be used in a quality control of the overall bridge performance. Considerations also include: natural aging, quality of the material; service life design methods; sustainable indicators; environmental, economic and social based indicators, performance profiles.

The final objective is the implementation of a performance indicator database for Europe with flexibility to accommodate country-specific requirements. The future implementation by different European countries will be hardly accomplished if the actual proposal derived from the work of *WG*1 had not taken into account what is actually carried out in the subject of bridge performance in the different countries involved in the Action. However, the proposal of global performance indicators should also take into account the advanced results on bridge performance gathered in the recent years because of the important research effort by several research groups in Europe and all around the world.

For this reason, the main objective of *WG*1 from the beginning was to gather as much as possible the actual state-of-the-art (operational indicators already in use by the bridge owners) but also the research indicators under investigation that may have a feasible application in the quality control plans of bridge operators in the near future. This huge effort had not been possible without the effort in time and contributions by the representatives of COST countries in the Management Committee as well as from stakeholders, academia, industry and operators, all of them under the umbrella of *WG*1. And, of course, could not be possible without the work and dedication of the leader and vice-leader of the *WG*1.

Their effort on clustering and homogenization of the input information provided by more than 30 European countries made possible to reduce the huge amount of information delivered by the different operators and researchers to a reasonable and manageable number of performance indicators that will be the basis for the future work in the COST Action by *WG*2 and *WG*3. My deepest acknowledge and thanks to all the people that made possible this first report of the Action.

Barcelona, Spain, July 2016,

(Joan Casas, Vice-Chair)

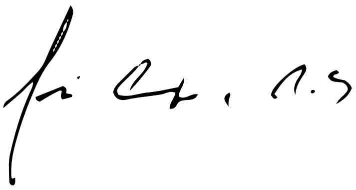
During the implementation of asset management strategies, maintenance actions are required in order to keep assets at a desired performance level. In case of roadway bridges, specific performance indicators are established for their components. These indicators can be qualitative or quantitative based, and they can be obtained during principal inspections, through a visual examination, a non-destructive test or a temporary or permanent monitoring system.

Then, obtained indicators are compared with performance goals, in order to evaluate if the quality control plan is accomplished. It is verified that there is a large disparity in Europe regarding the way these indicators are quantified and how such goals are specified. Therefore, COST Action TU1406 aims to bring together, for the first time, both research and practicing community in order to accelerate the establishment of a European guideline in this subject (www.tu1406.eu). It will be also analysed new indicators related to sustainable performance of roadway bridges.

This Action is divided in six Working Groups (*WG*), namely: (i) Performance Indicators; (ii) Performance Goals; (iii) Establishment of a Quality Control Plan; (iv) Implementation in a Case Study; (v) Drafting of guideline / recommendations; and (vi) Dissemination. This report focus the development of *WG*1, during the first Grant Period, under the coordination of Prof. Alfred Strauss and Prof. Ana Mandić Ivanković. For the following report, there was a huge investment of time and contributions from several countries from all the COST space, from people from different stakeholders from academia to industry and operators, and from different ages and gender.

It was a very important step towards the success of the Action. From my side I would like to personally acknowledge those who gave such an important contribution. I am sure that this document will be used for the future of the bridge engineering field.

Guimarães, Portugal, July 2016,



(Jose Campos e Matos, Chair)

ACKNOWLEDGEMENTS

This report is based upon work from COST Action TU1406 supported by COST (European Cooperation in Science and Technology. This *WG*1 report has been strongly supported by the COST Action TU1406*WG*1 members, the Core Group, the Management Committee, and the national nominated person who performed the screening. Members of these groups are shown in http://www.tu1406.eu/ and the attached pen drive. We highly acknowledge their contribution.

FIGURES

TABLES

SYMBOLS

QC	Quality Control
WG	Working Group
LCC	Life Cycle Cost
PI	Performance Indicator
PG	Performance Goal
PT	Performance Threshold
PL	Performance Level
PM	Performance Method
PC	Performance Criteria
KPI	Key Performance Indicator
MC	Management Committee
SHM	Structural Health Monitoring

DEFINITIONS

- Asset management (*ISO 55 000*): coordinated activities of an organization to realize value from assets; Realization of value will normally involve a balancing of costs, risks, opportunities and performance benefits.
- Damage(*SHM* Glossary): disruption or change in the condition of a structure or its components, caused by external actions, such that some aspect of either the current or future performance of the structure or its components will be impaired. The unfavourable change may refer to mechanical properties of construction materials and/or to geometrical properties of a structural system (including changes to the structural members, member connections, and supports).
- Deterioration (*MC2010*): Worsening of condition with time, or a progressive reduction in the ability of a structure or its components to perform according to their intended functional specifications.
- Deterioration mechanism (*MC2010*): Process of the cause and development of deterioration (Scientifically describable).
- Damage detection (*SHM* Glossary): Process of ascertaining whether the damage to structure exists or not. Three main approaches in damage detection are visual inspection, non-destructive testing, and structural health monitoring.
- Damage identification (*SHM* Glossary): In addition to damage detection and characterization, damage identification includes ascertaining the cause of the damage and its consequences.
- Lifecycle cost (*LCC*) (*CEN* – Ageing Behaviour of Structural Components for Integrated Lifetime Assessment and Asset Management): Cost of an asset or its parts throughout its lifecycle, while fulfilling its performance requirements.
- Performance assessment (*CEN* - Ageing Behaviour of Structural Components for Integrated Lifetime Assessment and Asset Management): A set of activities performed to verify the reliability of an existing structure for future use.
- Performance criteria (*MC2010*): Quantitative limits, associated to a performance indicator, defining the border between desired and adverse behaviour.
- Performance evaluation (*ISO 22301*): Process of determining measurable results.
- Performance goal: Type of structure property (behaviour) that is required based on assessment of different performance indicators.
- Performance index: An assessed parameter of the bridge, dimensionless number or letter on a scale that evaluates the parameter involved on an *X* to *XN* scale, *X* being a very good condition and *XN* a very poor one.
- Performance indicator (*MC2010*): A superior term of a bridge characteristic, which indicates the condition of a bridge. It can be expressed in the form of a dimensional performance parameter or as a dimensionless performance index.
- Measurable/testable parameter (i.e. characteristic of materials and structures) that quantitatively describes a performance aspect.
- Performance level: Qualification of a structure or a structural element, which is established by verifying its behaviour against the performance requirements. A satisfactory performance level is reached when a structure or a structural element has demonstrated a sufficient behaviour to meet the performance requirements. In the opposite case, the performance level of a structure or a structural element is considered to be unsatisfactory.
- Performance threshold (*IRIS* - GLOSSARY OF RISK RELATED TERMS): A value that constitutes a boundary for purposes such as: a) monitoring (e.g. an effect is observed or not), b) assessing (e.g. an effect is low or high), and c) decision-making (e.g. an effect is critical or not).
- Reliability: The probability that a system or component will meet its performance requirements under given conditions and during a given period of time.
- Repair (*SAMCO*): Improvement of the conditions of a structure by restoring or replacing existing components that have been damaged.
- Risk (*Hans04*): The risk refers to danger, hazards or loss of chance in an uncertain venture, and is defined as the product of the consequences of failure (Consequence of failure, *COF*) and the probability of entering this failure (Probability of Failure, *POF*).
- Safety (*Schn07*): In contrast to Risk, Safety is term used to describe a condition in which the risk is on an acceptable level.
- Risk-based Inspection (RBI), Risk-based Inspection Planning (*RBI*) (*VDI 4003*): Procedures for the evaluation of system areas and their components as well as of their associated inspection concept from a risk perspective in terms of safety, availability and cost (see also risk). Objective of *RBI* is to optimize the inspection intervals and consequently the maintenance costs while ensuring the required safety levels during operation of the system.
- Service life (*CEN* – Ageing Behaviour of Structural Components for Integrated Lifetime Assessment and Asset Management): period of time after installation during which a facility, or its component parts, meets or exceeds the performance requirements.
- Serviceability (*SAMCO*):The ability of a structure to be serving or capable of serving its intended purposes to the uses' satisfaction.

Further definitions are on the attached pen drive.

1. COST ACTION TU1406

1.1. SCOPE

In the past few years, significant worldwide research has been done regarding condition assessment of roadway bridges, namely through the use of non-destructive tests, monitoring systems and visual inspection techniques. Obtained values, which provide information regarding the assessed bridge state condition, are then compared with previously established goals. As a result, there are currently several methodologies to evaluate bridge condition. A similar problem was addressed with roadway pavements in the past. Although this was a worldwide problematic, in Europe it was solved through COST Action 354 (performance indicators for pavements).

More recently, the concept of performance indicator was introduced, simplifying communication between consultants, operators and owners. However, large deviations continue to exist on how these indicators are obtained and, therefore, specific actions should be undertaken in order to standardize this procedure. It is verified that Quality Control (*QC*) plans should always address the assessed performance indicators and pre-specified goals. However, these latter values are even more difficult to obtain as they are highly subjective.

1.2. OBJECTIVES

The main ambition of the Action is to develop a guideline for the establishment of *QC* plans in roadway bridges, by integrating the most recent knowledge on performance assessment procedures with the adoption of specific goals (Matos, 2016, Matos et al., 2016). This guideline will focus on bridge maintenance and lifecycle performance at two levels: (**i**) performance indicators, (**ii**) performance goals.

In order to reach this main general aim, the following more specific objectives/deliverables have been considered (Matos, 2016, Matos et al., 2016): (**i**) to systematize knowledge on QC plans for bridges, which will help to achieve a state-of-art report that includes performance indicators and respective goals; (**ii**) to collect and contribute to up-to-date knowledge on performance indicators, including not only technical indicators but also environmental, economic and social ones; (**iii**) to establish a wide set of quality specifications through the definition of performance goals, aiming to assure an expected performance level; (**iv**) to develop detailed examples for practicing engineers on the assessment of performance indicators as well as in the establishment of performance goals, to be integrated in the developed guideline; (**v**) to create a data basis from COST countries with performance indicator values and respective goals, that can be useful for future purposes; (**vi**) to support the development of technical/scientific committees.

To achieve these objectives, it was decided to structure the work in several Working Groups (*WG*), as presented in by Matos et al. 2016 and *Casas* 2016:

- ***WG1*: Performance indicators**. The goal is to explore those performance indicators of bridge structures, in the course of international research cooperation, which capture the mechanical and technical properties and its degradation behaviour, already partly covered by code specifications. Considerations also include: natural aging, quality of the material; service life design methods; sustainable indicators; environmental, economic and social based indicators, performance profiles. The final result is the implementation of a performance indicator database for Europe with flexibility to accommodate country-specific requirements. Further information on this *WG* can be found in Strauss (2016).Objectives of Working Group 1 therefore are among others the characterization of bridge performance indicators, which can address: (**a**) the safety: the load factor, the reliability index to *ULS*; (**b**) the serviceability: the condition index, the reliability index to *SLS*; (**c**) the availability, robustness; (**d**) the costs: the total *LCC*, values related to durability aspects; and (**e**) aspects of environmental efficiency: CO2 foot-print. Leader: Alfred Strauss, Vice-Leader: Ana MandićIvanković.
- ***WG2*: Performance goals**. The objective is to provide an overview of existing performance goals for the indicators previously identified in *WG*1 and to develop technical recommendations which will specify the performance goals. These goals will vary according to technical, environmental, economic and social factors. Further information on this *WG* can be found in Stipanovic and Klanker (2016). Objectives of Working Group 2therefore are among others to identify existing performance goals (where the term goal pertains to quantifiable requirement and/or threshold value) for the indicators previously indicated in *WG*1. The performance goals will vary according to technical, environmental, economic and social factors. Leader: Irina Stipanovic Vice-Leader: Lojze Bevc.
- ***WG3*: Quality Control plans**. Based on the results of *WG* 1 and *WG* 2 as well as on survey of existing approaches in practice, the objective of this *WG* is to provide a methodology with detailed step-by-step explanations for establishment of *QC* plans for different types of bridges. The *QC* plan has to relate performance goals, which are user/society related, e.g.: Traveling time; Traffic allowance; Safety level; Comfort/Serviceability; Further information on this *WG* can be found in Hajdin (2016). Objectives of Working Group 3 therefore are among others based on results from *WG*1 and *WG*2, as well as on a survey of existing approaches in practice, the objective of Working Group 3 is to provide a report with detailed step-by-step explanations for the establishment of *QC* plans for different types of bridges. The *QC* plans will address the dynamics and uncertainty of the processes that may significantly compromise bridge performance. Leader: Rade Hajdin, Vice-Leader: MatejKušar.
- ***WG4*: Implementation in a case study**. A series of benchmarks will be developed during Working Group 4. To this end, some of the performance indicators identified in *WG*1 will be computed for a set of roadway bridges over EU. These indicators will be then compared with specific goals, as identified in *WG*2. At the end of the process, a *QC* plan will be applied to those bridges utilising recommendations from *WG*3. A data basis will be then established for benchmarking. Leader: Amir Kedar, Vice-Leader: Sander Sein.

- ***WG5*: Drafting of guideline/recommendations**. Working Group 5 focuses on the development of guidelines, drawing support from all the other *WG's*. These guidelines for a systematic maintenance and management of highway bridge assets will acknowledge the variation of philosophical, technical and implementation methodologies throughout the EU, with the expectation that the delivered framework will be scalable and portable for standardised implementation in existing or new infrastructure networks. Leader: Vikram Pakrashi, Vice-Leader: Helmut Wenzel.
- ***WG6*: Dissemination**. The aim of this *WG* is to disseminate all results which were obtained in all the other *WG*s. Dissemination consists in establishing liaisons with existing national and international associations, conferences, working groups and journals. Also, this group will be responsible to continuously update the website as well as all the other dissemination frameworks. Leader: Guðmundur Guðmundsson, Vice-Leader: Stavroula Pantazopoulou

The target groups and end users who will exploit the outcome of this Action are (Matos, 2016, Matos et al., 2016):

i. public/private owners, as their assets will be maintained in an upscale level;
ii. operators, as standardized procedures for reducing maintenance costs, guaranteeing the same quality-level, will be introduced;
iii. design and consultant engineers, as the assessment of roadway bridges performance will be established in a uniform way, according to the developed guideline;
iv. equipment and software companies, as a new perspective will be given, regarding the most suitable equipment and software for the assessment of roadway bridges;
v. academics and researchers engineers, as they will take an advantage of their involvement in the guideline preparation;
vi. students, as they will benefit from COST tools (e.g. training schools) and from the contact with different stakeholders involved in this Action;
vii. relevant European, international and national associations, with which the main outcomes of this Action will be shared;
viii. standardization bodies and code writers, which will benefit from the developed guideline.

2. FRAMEWORK

Each construction, during its life cycle, will face deterioration depending on several factors such as the environmental condition, the natural aging, the material quality, the execution of works and the planned maintenance. Therefore, Performance Indicators (*PI*) for the present and future structural conditions on deterministic and probabilistic level have to be defined and determined.

Management systems, capturing different degradation processes, are very often used in relation to lifecycle analyses methods. Such systems, developed for a structural condition assessment, are usually based on deterministic performance prediction models which describe the future condition by a functional correlation between structural condition attributes, such as the structural age, and the mechanical, chemical and thermal loading processes.

Performance Indicators *PI's* or in particular Key Performance Indicators *KPI's* make it possible to define a set of objectives aimed to establish *QC* plans which ensure desired bridge quality service. However, those plans vary from country to country and, in some cases, within the same country.

This leads to large variations in roadway bridges quality. Accordingly, this Action aims to achieve the European economic and societal needs by standardizing the condition assessment and maintenance level of roadway bridges.

The practical implementation of the above mentioned models requires detailed information about its variables. Therefore, it is extremely important to analyze such indicators in terms of used assessment frameworks (e.g. what kind of equipment and software is being used), and in terms of the quantification procedure itself. **Table 1** provides an overview on objectives addressed in this COST Action TU1406 action.

Table 1. COST Action TU1406 impacts (Matos, 2016, Matos et al., 2016)

Impact	Description
Environmental/Sustainability	Decrease of bridge lifecycle maintenance and repair costs; Increase of service life; Decrease of total energy consumption and carbon footprint; Increase of mechanical, durability and environmental performance.
Economic and societal	Improve user satisfaction; New job opportunities associated with new *QC* services; Improve economic efficiency; Increase competitiveness in structural engineering industry; Enhance risk management.

Impact	Description
Well-being of general public	Decrease of maintenance, repair and reconstruction activities; Decrease of downtime situations; Decrease of disruptions; Increase of user comfort.
Research community	Better perception of the practice problems; Cooperation improvement between research and practice; Establishment of reliable comparisons between countries; Improvement on research developments and practical procedures; Reduction of the gap between countries.

2.1. SURVEY

2.1.1. FIRST SURVEY PHASE

Based on the main objectives of chapter 2 a technical survey was planned among the participating countries with a double objective: (**1**) to collect what is being done across Europe regarding the quality specifications for roadway bridges and (**2**) to collect proposals for enhancement.

Then, it was mandatory to look over both application and research documents as well as to performance indicators already in use by the highway agencies and those which are still in a developing stage and require research work before they can be fully adopted and implemented in real world. In order to establish a standardization procedure for the assessment of performance indicators, namely, those that should be considered in a *QC* plan, as well as to define performance goals, a network of experts is needed.

Such network should incorporate people from different stakeholders (e.g. universities, institutes, operators, consultants and owners) and from various scientific disciplines (e.g. on-site testing, visual inspection, structural engineering, sustainability, etc.). As a starting point it was decided to look into available guidelines and documents, in use by roadway bridge owners and operators. The reason for such decision looks quite evident since:

1. In most countries bridge performance is good. Therefore, agencies, at least in these countries, are doing a good job;
2. It is important to exactly know what are stakeholders doing in order to improve and enhance (if required) their procedures and rules;
3. The implementation of a common methodology across Europe, with flexibility to accommodate country-specific requirements, needs to know what is being done now. Too many changes will make bridge owners and operators reluctant to apply the harmonized methodology in their daily work. In addition, the new harmonized methodology can not disregard all the knowledge accumulated by owners/operators along many years of bridge inspection and maintenance.

In the first survey round (see **Fig. 1**), therefore, a questionnaire was drawn up with predefined performance indicators based on the afore mentioned characteristics and the country-specific situations. In addition to the survey there was the request to upload and mark the phrases associated with performance indicators in the documents that are used in the country specific inspection and evaluation process of road bridges.

Following aspects served for the definition of performance indicators: the widely agreed performance goals are the following: any bridge should be safe, functional (serviceable), available (to the user), cheap (looking at the total lifecycle cost) and environmentally friendly. In this sense, some possible performance indicators could be adopted in the following way:

1. Concerning the goal of safety: the load factor, the safety factor, the reliability index to *ULS*;
2. Concerning the goal of serviceability: the condition index, the reliability index to *SLS*;
3. Concerning the goal of availability: robustness (the bridge should be minimally affected by external conditions not specifically foreseen during design), resilience (the bridge should be quickly recovered from any undesired disruption);
4. Concerning the goal of affordability: the total lifecycle cost, values related to the durability aspects (a more durable bridge will be a bridge cheaper to maintain). For instance: diffusivity coefficient of chlorides in concrete, permeability of concrete cover;
5. Concerning the goal of being environmentally friendly: CO_2 foot-print.

2.1.2. SECOND SURVEY PHASE

As mentioned in *Casas* (2016), the COST Action TU1406 Geneva Workshop in September of 2015 was usefully in order to set the essential steps of *WG*1 to gather more information related to performance indicators used in practice and under research. Each *WG* member was asked (a) to participate in the workshop, and (b) to prepare a poster or oral presentations with the following order:

- Extract from the available documents the most important performance indicators.
- Show the formulation and the procedure on how to obtain the *PI*.
- Show the thresholds with respect to each *PI*, if available.
- Show the goals with respect to each *PI*, if available.

- Characterize, based on their experience, if their indicated or proposed *PI* are already applied by owners, operators, experts, and in which project phases.
- Characterize those groups that are important *PI*, but not applied now, or not applied now and needing further investigation in order to become fully implementable.

There are the following findings and important aspects associated with this first *PI* survey process (*Casas* 2016, Strauss et al. 2016 (**a**), (**b**)):

1. A complete translation of codes or guidelines as used by owners and operators from the national language to international European format has been deemed unnecessary, since only some pages are devoted to the subject of interest (performance indicator, performance goal, …);
2. The nomination of a responsible to collect the relevant parts of existing guidelines and translate them to English turned out to be much more effective. The responsible person must have good knowledge and expertise on inspection/assessment of existing bridges in order to identify the relevant parts;
3. The request for answering to a questionnaire and for uploading the relevant parts of the document, both the original and the translated versions was regarded as very significant. It supports to objectify the language translations, since (**a**) it was revealed that many times the same operation or concept has different English translations or wording, and (**b**) to avoid subjectivity in some way;
4. Because of the objective to propose enhancements to the existing practice of performance assessment by the different owners and showing recent advances and new performance indicators two types of documents were asked for: operator documents (actually in use by the different Agencies in the form of guidelines or recommendations) and research documents;
5. Due to the different languages used across COST countries and the different formats of both type of documents (guideline or research oriented) it was decided to nominate in each country the following persons with different tasks:
   - One of the two Management Committee members nominated by each participating country (according to COST Action rules) is responsible to contact owners and operators of highway bridges asking for available documents in practice;
   - A Core Group for *WG*1 was created to prepare the tutorials for the screening of documents, to process screened documents, fill-in the database and finally analyze the database in order to obtain the main results and conclusions;
   - A nominated country responsible person is in charge of gathering, screening and processing national applied documents according to some guidelines and tutorials elaborated by the*WG*1 Core Group. He is also the responsible, jointly with the nominated person from the *MC*, to identify the research groups in each country and ask them to provide information about new proposals for performance indicators still in research phase.

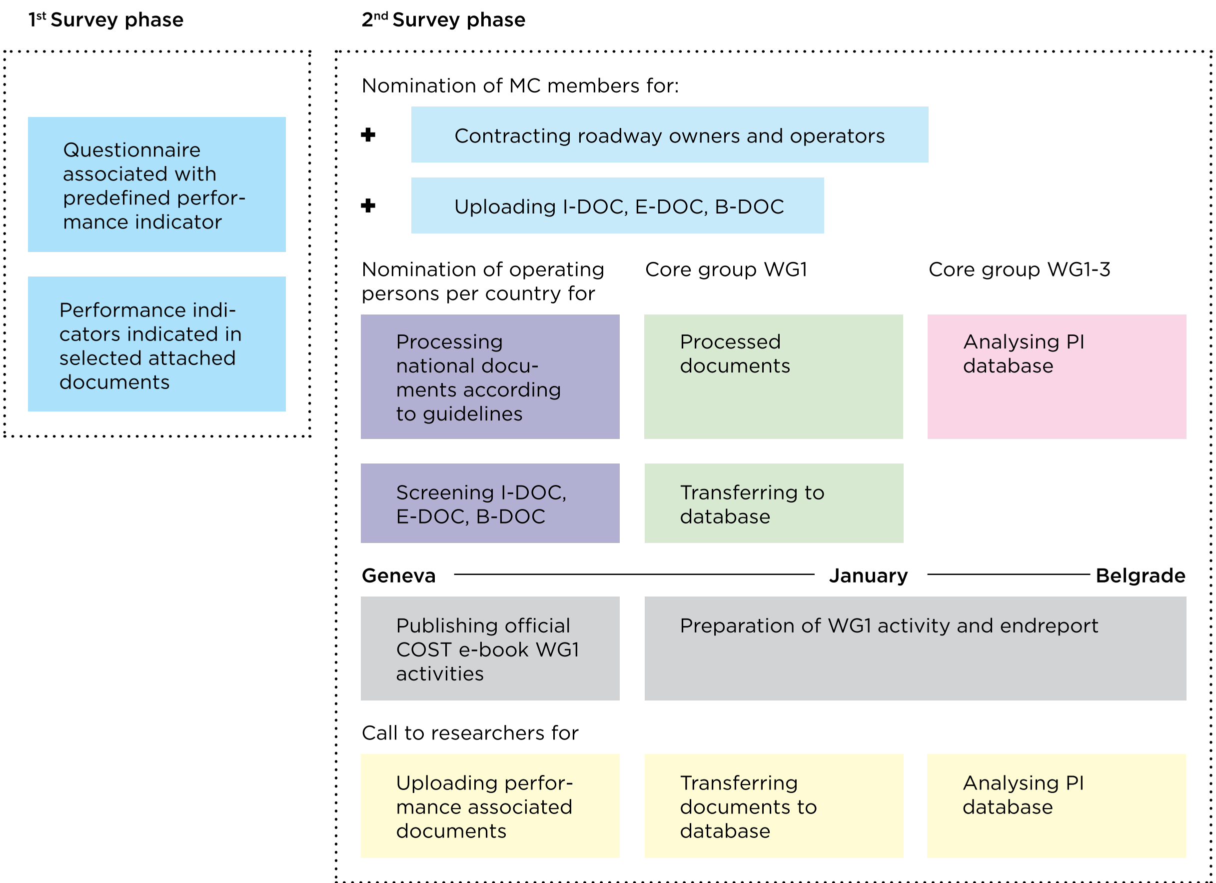


Fig. 1. Technical survey on performance indicators (I-DOC inspection document, E-DOC evaluation document, B-DOC background document)

Based on the findings of the first survey it was decided in the Geneva meeting to carry out a systematic screening on practical national inspection and evaluation documents and on research documents in order to discover in a comprehensive manner the usage of *PI* (performance index), *PG* (performance goal), *PT* (performance threshold). For these screening processes Excel templates were developed to support the nominated persons in their screening.

There are two persons of each country involved in this process associated with the practical national documents: one of the *MC* members, with the responsibility to build up the contact and activate the national highway agency to support in the screening, and the national nominated person who performs the screening. The Excel template and the development of the associated database are described in more detail in the next section (see also the attached pen drive).

2.2. STRUCTURE AND DEVELOPMENT OF THE DATABASE

Through *WG*1 activities, the development of a performance indicators database has been defined as an essential component of the COST Action TU1406. The core of the survey process for the key performance indicators (*KPI's*) and performance indicators (*PI's*) is given in **Fig. 2**. The COST countries must choose beforehand the relevant documents (e.g. inspection, evaluation, research etc.) from which the *PI's* and *KPI's* and related information are going to be extracted. To support this process, a user interface is necessary. Here, it must be acknowledged that the amount and level of information varies from document to document, even in those of the same type. Thus, one of the main requirements in the survey is to allow an unrestricted data input.

The user interface for the survey is structured in Excel (see **Figs. 2** and **3**), where the information may be stored in four groups: Performance level, Damage, Performance indicator/index and Performance assessment. Besides this data, there is an opportunity to add additional references and specific information about a group element (e.g. evaluation process, formula, Figure, etc.). The background for this structure from the screening of Austrian national document (Bundesministerium für Verkehr, Innovation und Technologie, 2011) and two documents from United Kingdom (County Surveyors Society CSS, 2004).

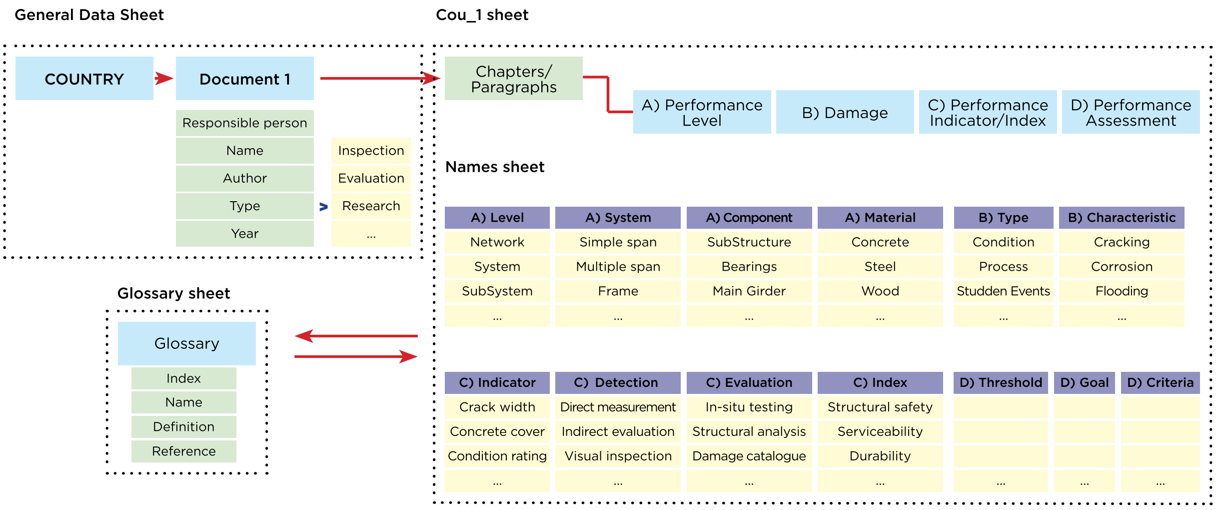


Fig. 2. Database; Core of the survey process

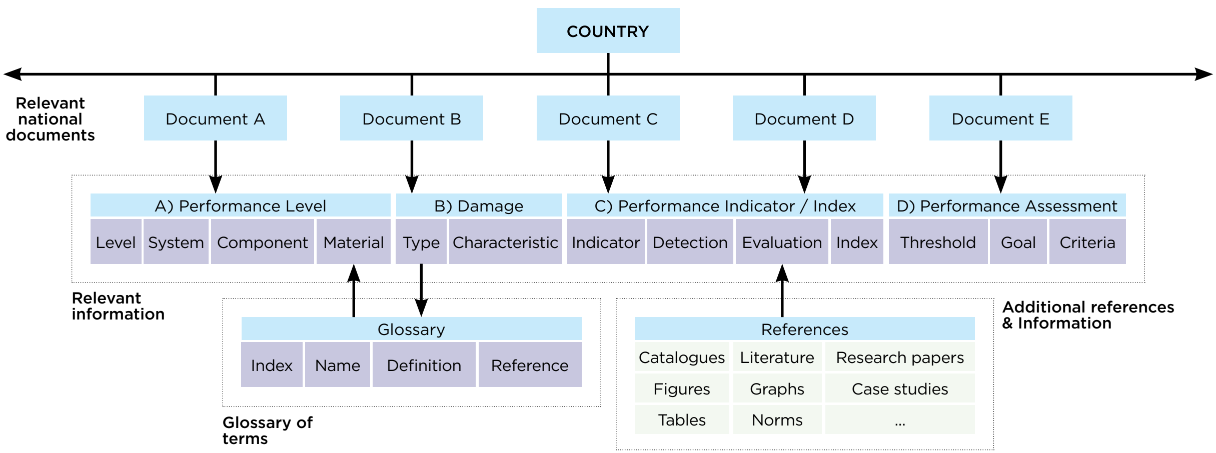


Fig. 3. Database; Data structure of the user interface in EXCEL sheets

The database is divided into the following documents, which is also shown in **Fig 3**.

- The input document is the “Blank” Sheet. With the Blank Sheet it is also possible to create new terms, which are furthermore put into categorization;
- The background document “Names Table” includes information from the pen drive, which itself extracts information from the Glossary;
- The General Data Sheet is the casual Database sheet;
- The Cou_num Sheet allows the documentation of the screened documents.

In order to give support to the screening process interface, a Glossary (see section 4) of key terms is required to store the information and terminology related to *PI*, *PG*, *PT* and *PM*. It has been prepared based on the information from German and Austrian documents (BASt, 2015, Bundesministerium für Verkher, Innovation und Technologie, 2011). During the screening process it is essential to update the Glossary. The main idea is that every COST Action TU1406 country should add national specific information in their own language and translate them into English. The Glossary is acting as a background document which definitions are used to support the database. For the development of the sheet “Names Table”, the first step was to add five columns to the Glossary. Furthermore a categorization in *PI*, *PT*, *PG*, *PC*, and *PM* was implemented, see **Figs. 5** to **7**. Additionally, the *WG*1 did the request of expanding the Glossary and implementing a verification in relation to missing entries.

Beside the Glossary, a “Damages Sheet” was applied. In this sheet the nominated persons were able to fill in the national damages which are not comprised in the Glossary. All the interfaces prepared for the screening of national relevant documents were prepared with the aim of being user friendly and allowing free input. In the Glossary this was made possible by adding the sheet “New terms”. Here, interface users were free to add additional concepts, definitions, explanations and keywords related to performance indicators, goals, thresholds, criteria and methods, see **Fig. 5**. Furthermore it was possible to fill in new country specific terms into the sheet “New Terms”. The country specific terms sheet is used to translate the contents of the sheet Glossary (terms, definitions, keywords, ...) to the users native language. For the successful use of the Glossary file as well as Database interface, the Tutorial (Strauss, Vidovic, Tanasic, & Zambon, 2015) was prepared to give instructions on how to perform extraction of information from relevant documents, see **Fig. 5**. In addition, two examples are given, which supported in the screening process. To summarize:

- The main sheets in the interface are: GeneralData, Cou_Num, and Names_Table sheets;
- GeneralData comprises the basic information on chosen relevant documents for screening;
- Names_Table holds the information of the drop-down lists for Cou_Num sheets and the idea is to append this data simultaneously with the Glossary during the surveying process by users; For instance, by clicking on the category Materials user can choose: aluminium, asphalt, brick, concrete, iron, reinforcement, steel and wood; Drop-down lists are likewise defined for the performance index, performance indicators and levels, bridge elements, damages, detection methods, goals, thresholds, etc;
- With regard to the number of documents, there are several Cou_Num sheets; Names of these sheets are automatically given in the form of /first three country letters/_Num, where Num refers to document number in GeneralData sheet; In Cou_Num sheets the core information from a specific document is stored, see **Table 2**; The input of data is realized row-by-row, following the chapters/paragraphs in a document, where the information for each data group is selected from the drop-down lists (Names_Table).

After achieving the comprehensive quantification of the key performance indicators KPIs and respective performance goals *PG* in the Database, the establishment of the Quality Control plan will follow. In the data surveying process 37 countries are included, which will bring the *KPI* database on the standardized European level.

Document	*Handbook of damages on bridge elements*
Chapter/ Paragraph/ Section	A. Oštećenja prilaza i čunjeva - A-1

Add Chapter/Paragraph

Hide/Show Chapter

A) Performance Level				B) Damage		C) Performance Indicator/Index				D) Performance Assessment		
level	system	component	material	type	characteristic	indicator	detection	evaluation	index	threshold	goal	criteria
Element	All bridge types	Embankment		Damage_State	Erosion	Damage degree	Direct_Measurement			affected area	Damage Assessment	
Sub_System	All bridge types	Access roads		Damage_State	Asphalt pavement cracking	Damage degree	Direct_Measurement			crack width (r	Damage Assessment	

Chapter/ Paragraph/ Section	B. Donji ustroj - B.1. Oštećenja temelja upornjaka i stupova - B1-1

Hide/Show Chapter

A) Performance Level				B) Damage		C) Performance Indicator/Index				D) Performance Assessment		
level	system	component	material	type	characteristic	indicator	detection	evaluation	index	threshold	goal	criteria
Element	All bridge types	Foundations		Damage_State	Scour/Erosions	Damage degree	Direct_Measurement			affected area	Damage Assessment	
Element	All bridge types	Foundations		Damage_State	Abrasion	Damage degree	Direct_Measurement			affected area	Damage Assessment	
Element	All bridge types	Foundations		Damage_State	Abrasion	Damage degree	Direct_Measurement			affected dept	Damage Assessment	
Element	All bridge types	Foundations		Damage_State	Settlements	Damage degree	Direct_Measurement			sag (cm)	Damage Assessment	
Element	All bridge types	Foundations		Damage_State	Degradation	Damage degree	Direct_Measurement			affected area	Damage Assessment	
Element	All bridge types	Foundations	Concrete	Damage_State	Spalling	Damage degree	Direct_Measurement			affected area	Damage Assessment	
Element	All bridge types	Foundations	Concrete	Damage_State	Spalling	Damage degree	Direct_Measurement			affected dept	Damage Assessment	
Element	All bridge types	Foundations	Concrete	Damage_State	Cracks	Damage degree	Direct_Measurement			crack width (r	Damage Assessment	
Element	All bridge types	Foundations	Concrete	Damage_State	Reinforcement corrosion	Damage degree	Direct_Measurement			affected area	Damage Assessment	

Fig. 4. Example of the excel sheet with the input gathered in the database

GLOSSARY SHEETS

GLOSSARY	DAMAGES	NEW TERMS	COUNTRY SPECIFIC
1. Assign: Column A PI Column B *PT* Column C *PG* Column D *PC* Column E *PM* 2. Add missing Parameters	3. Add damage terms	4. Add country specific terms	5. Translate the keywords to country specific language

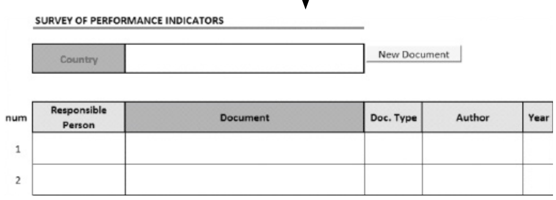
Performance Indicator	Peformance Threshold	Performance Goal	Performance Criteria	Performance Method	Begriff (Deutsch)	Term (English)	Source	Definition	Source	Keywords	Projekt Relevance
X					Abnutzung	Wearout		Degradation of external coatings caused by chemical and/or physical processes	[DIN 31051]	Building conservation	FE 15.0510 (Schädigungspotenziale)
	X				Abnutzungsgrenze	Wearout Limit		The accepted or specified minimum value of degradation levels	[DIN 31051]	Building conservation	
					Abnutzungsprognose	Wearout Prognosis		Assessment of the service behavior of a Component (Unit), at the aim to predict future demand requirements on the basis of the known or assumed loads, starting from an actual state of the Component	[DIN 31051]	Building conservation	
	X	X			Abnutzungsvorrat	Wearout Reserve		Stock of the possible function executions under specified conditions, of a unit due to the manufacture, repair or Inherent improvement .	[DIN 31051]	Building conservation	
					Abschnitt (ASB)	Section / Segment		As a section directed part of the road network is called, which lies between two consecutive nodes. It is limited by the conditions laid down in the network nodes.	[ASBNetzdaten]	Transportation and Transportation Infrastructures	

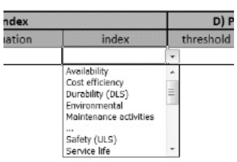
A	B	C	D	E
Performance Indicator	**Peformance Threshold**	**Performance Goal**	**Performance Criteria**	**Performance Method**
X				
	X			
	X	X		

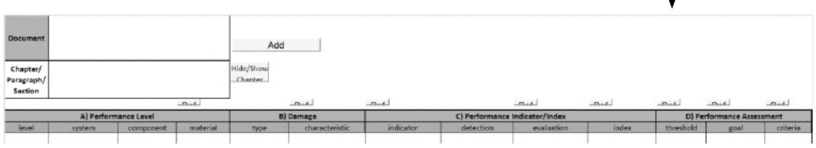
DATABASE SHEETS

BLANK	NAMES TABLES	GENERAL DATA	COU_NUM
Not to be used!!!	- Contains the informa-tion of the drop-lists - Terms from the glos-sary are included 4. Add you terms too	5. Start fulfilling the database 6. For every document create one COU_NAME Sheet	Automatically given name of sheet in the form of/First three country letters/_NUM-BER 7. Fill the table

Doc_Type	Performance_Index (PI)	Performar
Inspection	Availability	Bearings d
Evaluation	Cost efficiency	Concrete c
Research	Durability (DLS)	Crack widt
	Environmental	Deteriorati
	Maintenance activities	....
	...	Chemical p
	Safety (ULS)	Damage
	Service life	Damage d
	Serviceability (SLS)	Damping
	...	Ductility





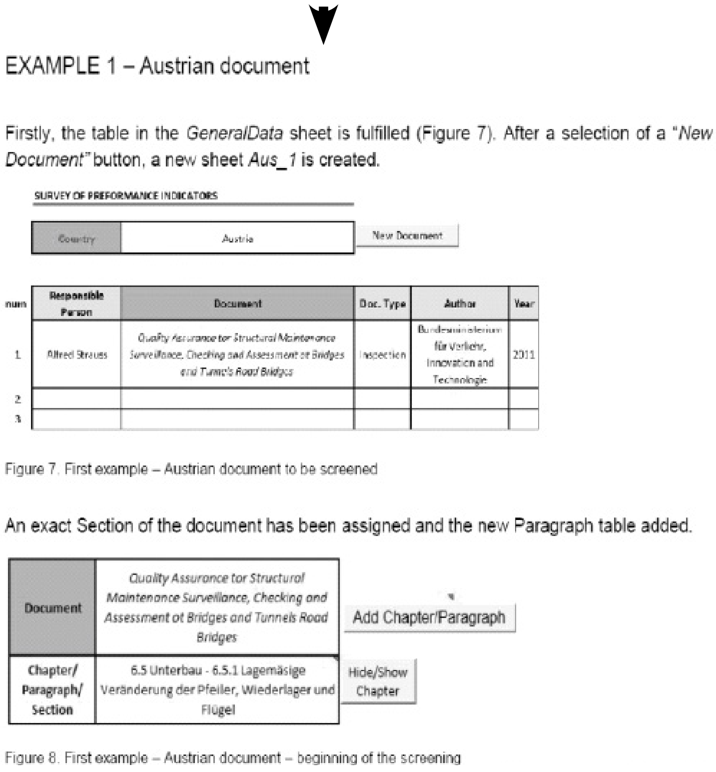


TUTORIAL

= PROVIDES THE EXPLANATIONS OF THE DATA SURVEYING PROCEDURE AND ILLUSTRATES THE PROCEDURE AND ILLUSTRATES THE PROCESSES OF FILLING THE DATABASE

= EXPLAINS HOW ONE SHOULD USE DATABASE AND GLOSSARY FILES

= PROVIDES EXAMPLES FOR SCREENING



EXAMPLE 1 – Austrian document

Firstly, the table in the *GeneralData* sheet is fulfilled (Figure 7). After a selection of a "*New Document*" button, a new sheet *Aus_1* is created.

SURVEY OF PREFORMANCE INDICATORS

Country	Austria	New Document

num	Responsible Person	Document	Doc. Type	Author	Year
1	Alfred Strauss	*Quality Assurance for Structural Maintenance Surveillance, Checking and Assessment of Bridges and Tunnels Road Bridges*	Inspection	Bundesministerium für Verkehr, Innovation and Technologie	2011
2					
3					

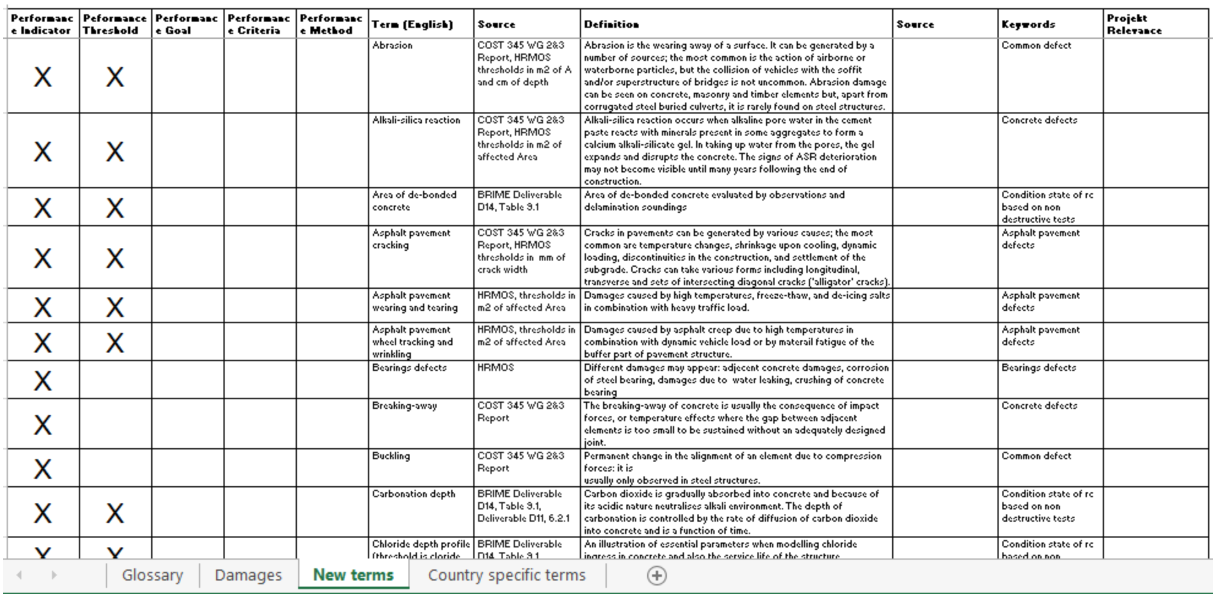
Figure 7. First example – Austrian document to be screened

An exact Section of the document has been assigned and the new Paragraph table added.

Document	*Quality Assurance for Structural Maintenance Surveillance, Checking and Assessment of Bridges and Tunnels Road Bridges*	Add Chapter/Paragraph
Chapter/ Paragraph/ Section	6.5 Unterbau - 6.5.1 Lagemäsige Veränderung der Pfeiler, Wiederlager und Flügel	Hide/Show Chapter

Figure 8. First example – Austrian document – beginning of the screening

Fig. 5. Database and associated documents



Performance Indicator	Peformance Threshold	Performance Goal	Performance Criteria	Performance Method	Term (English)	Source	Definition	Source	Keywords	Projekt Relevance
X	X				Abrasion	COST 345 WG 2&3 Report, HRMOS thresholds in m2 of A and cm of depth	Abrasion is the wearing away of a surface. It can be generated by a number of sources; the most common is the action of airborne or waterborne particles, but the collision of vehicles with the soffit and/or superstructure of bridges is not uncommon. Abrasion damage can be seen on concrete, masonry and timber elements but, apart from corrugated steel buried culverts, it is rarely found on steel structures.		Common defect	
X	X				Alkali-silica reaction	COST 345 WG 2&3 Report, HRMOS thresholds in m2 of affected Area	Alkali-silica reaction occurs when alkaline pore water in the cement paste reacts with minerals present in some aggregates to form a calcium alkali-silicate gel. In taking up water from the pores, the gel expands and disrupts the concrete. The signs of ASR deterioration may not become visible until many years following the end of construction.		Concrete defects	
X	X				Area of de-bonded concrete	BRIME Deliverable D14, Table 9.1	Area of de-bonded concrete evaluated by observations and delamination soundings		Condition state of rc based on non destructive tests	
X	X				Asphalt pavement cracking	COST 345 WG 2&3 Report, HRMOS thresholds in mm of crack width	Cracks in pavements can be generated by various causes; the most common are temperature changes, shrinkage upon cooling, dynamic loading, discontinuities in the construction, and settlement of the subgrade. Cracks can take various forms including longitudinal, transverse and sets of intersecting diagonal cracks ('alligator' cracks).		Asphalt pavement defects	
X	X				Asphalt pavement wearing and tearing	HRMOS, thresholds in m2 of affected Area	Damages caused by high temperatures, freeze-thaw, and de-icing salts in combination with heavy traffic load.		Asphalt pavement defects	
X	X				Asphalt pavement wheel tracking and wrinkling	HRMOS, thresholds in m2 of affected Area	Damages caused by asphalt creep due to high temperatures in combination with dynamic vehicle load or by materail fatigue of the buffer part of pavement structure.		Asphalt pavement defects	
X					Bearings defects	HRMOS	Different damages may appear: adjecent concrete damages, corrosion of steel bearing, damages due to water leaking, crushing of concrete bearing		Bearings defects	
X					Breaking-away	COST 345 WG 2&3 Report	The breaking-away of concrete is usually the consequence of impact forces, or temperature effects where the gap between adjacent elements is too small to be sustained without an adequately designed joint.		Concrete defects	
X					Buckling	COST 345 WG 2&3 Report	Permanent change in the alignment of an element due to compression forces: it is usually only observed in steel structures.		Common defect	
X	X				Carbonation depth	BRIME Deliverable D14, Table 9.1, Deliverable D11, 6.2.1	Carbon dioxide is gradually absorbed into concrete and because of its acidic nature neutralises alkali environment. The depth of carbonation is controlled by the rate of diffusion of carbon dioxide into concrete and is a function of time.		Condition state of rc based on non destructive tests	
X	X				Chloride depth profile (threshold is cloride	BRIME Deliverable D14, Table 9.1	An illustration of essential parameters when modelling chloride ingress in concrete and also the service life of the structure		Condition state of rc based on non	

Glossary | Damages | New terms | Country specific terms

Fig. 6. Example of new terms sheet filled by Croatian representatives

Performance Indicator	Peformance Threshold	Performance Goal	Performance Criteria	Performance Method	Begriff (Deutsch)	Term (English)	Source	Definition	Source	Keywords	Projekt Relevance
			X		Risiko	Risk		The risk refers to danger, hazards or loss of chance in an uncertain venture, and is defined as the product of the consequences of failure (Consequence of failure, CoF) and the probability of entering this failure (Probability of Failure, POF).	[Hans04]	Safety and Reliability	FE 15.0508 (Bewertung), FE 15.0509 (Machbarkeitsstudie), FE 15.0510 (Schädigungspotenziale)
				X	Risikobasierte Inspektionsplanung (RBI)	Risk-based Inspection (RBI) Risk-based Inspection Planning (RBI)		Procedures for the evaluation of system areas and their components as well as of their associated inspection concept from a risk perspective in terms of safety, availability and cost (see also risk). Objective of RBI is to optimize the inspection intervals and consequently the maintenance costs while ensuring the required safety levels during operation of the system.	[VDI 4003]	Safety and Reliability	FE 15.0508 (Bewertung), FE 15.0509 (Machbarkeitsstudie), FE 15.0510 (Schädigungspotenziale), FE 15.0538 (Systemanalyse)
					Road (GDF)	Road		Term from GDF. A Road pooled road elements and junctions between intersections. This is used for structuralizing and is part of Level 2 of GDF. The closest term of ASB is the section or branch.	[ASBNetzdaten]	Transportation and infrastructures	
					Road Element (GDF)	Road Element		Term from the GDF standard. A Road Element describes a roadway between two points, in which a transport connection consists. A road element corresponds to a street element in the ASB.	[ASBNetzdaten]	Transportation and infrastructures	
		X			Robustheit	Robustness	[VDI 6200]	Property of a structure or structural element, not to fail suddenly, with no previous signs; or to announce the loss of sufficient bearing capacity by large deformations or cracks.	[VDI 6200]	Structural Maintenance	
					Rückhaltesysteme an Straßen	Road Restraint Systems	[EC1-2]	General name for vehicle restraint system and pedestrian restraint system used on the road. Road restraint systems may be, according to use: permanent (fixed) or temporary (demountable, i.e. they are removable and used during temporary road works, emergencies or similar situations), deformable or rigid, single-sided (they can be hit on one side only) or double-sided (they can be hit on either side).	[EC 1-2]	Transportation and infrastructures	
X					Schaden	Damage		The term damage in the context of the structure inspection means change of structure condition or structural element condition. The damage can influence on the level of safety (S), traffic safety (V) and/or durability (D).	[RI-EBWPRÜF]	Structural Maintenance	FE 15.0510 (Schädigungspotenziale), FE 15.0538 (Systemanalyse)
X	X				Schadensausmaß	Extent of Damage Damage Degree		The degree of damage determined according to RI-EBW-PRÜF.	[RI-ERHING-OSA]	Structural Maintenance	FE 15.0510 (Schädigungspotenziale), FE 15.0538 (Systemanalyse)
			X		Schadensbewertung	Damage Assessment		Damage assessment in terms of the level of safety (S), traffic safety (V) and durability (D) is carried out in general according to damage examples given in RI-EBW-PRÜF.	[RI-EBWPRÜF]	Structural Maintenance	FE 15.0538 (Systemanalyse)
X					Schadensbild	Damage Pattern		Common display of individual damages, which are interdependent, on the structural element or the entire structure.	[RI-ERHING-OSA]	Structural Maintenance	FE 15.0510 (Schädigungspotenziale), FE 15.0538 (Systemanalyse)

Fig. 7. Glossary discussion – country specific terms sheet.

Table 2. Summary of the documents of some countries included in the database (the full list of documents is provided in the attached pen drive).

Country	Document	Doc. Type	Author	Year
Austria	Quality Assurance for Structural Maintenance - Surveillance, Checking....	Inspection	BMVIT	2011
Bosnia and Herz.	Zakon o cestama federacije bosne i hercegovine / law on roads of	Inspection	Parlament federacije BiH/Federati...	2010
	Odluka o kategorizaciji cesta u autoceste i brze ceste, magistralne ceste	Inspection	Vlady FBiH/Government of FBiH	2014
	Pravilnik o održavanju javnih cesta / Regulations the maintenance of public	Inspection	Federalnom ministarstvu prometa...	2010
	Smjernice za projektovanje, građenje, održavanje i nadzor na ce	Inspection	RS-FB&H/3CS - DDC	2005
	Uputstvo za inspektore mostova / instructions for inspectors of	Evaluation	BCEOM Society Francaise D'Ingenere	2004
	MOSTOVI / BRIDGES	Research	Prof. Boris Koboevic, Prof. Bisera...	1994
	Inspekcijski formular za pregled mosta / The inspection form for an overvie	Inspection	Prof. Bisera Karalic-Hromic	2004
Croatia	Handbook of damages on bridge elements	Evaluation	Hrvatske ceste d.o.o., dr. sc. Danijel...	2014
	Guidelines for bridge inspections	Inspection	Hrvatske ceste d.o.o.	2014
	HRMOS manual – Bridge management	Inspection	Hrvatske ceste d.o.o.	1999
	HRMOS manual – Bridge management – General bridge inspection	Inspection	Hrvatske ceste d.o.o.	1999
	Handbook of damages on bridges	Inspection/ev.	Hrvatske autocesete d.o.o.	2010
	Guideline for bridge evaluation	Evaluation	Hrvatske autocesete d.o.o.	2010
	Bridge Management Planning	Background doc.	Hrvatske autocesete d.o.o.	2008
Czech Republic	ČSN 73 6221 Inspection of road bridges	Inspection	UNMZ Ústav pro technickou...	2011
	ČSN 73 6222 Load capacity of road bridges	Evaluation	UNMZ Ústav pro technickou...	2009
	Catalogue of the bridge damages and defects	Inspection	Pontex spol. s r.o.	2008
	TP72 Diagnostics of road bridges	Inspection	Pontex spol. s r.o.	2008
	TRP201 Measuring and monitoring of the cracks in the concrete bridges	Inspection	CTU in Prague, Klokner institute	2008
	ČSN 73 6209 Load tests of bridges	Evaluation	UNMZ Ústav pro technickou...	1996
	Damages of railway bridges	Inspection	SŽDC TÚDC	2009
	Rules for the assessment of the load capacity of railway bridges	Evaluation	SŽDC TÚDC	2014
	SŽDC S5 management of bridges(railway)	Inspection	SŽDC TÚDC	2012
	TP120 Maintenance, repairs and refurbishment of concrete road bridges	Inspection	Pontex spol. s r.o.	2010
	TP175 Evaluation of the remaining life of concrete road structures	Evaluation	SVÚOM s.r.o.	2006
	TP215 The application of the modal analysis for the road bridges evaluation	Evaluation	CTU in Prague, Faculty of civil eng.	2009

2.3. DATABASE - PROCESSING

The collecting and screening of documents, together with filling the above described database, started in September 2015, and at the time of writing this Report several countries were still in the course of this process. Currently, 31 out of 36 countries, see **Table 3**, finished the process and successfully delivered their databases.

Table 3. List of the nominated countries and members who completed the screening process

Name	Country
Alfred Strauss	Austria
Bisera Karalić Hromic	Bosnia and Herzegovina
Ana Mandić Ivanković	Croatia
Pavel Ryjacek	Czech Republic
Michael Havbro Faber	Denmark
Sander Sein	Estonia
Markku Leivo	Finland
André Orcesi	France
Elena Dumova-Jovanoska	Macedonia
Volkmar Zabel	Germany
Yiannis Xenidis	Greece
György Farka	Hungary
Guðmundur Valur Guðmundsson	Iceland
Vikram Pakrashi	Ireland
Amir Kedar	Israel
Raffaele Landolfo	Italy
Ainars Paeglitis	Lativa
Donatas Jatulis	Lithuania
Stefan Maas	Luxembourg
Irina Stipanovic	Netherlands
Claus Larsen	Norway
Jan Bień	Poland
José Matos	Portugal
Rade Hajdin	Serbia
Josef Vičan	Slovakia
Lojze Bevc	Slovenia
Joan R. Casas	Spain
Mohammed Safi	Sweden
Eleni Chatzi	Switzerland
Kadir Özakgül	Turkey
David Cleland	United Kingdom

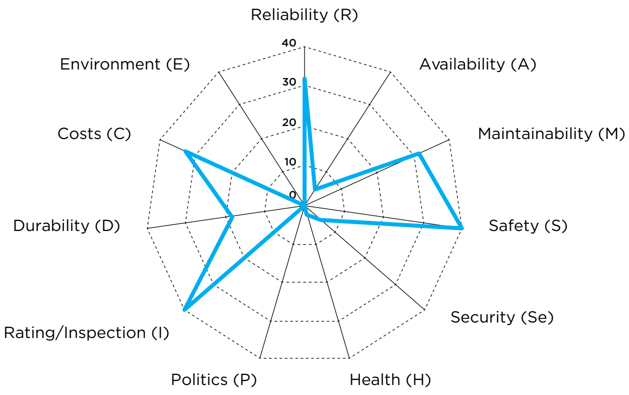
2.4. DATABASE – FINDINGS

In **Fig. 4** there is an example on how the filled material in the Excel sheet looks like. The selected screening methodology is based on a deep analysis of the existing bridge inspection and evaluation policies in European countries and the main performance indicators used with the objective to define a common group of quality specifications and control plans that can be assumed by all these countries in the next future. This, with the aim to manage the existing roadway infrastructure from an European and not only a country-specific perspective.

As expected, the information provided by each country is quite heterogeneous, despite the tutorial prepared to facilitate the input of data. In some way, there was also some misunderstanding about what are performance indicators and how are they obtained. For instance, the surface of a concrete abutment affected by corrosion or the deck area affected by concrete spelling are not quite performance indicators, but quantities that can be used to assess the performance of the bridge. Therefore, an additional clustering and homogenization process as presented in chapter 4 has been processed.

To summarize: the most widely used performance indicator is the condition index, condition rating, deterioration index, ..., or some other nomenclature used by different countries and operators, mainly obtained from visual inspection. All surveyed countries have a performance indicator related to this subject. In many countries, this is the only performance indicator used in practice by bridge owners and operators. However, some countries like Denmark and The Netherlands have started to use other relevant indicators in the assessments made by bridge owners, and not only at research level.

For instance in Denmark, the concepts of remaining service life, safety index-reliability, vulnerability and robustness appear. In The Netherlands the performance is measured in terms of reliability, availability, maintainability and safety/risk (RAMS) among others. The concept of risk is respectively used to define several new indicators: social indicator, environmental indicator, economic indicator and political indicator (requirements for public image). **Fig. 8** illustrates, for example, some *KPI's* which are usable for the *QC* topics of *WG*3 and that could be discovered in the documents and databases of the screening process of the 31 countries, a performed selection process, still in progress, is shown in a file in the pen drive.



Key Performance Indicators, *KPI*'s	Country Specific Mentioned
Reliability (R)	31
Availability (A)	5
Maintainability (M)	32
Safety (S)	40
Security (Se)	5
Health (H)	2
Politics (P)	0
Rating/Inspection (I)	39
Durability (D)	18
Costs (C)	32
Environment (E)	0

Fig. 8. Number of Performance indicators related to the pre-defined Key-Performance Indicators *KPI*s based on the categorized, homogenized and reduced Performance indicators of the findings from the screening and processing of the national applied documents

In the first review of the screening background documents, and the database for performance indicators, the following facts can be identified:

- *Inspection and monitoring strategies associated with performance indicators*
  - Inspection and monitoring strategies for existing bridges, aim at the evaluation and assessment of structural safety and reliability (load carrying capacity, serviceability), see **Fig. 8**, with the ultimate objective of determining the traffic safety.
  - Monitoring and evaluation measures are recommended with the aim of improving the understanding and the general assessment of the condition of the structure or also as a special inspection which enables the identification and localization of damage in time. The ultimate objective is to safeguard the performance over the whole life-span.
  - The basis of any kind of monitoring is always a detailed inspection. Such inspections may be sub-dived in four time-related categories:
    - Visual inspections, e.g. yearly basis.
    - Simple checks, for instance 3 years after every main inspection.
    - In-depth examinations or main inspections, for instance every 6 years.
    - Special inspections, following exceptional occurrences or incidents.
  - In case of defects or deficiencies, special inspections and further tests or examinations have to be conducted with the aim of assessing whether or not these defects have any impact on the serviceability of the structure. On this basis, it shall be decided whether the deficiencies and/or damages are to be repaired in the course of the next maintenance action. In general, in-depth examinations should be performed at intervals of no longer than 6 years.
- *monitoring associated with performance indicators*
  - The aim of monitoring is to ensure both the reliability and the availability of the structural elements and the whole system. The results of the individual monitoring tasks can be transferred into a general and objectified evaluation system e.g. via an evaluation matrix. The key elements of the evaluation system are the assessment of any reductions of functionality and the decisions regarding necessary measures.
  - Monitoring of structures is a non-destructive method for evaluating a structure's condition which is based on measurement data. It may be applied either manually or mathematically at defined intervals. The collected measurement data may describe either the load side or the resistance side. Depending on the measurement task, various physical values can be collected at different intervals. The advantage of structural monitoring lies essentially in the fact that distinct information about a physical value is collected over a longer period of time at defined intervals. This may under certain circumstances enable predictions on the future behaviour of any of the physical values of the structure. As an added bonus, any change in a physical value (structural property) can be observed over time.
  - Under no circumstances can monitoring actions replace detailed structural inspection. Monitoring should be always complementary to inspections and add additional information on individual physical parameters regarding the prescription of maintenance works.
- *rating index associated with the performance indicators*

- For many of the countries in COST Action TU1406 a rating system in a somehow similarly form as shown in the following table are used for the performance assessment.

Table 4. Exemplary rating system

Rating Index	Description
1	No or very slight damage, normal age-related wear and tear, aesthetic damage. No decrease in load carrying capacity, serviceability and predicted life time. No measures required.
2	Slight damage, production defects with no signs of further deterioration. No decrease in load carrying capacity and serviceability. If no suitable measures are taken, the predicted life time will decrease. Repair measures are required in the course of the next maintenance action.
3	Moderate to severe damage with no decrease in load carrying capacity and serviceability. Signs of deterioration regarding load carrying capacity and serviceability. Medium-term maintenance and repair actions are necessary in order to preserve the serviceability and expected life time of the structure.
4	Severe damage, with no decrease in load carrying capacity. Deterioration in terms of serviceability and expected life time can already be observed. Maintenance measures are to be instigated as soon as possible in order to safeguard the serviceability and the expected life time. Such measures may be substituted by additional special inspections within a defined time frame.
5	Extreme damage with impact on the load carrying capacity of the structure. Repair and maintenance measures must be performed immediately.

Table 5. Evaluation levels

Evaluation on level 1	The recalculation according to level 1 is a classification of the structure according to current standards in order to ensure the safety standards specified therein in compliance with the condition Ed = Rd. Ed denotes the rated value of the effect of an impact, and Rd denotes the rated value of a resistance.
Evaluation on level 2	In the recalculation according to level 2, deviations from the partial safety values specified in the current standards are allowed. However, it is necessary to ensure that the prerequisites for reducing partial safety values during the remaining life time are observed.
Evaluation on level 3	In the recalculation according to level 2, deviations from the partial safety values specified in the current standards are allowed. However, it is necessary to ensure that the prerequisites for reducing partial safety values during the remaining life time are observed.
Evaluation on level 4	If the results of the recalculations according to stages 1, 2 and 3 have not produced a satisfactory result, then a lower deviation of the safety level required may be permitted in extraordinary cases. In this event, a very detailed justification in combination with appropriate substitution measures is indispensable.

2.5. DATABASE – HOMOGENIZATION

After collecting input data from different countries based on surveying of inspection and evaluation documents related to bridge maintenance, assessment and management it was concluded, as mentioned before, that results are partly heterogeneous with a number of overlaps.

This mainly results from a free interpretation leeway and different know-how of experts in visual inspections, performance evaluation, performance assessment and decision making. Therefore, a critical overview of contributions from different countries, with respect to the content and definitions, was necessary. The details of the homogenization procedure are given in Chapter 4.

The nominated persons were asked again to verify their performance and damage specific inputs by comparing it with the homogenized and categorized terms of the document “Indicators&Goals” which are available by a drop-down list in the extended homogenization field, as illustrated in **Fig. 9** on the right side.

This procedure with the extended homogenized fields by retaining the original information of the databases allows an effective comparison of the performance quantities between countries. The extended databases are available on the pen drive.

2.6. FROM PERFORMANCE TO KEY PERFORMANCE INDICATORS

2.6.1. GENERAL

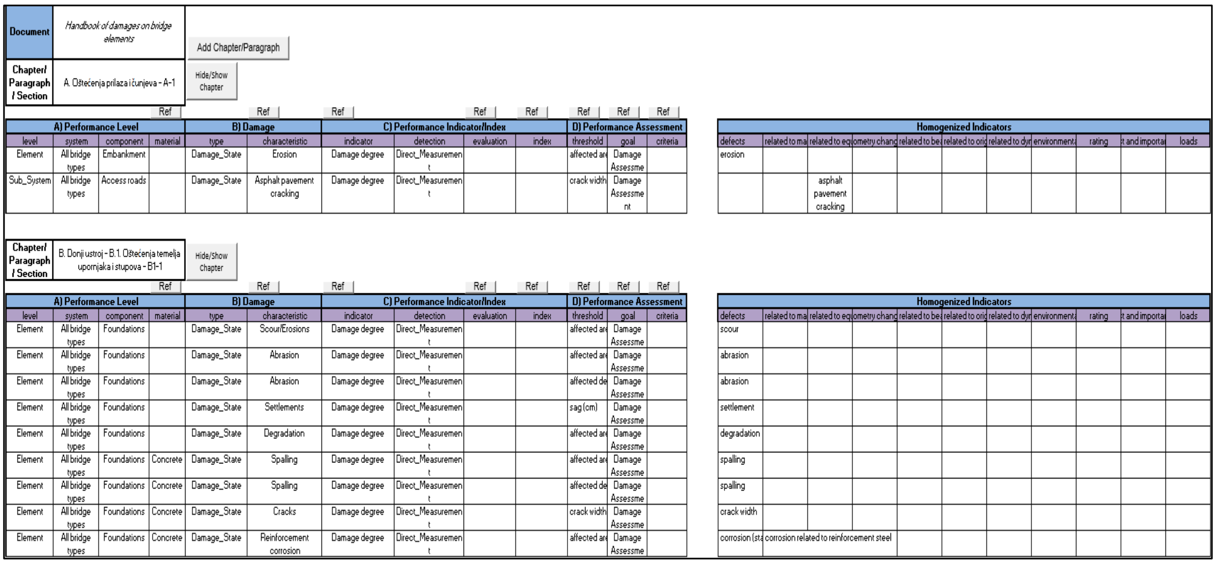
As a basis for the classification of the *PI*’s and *KPI’s*, the document “Indicators&Goals” for the homogenization and Categorization, see Chapter 4, serves as Background Document. For each defined category in the document, additional columns are added to define the performance indicator properties, the goals, and to group it into the pre-defined *KPI’s*.

2.6.2. NEXT STEPS

The sketched preparation of data allows now the discussion:

- On Key Performance Indicators *KPI’s* (Framework) and performance indicators *PI*’s, in particular, the discussion of results from country to country. Which are the more appropriate indicators e.g. for concrete structures;
- On umbrella indicators that can be gathered according to their characteristics or their membership to the Key Performance Indicators *KPI’s*, see **Fig. 8**;
- On *PI*’s, that are the same in their application for operators and researchers;
- On the importance of *PI*’s in the assessment process for operators, for researchers, and for decision makers;
- On the importance of *PI*’s in the assessment process regarding the type of structure and the used material;
- On the interaction of *PI*’s and their combination;
- On research associated *PI*’s and their acceptance and applicability in practice;
- On practical examples from the database.

The survey associated files are available on the attached pen drive



Document	*Handbook of damages on bridge elements*
Chapter/ Paragraph / Section	A. Oštećenja prilaza i čunjeva - A-1

Add Chapter/Paragraph

Hide/Show Chapter

A) Performance Level				B) Damage		C) Performance Indicator/Index				D) Performance Assessment		
level	system	component	material	type	characteristic	indicator	detection	evaluation	index	threshold	goal	criteria
Element	All bridge types	Embankment		Damage_State	Erosion	Damage degree	Direct_Measurement			affected ar	Damage Assessme	
Sub_System	All bridge types	Access roads		Damage_State	Asphalt pavement cracking	Damage degree	Direct_Measurement			crack width	Damage Assessment	

Homogenized Indicators										
defects	related to ma	related to eq	ometry chang	related to be	related to orig	related to dyn	environmenta	rating	t and importa	loads
erosion										
		asphalt pavement cracking								

Chapter/ Paragraph / Section	B. Donji ustroj - B.1. Oštećenja temelja upornjaka i stupova - B1-1

Hide/Show Chapter

A) Performance Level				B) Damage		C) Performance Indicator/Index				D) Performance Assessment		
level	system	component	material	type	characteristic	indicator	detection	evaluation	index	threshold	goal	criteria
Element	All bridge types	Foundations		Damage_State	Scour/Erosions	Damage degree	Direct_Measurement			affected ar	Damage Assessme	
Element	All bridge types	Foundations		Damage_State	Abrasion	Damage degree	Direct_Measurement			affected ar	Damage Assessme	
Element	All bridge types	Foundations		Damage_State	Abrasion	Damage degree	Direct_Measurement			affected de	Damage Assessme	
Element	All bridge types	Foundations		Damage_State	Settlements	Damage degree	Direct_Measurement			sag (cm)	Damage Assessme	
Element	All bridge types	Foundations		Damage_State	Degradation	Damage degree	Direct_Measurement			affected ar	Damage Assessme	
Element	All bridge types	Foundations	Concrete	Damage_State	Spalling	Damage degree	Direct_Measurement			affected ar	Damage Assessme	
Element	All bridge types	Foundations	Concrete	Damage_State	Spalling	Damage degree	Direct_Measurement			affected de	Damage Assessme	
Element	All bridge types	Foundations	Concrete	Damage_State	Cracks	Damage degree	Direct_Measurement			crack width	Damage Assessme	
Element	All bridge types	Foundations	Concrete	Damage_State	Reinforcement corrosion	Damage degree	Direct_Measurement			affected ar	Damage Assessme	

Homogenized Indicators										
defects	related to ma	related to eq	ometry chang	related to be	related to orig	related to dyn	environmenta	rating	t and importa	loads
scour										
abrasion										
abrasion										
settlement										
degradation										
spalling										
spalling										
crack width										
corrosion (sta	corrosion related to reinforcement steel									

Fig. 9. Homogenized Croatian database

3. GLOSSARY

3.1. GENERAL

In the first *WG* meeting, held in Geneve, the establishment of a Glossary, partly sketched in **Figs. 5** to **7**, to add the definition of performance indicators was agreed upon. Then, the *WG*1 Core Group worked on the structure of the Glossary, which is to include any technical terms relevant for COST Action TU1406. The survey data of the research project “intelligent bridge (BASt 2014, 2015)” was used as a basis.

The objective was to define the technical terms, including the performance indicators, and to list them in English. The aim of the research focus, which was established by BASt and is funded by the German Federal Ministry of Transport, Building and Urban Development (BMVBS), is the development of an adaptive system for the real time collection and evaluation of relevant information about changes in load and resistance.

Due to the interdisciplinary nature of COST Action TU1406, it is expedient (as is the case for the overall BASt project) to collect, in a harmonized format, all the relevant technical terms into one document. This should make it possible to create a collective linguistic framework and to avoid any misunderstandings resulting from differing views on the definition of terms or incorrect interpretations.

3.2. EDITING PROCEDURE

Prior to the development of the Glossary, the technical terms relevant for the work in the BASt project (BASt 2014, 2015), and consequently in COST Action TU1406, were determined and compiled in a tabular format. The studied literature encompasses regulations and guidelines including those by DIN, VDI, BASt, MC2010, EN19xx, RVS, BMVIT and BMVBS.

The interim reports and other national documents by COST partners, together with other technical literature, were also analyzed with regard to their usage of technical terms.

Definitions of terms established in regulations and guidelines, together with their translations into English, were usually accepted. In all other cases, definitions were developed on the basis of both literature research and practical experience.

At this point, adequate English translations are not yet available for all the terms. Missing translations will be completed in the further course of the project and discussed with the involved parties. Following the literature research, the Glossary created by the *WG*1 Core Group was reviewed with regard to the following criteria:

- Completeness.
- Correctness of English translation.
- Definition of terms.
- Assignment of key words.

The glossary associated files are available on the attached pen drive

4. OPERATORS DATABASE

4.1. CLUSTERING AND HOMOGENISATION OF PERFORMANCE INDICATORS

After collecting the input from different countries, based on surveying of inspection and evaluation documents related to bridge maintenance, assessment and management, it was concluded that results are partly heterogeneous with a number of overlaps.

This mainly results from free interpretation leeway and different know-how of experts in visual inspections, performance evaluation, performance assessment and decision making.

Additionally, it is not unusual for different bridge operators in the same country to use different approaches in bridge management. For example, within damage handbooks *Croatian roads ltd.* are using the categorisation of damages primarily in relation to each component and secondly according to material of which it is composed and *Croatian highways ltd.* at the first level according to the material and at the second level in relation to the component.

Despite this, at the end almost the same type of damages are covered and bridge inspection is carried out by bridge elements (components).

Therefore, a critical overview of contributions from different countries, with respect to the content and definitions, was necessary. This chapter presents an attempt of *WG*1 leaders to homogenise the terms to be used within the *PI* database. **Fig. 10** shows the main steps of this procedure.

SURVEYING	>	CLUSTERING	>	HOMOGENISATION
of inspection & evaluation documents from different countries		of performance indicators to several groups		of performance indicators for applied database

Fig. 10. Procedure for the homogenisation of *PI*s of applied database.

In order to do so, clustering of performance indicators into several groups is suggested, see **Fig. 11**. Clustering was guided with the thought that it should allow to more easily identify methods and procedures for revealing and quantifying performance indicators as well as to define levels of their contribution to a certain structural performance goal. This will be further discussed in the following chapters.

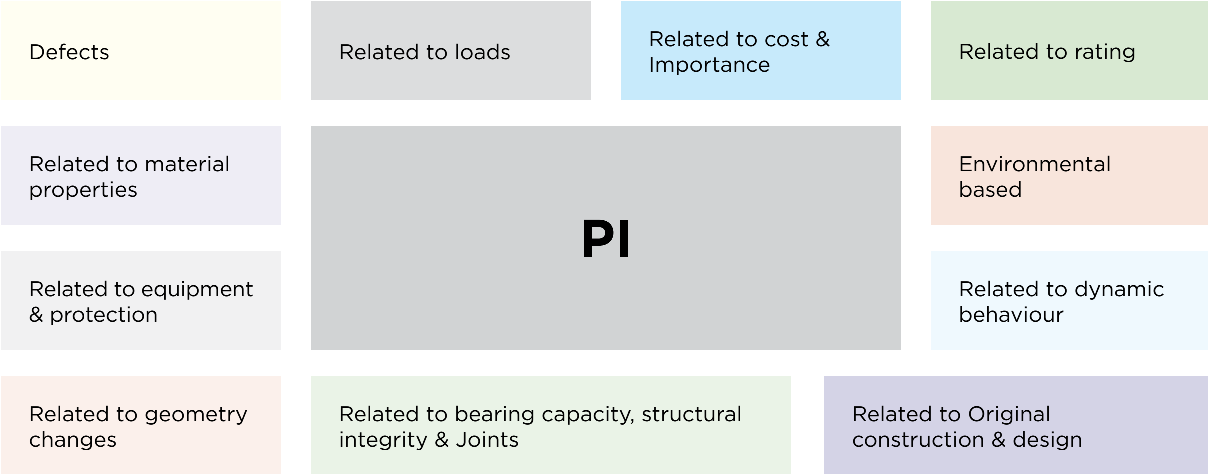


Fig. 11. Main clusters of Performance Indicators related terms.

The clustering procedure allowed to reduce the list of terms related to performance indicators in half, from more than 700 of terms to 385. A cut-out from the list of clustered terms is shown at the **Fig. 12**. Further, the clustering served for homogenisation of the Croatian database as the basis for the homogenisation of complete European Database, in order to harmonize the Performance Indicators from a European perspective.

defects	**related to material properties**	**related to equipment & protection**	**geometry changes**	**related to bearing capacity, structural integrity and joints**	**related to original construction & design**	**related to dynamic behaviour**	**environment al based (common appearance)**	**rating**	**cost and importance**	**loads**
abrasion	acids attacks	absence (missing) of equipment component	buckling	absent (missing) structural component	accessibility to damage	atypical vibrations	biological growth	advanced deterioration process	bridge importance (size)	gross weight of a vehicle
absence/ missing	aggregate segregation	approach slab settlement	cross incline of road	accumulated dirt and deposits in joints	bad design	damping	climate change	condition note	element functionality level	permanent loading
aggradation (alluviation)	aging of material	asphalt pavement cracking	deformation	anchorage blocks deficiency	carrying capacity factor	frequency	environmental exposure	condition of a bridge	importance of bridge element	traffic loading
blistering	alkali aggregate reaction (alkali-silica reaction)	asphalt pavement wearing and tearing (rutting ravelling)	denivelation	anchorage deficiency or failure	concrete cover	noise	freeze-thaw	condition rating	price of the new element	
blocking	alkali aluminium reaction	asphalt pavement wheel tracking and wrinkling and undulation	differential movement	arch ring separation	cracks due to curing and forming	real dynamic behaviour	humidity	damage	sum of costs for repair of individual damages	
bulging	bad concrete compaction	blistering paint	displacement	barrel damage to stone arches	design codes	relative vibrations between elements	moisture	damage assessment	traffic restriction	
cavitation	bedding mortar failure	cladding damages	distortion	bearing defects	design load	sound	soot	damage degree	traffic volume	
clogged	bituminous binder immersion	cladding deformations	flattening	bearing fracture extension	design load by road ID	vibrations/ oscillations	subterranean water flow	damage evolution		
coating loss	calcification	clogged collector	height difference	bearings displacement	dimensions		temperature	damage extension		

defects	related to material properties	related to equipment & protection	geometry changes	related to bearing capacity, structural integrity and joints	related to original construction & design	related to dynamic behaviour	environment al based (common appearance)	rating	cost and importance	loads
contamination	carbonation	clogged drain	inclinations	brick crushing	ductility		vegetation	damage of high risk for safety		
corrosion (state)	chemical attack	clogged manhole	misalignment	buckling of the masonry	excessive strain			degradation process on action		
crack length	chemical parameter	clogged pipe	movements	cable rupture	execution/ construction defects			deterioration index		

Fig. 12. Cut-out from clustering table of *PI* related terms for homogenisation of the applied database.

An example of homogenisation within the Croatian database is shown at the **Fig. 13**. For each available cluster of performance indicators, one example for converting terms from original database into a homogenised one is given. Upon homogenisation from all countries the final number of indicators should be significantly reduced. Then the further process will require what *PI*s are crucial and should always be used, and which are specific-based, for example varying with the bridge type.

Further, reduction of performance indicators should be done through categorisation associated with the requirements of *WG*2 – Performance goals & *WG*3 – Establishment of a *QC* plan. This will include weighting of performance indicators importance for reaching performance goals and establishing the final quality control plan.

A) Performance Level				B) Damage		C) Performance Indicator/Index		D) Performance Assessment			
level	**system**	**component**	**material**	**type**	**characteristic**	**indicator**	**detection**	**threshold**	**goal**		
Sub-System	All bridge types	Super Structure	Concrete	Damage State	Cracks	Damage degree	Direct Measurement	Crack width (mm)	Damage Assessment	>	**Defects** Crack width
Sub-System	All bridge types	Super Structure	Concrete	Damage State	Honey-combing	Damage degree	Direct Measurement	Affected area (m2)	Damage Assessment	>	**Material properties** bad concrete compaction
Sub-System	All bridge types	Super Structure		Damage State	Freeze-thaw	Damage degree	Direct Measurement	Affected area (m2)	Damage Assessment	>	**Environmental based** Freeze-thaw
Sub-System	All bridge types	Super Structure	Brick	Damage State	Disintegration of mortar	Damage	Visual Inspection		Damage Assessment	>	**Structural integrity & joints** Disintegration of mortar
Sub-System	All bridge types	Railings	Steel	Damage State	Missing Parts	Damage degree	Visual Inspection		Damage Assessment	>	**Equipment and protection** Absence of equipment component
System	All bridge types			Damage State	Buckling	Damage degree	Visual Inspection		Damage Assessment	>	**Geometry changes** Buckling
System	All bridge types		Concrete	Damage State	Execution defects	Damage degree	Direct Measurement	Affected area (m2)	Damage Assessment	>	**Original construction & design** Execution/construction defects
Element				Damaging process	Low damage degree (first phase)	Damage degree	Visual Inspection	Upper limit + Duration of damage	Damage Assessment	>	**Rating** Damage degree +damage evolution
Element						Importance of bridge element		Quantitative scale of values	Element importance assessment	>	**Cost & importance** Importance of bridge Element

Fig. 13. Example of homogenisation of terms within the Croatian database.

4.2. CATEGORISATION OF PERFORMANCE INDICATORS

Management of road bridges comprises coordinated activities to realize their optimal value, which involves balancing of costs, risks, opportunities and performance goals. Performance goal may be considered as a type of bridge property or behaviour that is required during its lifetime. Different types of performance goals need to be reached at different levels of a roadway bridge asset, as a part of its efficient and effective maintenance strategy.

For example, functionality of a specific bridge element (such as the stability of an abutment, bending capacity of a main girder or the retention level of a safety barrier) is a performance goal at the component level. Adequate seismic performance of a complete bridge structure is a goal at the system level, but taking into account the relative importance into the network and the consequences of its collapse it may become a goal at the network level. Whether the goal will be (or is) achieved or not, may be assessed through the evaluation of various performance indicators, which additionally implies knowledge of their respective levels of influence to an observed performance goal. Performance indicator may be defined as superior term of a bridge characteristic that has the possibility to indicate the condition of a bridge. It can be expressed in the form of a dimensional performance parameter or as a dimensionless performance index.

The former is a measurable/testable parameter that quantitatively describes a certain performance aspect (e.g. crack width) and the second one is a qualitative representation of performance aspect (e.g. importance of a bridge component in the whole bridge structure or importance of a bridge in the complete network). To evaluate certain performance indicator, performance thresholds or criteria must be set. A threshold value constitutes a boundary for purposes such as: a) monitoring (e.g. an effect is observed or not), b) assessing (e.g. an effect is low or high), and c) decision-making (e.g. an effect is critical or not). A criterion is a characteristic that is relevant for the choice between processes e.g. such as maintenance actions or others.

Although the interaction of different performance indicators is inevitable (see **Fig. 19**), their categorization into technical, sustainable and socio-economic indicators through component, system and network level is proposed in this Chapter in order to more easily identify methods for their quantification and level of their influence to a certain performance goal. More detailed categorization of damages as performance indicators should contemplate their origin (based on clustering as given in previous Chapter), related detection methods, performance thresholds and evaluation methods, and finally the level and extend of their influence to a certain performance goal quantifiable in terms of monetary units.

4.2.1. PERFORMANCE INDICATORS AT THE COMPONENT LEVEL

Bridge inspection is in general carried out by bridge elements (components) forming three main bridge sub-systems: substructure, superstructure and roadway (Croatian roads ltd. 2014 & Croatian highways ltd. 2010 a). Bridge components, including constitutive materials are given in **Table 6**.

Fig. 14. Three main bridge sub-systems: substructure, superstructure and roadway/equipment.

Table 6. Bridge elements for categorization at the component level.

Substructure	Superstructure	Roadway + equipment
Foundations (concrete)	Superstructure (reinforced concrete)	Pavement
Deep foundations, piles (concrete)	Superstructure (prestressed concrete)	Curb & Cornices
Deep foundations, piles (steel)	Superstructure (steel)	Railings & railing anchorage, barriers
Deep foundations, piles (timber)	Superstructure (composite)	Sidewalk (Pedestrian walkway)
Abutments (concrete)	Superstructure (timber)	Bearings
Abutments (masonry)	Superstructure (brick)	Expansion joints
Piers (concrete)	Superstructure (stone)	Drainage
Piers (steel)	Arch (concrete)	Lighting
Piers (masonry)	Arch (masonry)	Signalization
...	...	...

4.2.1.1. TECHNICAL ASPECTS

At the bridge component level, one of the important goals to be reached (or task to be performed) is damage assessment. This implies the detection of damages but also their identification and evaluation within the set thresholds (**Fig. 15**).

Damage of a bridge element is a physical disruption or a change in its condition, caused by external actions, such that some aspect of, either the current or future performance of the component (and perhaps consecutively a complete structure) is impaired.

DAMAGE DETECTION >	DAMAGE IDENTIFICATION >	D. EVALUATION BASED ON D. THRESHOLD >	DAMAGE ASSEMENT
1. Visual inspection 	2. Delamination + corrosion at the bridge pier due to aggressive maritime environment and thin concrete cover, which may lead to reduced resistance and durability	3. Based on affected area - high degree of damage;	4. More detailed inspections and testing are necessary
5. Chloride content measurements		6. Based on chloride content - advanced deterioration process	7. Damage assessment may lead to a routine or special repair

Fig. 15. Damage assessment implies the detection of damages as well as their identification and evaluation.

Four main approaches in damage detection are visual inspection, non-destructive testing, probing and structural health monitoring. (**Fig. 16**). In addition to damage detection and characterization, damage identification includes ascertaining the cause of damage and its consequences and damage evaluation comprises the degree or/and extend with respect to the set threshold value.

Besides most commonly set up upper limit, an additional threshold in damage assessment may be the duration of damage phase, which will give a clue in which phase of damage progress the element is found: low, moderate or high. The former will request the protection from further progression, the second one will require a routine repair and the last one requests more detailed inspections and testing leading to a routine or special repair.

An example for categorisation of damage as a primary performance indicator, by taking into account related detection methods, performance thresholds and evaluation methods, is given in **Table 7**.

This categorisation should be done at the level of each bridge component as for example crack detection will be assessed differently depending on where it is found, what is its width, its orientation, and origin.

Fig. 16. Main approaches in damage detection: visual inspection, non-destructive testing, probing and structural health monitoring.

For instance, corrosion is a damage process. In addition, it should be established the difference between damage state and damage process, as the former should be evaluated based on extent or degree of damage whereas the latter should be based on the phase of the damage process.

Nonetheless, it is evaluated as a damage state based on the extension of damage, such is for example the affected area of a component (in m2) or the percentage of damaged cross section of reinforcement (in %). On the other hand, if chloride content or carbonization depth is being measured, it can be possible to evaluate in which phase of the corrosion process the component is found to be.

Upon assessing damages of a particular bridge element, the component functionality level may be evaluated. Accordingly, the element may be evaluated in best condition when no damage is detected, with unquestionable function when damage is in initial phase, with function not been compromised when damaged is moderate and with questionable function or element is out of function when damage has high degree and/or extend.

Table 7. Example of categorization of damage degree/extend as a primary performance indicator for concrete superstructure.

Damage type (characteristics)	Damage indicator	Damage detection	Damage threshold	Damage evaluation
Abrasion	Affected area (m2) + Affected depth (cm)	Visual inspection + Direct measurement	Classes / upper value + damage phase duration	Grades according to handbook of damages
....				
Cavities	Speed of reflected signal	Acoustic emission		Results analysis
	Resonance in amplitude-frequency spectra	Impact-echo test		Results analysis
Corrosion	Affected area (m2)	Visual inspection + Direct measurement	Classes	Grades according to handbook of damages
	Percentage of damaged cross section of reinforcement (%)	Specialist detailed inspection	Upper values of the phase + damage phase duration	Grades according to handbook for assessment
	Physical parameter	In situ testing		Testing analysis
	Potential (mV)	Half-cell potential measurements	Classes and lower limit	Evaluate risk of corrosion
	Chloride content (%)	Probing at concrete samples in laboratory	Critical value	Quantitative analysis
	Carbonization depth (mm)	Laboratory testing of collected material	carbonization depth limit	Evaluate risk of corrosion
		Corrosion Monitoring systems		Monitoring of corrosion progress
Cracks	Crack width (mm)	Visual inspection + Direct measurement	Classes / upper value + damage phase duration	Grades according to handbook of damages
	Crack width/depth	Ultrasonic velocity test	Upper limit	Testing analysis
	Existence	Hammer sounding		
		SHM of cracking		Monitoring of cracks evolution
Delamination	Affected area (m2) + Affected depth (cm or mm)	Visual inspection + Direct measurement	Classes	Grades according to handbook of damages
Deflection	Long-term deflection	Visual inspection + Direct (periodic long lasting) measurement	Upper limit	Monitoring of deflection evolution
Fatigue	Damage degree	Visual inspection	Classes	Damage catalogue
		Fatigue damage or fatigue cracks sensors		Monitoring of fatigue damage evolution
Insufficient concrete cover	Affected area (m2)	Visual inspection + Direct measurement	Classes	Grades according to handbook of damages
Insufficient concrete quality	Physical parameter	Probing		Probing analysis
		Rebound hammer		
Scour	Hydraulic inadequacy, depth	Direct measurement	Upper limit	Inspection
	Differential rotation + displacements	Direct measurement	Upper limit	Monitoring of score criticality
	Differential settlement	Direct measurement	Upper limit	Monitoring of score criticality
		Scour monitoring devices		Monitoring of score criticality
Spalling	Affected area (m2) + Affected depth (cm or mm)	Visual inspection + Direct measurement	Classes	Grades according to handbook of damages
.....				

4.2.1.2. SOCIO-ECONOMIC ASPECTS

At this level, socio-economic aspects are to be included. A ratio of sum of costs for repair of individual damages and price of the new element is an indicator of the element's general condition assessment. A threshold for this indicator may be set as a quantitative scale of value showing the gradation of the element condition assessment. For all elements, for which this ratio is above 1.0, replacement with a new element should be predicted.

4.2.2. PERFORMANCE INDICATORS AT THE SYSTEM LEVEL

In order to assess the impact of the damaged element functionality to the entire structure, the importance of the bridge element is to be evaluated according to following criteria: structural safety and serviceability, traffic safety and durability (DIN 1076 1999).

The qualitative scale of values (see example in **table 8**) based on the Guideline for bridge evaluation, Croatian highways ltd. 2010 b) may show how the collapse of a particular element would affect each criteria. Besides technical indicators, at this level sustainability and socio-economic indicators will assume an essential impact to performance requirements.

Additionally, indicators related to scientific achievements in, for example, testing and monitoring, dynamic behaviour and reliability of bridge structures, should be included at this level, as well. Some contemplation on those indicators are given based on the survey of research-based indicators at the European level in Chapter 5.

For example, bridge reliability assessment will require an adequate knowledge level on particular bridge related properties such are for example stiffness changes and local bridge traffic loading which requires investment in additional inspection, testing or monitoring method, advanced modelling techniques and updating data on bridge resistance and loads.

Research-based performance indicators, including those that may be put in practice as well as those in whose development is worth investing, have the potential to improve existing structural performance assessment methods and consequently the management of roadway bridges at the European level.

4.2.2.1. TECHNICAL CRITERIA

Technical criteria at this level are those related to bridge safety and serviceability as main performance goals used in existing inspection and evaluation documents. Based on this criteria, it may be decided that collapse of a particular element will have no influence to safety and serviceability of the bridge, has influence to a part of a bridge structure or has influence to the entire bridge structure (**Table 8**).

4.2.2.2. SUSTAINABILITY CRITERIA

When meeting performance requirements is evaluated, under given condition during a given period of time, sustainability issues occur. Durability may be considered as a sustainable performance goal which needs to be included as a criteria for condition assessment of bridge sub-systems comprising roadway, substructure and superstructure as well as the entire bridge condition assessment.

Based on durability criteria, it may be decided that the collapse of a particular element will have no influence to the durability of other components or by the contrary that the collapse of a particular element will cause a reduced durability of other components (**Table 8**).

Table 8. Example of the component functionality importance at system level according to different criteria.

Structural safety criteria	Traffic safety criteria	Durability criteria
	collapse of particular element...	
has no influence to the bridge safety 1: *railing*, *curb*, *embankment*, ...	has no influence to traffic flow 1: *cornices*, ...	have no influence to durability of other components 1: *railing*, *main girder*, *arch*, *pier*, *foundation*, ...
has influence to a part of a bridge structure 2: *cornices*, *cross girders*, *bearing*, wing, ...	causes speed limitation 2: *sidewalk with barrier*, ...	will cause reduced durability of other components 2: *expansion joint*, *pavement*, *curb*, *drain*, ...
has influence to an entire bridge structure 3: *main girders*, *arch*, *pier*, *foundation*, ...	causes local traffic redirection 3: *sidewalk*, *embankment*, *curb*, *drainage*, ...	
	complete traffic suspension 4: *barriers*, *pavement*, *expansion joint*, *roadway slab*, ...	

4.2.2.3. SOCIO-ECONOMIC CRITERIA

Traffic safety may be considered as a socio-economic performance goal. Namely, as criteria for condition assessment of bridge sub-systems or entire bridge condition assessment, it is expressed in levels of traffic limitation or congestion: collapse of a particular element has no influence to traffic flow, causes speed limitation, causes local traffic redirection or complete traffic suspension (**Fig. 17**).

An additional indicator to be raised at the system level is the element general condition assessment, which will help to assess the condition of a sub system and consequently the entire bridge.

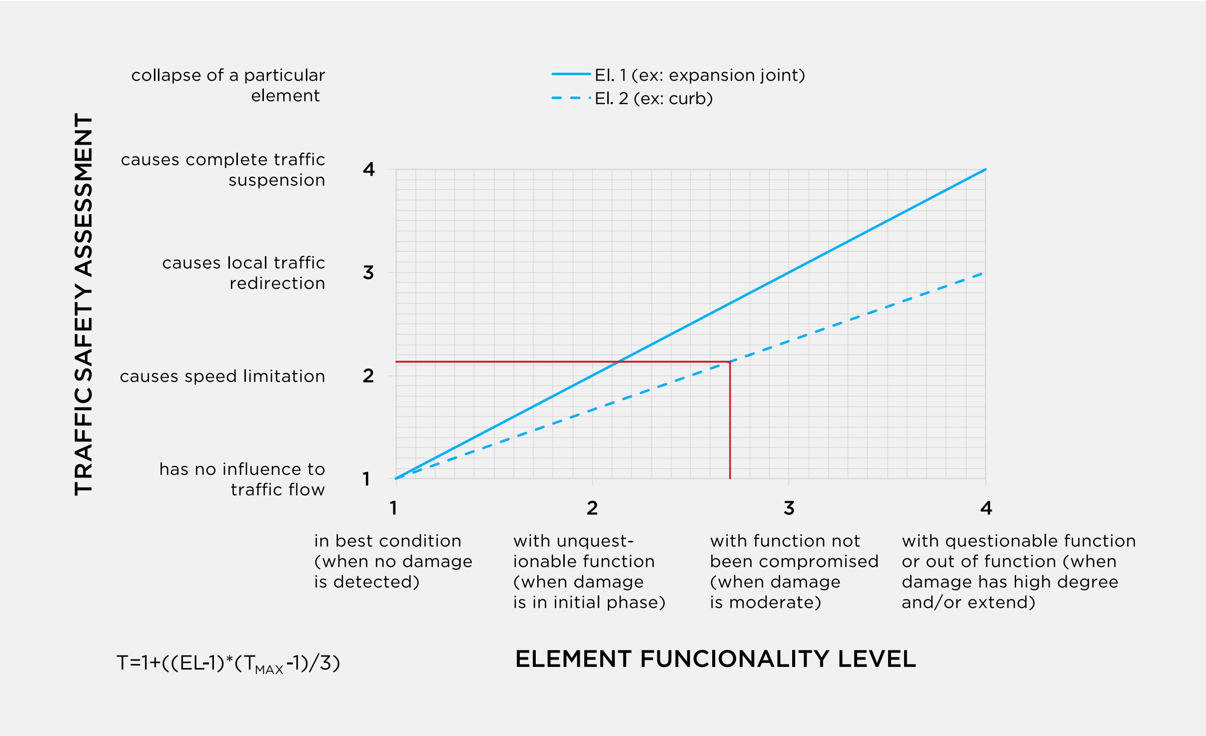


Fig. 17. Example of the element functionality level influencing the traffic safety criteria.

An example of traffic safety assessment based on element functionality level is presented at **Fig. 17**. In this case, element functionality level may be graded from 1, which means that the element is in the best condition (when no damage is detected), to 4, which means that element is out of order (when damage is of high degree and extend).

This example is based on the Guideline for bridge evaluation (Croatian highways ltd. 2010 b).

4.2.3. PERFORMANCE INDICATORS AT THE NETWORK LEVEL

At the network level, based on bridge condition assessment gained through standard inspection and evaluation procedures with additional evaluation of bridge importance in the network, the primary goal to be reached is priority repair ranking. Bridge condition assessment is based on four criteria: structural safety and serviceability, durability, traffic safety and general bridge condition (Bleiziffer et al. 2012).

On the other hand, bridge importance in the network is based on five criteria: road category, annual average daily traffic, detour distance, largest span, total length (Kuvacic, Juric 2005). Based on experience in bridge management from the practice, the weight of bridge condition assessment is 75% while the bridge importance weights 25 % in priority repair ranking.

Criteria related to bridge condition are based on damage assessment procedure overviewed in this paper based on existing inspection and evaluation documents. Weights of four criteria indicating bridge condition assessment, based on practical experience in bridge management, are contemplated as follows: structural safety and serviceability 30%, durability 10%, traffic safety 30% and general bridge condition 30%.

The first three criteria related to bridge importance - road category, annual average, daily traffic and detour distance - are mutually independent and equally important for decision on bridge importance.

Criteria of the largest span and criteria of the total length describe the common demands on the construction and property value and therefore their importance in total may be considered as equal to other criteria. Therefore following weights are suggested: road category 25%; annual average daily traffic 25%; detour distance 25%; largest span 12.5% and total length 12.5%.

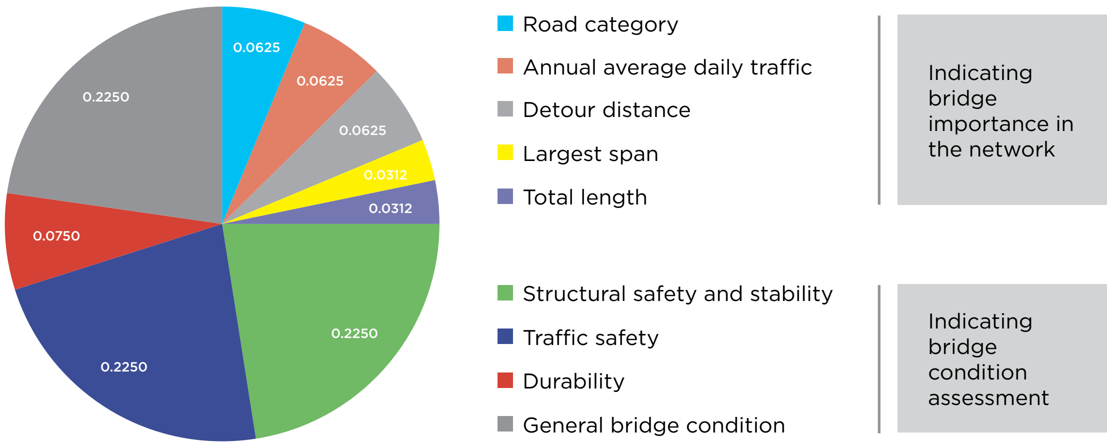


Fig. 18. Example of weight of performance criteria for priority repair ranking

Such criteria are reduced to comparable values with the help of preference functions and of an adequate threshold of indifference and preference for each criteria (Croatian highways ltd. 2008). At this level, indicators related to scientific achievements such as bridge reliability assessment, should be continuously developed from previous level and included into priority repair ranking.

Priority repair ranking, at the same time, is an essential indicator for the final goal: optimal management plan of roadway bridges, which is to be evaluated through decision ranking by power and weakness of decisions as proposed, for example, in Croatian highways (2008).

4.3. PERFORMANCE INDICATORS VS. GOALS (TASKS) WITHIN BRIDGE MANAGEMENT

The contemplations from the previous Chapter are presented through the comprehensive scheme presented at **Fig. 19**. At the bridge component level, one of the first tasks is the damage assessment. Upon assessing damages of a particular bridge element, the component functionality and safety level may be evaluated. At this level, socio-economic aspects are to be included.

A ratio of sum of costs for repair of individual damages and the price of the new element is an indicator of the element's general condition assessment.

In order to assess the impact of the damaged element functionality to the entire structure, the importance of the bridge element is to be evaluated according to the following criteria: structural safety and serviceability, traffic safety and durability. Importance of the element is a weight to be considered in the assessment at the system level from the component level.

Element general condition assessment needs to be raised from the component to the system level, which will help to assess the condition of a sub system and consequently of the entire bridge.

Additionally, research-based performance indicators should be included. For example, bridge reliability assessment requires a comprehensive knowledge on the particular bridge related properties such as, for example, stiffness changes and local bridge traffic loading, which in turn requires investment in additional inspection, testing, SHM technologies and tools.

At the network level, the primary goal to be attained is priority repair ranking, based on the bridge condition assessment including evaluation of bridge importance in the network. At this level, the research-based performance indicators (e.g. bridge reliability assessment), need to be continuously developed from the previous level and included into priority repair ranking.

Priority repair ranking, at the same time, is an essential indicator for the final aim – optimal management plan of roadway bridges.

It is obvious from this overview that interaction of different types of indicators is inevitable but their categorization will allow to more easily identify methods for their quantification and level of their influence to a certain structural performance goal.

On the other hand, it may be noticed that categorization into indicators and goals very often overlaps as, at one step of the bridge assessment procedure, a certain parameter is a goal and at the next step, it becomes the performance indicator for a much wider goal.

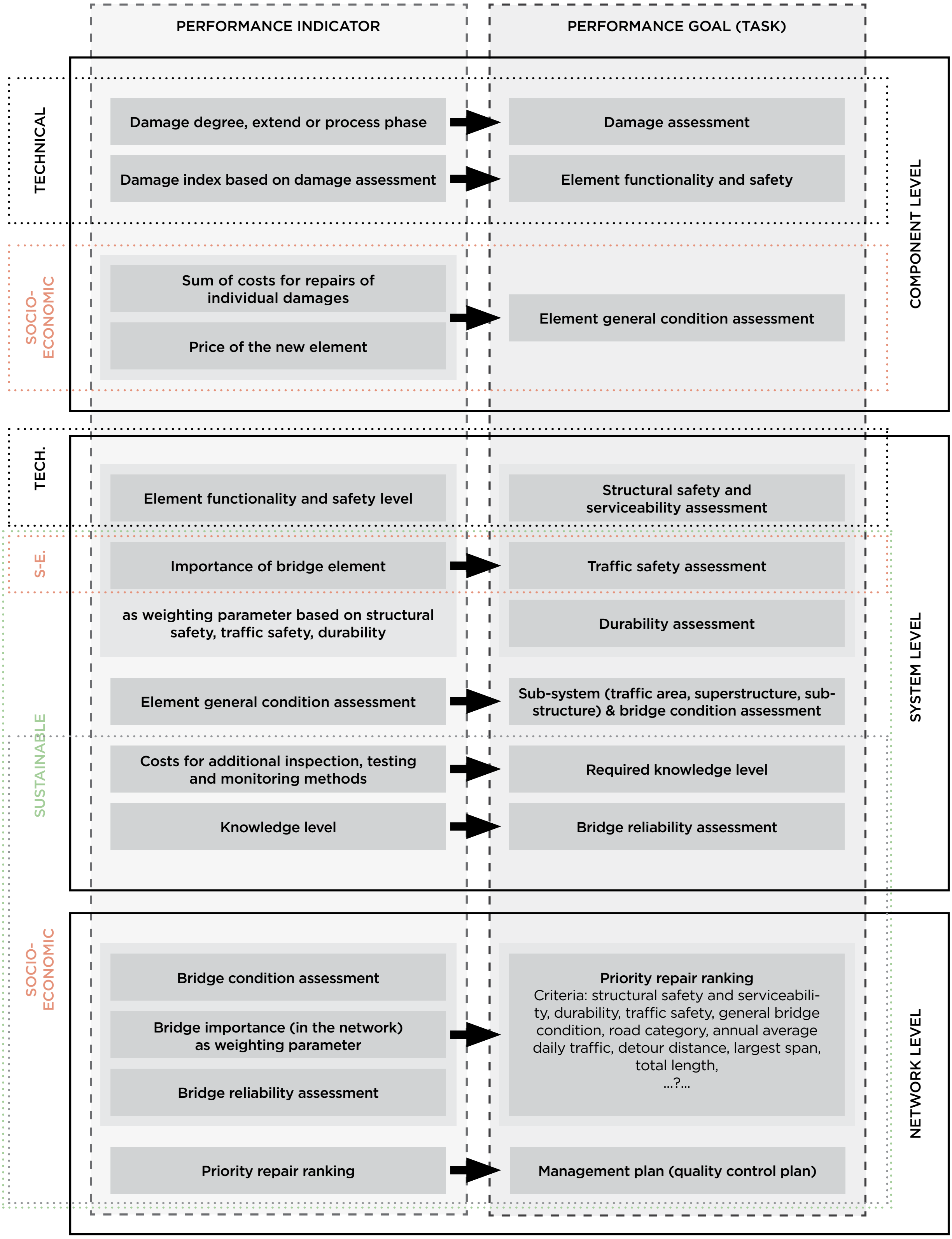


Fig. 19. Interaction of indicators and goals (tasks) related to structural performance within bridge management

A more specific flowchart starting from damage as the first performance indicator at the component level is presented at **Fig. 20**.

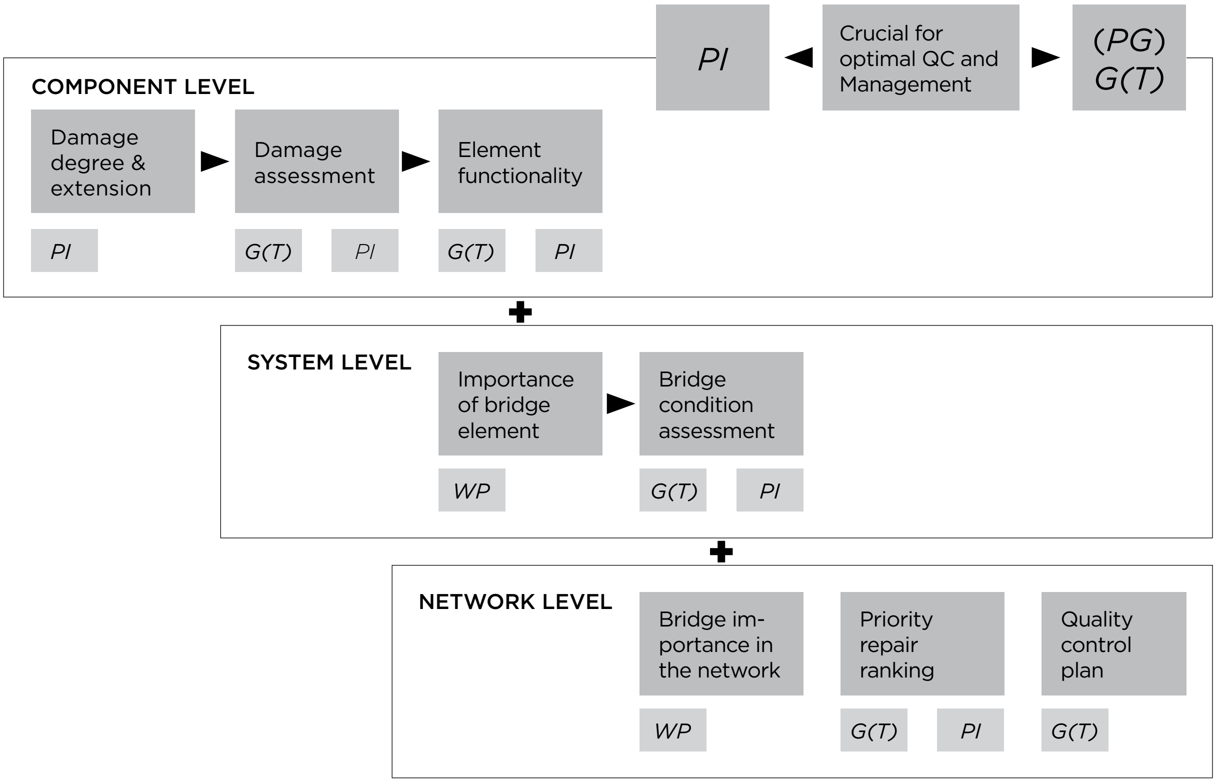


Fig. 20. Interaction of indicators - *PI*, goals (tasks) - *G(T)* and weighting parameters - *WP* within bridge management

The first goal or task at the component level is to assess the damage. Upon damage assessment of a particular bridge element, damage index becomes an indicator for the next goal – evaluation of component functionality level.

At the system level, the element functionality as an indicator, together with the importance of a bridge element as weighting parameter are crucial for the following goal – bridge condition assessment.

Rising to a network level makes bridge condition assessment an indicator which together with the bridge importance in the network as a weighting parameter will influence the next goal – priority repair ranking. Finally, priority repair ranking may be considered as an indicator for a Quality Control plan.

Further progress will be developed at the level of the *WG*2 – Performance goals & *WG*3 – Establishment of a *QC* plan. It is necessary to emphasise, that terms used here as ''goals'' need to be realized as ''tasks'' within the levels of bridge management related to structural performance, while actual performance goals such as safety, security, reliability, availability, maintainability, sustainability, cost- efficiency and others will be determined through *WG*2 based on *WG*3 requirements.

What would be the most demanding is to select the most important indicators for achieving the goals crucial for optimal quality control and to allocate them with appropriate weights.

5. RESEARCH DATABASE

5.1. COLLECTION OF RESEARCH BASED PERFORMANCE INDICATORS

Collecting and surveying of research-based performance indicators, in order to reveal those that are already applicable in practice as well as those in whose development is worth investing, is envisaged to improve existing performance assessment methods within bridge maintenance systems and consequently the management of roadway bridges at the European level.

As mentioned previously, indicators related to scientific achievements in, for example, testing and monitoring, dynamic behaviour and reliability of bridge structures should be included and continuously developed.

An example of extending the applied database with the research-based one is given at **Fig. 21**.

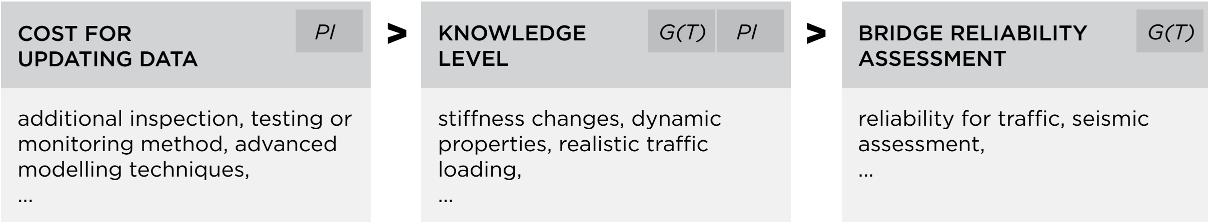


Fig. 21. Example of performance indicators and goals (tasks) interactions for extending the applied database with scientific achievements

Namely, bridge reliability assessment requires a comprehensive knowledge on the bridge properties such as, for example, stiffness changes and local traffic loading, which in turn requires investment in additional inspection, testing, SHM technologies and tools. Therefore, the cost for updating data may be considered as an indicator for reaching the higher knowledge level on bridge, and in further step, realized knowledge level becomes an indicator for the bridge reliability assessment.

For example, Structural Health Monitoring provides a very wide range of activities which, through different technologies and algorithms, may supply information about the performance of existing and new structures over their lifecycle. But, in order to convince infrastructure owners and operators to invest in SHM systems, the utility of SHM need to be revealed by quantifying its value. Upon identifying performance indicators that may be detected/evaluated and possibly quantified with available SHM technologies (e.g. corrosion progress, cracks evolution, deflection evolution, fatigue damage evolution, score criticality, weight in motion monitoring, ...) their importance in achieving crucial performance goals should be weighted. Collecting of research-based indicators is still an ongoing process through which several important questions need to be answered in order to extend the operators database:

- What is the type of indicator?
- Is there related mathematical formulation?
- What is the threshold related to performance goal?
- What are intentions of this indicator, where is it to be applied?
- What is the level of its maturity within the research?
- Through which type of case study is it verified?

Namely, answering this type of questions will help not only to identify research indicators, but also to decide which operational indicators are the most important and significant within the collected database from the actual state of practice in different countries. Following the experience with the Operational Database, the clustering of research-based indicators would probably be necessary in order to harmonize the Performance Indicators from a European perspective. Clustering, based on documents surveyed so far, is proposed at the **Fig. 22**. The difference compared to clusters developed from Operational database (**Fig. 11**) clearly shows the areas where more research and extension with research-based indicators is needed.

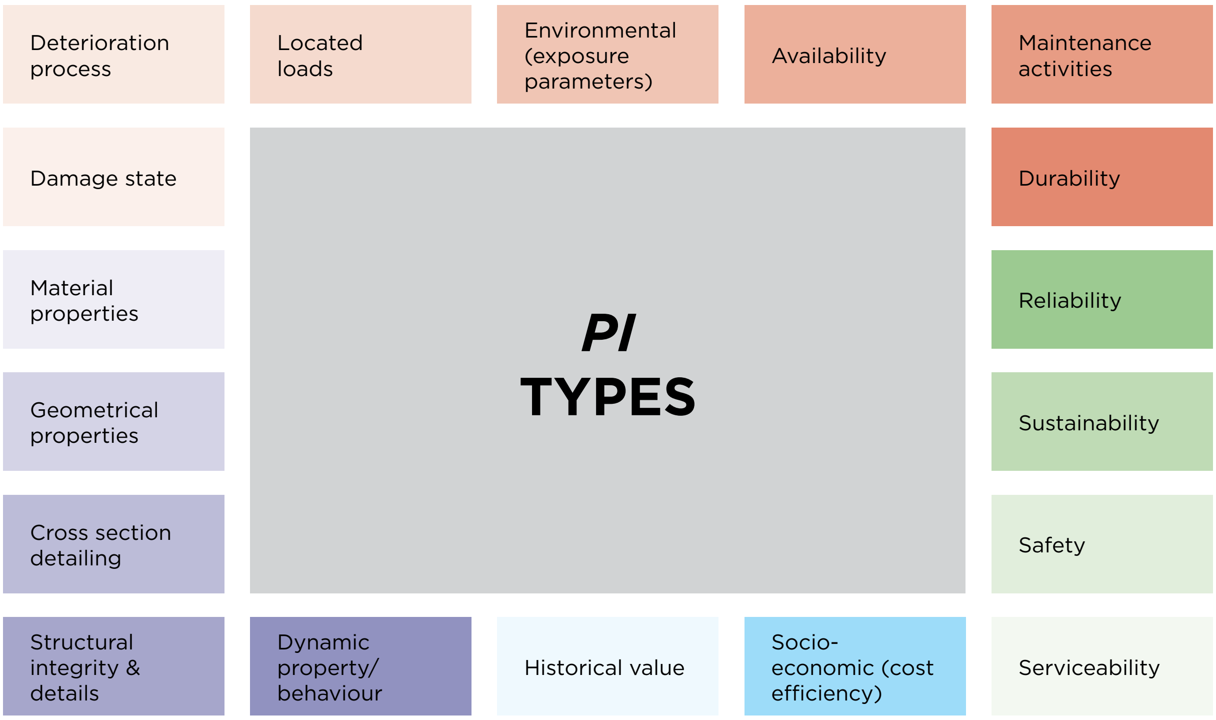


Fig. 22. Possible clusters of research based performance indicators.

5.2. SUSTAINABILITY ISSUES

Within the development and extension of Performance Indicators Database, we need to be aware that sustainability refers not only to the ecological protection, but has enlarged its roots towards a multi-dimension approach intended as the interaction of the so-called triple bottom line: the environment, the economy and the society. Although much more work is done in the area of sustainable buildings, several studies have been carried out in order to define a set of indicators able to evaluate the performance of infrastructures and bridges according to the sustainability criteria.

Starting from the early '90s, the International Organisation for Economic Co-Operation and Development (OECD, 1997) carried out a research on Performance Indicators for the Roads Sector, and identified 15 performance indicators among those used by road administrations throughout the world. Most of them are related to road user's satisfaction and can be viewed as a reference point to assess the social performance of a bridge. The OECD indicators include:

- average road user costs;
- level of satisfaction regarding travel time and its reliability and quality of road user information;
- protected road user risk;
- unprotected road user risk;
- environmental policy/programmes;
- processes in place for market research and customer feedback;
- long-term programmes;
- allocation of resources to road infrastructure;
- quality management/audit programmes;
- forecast values of road costs vs. actual costs;
- overhead percentage;
- value of assets;
- roughness;
- state of road bridges;
- satisfaction with road condition.

Later on, Ugwu et al. (2006), carried out a sustainability appraisal in infrastructure projects with the aim to calculate a sustainability index of design options.

The authors proposed an analytical decision model and a structured methodology and provided also several recommendations for developers and users such as: i) to include stakeholders involved in infrastructure project delivery; ii) to define quantifiable, effective, relevant, understandable and usable indicators. In this perspective, they proposed a set of sustainability indicators (**Fig. 23**), also providing their significance at each stage of the life cycle.

KEY INDICATORS			
ECONOMIC			
Direct cost	Initial cost Life cycle cost	Indirect cost	Resettling cost of people Rehabilitating cost of Ecosystem Adverse impact on tourism values Employment of labour
ENVIRONMENTAL			
Land use	Extent of land acquisition Extent of tree falling Extent of loss of habitat of feeding grounds Connectivity with hinterland	Air	Impact as to assessment under *EIAO* Air outlet design Ventilation design - during construction Ventilation design - service stage
Water	Impact as to assessment under Water reuse	Ecology	Impact as to assessment under EIAO Re-provision of habitat
Noise	Impact as to assessment under *EIAO* Design flexibility towards noise reduction measures	Visual impact	Impact as to assessment under *EIAO* View from *ACABAS* Harmony with surrounding
SOCIETAL			
Cultural heritage	Extent of encroachment upon concerned areas Footprint of project in archaeological site Complaints from local parties/villages	Availability	Those associated/complementary with the chosen materials (alternative sourced construction materials)
Public Access	Extent of diversion Extent of blockage	Public Perception	Views from district councils Fung Shui
Resource Utilization		Site Access	Route(s) for waste disposal Route(s) for construction traffic
Material	Construction Material	Quality Assurance	Erase of quality control
Type	Prefabricated material Innovative material	Constructibility	Early contractors involvement (*ECI*) Early suppliers involvement (*ESI*)
Re-usability	Re-usability of moulds, form-work, etc. Scrap value after decommissioning		

Fig. 23. An extract from the set of indicators identified in Ugwu et al. (2006)

From an engineering viewpoint, a significant approach is given by Dong et al. (2013), where the authors quantified the time-variant sustainability performance of bridges under seismic and flood hazards, providing a measure of the social, environmental, and economic impacts.

Another quantitative approach for the design of bridges from a sustainability-based perspective, integrating environmental, economic and social criteria over the lifecycle is proposed by Gervásio & da Silva (2013). Those authors proposed a set of indicators (**Fig. 24** left) together with instructions for their quantification, normalization, weighting and combination.

Other interesting findings are reported in Serpell (2015) where the author firstly investigated current methods for the Sustainability Assessment of Road-Bridges and then proposed a set of relevant indicators (**Fig. 24** right).

Sustainability impacts during infrastructure lifecycle	
Environment	Abiotic depletion Acidification Eutrophication Global warming Ozone layer depletion Human toxicity Terrestrial eco-toxicity Photochemical oxidation
Economy	Initial costs Operation, maintenance and repair costs End-of-life costs
Society	User costs Vehicle operations costs Driver delay costs Safety costs Aesthetics Noise

(a)

Sustainability impacts during infrastructure lifecycle	
Environment	Recycling potential of waste materials Carbon footprint Water usage Impact on drainage & water quality Impact on ecology Impact on local/regional air quality Impact on soil contamination
Economy	Loss/gain in revenue of local business Financial cost Preparation for economic risk Impact of economic innovation
Society	Impact on transport Impact on community facilities Impact on social health & well-being Impact on cultural heritage Impact on stakeholder engagement Impact on employment rates

(b)

Fig. 24. A list of indicators according to (a): Gervásio & Da Silva (2013); (b): Serpell (2015)

Based on the short overview it may be noticed that some discrepancies still exists among the available studies. Several studies are more "structural engineering oriented" and focus mainly on the structural performances of infrastructures during the lifecycle and related life cycle costs.

Some others are more "sustainability-based" and consider different impacts on the environment, the economy and the society but, sometimes, neglect the technical/functional dimension.

6. CONCLUSIONS AND FUTURE DEVELOPMENTS

At the level of Operational Database, more work is necessary to identify key performance indicators. Further extension of Operational Database with the Research-based one should help in the following two main tasks:

1. to select the most important Performance Indicators for achieving Performance goals that are crucial for optimal Quality Control Plan within bridge management
2. to allocate them with appropriate weights (importance level).

In order to select the most important Performance Indicators the following steps should be followed:

1. Define crucial Performance Goals (for example: safety, serviceability, reliability, durability, availability, maintainability, ...)
2. Categorise Performance indicators in relation to Performance Goals (at different levels: component, system, network; taken into account different aspects: technical, sustainability, socio-economic),
3. Answer following questions:
   - Is it measurable?
   - Is it quantifiable?
   - Is target value available?
   - Is it valid for ranking purposes?
   - Does it allow decision with economic implications?

The overall database should include the most important indicators for achieving the goals crucial for optimal quality control.

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