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## Standardization of quality control plans for highway bridges in Europe: COST Action TU 1406

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# Standardization of quality control plans for highway bridges in Europe: COST Action TU 1406

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**Abstract.** In Europe, as all over the world, the need to manage roadway bridges in an efficient way led to the development of different management systems. Hence, nowadays, many European countries have their own system. Although they present a similar architectural framework, several differences can be appointed. These differences constitute a divergent mechanism that may conduct to different decisions on maintenance actions. Within the roadway bridge management process, the identification of maintenance needs is more effective when developed in a uniform and repeatable manner. This process can be accomplished by the identification of performance indicators and definition of performance goals and key performance indicators (KPI), improving the planning of maintenance strategies. Therefore, a discussion at a European level, seeking to achieve a standardized approach in this subject, will bring significant benefits. Accordingly, a COST Action is under way in Europe with the aim of standardizing the establishment of quality control plans for roadway bridges.

## 1. Introduction

An efficient transportation network is essential for the modern society from the economic, societal and environmental point of view. Today, it is a challenge for operators to manage road infrastructures under their responsibility in an efficient way, meeting the present and future needs of the community they serve. Therefore, quality control plans have to be implemented by the operators in order to serve the increasing public demands with the always limited budget available for maintenance.

For this purpose, the authorities need to produce an asset management plan, which should not only define the goals to be achieved by exploiting the roadway bridge network, but that should also identify the investment needs and priorities based on life-cycle cost criteria. As a result, many European countries have their own system. Although they present a similar architectural framework, several differences can be appointed, for example, with regard to the condition assessment procedure and the use of life-cycle cost schemes. These differences constitute a divergent mechanism that may conduct to different decisions on maintenance actions, although affecting to the same transnational traffic.

Within the roadway bridge management process, the identification of maintenance needs is more effective when developed in a uniform and repeatable manner. This process can be accomplished by the evaluation of performance indicators, improving the planning of maintenance strategies. Therefore, a discussion at a European networking level, seeking to achieve a standardized approach in this subject, will bring significant benefits. Accordingly, COST Action TU-1406 aims to standardizing the establishment of quality control plans for roadway bridges. In this context, a first step would be the



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establishment of specific recommendations for the assessment of roadway bridges, namely, used methods for the quantification of performance indicators. A set of reference time periods for these assessment actions should be also presented. A second step would be the definition of standardized performance goals. Finally, a guideline for the establishment of quality control plans in roadway bridges would be developed. Moreover, the concept of sustainable roadway bridge management, involving the evaluation of environmental, economic and social performance indicators during the whole life cycle, is also highlighted.

In the following, these aspects are fully developed.

## 2. Objectives and main beneficiaries

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 [1,2]. This guideline will focus on bridge maintenance and life-cycle performance at two levels: (i) performance indicators, (ii) performance goals. The possibility to incorporate new indicators related to sustainable performance will also be considered. By developing new approaches to quantify and assess bridge performance, as well as quality specifications to assure expected performance levels, bridge management strategies will be significantly improved, enhancing asset management of ageing structures in Europe.

In order to reach this main general aim, the following more specific objectives/deliverables have been considered [1,2]: (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.

The target groups and end users who will exploit the outcome of this Action are: (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; (iv) academics and research engineers, as they will take an advantage of their involvement in the guideline preparation; (v) students, as they will benefit from COST tools (e.g. training schools) and from the contact with different stakeholders involved in this Action; (vi) relevant European, international and national associations, with which the main outcomes of this Action will be shared; (vii) standardization bodies and code writers, which will benefit from the developed guideline.

## 3. Performance indicators database

It is known that management systems are supported in QC plans which, in turn, are supported by performance indicators. Therefore, it is highly 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. These are the objectives of working group 1 of the Action, with the aim to define:

(a) Technical indicators: the goal is to explore bridge structures performance indicators, in the course of international research cooperation, which captures the mechanical and technical properties and its degradation behaviour. Moreover, environmental condition, natural aging, and quality of

material regarding to determined indicators will be investigated and evaluated in their meaningfulness. These considerations, however, also include service life design methods, aimed at estimating the period of time during which a structure or any component is able to achieve the performance requirements defined at the design stage with an adequate degree of reliability. Based on the input information quality (mainly concerning the available degradation models), it is possible to distinguish among deterministic methods, usually based on building science principles, expert judgment and past experience, which provide simple estimations of service life, and probabilistic methods;

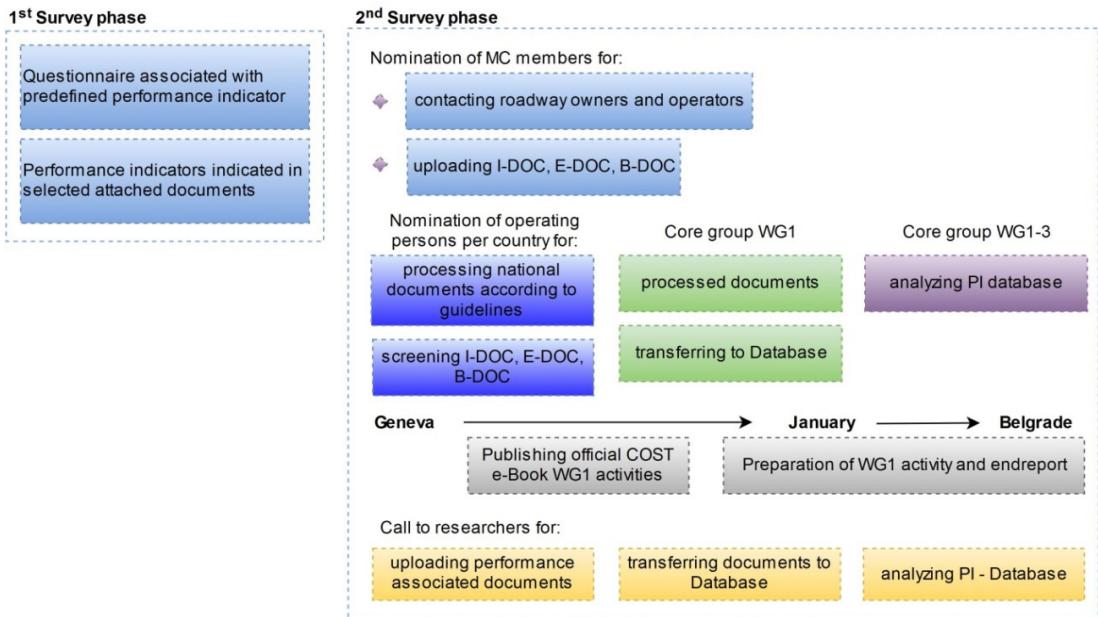
(b) Sustainable indicators: in addition to technical performance indicators, which characterize the ultimate capacity as well as serviceability conditions, environmental based sustainability indicators will also be formulated. These variables characterize the environmental impact of a structure in the course of its total life cycle, expressed in terms of total energy consumption, carbon footprint (CO<sub>2</sub> emissions), raw materials balance, etc. These indicators can be separated into direct and indirect, where the former are related to the construction/maintenance itself and the latter are caused e.g. as consequence of limited functionality;

(c) Other indicators: other sustainable indicators, economic and social based, may be used to evaluate bridge performance. These indicators, based on the technical performance of a structure, capture additional aspects that may influence the decision process and typically represent the discounted (accumulated) direct or indirect costs associated with construction and maintenance. Summed up over the full life-time, they represent part of or the full life-cycle costs. They can, in the context of multi-objective optimization, be understood as a weighting scheme to arrive to a single objective function to be minimized.

The determination of performance indicators for bridge structures from European countries and its harmonization on a European level is complex, extensive, and time consuming. These facts were confirmed in processing WG 1 “Performance indicators” of the COST TU1406. There are the following findings and important aspects associated with the Performance Indicator Survey Processes that was undertaken at the beginning of the project, as presented in Figure 1 [3,4]:

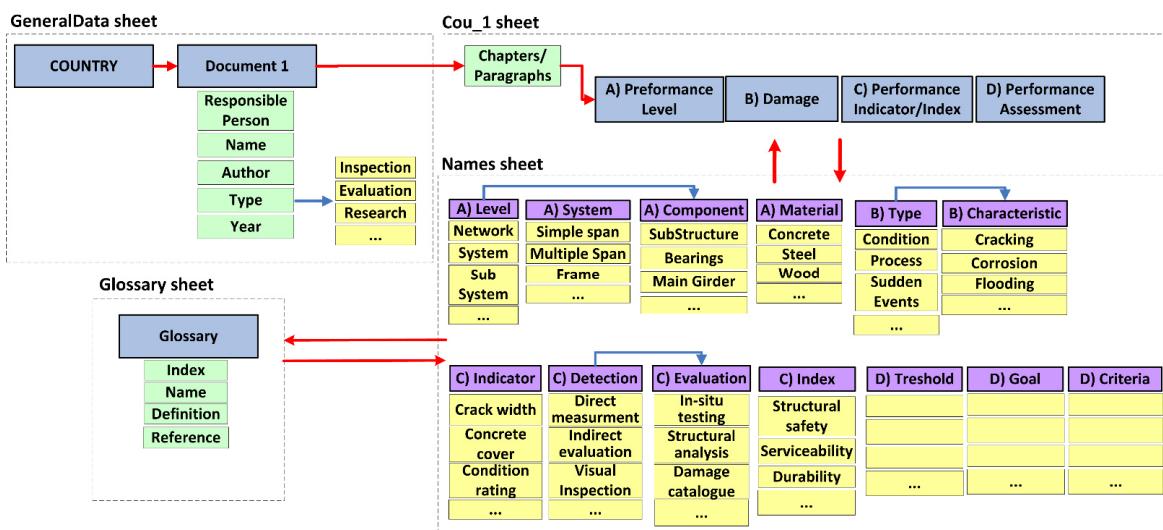
- A complete translation of codes or guidelines as used by owners and operators from the national language to international European format has been considered as unnecessary, since only some pages are devoted to the subject of interest (performance indicator, performance goal,...).
- The nomination 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
- A request for replying the questions in the questionnaire, and for up-loading 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.
- 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 are asked for: operator documents (actually in use by the different Agencies in the form of guidelines or recommendations) and research documents.
- Due to the different languages used across Europe and the different formats of both type of documents (guideline or research oriented) it was decided to nominate in each country several persons with the main tasks of contacting owners and operators of highway bridges asking for available documents in practice (operational performance indicators), for the preparation of tutorials for the screening of documents, processing screened documents, fill-in the data base and finally analyze the data base and to obtain the main results and conclusions. Those persons were also responsible to identify the research groups in each country and ask them to

provide information about new proposal still in the researching phase for performance indicators (research performance indicators).



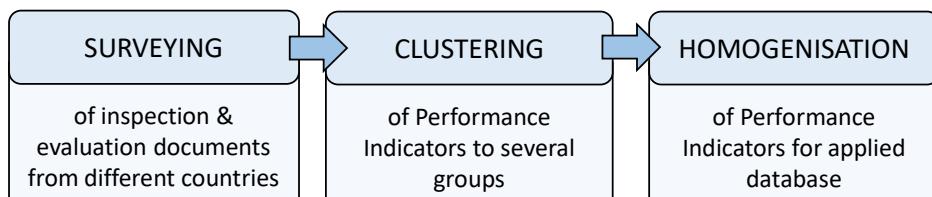
**Figure 1.** Technical survey on performance indicators (I-DOC inspection document, E-DOC evaluation document, B-DOC background document).

The final result of WG1 has been the publication of a report on these performance indicators and how they have been categorized and homogenized [5]. The core of the survey process for the key performance indicators (KPI's) and performance indicators (PI's) is given in Figure 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 between documents, even in those of the same type. Thus, one of the main requirements in the survey is to allow an unrestricted data input.



**Figure 2.** Database - core of the survey process.

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. Therefore, a critical overview of contributions from different countries, with respect to the content and definitions, was necessary in order to homogenise the terms to be used within the PI database. Figure 3 shows the main steps of this procedure.



**Figure 3.** Procedure for the homogenization of PIs of applied database.

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.

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

**Table 1.** Definitions of parameter readiness level.

Ranking	(PRL) Parameter Readiness Level	Definition
1	basic principles observed	The <b>principles underlying</b> the parameter are known
2	<b>parameter</b> concept formulated	The parameter is applied in <b>analytical studies</b>
3	experimental proof of concept	<b>Analytical and experimental studies (indoor)</b> performed on a <b>laboratory scale on a component level</b> to validate analytical predictions
4	<b>parameter</b> validated in laboratory	<b>Experimental studies</b> are performed in laboratory on a <b>reduced scale model</b> of the structure/asset to produce a database for which estimate the parameter
5	<b>parameter</b> validated in laboratory in simulated environment	<b>Experimental studies</b> performed in controlled laboratory (or outdoor) on a <b>large model</b> of the structure/asset <b>reproducing real environmental conditions</b> to produce a database for which estimate the parameter
6	<b>parameter</b> demonstrated in relevant environment	Experimental studies performed <b>on a real structure/asset</b>
7	<b>parameter</b> demonstrated in operational environment	<b>Performance goals</b> are defined
8	system complete and qualified	<b>Testing protocols</b> are defined
9	Actual system proven in operational environment	<b>Decisions</b> on possible interventions in a bridge (repair, maintenance,...) are made

To this end, Table 1 is prepared to check for the maturity/readiness of the proposed indicator. Level 9 means maximum maturity: the performance indicator is ready for practical use.

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.

#### 4. Performance goals

The objective of WG2 (performance goals) is to provide an overview of existing performance goals for the indicators previously identified in WG1 and to develop technical recommendations which will specify the performance goals. These goals will vary according to technical, environmental, economic and social factors.

Performance goals are usually defined at different levels, from high-level strategic decisions to low-level, object-specific objectives. Further information on this WG can be found in [6]. This paper presents structure and basic ideas for the development of a guideline document linking different aspects of performance goals and bridge performance. It is explained there how bridge performance goals should be set as a multi-objective system, taking into account different aspects of bridge and network performance. The basis of the approach is the work developed so far in the Netherlands. Netherlands' Rijkswaterstaat (RWS) has developed RAMS SHEEP concept, which additionally to RAMS (Reliability, Availability, Maintainability and Safety) defines the following aspects: Security, Health, Environment, Economics and Politics [7], where each criterion is defined as follows:

- Security: related to the safety of a system regarding to vandalism and unreasonable human behavior.
- Health: being related to physically, mentally and socially defined aspects.
- Environment: concerns the physical environment requirements.
- Economics: regarding the relationship between cost and value.
- Politics: concerning political-administrative and social requirements.

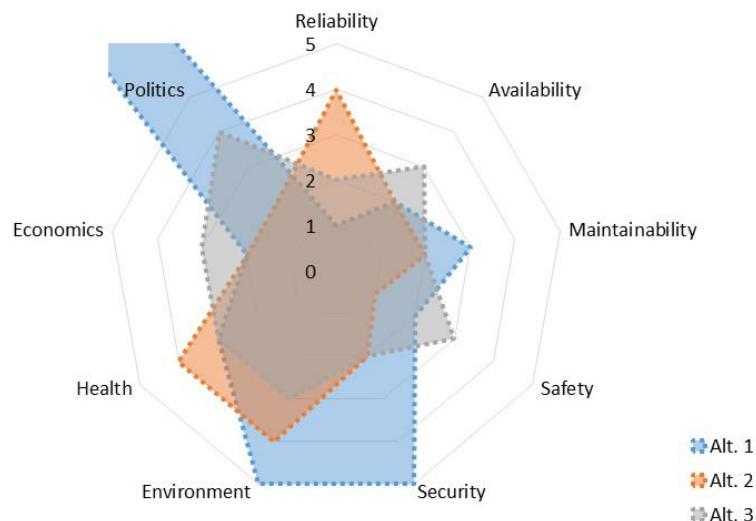
However, practical indicators for quantification of these aspects within the risk assessment procedure are still lacking.

In Australian Roads documents [8,9], the following objectives are identified: Functionality (minimization of traffic delays), Safety (safe for intended use), Aesthetics (maintenance of an acceptable appearance), Sustainability (no backlog of repairs, and the workload remains at a manageable level ), and Economic (maintenance is based upon lifecycle cost analysis).

Multi-criteria decision-making (MCDM) provides a systematic approach to combine these inputs with benefit/ cost information and decision-maker or stakeholder views to rank the alternatives. MCDM is used to identify and quantify decision-maker and stakeholder considerations about various (mostly) non-monetary factors in order to compare alternative courses of action [10]. Hierarchy structure for linking multi-objective bridge performance goals, covering most of the previously mentioned aspects with performance indicators is required. Possible result of multi-criteria assessment of different bridge maintenance alternatives is shown in Figure 4, which can be finally used for a decision making about the optimal maintenance or design alternative.

Alternatively, the multiple performance criteria can be combined into a so-called utility function, in which all the criteria are brought into a single scale. In order to transform the various out into a single (mostly monetary) scale it is necessary to establish weight factor for the individual types of criteria. Some of the weight factors are available in some countries (for example weight factor for traffic delays, noise, injuries etc.), depending on the selection of criteria, some weight factor may still need to be developed. In the development of the weight factors the starting point can be taken in the qualitative approach mentioned above, from which the apparent relative weight can be deducted. Once the possible outcomes have been brought to a single scale, the best decision can be found as a formal

optimized decision process, in which option with the maximum “utility” shall be selected as the recommended decision.



**Figure 4.** Spider plot as a possible result of multi-objective assessment of different maintenance alternatives against different performance aspects.

One of the main challenges in future research is how to quantify performance goals other than technical, and how to link strategic level to the performance requirements on the project level. Network or even societal goals tend to be rather broad in their definition. Furthermore, there is often no exclusive relationship between performance indicators set at a lower level and goals at a higher level. An important notion is that in many countries, the main focus of bridge management is still the condition assessment of the particular objects or elements thereof.

## 5. 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 WG3 (Quality Control Plans) 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. In terms of bridges the quality can be defined as degree to which the bridge performance fulfils the performance goals. Given that the road bridges serve primarily their users by providing them a fast and safe crossing, one should try to derive performance goals from their desires and expectations. The users desire:

- maximum (unrestricted) weight allowance
- maximum (unrestricted) clearance
- minimum (zero) fatalities and/or injuries due to bridge collapse
- maximum (24/7) availability

The general public demand

- minimum (no) noise
- minimum (no) pollution and sometimes
- good (spotless) visual appearance i.e. no signs of deterioration

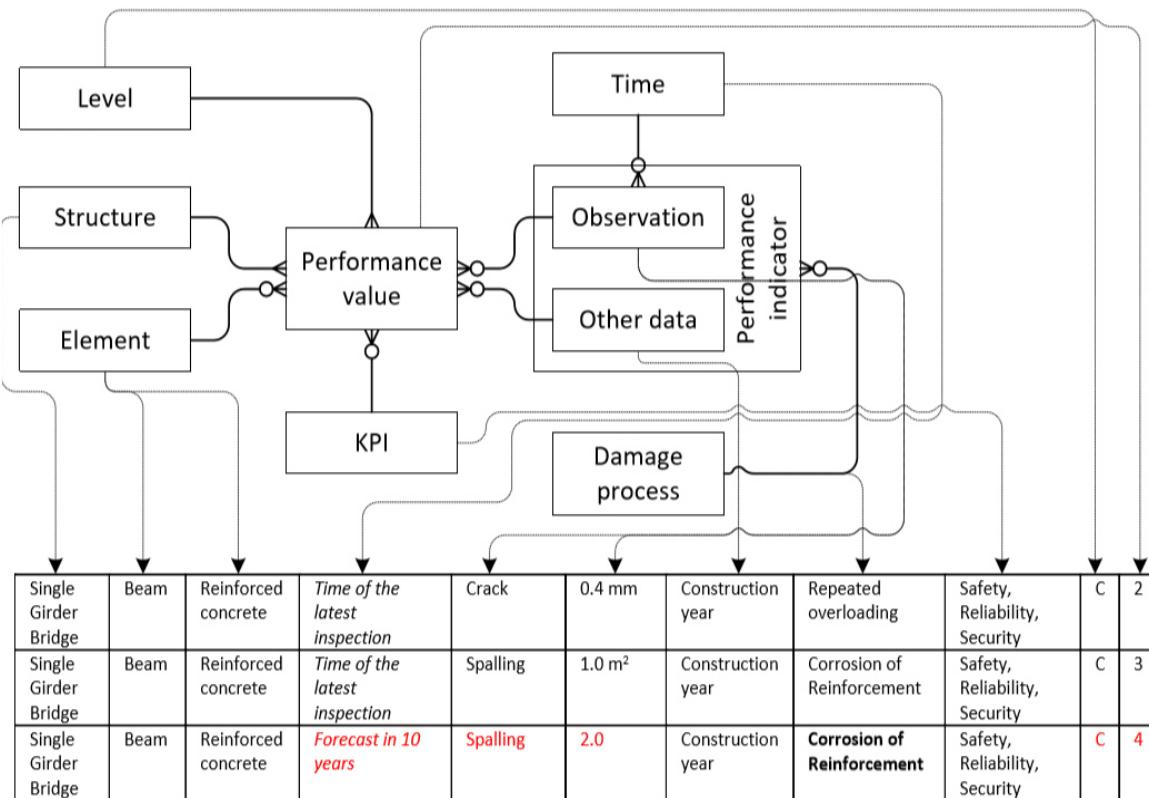
The owner and/or operator, however, strive to spend as little money as possible for the maintenance and operation. These conflicting desires and demands need to be resolved in a political process and thus implicitly define the performance goals. The resolution is carried out by the following stakeholders:

- Users, which are represented by government bodies, interest groups, transport corporations, car industry, etc.
- General public, which is represented by neighborhood associations, environmental groups, professional associations, etc.
- Owner, which is a government body itself, an agency controlled by the government, a concessionaire, private corporation, etc.

The main challenges in the development of a quality control plan for highway bridges are the following:

- Quality assurance and control is important in all industrial fields and construction industry is no exception. Bridge management is a part of construction industry activities that ensures that the bridge attains the desired service life and quality level. Important parts of any BMS are quality assurance and control plans that must provide the basis for quality data acquisition and processing. Reliable data related to the condition of the structures is essential for all further processes, however ensuring continuously the quality of this data is a demanding task, as the data acquisition is mainly based on periodic visual inspections.
- Data processing and decision models, on the other hand, are dependent on preselected criteria and decision methods. A well-designed decision model will yield reliable result through the lifetime of its use.
- The third component of quality assurance and control in bridge management is maintenance planning. Bridges differ in size, condition, structural design, materials used etc., therefore these specific features need to be acknowledged in the maintenance plans. Designing unique plan for every bridge is irrational and designing a general plan for all bridges impossible. Additionally, optimizing maintenance for individual bridge may worsen optimization on the network level and viceversa. A compromise has to be made in order to implement a quality plan successfully into practice.

The general framework to evolve from performance indicators to key performance indicators and to quality control plans is shown in Figure 5. Further information on this WG can be found in [11].



**Figure 5.** Road-map in use in WG3.

### Acknowledgements

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