Performance indicators for road bridges – categorization overview

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Abstract. An overview of the performance indicators' categorization based on results of the screening process of the inspection and evaluation documents for roadway bridges performed under the auspices of COST action TU 1406 is proposed. Additionally research based indicators are contemplated in order to raise existing European maintenance practice to a higher level.

Keywords: performance, indicators, thresholds, detection, evaluation, technical, sustainable, socio-economic.

1 Introduction and motivation

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 type of bridge property or behavior 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 abutment, bending capacity of a main girder or 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 consequences of its collapse it becomes the goal at the network level.

Whether the goal 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 have 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 measurable/testable parameter that quantitatively describes certain performance aspect (for example crack width) and the second one is qualitative representation of performance aspect (for example 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. 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, their categorization into technical, sustainable and socio-economic indicators through component, system and network level is proposed in order to more easily identify methods for their quantification and level of their influence to a certain structural performance goal. This categorization should contemplate the origin of indicators, level and extend of their influence.

Besides related detection methods, performance thresholds and evaluation methods, interactions between performance indicators and performance goals will be contemplated as they are in general crucial for optimal quality control and management of road bridges.

2 Performance indicators at the component level

Bridge inspection is 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 1.

Table 1. 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
…	…	…

2.1 Technical indicators

At the bridge component level, one of the important performance goal to be reached is damage assessment. This implies detection of damages but also their identification and evaluation. Damage of a bridge element is physical disruption or 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.

Table 2. Example of categorization of damage degree or 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		Acoustic emission		Acoustic emission 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
Cracks	Crack width (mm)	Visual inspection + Direct measurement	Classes / upper value + damage phase duration	Grades according to handbook of damages
		Monitoring		
Delamination	Affected area (m2) + Affected depth (cm or mm)	Visual inspection + Direct measurement	Classes	Grades according to handbook of damages
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
Spalling	Affected area (m2) + Affected depth (cm or mm)	Visual inspection + Direct measurement	Classes	Grades according to handbook of damages
…..				

Four main approaches in damage detection are visual inspection, nondestructive testing, probing and structural health monitoring. In addition to damage detection and characterization, damage identification includes ascertaining the cause of the damage and its consequences and damage evaluation comprises degree or/and extend with respect to the set threshold value. Besides most commonly set up upper limit, additional threshold in the damage assessment may be duration of damage phase, which will give a clue in which phase of damage progress the element is find: 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. Upon assessing damages of a particular bridge element, the component functionality level may be evaluated. 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.

2.2 Socio-economic indicators

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. Threshold for this indicator may be set as quantitative scale of value showing gradation of element condition assessment. For all elements for which this ratio is above 1.0 replacement with a new element should be predicted.

3 Performance indicators at the system level

In order to assess the impact of the damaged element functionality to the entire structure, the importance of bridge element is to be evaluated according to following criteria: structural safety and serviceability, traffic safety and durability (Croatian highways ltd. 2010 b). Qualitative scale of values 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 essential impact to performance requirements.

Additionally, indicators related to scientific achievements in, for example, testing and monitoring, dynamic behavior and reliability of bridge structures should be included at this level, as well. Some contemplation on those indicators will be given after the survey of research based indicators at the European level. For example, bridge reliability assessment will require adequate knowledge level on bridge properties such are for example stiffness changes and realistic traffic loading which requires investment in additional inspection, testing or monitoring method, advanced modeling techniques and updating data on bridge resistance and loads.

3.1 Technical indicators

Technical indicators 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 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 an entire bridge structure.

3.2 Sustainable indicators

When meeting performance requirements is evaluated, under given condition during a given period of time, sustainability issues occur. Therefore durability may be considered as sustainable performance goal which needs to be included as a criteria for condition assessment of bridge sub-systems comprising roadway, substructure and superstructure and for entire bridge condition assessment. Based on durability criteria, it may be decided that collapse of particular element will have no influence to durability of other components or contrary that collapse of particular element will cause reduced durability of other components.

3.3 Socio-economic indicators

Traffic safety may be considered as 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.

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

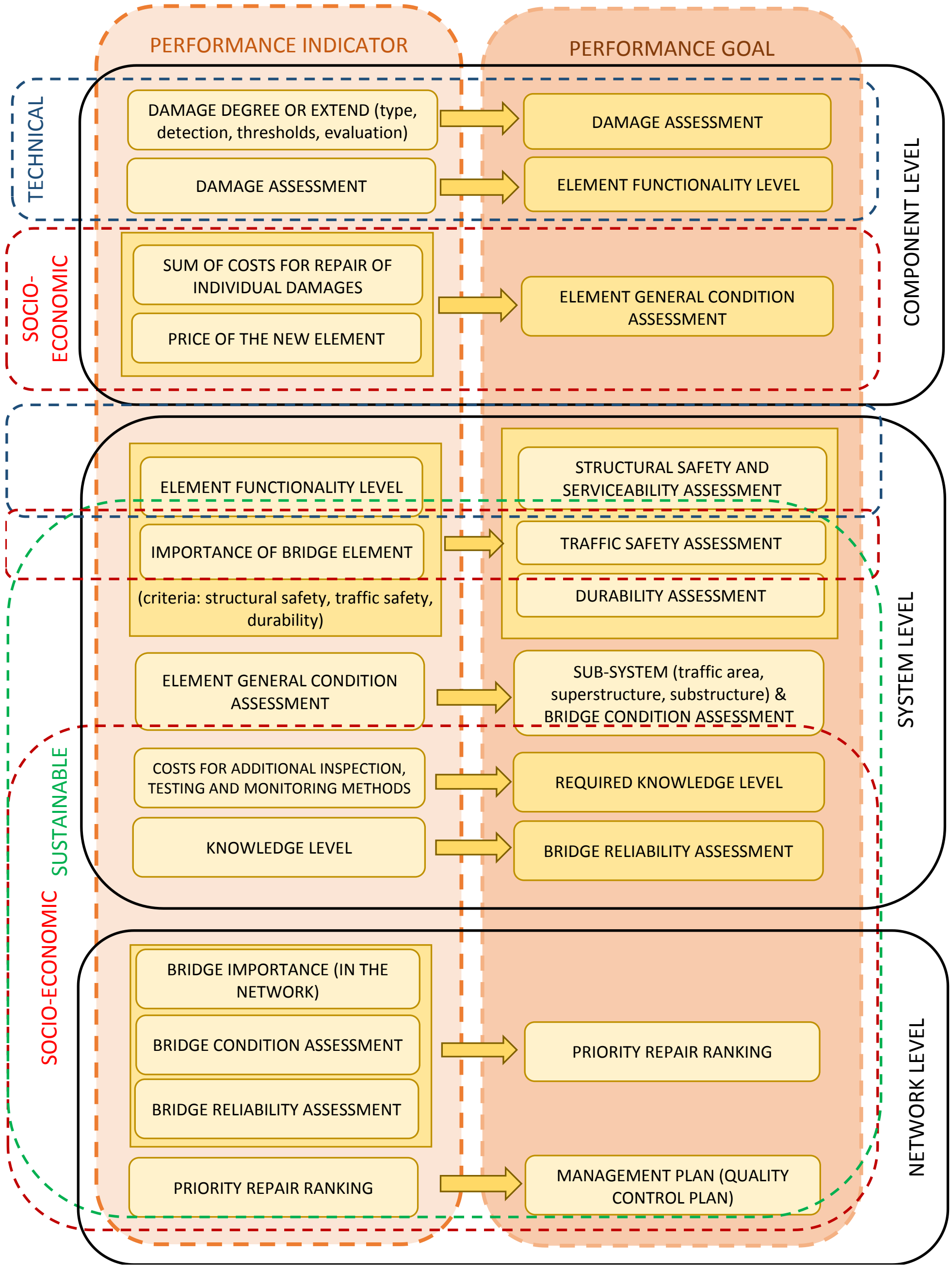


Fig. 1. Interaction of performance indicators and performance goals

4 Performance indicators at the network level

At the network level, based on the 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 based on four criteria: structural safety and serviceability, durability, traffic safety and general bridge condition, may be contemplated as sustainability indicators at the network level. On the other hand, bridge importance in the network, which is based on five criteria - road category, annual average daily traffic, detour distance, largest span, total length - may be considered as socio-economic indicator. Criteria related to bridge condition are based on damage assessment procedure overviewed in this paper based on existing inspection and evaluation documents. 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. Criteria are reduced to the comparable values with the help of preference functions and adequate threshold of indifference and preference for each criteria (Croatian highways ltd. 2008). At this level indicators related to scientific achievements such is bridge reliability assessment, should be continuously developed from previous level and included into priority repair ranking.

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

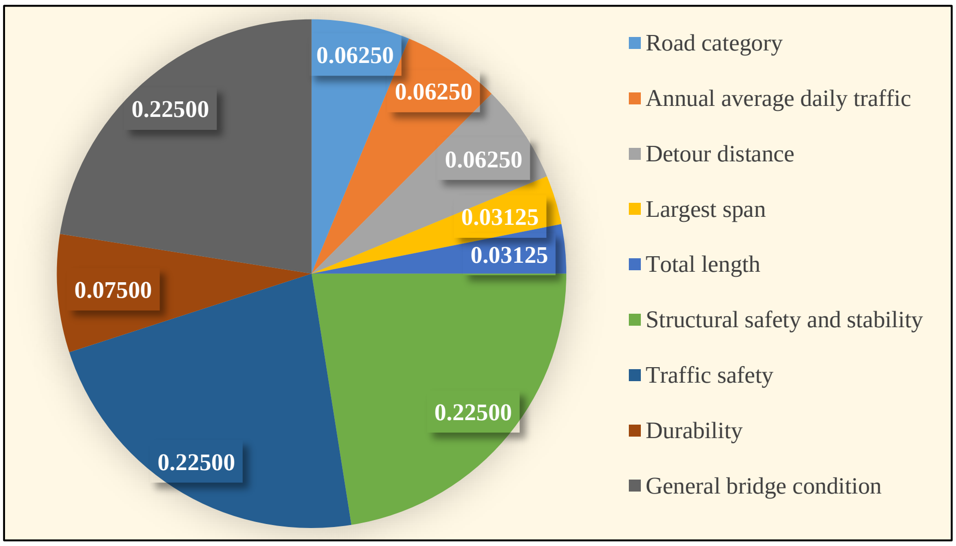


Fig. 2. Example of weight of performance criteria for performance goal - priority repair ranking

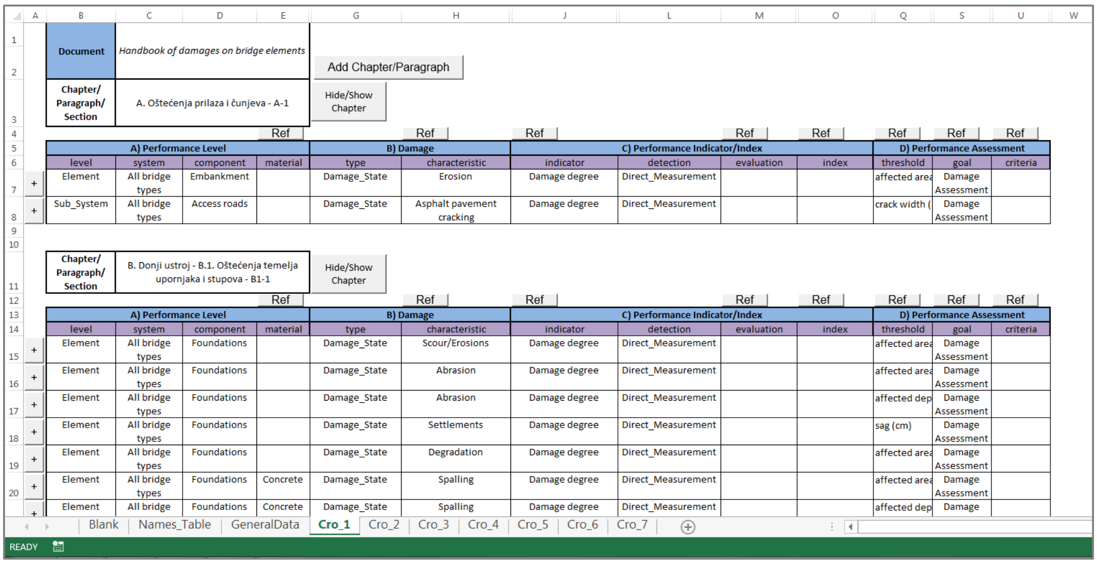
5 Performance indicator Data Base from an European perspective

One of the main objectives in the COST TU 1406 action is to build a performance indicator data base that supports in the objectives of WG2 to WG3. This process included (a) a survey process through understanding regarding performance indicators / goals / thresholds etc. among the participants of the COST action, (b) the creation of a glossary associated with the components, damages, performance of bridge structures, (c) the screening of national inspection and evaluation documents (see Fig. 3) with respect to performance- indicators, thresholds, goals etc. and (d) the definition of the structure of the performance indicator database, as shown in Fig. 4. (see also Casas 2016, Strauss et al. 2016, Strauss and Mandic Ivankovic 2016).

Country	Document	Doc. Type	Author	Year
Austria	Quality Assurance for Structural Maintenance - Suveilance, Checking and As	Inspection	BMVIT	2011
Bosnia and Herz.	ZAKON O CESTAMA FEDERACIJE BOSNE I HERCEGOVINE / LAW ON ROADS OF	Inspection	Parlament Federacije BiH / Federation Parli	2010
	Odluka o kategorizaciji cesta u autoceste i brze ceste, magistralne ceste i re	Inspection	Vlada FBiH / Government of FBiH	2014
	Pravilnik o održavanju javnih cesta / Regulations the maintenance of public	Inspection	Federalnom ministarstvu prometa i komuni	2010
	SMJERNICE ZA PROJEKTOVANJE, GRAĐENJE, ODRŽAVANJE I NADZOR NA CES	Inspection	RS-FB&H/3CS – DDC	2005
	UPUTSTVO ZA INSPEKTORE MOSTOVA / INSTRUCTIONS FOR INSPECTORS OF	Evaluation	BCEOM Societe Francaise D'Ingenere	2004
	MOSTOVI / BRIDGES	Research	Prof. Boris Koboević, Prof. Bisera Karal	1994
	Inspekcijski formular za pregled mosta / The inspection form for an overvie	Inspection	Prof. Bisera Karalić-Hromić	2004
Croatia	Handbook of damages on bridge elements	Evaluation	Hrvatske ceste d.o.o., dr.sc. Danijel Tenžera	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/evaluatio	Hrvatske Autocesete d.o.o.	2010
	Guideline for bridge evaluation	Evaluation	Hrvatske Autocesete d.o.o.	2010
	Bridge Management Planning	Background docume	Hrvatske Autocesete d.o.o.	2008
Czech Republic	ČSN 73 6221 Inspection of road bridges	Inspection	UNMZ Ústav pro technickou normalizaci, me	2011
	ČSN 73 6222 Load capacity of road bridges	Evaluation	UNMZ Ústav pro technickou normalizaci, me	2009
	Catalouge 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 normalizaci, me	1996
	Damages of railway bridges	Inspection	SŽDC TÚDC	2009
	Rules for the assesment 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

Fig. 3. Cutout of codes and guidlines used for the performance indicator database

In the next process step the PI data base inputs obtained from the 34 European countries will be analyses according to the categorizations, that have been presented in sections 2 to 4, in order to finally obtain a homogenized database that contains P-indicators, P-goals, P-thresholds, P-criteria, etc. from an European perspective.



Document: *Handbook of damages on bridge elements*

Chapter/Paragraph/Section: A. Oštećenja prilaza i čunjeva - A-1

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 (	Damage Assessment	

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

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 dep	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	Foundations	Concrete	Damage_State	Spalling	Damage degree	Direct_Measurement			affected dep	Damage	

Fig. 4. Cutout of the performance indicator data base of the COST TU 1406

6 Conclusions & Future Activities

It is obvious from the overview presented in this paper 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 performance indicators and performance goals very often overlaps (even with performance criteria) as, at the one step of bridge assessment procedure, the certain parameter is a performance goal and at the next step, it becomes the performance indicator for much wider goal.

Based on this example the overall categorization of performance indicators and goals from a global European perspective may be established. This categorization should include survey of inspection and evaluation documents related to standard maintenance activities but also research based indicators that will be useful for improvement of management of roadway bridges.

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