ASCAM

***A**sset Service **C**ondition **A**ssessment **M**ethodology*

Deliverable No.3

Inventory Bridge Management practices

Final report

November, 2012

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This project was initiated by **ERA-NET ROAD**

CONTENT:

1 Introduction

This introduction is split in a general introduction equal for all reports and a specific one for each specific report.

1.1 General Introduction to the ASCAM reports

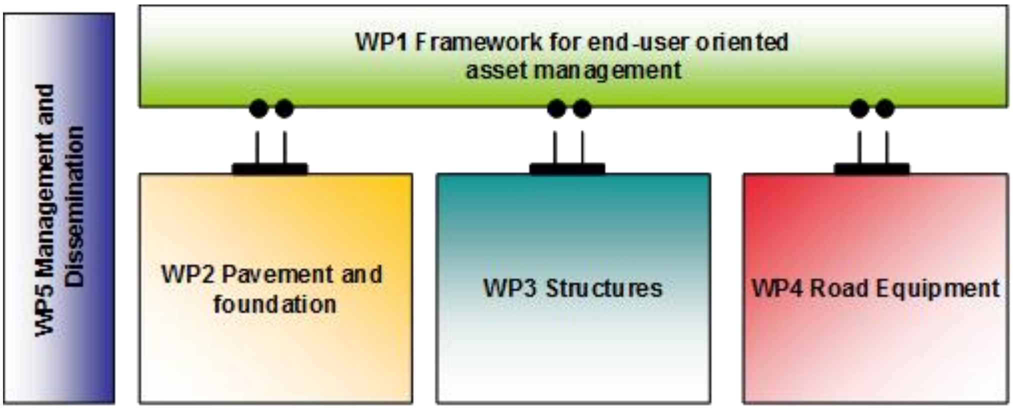
The aim of the ERANET ROAD program "Effective asset management meeting future challenges" is to improve the management of the European road network, resulting in an improvement of the performance of the network. One of the topics within this program is the development of a framework for optimized asset management [ref: Effective asset management meeting future challenges, Description of Research Needs (DoRN), version 3.3, January 2010].

Maintenance managers on all levels are faced with the same dilemma. On the one hand, they are given "end-user services levels" (objectives like reliability of traffic time, traffic safety, sustainable maintenance program), and on the other hand, they have their assets, the asset condition and a (dynamic) portfolio of measures which can be taken to ascertain the "end-user service levels". The dilemma arises through the need for an optimal trade-off between available budget and required budget for ascertaining the service levels.

ASCAM focuses on a framework for optimized asset management and relates asset condition prediction to measures and network value (end user service levels). It creates a framework to connect existing asset management practices into a holistic, integrated cross asset, pro-active approach. It relates technical to societal issues, like pavement degradation or failures in the "dynamic traffic management systems" to end-user service levels such as efficient traffic flow, safety, reliability of travel time, noise pollution or environmental issues. It links micro, meso and macro levels in asset management and the aims and objectives on the different levels, combining existing knowledge, tools and practices. The framework will enable policy makers, maintenance managers and their specialists to communicate on different levels and to overcome the boundaries between fields of knowledge.

In this study, a proof of concept of the framework is developed in which existing knowledge, tools and practices are implemented and linked to end user service levels.

The following approach was taken within this project in order to develop and deliver the proof-of-concept of this framework: Five work packages were established. In one of them (WP5) all management and dissemination activities were performed. In three other work packages (WP2, 3 and 4) an inventory of existing asset management practices in the EU was made, divided according to asset type (pavement, structures and road equipment, respectively). The results were intended and used in the last work package (WP1) for assessing the feasibility and appropriateness of the framework which was developed in this work package. Also in work package 1, a proof-of-concept in the form of a numerical implementation was made. With this demonstrator, the effects and possibilities of applying the framework on asset management was shown. The project layout is given in the figure below.



Reports
The work done is reported in 5 reports, a power point presentation and demonstrator with a user guide. The 5 reports are:

- Framework principles
- Inventory Pavement Management practices
- Inventory Bridge Management practices
- Inventory Road Equipment Management practices
- End report ASCAM

The inventories performed in work packages 2, 3 and 4 deliver a representative view on asset management in Europe, including its diversity over the different countries. Such an inventory is efficient and effective for assessing the feasibility and appropriateness of the framework and to deliver the proof-of-concept. They are not intended and do not deliver a full comprehensive inventory of all available asset management systems. Therefore it is possible that NRA's will miss certain information or systems.

The terminology used in asset management is not consistent across Europe. This is due to the diversity in e.g. approach, level of implementation, etc. In our reports, no attempt is made to identify these discrepancies. This was by no means the purpose of this project. However, this necessarily compromises the readability of these reports.

In the reports of WP2, 3 and 4 an attempt was made to develop the existing asset management system a step further towards the framework principles, by developing relations between asset conditions and EUSL. This is an innovative step, which required temporarily abandoning conventional definitions of sometimes well-established concepts as, for instance, safety.

This report concerns "Inventory Bridge Management practices".

1.2 Introduction to this report

The main objective of this work package is to gather data from existing management systems for structures, with the main focus on bridges. These systems will be evaluated in terms of the end-user service levels and on their asset condition concepts. Based on the existing experience and cost analyses related to different repair and maintenance techniques, an inventory of repair methods will be delivered in order to compare an NRA's costs when providing the required service level.

This inventory of the existing practices, with emphasis on measures, costs, asset condition and user service level data was produced in Task 3.1. Data from previously performed structural condition assessments were compiled in order to correlate characteristics, requirements and end of service life for each type of structure and structural element. The efficiency of condition assessment directly influences the choice of repair and maintenance technique. A database connecting the type of structural damage, repair method and related costs was delivered.

An assessment and elaboration of the results was performed in Task 3.2, in terms of the framework with emphasis on relationships between measures, asset condition and end user service levels. The main goal of ASCAM was to establish a framework in which implicit relationships in existing practices between measures/interventions, asset condition and end user service levels (e.g. skid resistance and safety) are identified. Relationships between condition assessment and maintenance measures are a very important issue which needs to be assessed in the form of trigger levels of degradation that lead to the implementation of interventions. Based on that relationships a connection between threshold degradation and different end user service levels are analysed and established.
In this task, End User Service Levels (EUSL) are divided into three categories:

1. Serviceability EUSL
    a. Road users (car, truck, motorcycle drivers, bicyclists)
    b. Pedestrians
2. Environment EUSL
    a. Pollution
    b. Noise
    c. Neighbourhood
3. Socio-economic or societal EUSL
    a. Local (people living in the vicinity of the road, municipality – society on local level)
    b. Regional (society on regional level)
    c. National level (society on national level)

In this report an overview of the existing bridge management systems (BMS) is given based on the literature review (see References) and on the questionnaire survey within the ASCAM project. The main idea of the ASCAM inquiry was to collect information in more detail about the background and historical data from existing BMS in the countries of the partners in ASCAM or ERANET Road network.

Within WP3, data were gathered from the following countries and their respective road agencies:

Country	Agency / Institute	Person in charge
Croatia	IGH, HAC	Sandra Skaric Palic Smiljan Juric
Austria	AIT PEC Petschacher Consulting	Karoline Alten Markus Petschacher
Slovenia	ZAG	Aljosa Sajna

Bridge / Asset Management System (BMS / AMS)

1.3 Introduction

Functional and serviceable road infrastructure presents one of the most important prerequisites for economic growth of countries around the world. One of the key components of road infrastructure are bridges which present a vital link in any roadway network. It is estimated that the ratio of expenses per km of bridges or tunnels is 10 times the average expenses per km of roads [CEDR, 2010], while the length of bridges compared to whole length of road network is only approx. 2% but at the same time they present 30% of the value of the whole network [PIARC,1999]. When these statistics are taken into consideration, it is easy to understand why, in the past few decades, an increasing number of deteriorating bridges has led to the development of a number of Bridge Management Systems (BMS) and life cycle maintenance models like for example Branco&Brito, Frangopol's and Rijkswaterstaat's model [Kaneuji et al. 2006, Airaksinen 2006, BRIME 2000, Noortwijk J.M. et al. 2004].

BMS is defined as a rational and systematic approach to organizing and carrying out all the activities related to managing a network of bridges, including optimizing the selection of maintenance and improvement actions in order to maximize the benefits while minimizing the life-cycle costs (LCC) [Hudson et al., 1992]. BMS is designed for managing groups of bridges (can include thousands of structures) with limited financial resources.
The heart of a BMS is a database derived from the regular inspection and maintenance activities. The integrity of a BMS is directly related to the quality and accuracy of the bridge inventory and physical condition data obtained through field inspections [AASHTO, 1994]. Information such as the bridge name (ID), the location, and the construction date are stored. These data are considered the starting point for the system: drawings, maintenance records, and surveys are reviewed. The database and inventory allow bridge managers to be fully informed about the bridge stock under their control so that they can make informed decisions about future maintenance and repair activities.

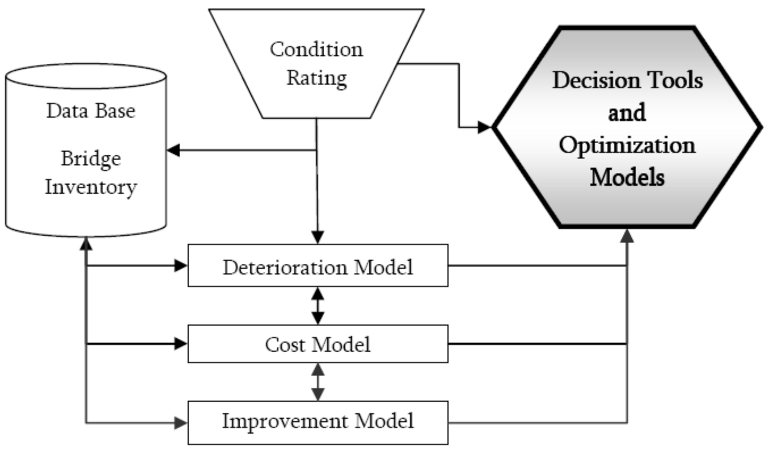


Figure 1: Basic components of a BMS [AASHTO, 2001]

Basic components of the BMS are shown in Figure 1. There are three main aspects addressed by BMS found in literature: condition assessment, modelling future degradation and optimisation of maintenance, repair and rehabilitation (MR&R) decisions and actions. These aspects are then analysed on project level and network level. Both levels are interrelated and should not be analysed separately which is often done in BMS.

1.4 Overview of existing BMS

Within several EU projects and international committee reports, the existing BMSs have been presented, with the basic information about their background, inputs and outcome. In Tables 1 to 4, the overview and basic information about existing BMSs worldwide are given.

Table 1: Questionnaire survey - basic information on BMS [Stryk & Pardi, 2009]

Country	***Year of BMS starting***	***Prioritisation in BMS***	***Number of bridges managed by BMS***	***Used system/software***
Bulgaria	2004/2005	No	1.312	Scan print-Freissinet
Croatia **	developed now	Yes	800 on highways	Oracle 10.G
Czech Republic	2002	Yes	20.490	IIS database + MS SQL Server
Estonia	2002	Yes	922	Pontis
France *	1999	No	9.000	own system
Germany *	2000/2001	Yes	38.000	SIB-Bauwerke; BMS-Optimisation-tools
Hungary	1996	Yes	6.000	adapted Pontis
Italy *	1986	Yes	3.626	Oracle, SQL server
Latvia	2002	Yes	1.775	LatBrutus
Serbia ***	1985	Yes	3.500	BPM
Slovakia	1998	Yes	7.664	Microsoft Access
Slovenia	1992	No	2.300	UNIX
UK	2001	Yes	8.600	Oracle
Ukraine ****	2006	Yes	2.203	Microsoft Sql Server, Borland Delphi

* original EU members, ** candidate country, *** potential candidate country, **** membership possible

Table 2: Overview of BMS from [BRIME D4, 1999]

Main Functions of BMS	**D**	**DK**	**E**	**F**	**UK**	**NO**	**FIN**	**SI**	**CA**	**NY (state)**
Name	SIB-Bauwerke	Danbro		Edouard and OA	NATS	Brutus				
Time of operation (years)	new	20			15	2	3	5		4
Number of bridges managed	34600	1400	15000	22000	9500	17000	15000	1760	25000	10000
Inventory of existing stock	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Schedule of inspection	Yes	Yes		Yes	Yes	Yes	Yes		Yes	Yes
Condition of structures (rating,…)	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bid for maintenance funds	No	Yes		Yes	Yes	Yes	?		Yes	Yes
Prioritising of maintenance work	No	Yes		Yes	Yes	Yes	?	Yes	Yes	Yes
Budget planning (long term)	No	Yes		No	Yes	Yes	Yes			Yes
Registering detailed cost information for actions	Yes	Yes		Yes						Yes
Safety assessments	No			No	Yes					Yes
Taking into account alternative maintenance strategies	No			No	Yes					Yes
Application of whole-life costing	No			No	Yes					Yes
Road user delays	No			No	Yes					
Deterioration prediction	No	No	No	No	No	No	Yes	No	Yes	Yes

Table 3: Overview of BMS from [IABMAS BMC 2010]

No.	Country	Owner	System		Contact person*	
			Name	Abb.	Name	E-mail
1	Canada	Ontario Ministry of Transportation and Stantec Consulting Ltd.	Ontarion Bridge Management System	OBMS	Reed Ellis	reed.ellis@stantec.com
2	Canada	Quebec Ministry of Transportation	Quebec Bridge Management System	QBMS	Reed Ellis	reed.ellis@stantec.com
3	Denmark	Danish Road Directorate	DANBRO Bridge Management System	DANBRO	Jørn Lauridsen	jorn.lauridsen@vd.dk
4	Finland	Finnish Transport Agency	The Finnish Bridge Management System	FBMS	Marja-Kaarina Söderqvist	Marja.Kaarina.Soderqvist@liikennevirasto.fi
5	Germany	German Federal Highway Research Institute	Bauwerk Management System	GBMS	Peter Haardt	Haardt@bast.de
6	Ireland	Irish National Road Association	Eirspan	Eirspan	Liam Duffy	lduffy@nra.ie
7	Italy	Autonomus Province of Trento	APT-BMS	APTBMS	Daniele Zonto	daniele.zonta@unitn.it
8	Japan	Kajima Corporation and Regional Planning Institute of Osaka	BMS@RPI	RPIBMS	Makoto Kaneuji	mackaneuji@kajima.com
9	Korea	Korean Ministry of Land, Transport and Maritime Affairs	Korea Road Maintenance Business System	KRMBS	K.H. Park	paul@kict.re.kr.
10	Latvia	Latvian State Road Administration	Lat Brutus	Lat Brutus	Ilmars Jurka	Ilmars@lvceli.lv
11	Netherlands	Dutch ministry of transportation	DISK	DISK	Leo Klatter	leo.klatter@rws.nl
12	Poland	Polish Railway Lines	SMOK	SMOK	Jan Bien	Jan.Bien@pwr.wroc.pl
13	Poland	Local Polish Road Administrations	SZOK	SZOK	Jan Bien	Jan.Bien@pwr.wroc.pl
14	Spain	Spanish Ministry of Public Works	SGP	SGP	Joan R. Casas	joan.ramon.casas@upc.es
15	Sweden	Swedish Road Administration	Bridge and Tunnel Management System	BaTMan	Bosse Eriksson Lennart Lindlad	bo-e.eriksson@vv.selennart.lindblad@vv.se
16	Switzerland	Swiss Federal Roads Authority	KUBA	KUBA	Rade Hajdin	rade.hajdin@imc-ch.com
17	United States of America	Alabama Department of Transportation	ABIMS	ABIMS	Eric Christie	christiee@dot.state.al.us
18	United States of America	American Association of State Highway and Transportation Officials	Pontis	Pontis	José Aldayuz	jaldayuz@mbakercorp.com

*All questionnaires were received between June 1 and October 31, 2009.

Table 4: Number of objects per object type [IABMAS BMC, 2010]

No.	Country	Name	Bridges	Culverts	Tunnels	Retaining Walls	Other objects	Total
1	Canada	QBMS	2.800	1.900	0	700	0	5.400
2	Canada	QBMS	8.700	0	0	500	0	9.200
3	Denmark	DANBRO	6.000	6.000	0	50	0	12.050
4	Finland	FBMS	11.487	3.078	20	0	100	14.685
5	Germany	GBMS	0	0	0	0	0	0
6	Ireland	Eirspan	2.800	0	0	0	0	2.800
7	Italy	APTBMS	1.011	0	0	0	0	1.011
8	Japan	RPIBMS	750	0	0	0	0	750
9	Korea	KRBMS	5.317	0	314	0	0	5.631
10	Latvia	Lat Brutus	934	845	0	0	0	1.779
11	Netherlands	DISK	4.000	600	14	20	161	4.795
12	Poland	SMOK	8.290	24.189	26	771	0	33.276
13	Poland	SZOK	0	0	0	0	0	0
14	Spain	SGP	13.252	5.979	0	0	3.277	22.508
15	Sweden	BaTMan	288	300	800	13	380	1.781
16	Switzerland	KUBA	5.000	1.250	365	1.000	725	8.340
17	USA	ABMS	9.728	6.112	2	0	0	15.842
18	USA	Pontis	500.000	250.000	0	0	0	750.000
Total			580.357	300.253	1.541	3.054	4.643	889.848

1.5 Overview of structure inventories

The heart of a BMS is a database derived from the regular inspection and maintenance activities. The integrity of a BMS is directly related to the quality and accuracy of the bridge inventory and physical condition data obtained through field inspections [AASHTO, 1994]. Information such as the bridge name (ID), the location, and the construction date are stored. Information about the structural parameters like its type, length, number of spans, etc. The current condition state and load carrying capacity is often accessible through the database. These data are considered the starting point for the structure analysis: drawings, maintenance records, and surveys are reviewed.

The database and inventory allow bridge managers to be fully informed about the bridge stock under their control so that they can make informed decisions about future maintenance and repair activities.

From the questionnaires answered within the ARCHES project (see Table 1), the following summary about 14 European countries involved in the study can be made:

> Information on inventory and inspections were collected in all countries. Traffic data are used within BMS in 10 out of the 14 monitored countries. Almost every BMS includes evaluations of structure and condition assessment. Most of the countries use maintenance planning and prioritization functions. BMS manage all types of bridges under the responsibility of the administrator, which mostly cover the whole primary network or its parts. In some cases the regional or municipal bridges are managed by BMS. Railway bridges are normally managed separately. [ARCHES, D 09, 2009]

ITable 5 is gives an the overview about archived construction information in 18 BMS analysed in IABMAS Bridge Management Committee [IABMAS BMC 2010].

Table 5: Archived construction information [IABMAS BMC, 2010]

No.	Country	Name	Basic data entered, uploaded reports	Uploaded reports	References	No or not given
1	Canada	QBMS	1			
2	Canada	QBMS	1			
3	Denmark	DANBRO		1		
4	Finland	FBMS				1
5	Germany	GBMS				1
6	Ireland	Eirspan		1		
7	Italy	APTBMS		1		
8	Japan	RPIBMS		1		
9	Korea	KRBMS			1	
10	Latvia	Lat Brutus			1	
11	Netherlands	DISK			1	
12	Poland	SMOK			1	
13	Poland	SZOK			1	
14	Spain	SGP		1		
15	Sweden	BaTMan	1			
16	Switzerland	KUBA	1			
17	USA	ABMS				1
18	USA	Pontis	1			
Total			5	5	5	3

In the UK guideline document *Management of Highway structures. A code of Practice* [Shetty et al., 2005] recommended classification of highway structures as shown in Table 6.

Table 6: Classification of highway structures [Shetty et al., 2005]

Asset Type (Level 1)	*Group (Level 2a)*	*Possible sub-group criteria (Level 2b)*		
		Structural Form	*Primary deck element**	*Material type*
structures	bridges	arch	solid spandrel open spandrel tied arch	masonry concrete
		slab	solid slab voided slab rib slab	reinforced concrete prestressed concrete
		beam/girder	I or H beams box beams girders	reinforced concrete prestressed concrete metal

**Primary Deck Element is the terminology used by the Bridge Condition Indicator; however, the Primary Deck Element is referred to as the Main Carrying Element by BRIME.*

From the collected answers, the following summary can be made:

In Slovenian BMS, the first categorization of the bridges is done according to the function (*Road Bridge, Pedestrian, Railway Bridge, Pedestrian Underpass, Culvert,…),* then by the type of structure (*Culvert, slab bridge, girder bridge, arch, frame bridge, …)*, with specifics of the structure *(length, number of spans, location).*

In Norwegian BMS, the first categorization of bridges is done according to the function (*Road bridge, Pedestrian bridge, Culvert, Ferry quay, Underpass, earth supporting walls)*, and it includes all types of structures, all static systems, all spans (min 2.5 meter total length), with specifics of the structure *(road number and coordinates, year of building, standard applied during design and construction).*

In French BMS, all types of bridges except railway bridges are included, as well as all types of structure and static system. Specifics of the structures are given (*span: total length, span length, number of spans; road location and also geodesic system; year of building, standard applied during design and construction).*

In the Croatian BMS, the following classification of bridges according to the type is used:
- arch and arched bridges (deck up, deck in the middle, deck down),
- girder of beam bridges (single-span beam, continuous girder, Gerber girder …),
- truss bridges (deck up, deck down),
- frame bridges (frames, bracing …),
- cable-stayed bridges,
- suspension bridges.

Moreover, according to the cross section profile, every type of the bridge is divided into several sub-types (girder bridge - solid slab, hollow slab, densely ribbed girder, normal ribbed girder …). According to material, the bridge structures are divided into concrete structures and elements, prestressed concrete, prestressed steel, composite steel and concrete, stone, brick, wood and various combinations of the mentioned materials. The main idea of the division is that, by using a combination of the type, shape and materials out of the offered catalogue of parts, each element of any structure can undoubtedly be defined.

1.6 Overview of components

During condition assessment of the structures in order to determine the overall bridge condition, structures are usually divided into components, as shown in Figure 2, which is a figure that describes Norwegian BMS.

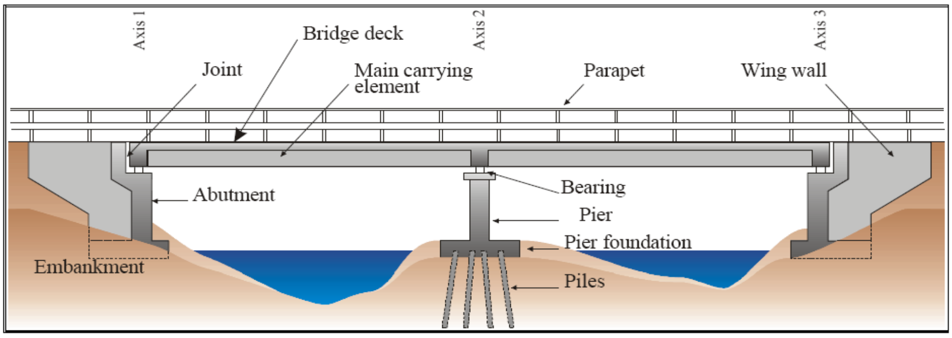


Figure 2: Example of elements of a bridge [BRIME D14, 2002]

The typical division into components is shown in Table 7, and also applied in Croatian BMS.

Table 7: Components of the bridge

Bridge equipment	Superstructure	Substructure
Pedestrian ways	Arch	Head beams
Curbs	Deck	Columns
Cornices	Girders	Abutments
Pedestrian guard rail		Foundation
Traffic barrier		
Rail expansion joints		

Bridge equipment	Superstructure	Substructure
Bearings		

From the collected answers within the ASCAM project, following summary about the bridge decomposition can be given:

Slovenian BMS uses the following division of structures into components given in Table 8.

Table 8: Slovenian system of bridge decomposition

Component	Description
Surroundings	Access, drainage, flood region
River bed	Bed (under bridge and outside bridge), riverbank (under bridge and outside bridge), protective measurements like dike, paving, ...
Foundation of	Embankment, piles, wing wall
Substructure	Abutment, pier, wing wall, supporting wall
Bearing	Different types
Superstructure	Slab, girder, secondary beam, arch, frame, ...
Bridge deck	Waterproofing membrane, asphalt, footpath, curbs
Joint, components according type	
Drainage system	
Traffic guiding & safety equipment; restrain system, fence, signs, ...	

The Austrian system is given in Table 9.

Table 9: Austrian system of bridge decomposition

Component	Description
Substructure	Foundation elements, abutments, piers, wing walls, drainage channels, embankments, etc.
Superstructure	Structure
Pavement	Road, sidewalk, and bicycle path pavement
Bearing	Structural bearing
Expansion joint	Expansion joint, incl. elastic pavement expansion joint
Water proofing/seals, dewatering	Seals and drainage systems e.g. in-/outlets, pipes, fixations
Edge beams	Edge beams including kerb stones and edge beam joints
Other fittings	Railings, guardrails, noise barriers, spray protection, antithrow screens, lighting, cables, general traffic signs, object specific traffic signs (e.g. clearance, weight limits), etc.

2 Defects / damages

An assessment of the bridge condition starts with the identification of defects/damages relevant for the evaluation, its bearing capacity, remaining service life and functionality. For every damage, the inspector has to identify the type of damage, the severity or degree of damage and its extent.
A catalogue of defects may be developed as a supporting document of the BMS to be used during condition assessment. Many countries have generated catalogues of defects to be used in every day practice. They allow for quick and certain descriptions of defects and, more importantly, for identification of potential origins of defects. A good catalogue will allow for anticipation of damage progression and its consequences for the future structural condition.
The catalogue should help technicians involved in the routine or special inspection of bridges to take correct and reliable decisions about the defect type, the associated deterioration process, the relevant cause and possible propagation of the damage. [ARCHES, D09, 2009]
The SAMARIS project developed an Internet based catalogue of defects (http://defects.zag.si/). It has been built on previous research undertaken in the European Commission's 4th Framework projects BRIME (Bridge Management in Europe) and COST action 345 on the assessment of highway structures, on work done in the PIARC committee C11, on USA State Department of Transportations' reports, national handbooks and other available instructions for condition assessment. It contains definitions, descriptions and photographs of both, typical and unusual defects found on highway structures. It uses examples from all over Europe to characterise the widest spectrum of defect types. The important feature of this catalogue is that it can be updated with new examples by any registered user.
This catalogue may help technicians involved in the routine or special inspection of bridges to take correct and reliable decisions about the defect type, the associated deterioration process, the relevant cause and possible propagation of the defect in the future. However, the final identification of detected defects should also be based on the expertise, engineering judgement and experience of the inspector.
The catalogue covers defects which can be detected on the components of highway structures constructed of concrete, masonry, timber and steel (Figure 3). Each sheet of the catalogue covers a particular type of defect and contains general definitions of the defect followed by illustrated examples (defect cases) from existing bridges (Figures 4 and 5). The definition of the defect comprises a description of the defect and possible causes, in some instances also the graduation criteria (stages) for the severity.

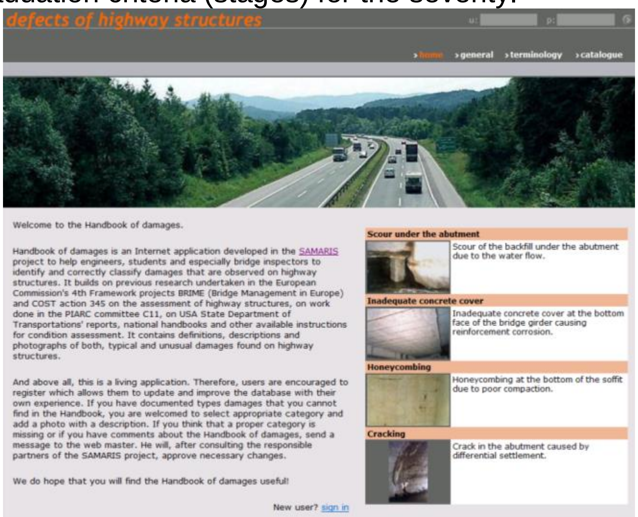


Figure 3: Defects software – opening page [SAMARIS http://defects.zag.si/index.php]

Every defect case should be documented by the following data:

- affected bridge component,
- affected structural member,
- relevant cause(s) of defect, to be selected and designated from possible causes, described in the definition of the damage; where more than one cause is found relevant, then all of them (or only the predominant one) should be stated,
- influencing factor, to be chosen among design, material, construction practice, overloading, environment and maintenance,
- specific influencing factor, to be designated in short form, additional data or explanations, if applicable, such as stage of severity of damage, and photographs illustrating the defect.

DEFECTS:

no	name		no	name	
1	**Geometrical changes**	0	4.3	Fracture of steel bar	2
1.1	Reduction of riverbed profile	2	4.4	Fracture of prestressing tendon	1
1.2	Deformation	2	4.5	Corrosion of anchorages for tendons	0
1.3	Displacement	1	4.6	Mechanical damages on anchorages	0
1.4	Deflection	2	4.7	Duct deficiencies	0
1.5	Other defects	1	4.8	Other reinforcing and prestressing steel defects	0
2	**Earthwork & foundation system**	0	5	**Steel, iron, aluminium**	0
2.1	Sliding	0	5.1	Corrosion	1
2.2	Settlement	0	5.2	Fatigue cracking	0
2.3	Erosion	3	5.3	Fracture cracking	0
2.4	Scour	2	5.4	Coatings	0
3	**Concrete**	0	5.5	Connecting devices	0
3.1	Cracks	0	5.6	Other steel, iron, aluminium defects	1
3.1	Cracks: Early age cracks	1	6	**Stone and brick masonry**	0
3.2	Cracks: Craze cracks	0	6.1	Scaling	0
3.3	Cracks: Structural cracks	7	6.2	Spalling	0
3.4	Cracks: Thermal and drying shrinkage cracks	1	6.3	Delamination	0
3.5	Cracks: Corrosion induced cracks	0	6.4	Loosened or missing masonry parts	0
3.6	Erosion: Abrasion	2	6.5	Cracking	0
3.7	Erosion: Cavitation	0	6.6	Friability	0
3.8	Efflorescence	1	6.7	Grout peeling/disintegration	0
3.9	Stratification	0	6.8	Corrosion of connecting parts	0
3.10	Honeycomb	2	6.9	Other masonry defects	0
3.11	Segregation	2	7	**Wood**	0
3.12	Pop-out	0	7.1	Splitting	0
3.13	Laitance	0	7.2	Decaying of wood	0
3.14	Stalactites	2	7.3	Decaying of impregnation	0
3.15	Leakage: Leakage through concrete and cracks	1	7.4	Corrosion of connecting parts	0
3.16	Leakage: Leakage at joints and embedded items	5	7.5	Other wood defects	0
3.17	Weathering	1	8	**Pavement**	0
3.18	Scaling	3	8.1	Cracks	0
3.19	Spalling	4	8.2	Loosened aggregate	0
3.20	Delamination	1	8.3	Rutting	0
3.21	Disintegration	3	8.4	Lateral uneveness, bump	0
3.22	Alkali-silica reaction (ASR)	2	8.5	Other pavement defects	0
3.23	Inadequate depth of concrete cover	3	9	**Waterproofing membrane**	0
4	**Reinforcing and prestressing steel**	0	10	**Other defects**	2
4.1	Corrosion of reinforcing steel	6	11	**Unclassified defects**	43
4.2	Corrosion of prestressing steel	1			

Figure 4: Defects software – types of defects [SAMARIS http://defects.zag.si/index.php]

Corrosion of reinforcing steel

Destruction of steel by electrochemical reaction with its environment. Corrosion process can be induced by carbonation or by penetration of chloride into concrete.

Carbonation induced corrosion will not occur neither in dry nor in water-saturated concrete, while the highest corrosion rate will occur when concrete cover is subjected to highly changing wetting and drying conditions. Rust products which are formed in the course of corrosion process have substantially higher volume (up to more than six times) than steel, what leads to splitting forces resulting in cracking and spalling, as visual signs and warning of progressing corrosion.

Chlorides induce the pitting corrosion in the form of substantial local reductions in section of the reinforcement what may lead to brittle failure of reinforcement, but the volume of corrosion products will increase to 50% only, thus giving little warning of ongoing corrosion.

The following damages, which can be identified by visual inspection are considered to be visual signs of progressing corrosion process:

- 1st stage - rust stains on concrete surface,
- 2nd stage - corrosion cracks,
- 3rd stage – spalling,
- 4th stage – delamination.

Rust stains on concrete surface

Rust stains due to teiforcement corrosion on the sides of the deckslab and disintegration of the edge beam due to freeze-thaw action

Structural member:
Bearing structure - Deckslab

Influencing factor:
Material

Specific influencing factor:
Inadequte concrete composition caused by erroneuos assessment of enviromental conditions

Corrosion induced cracks in concrete cover

Cracks along embedded reinforcing bars

Structural member:
Bearing structure - Deckslab

Influencing factor:
Construction method

Specific influencing factor:
Use of inadequate concrete composition resulting from lack of proper specification

Spalling from concrete cover over reinforcing bars

Structural member:
Pier - Columns

Influencing factor:
Construction method

Specific influencing factor:
Use of improper concrete type and inadequate placing method

Figure 5: Defects software – example of available information about a specific defect [SAMARIS http://defects.zag.si/index.php]

In tables 10 and 11, examples of defect catalogues related to the embedded construction materials (Croatia) and related to the type of the component (Austria) with information collected through ASCAM survey are shown.

Table 10: Example of catalogue of defects related to the embedded construction materials (Croatia)

DEFECTS RELATED TO THE EMBEDDED CONSTRUCTION MATERIALS			
CONCRETE	**REINFORCEMENT AND PRESTRESSING TENDONS**	**DEFORMATION**	**EARTH WORKS AND FOUNDATION**
• Cracks - Transversal cracks - Longitudinal cracks - Diagonal cracks - Cracks that make a pattern on the surface - Irregular cracks • Erosion - Abrasion - Cavitation • Efflorescence • Honeycombs • Segregation • Seepage: through cracks, through concrete surface • Seepage: on connections and work joints • Scaling • Delamination	• Corrosion of reinforcement • Corrosion of prestressing tendons • Reinforcement bar breakdown • Prestressing tendons breakdown • Corrosion of anchoring of prestressing tendons • Mechanical damage on prestressing tendons anchoring • Irregularities in tendons cables (ducts)	• Globally: movement • Globally: deflection • Locally: buckling • Locally: from impact	• Earth creep • Settlement • Erosion • Scour

Table 11: Catalogue of defects related to the type of the component (Austria):

DEFECTS RELATED TO THE TYPS OF COMPONENT		
1. SUBSTRUCTURE	**2. SUPERSTRUCTURE**	**3. FITTINGS**
1.1 Position changes of piers, bearings and wings This includes settlement, displacement, twisting and compression. **1.2. Channels, scouring and deposits** For structures at risk of scouring, the river bed in	**2.1. Timber structures** For timber structures, these include e.g. • Wear, compressional damage, obvious deflections and cracks • Missing fasteners • Good closure between load-bearing components	Conspicuous changes to the bridge fittings are to be detected, documented and evaluated. **3.1. Bearings, joints and expansion joints** For bearings and joints, these include e.g. • Cracks, corrosion protection, surface condition and anchorage

the region of the abutment foundations and piers along/in the water are to be checked for scour formations. The condition of the bedding and embankment protection, as well as of the plastering joints, vegetation and deposits which would block flood water, are to be checked around the bridge.
Incipient cracks on the banks and possibly changing flow directions are also to be noted.

1.3. Water outlets

Water emersion in the area of the substructure is to be noted.

1.4. Embankments, terrain

Changes in the terrain profile e.g. signs of landslides (tilted trees) and erosion near the structure are to be noted.

1.5. Timber or steel trestles, timber piles

For timber piles and trestles, the state of the wood and fasteners needs to be noted. For steel trestles, significant corrosion and damages need to be noted.

1.6. Abutments, wings, piers, and supports

Various changes such as concrete efflorescence, rusting, moisture, weathering, chipping, cracks as well as the state of joints is to be noted. Especially in the regions around the bearings, cracks and stains are to be checked.

• Gaping joints
• Signs of decay or vermin
• State of the surface coating of timber and steel components

2.2. Concrete, reinforced concrete and prestressed concrete structures

For concrete, reinforced concrete and prestressed concrete structures, these include e.g.
• Deflections and cracks, rusting, signs of moisture, efflorescence, rust stains, exposed rebars, chipping and weathering
• Special focus is to be placed on support banks (voids in concrete, foreign particle inclusion, strong staining/fouling).

2.3. Steel structures

For steel structures, these include e.g.
• Deflections
• Missing fasteners, loose connections
• Corrosion
• Coating damage

2.4. Composite structures

See point 2.2 and 2.3.

2.5. Ropes, tie rods

For ropes and tie rods, these include
• Corrosion
• Coating damage
• Impact damage
• Vandalism
• Unwinding chords of steel wire

2.6. Corrugated culverts

For corrugated culverts, these include e.g.
• Unusual deflections
• Completeness/loose fasteners
• Local scouring and deposits
• Loose components at the edging

2.7. Vaults

• Clearly noticeable limitations to movement
• Unusual bearing position
• Condition of the outer sealing of pot bearings

For expansion joints, these include e.g.
• sufficient movement (conspicuous gap width)
• Serviceability and impermeability of seals
• Serviceability, fouling and impermeability of dewatering system
• Loose or missing parts (sections, sidewalk covers, etc.)
• Mechanical damage
• Condition of the deck plate (cracks, break-away, differences in height, connection joints etc.)
• Unusual noise emission
• Corrosion
• For elastic pavement expansion joints, compressions and cracks

3.2. Carriageway-, sidewalk- and bicycle pavements

For carriageway-, walkway- and bicycle pavements, these include e.g.
• Compressions, rutting, break-away, voids, cracks, bitumen and subsequent grain loss, cement streaks on the surface and unusual wear
• Damage to joints
• Unevenness, differences in height

3.3. Waterproofing and dewatering

For waterproofing, these include e.g.
• Efflorescence, water stains on the structure and lateral infiltration

For dewatering systems, these include e.g.
• Damages, fouling, poor fixation, non-functioning drainage (e.g. wrong height of inlet), pipes, shafts, outfall drain, drainage ditch, seepage pits, and drainage trenches

3.4. Edge beams

	For vaults, these include e.g. • Water stains • Weathering • Efflorescence • Chipping and break-away • Cracks • Shape changes e.g. compressions For stone and masonry vaults, these additionally include • Loose or missing stones • Condition of joints	For edge beams, cornices, parapets, and central reservations made of concrete or steel, these include e.g. • Changes of position • Frost or de-icing salt damages • Cracks, chipping, corrosion, loose kerb stones, damaged joints • Damages to covers of cable routes **3.5. Other fittings** For other fittings such as railings, guardrails, parapet walls, lighting poles, snow and spray protections, these include e.g. • Surface condition, movement, state of the anchorage and possible damages e.g. due to impacts • Existence and state of the required traffic- and warning signs • Faults on cable routes, various protections and their fixation • Missing safety barriers **3.6. Viewing platforms** For various viewing installations etc., these include e.g. • Conspicuous changes to stationary ladders, stairs and gangways

3 Condition assessment

For the purpose of bridge inspections, three levels of inspections are usually defined in order to assess the condition of existing structures, as shown in Figure 6:

- routine inspection – performed by road authorities' personnel
- main inspection – performed by qualified experts from certified professional institutions
- detailed inspection – extended main inspection by in-situ and laboratory testing, usually carried out when required.

Another hierarchy of the condition assessment inspections is shown in Figure 7.

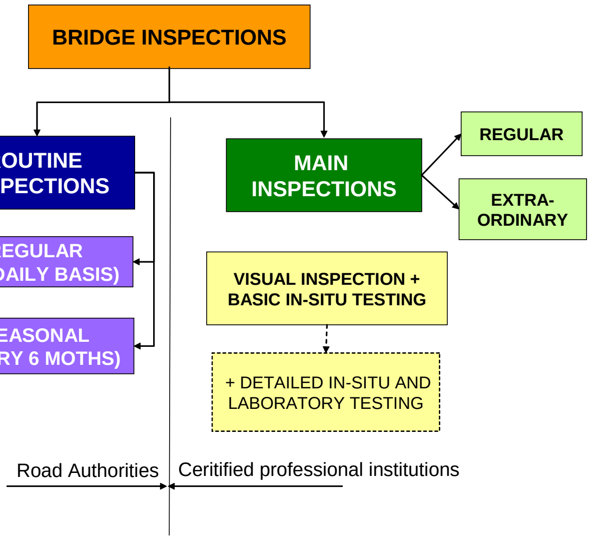


Figure 6: Types of bridge inspection within a bridge's maintenance procedure

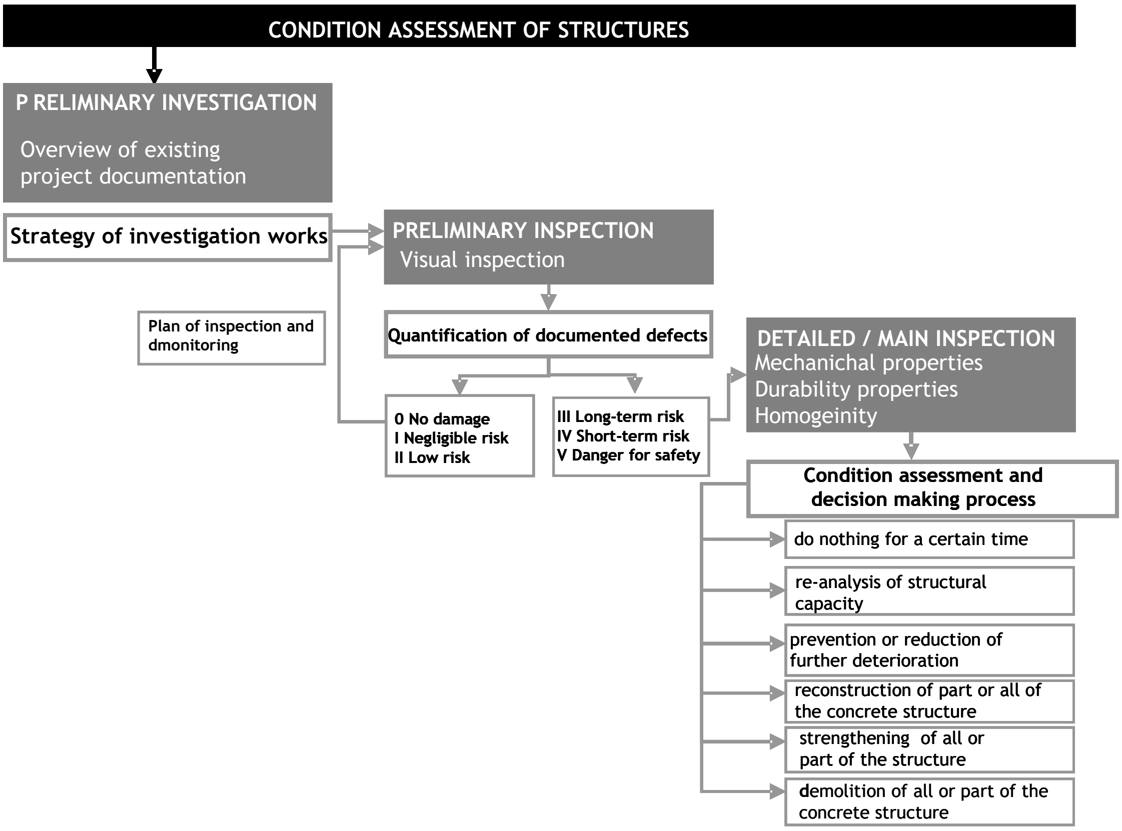


Figure 7: Condition assessment procedure

3.1 Overview of inspection practices

In the ARCHES project, a survey of 14 European countries, with focus on Eastern Europe was performed. In these countries, different levels of inspections are carried out on bridges, with the basic categorization into general (routine), major and detailed inspection. The most common interval for general (routine) inspection is 1 year; 3 months in Italy, 6 months in Croatia, 2 years in Slovenia and UK, 3 years in Germany; in the Czech Republic, Slovakia and Ukraine it depends on the condition of a bridge. In case of main inspections, the interval starts with 1 year (e.g. Italy), 2 years in Croatia, Serbia and Slovenia, 3 years in France, 5 years in Bulgaria and Latvia, 6 years in UK, 10 years in Hungary; and in the Czech Republic, Slovakia and Ukraine, the interval depends on the condition of a bridge. An overview is also given in Table 10. A detailed inspection is normally only carried out when required. In all cases, the results of bridge inspections are stored in a database. [ARCHES D09, 2009]
Additional information collected within ASCAM is presented in Table 12.

Table 12: Inspections practice in Austria, Croatia and Slovenia

Routine inspection			
Country	*Time interval*	*Type of inspection*	*Done by*
Austria	During road patrol At least every 4 months where there is no operation office	Inspection drive	Owner, concessioner
Croatia	At least every 6 months	Inspection drive	Owner
Norway	Every 1 year	Visual inspection	Region office or consultant
France	Every 1 year	Visual inspection (IQOA standard)	
Slovenia	Every 2 years	Visual inspection	Engineers
Main (major) inspection			
Austria	Every 2 years	visual inspection, without the aid of special equipment or gear. Access to individual components (e.g. bearings), which require in-depth examination, has to be granted.	
Croatia	Every 2 years	visual inspection	Certified engineer
Norway	Every 5 years	visual inspection	Region office or consultant
France	Every 3 years	Visual inspection (IQOA standard)	
Slovenia	Every 5 years	visual inspection	Engineers
Detailed inspection			
Austria	Every 6 years, can be extended to 12 years under certain conditions	Visual inspection + special examination when needed	Bridge experts (specialised engineers)
Croatia	When needed (on demand)	Visual inspection + in-situ and laboratory testing	Certified engineers
Norway	If needed. Special inspection of cables and structures under water.	Visual inspection + survey + other methods	Region office or consultant
France	Every 6 years (only for special bridges and in case of serious	Visual inspection by a specialized engineer (IQOA	

	or heavy pathology)	standard) and, when necessary, accurate measures (standards, technical recommendations)	
Slovenia	When needed (on demand)	Visual inspection + in-situ and laboratory testing	Specialised institutions

During main and detailed inspections, the examiner has to judge the basic static conditions of the assessed structure and the effect of defects on its load bearing capacity, serviceability and durability. In the regular assessment report, static calculations are usually not performed. When the need for recalculations of the statics is reported, further investigations are done and then followed by static assessment.
In Table 14, the overview of the assessment methods, with suggested standards, recommendations and units used for the expression of defects is given.

All data collected through inspections are imported into the existing Bridge Management System (BMS) or Asset Management System (AMS). In this way, the database which is the core of every BMS is updated and maintained. These data, together with information generated during the design, construction and maintenance of structures presents the foundation for all other parts of the BMS (future condition prediction, deterioration curves, maintenance planning…) so accuracy and validity of this information is crucial.

Table 13: Overview of inspection levels and time intervals in 14 European countries [ARCHES D09, 2009]

Country	Routine inspection			Major inspection			Detailed inspection		
	Yes/No	Interval	Done by	Yes/No	Interval	Done by	Yes/No	Interval	Done by
Bulgaria	Yes	1 year	Regional Road Administration	Yes	5 years	Regional Road Administration	Yes	if there is a problem	Regional Road Administration
Croatia	Yes	0.5 year	Croatian Motorways	Yes	2 years	certified engineer	Yes	if needed	certified engineer
Czech Republic	Yes	1 year - level I-III 0.5 year - level IV-VII	administrator	Yes	max 6 year depend on type and condition of bridge	authorised individual or legal entity	Yes	as necessary	authorised individual or legal entity
Estonia	Yes	1 year	Local agencies of ERA	-	-	-	Yes	3 years	TECER
France	Yes	1 year	Local roads offices	Yes	3 years	Local Roads and Bridges laboratories	Yes	6 years	Local Roads and Bridges laboratories
Germany	Yes	3 years	Federal states administration/ engineering company	Yes	3 years after routine inspection	Federal states administration/ engineering company	Yes	on demand	specialised engineering company /university
Hungary	Yes	1 year	bridge country engineers	Yes	10 years	independent consultants	Yes	before design	designer
Italy	Yes	3 months	technician	Yes	1 year	graduated engineer	Yes	1-2-5 years	graduated engineer/technician
Latvia	Yes	1 year	administrator	Yes	5 years	authorised consulting company	Yes	under exceptional circumstances	authorised consulting company
Serbia	Yes	1 year	Local enterprise roads of Serbia	Yes	2 years	Public enterprise roads of Serbia	Yes	as necessary	reconstruction designer
Slovakia	Yes	1 year - level I-IV 0.5 year - level V-VII	administrator	Yes	depends on type of bridge	administrator or authorised individual or legal entity	Yes	under exceptional circumstances	administrator or owner
Slovenia	Yes	2 years	engineers	Yes	5 years	engineers	Yes	as requested	specialized institutions
UK	general	2 years	maintaining agent	principal	6 years	maintaining agent	special	as necessary	maintaining agent
Ukraine	Yes	on demand	licensed and qualified enterprises	Yes	depends on bridge, from 1 to 7 years	licensed and qualified enterprises	Yes	on demand	licensed and qualified enterprises

Table 14: Assessment methods used in detailed inspection in Croatia

		Method	*Standard*	*Unit*
Routine inspection		Visual inspection	DIN 1076, Directive RI-EBW-Pruf 88	m^3, m^2, m
Major inspection		Visual inspection		m^3, m^2, m
Detailed inspection		Visual inspection		m^3, m^2, m
	In-situ	Drilling of cores for laboratory testing	EN 12504-1:2000	
		Determination of carbonation depth with in-situ method	CR 12793:2004 ;	mm
		Taking concrete dust samples for chloride content determination	-	-
		Determination of degree of reinforcement corrosion by measuring of potential and electrical resistivity of concrete	ASTM C876-99	mV, corrosion degree in % per m^2
	Lab testing	Determination of compressive strength and density of concrete	EN 12504-1:2000	MPa, kg/m^3
		Determination of chloride content through the depth of concrete,	EN 14629:2004;	Cl- % by mass of concrete or cement
		Determination of specific capillary absorption coefficient	EN 480-5:1997	$kg/m^2 h^{1/2}$
		Determination of gas permeability coefficient	EN 993-4:1995.	x $10^{-16} m^2$

In special cases, the use of the following inspection methods can be useful:

- Ultrasound inspection e.g. testing the homogeneity of concrete around the anchors and wire fractures
- Georadar e.g. to test component and cover thickness
- Thermography e.g. to test for water and moisture stains in vaults
- Magnetic methods e.g. to find wire fractures and flaws in welding lines
- Corrosion measurements.

In the Austrian guidelines for the assessment of road bridges, additional guidelines, norms and references are recommended:

- RVS 12.01.12 Standards in der betrieblichen Erhaltung von Landesstraßen - Grundtext,
- ÖNORM B 2107-3 Umsetzung des Bauarbeitenkoordinationsgesetzes,
- ÖNORM B 4021 Brückenlagerausstattung - Anforderungen, Herstellung und Produktionskontrolle,
- ÖNORM B 4022 Brückenlager - Anforderungen an das Bauwerk, den Lagereinbau, die Lagerauswechslung und die Fachkraft für Lager,
- ÖNORM EN 1337 Structural Bearings, parts 1 – 11,
- ÖVBB guideline,
- ÖNORM EN ISO 4628 part 3 Paints and varnishes -- Evaluation of degradation of coatings - Designation of quantity and size of defects, and of intensity of uniform changes in appearance - Part 3: Assessment of degree of rusting,
- ONR 24023 Hinweise für die Bemessung von Brückenlagern (Instructions for the design of bridge bearings) (2007),
- GZfP-Merkblatt B 3
- RVS 13.03.01 Monitoring von Brücken und anderen Ingenieurbauwerken (2011),
- RVS 13.03.21 Geankerte Konstruktionen (1995)
- RVS 13.03.31 Straßentunnels – baulich konstruktive Teile (1995),
- RVS 13.03.51 Wegweiserbrücken (2003),

- RVS 13.03.61 Nicht geankerte Stützbauwerke (2010),
- RVS 13.03.71 Lärmschutzbauwerke (2009),
- RVS 13.03.81 Wannenbauwerke (2010),
- RVS 13.04.11 Brückenbauwerke
- RVS 15.04.31 Brückenentwässerung - Verbindlicherklärung + Grundtext,
- RVS 15.04.41 Ausstattung, Einbau und Wartung - Verbindlicherklärung + Grundtext,
- RVS 15.04.51 Ausführungsbestimmungen - Grundtext,
- RVS 15.05.11 Stahlkonstruktionen,
- RVS Arbeitspapier Nr. 12 Objekts- und Bauteilbewertung bei Brückenprüfungen,
- ÖNORM B 4706 Betonbau - Instandsetzung, Umbau und Verstärkung,
- DIN 1076 Ingenieurbauwerke im Zuge von Straßen und Wegen, Überwachung und Prüfung, Beuth Verlag, Berlin 1999,
- Straßenforschungsheft 145 Die zerstörungsfreie Prüfung von Brücken Literaturstudie unter besonderer Berücksichtigung der Massivbrücken,
- Straßenforschungsheft 338 Verfahren zur Vorhersage des Umfanges von Brückensanierungen,
- RI-EBW-PRÜF: Richtlinie zur einheitlichen Erfassung, Bewertung, Aufzeichnung und Auswertung von Ergebnissen der Bauwerksprüfungen Ri- EBW- Prüf nach DIN 1076,Verkehrsblatt Verlag, Dortmund 1998.

3.2 Condition rating

Condition ratings are adopted to describe the current condition of the bridge, compared to its condition at the time of construction. Usually, the condition of the bridge is assessed by means of an inspection. The regular inspection of bridges is essential for alerting bridge engineers to the deterioration of the bridge for a variety of reasons: vehicle accidents or defects, fracture, or material breakdown. Inspections also enable bridge engineers to determine future maintenance requirements. In general, the condition rating can be categorized into bridge (structure) ratings and component ratings.

Within the survey of IABMAS Bridge Committee, information about the number of condition states used in each system was collected, given in Table 15.
The majority of systems use ratings of six condition states or fewer. Although noted in the questionnaire as “not given”, it is known that Pontis can handle up to five condition states. In Pontis the number of condition states used depends on the organization that licenses it. The range of condition states currently being used is three to five, with four being the most common. [IABMAS BMC, 2010]

Table 15: Number of condition evaluation states (levels) [IABMAS, 2010]

No.	Country	Name	Number of condition states								
			3	4	5	6	7	8	9	100	Not given
1	Canada	QBMS		+							
2	Canada	QBMS		+							
3	Denmark	DANBRO				+					
4	Finland	FBMS		+							
5	Germany	GBMS									+
6	Ireland	Eirspan		+							
7	Italy	APTBMS			+						
8	Japan	RPIBMS			+						
9	Korea	KRBMS			+						
10	Latvia	Lat Brutus		+							
11	Netherlands	DISK				+					
12	Poland	SMOK				+					
13	Poland	SZOK				+					
14	Spain	SGP								+	
15	Sweden	BaTMan	+								
16	Switzerland	KUBA			+						
17	USA	ABMS							+		
18	USA	Pontis									+
Total			1	5	4	4	0	0	1	1	2

From the ARCHES project, the outcome of the survey would be that most BMS use 5 condition evaluation levels, as presented in Table 16.

Table 16: Overview of number of condition evaluation levels [ARCHES D09, 2009]

No	Country	Number of evaluation levels
1	Bulgaria	5
2	Croatia	6
3	Czech Republic	7
4	Estonia	4
5	France	5
6	Germany	5
7	Hungary	5
8	Italy	7
9	Latvia	9
10	Serbia	6
11	Slovakia	7
12	Slovenia	5
13	UK	N/A
14	Ukraine	5

The main differences between existing assessment methods within BMS are in the level of final condition rating, which differentiate from element to the structure level and even to the network level. Usual condition assessment is performed on the element level and then integrated and / or recalculated into structural level assessment, which may then be used for the prioritisation in the maintenance decision making process on the network level.

An overview of the survey from ARCHES concerning condition rating levels and relations between element and structure level is given in Table 17. [ARCHES D09, 2009]

Table 17: Overview of condition rating levels (element – structure) and their relation [ARCHES D09, 2009]

Country	Is the condition stored for the whole bridge or for individual elements?	What is the method used for rating the condition of bridges?
Bulgaria	both	instruction for condition rating, catalogue of damages
Croatia	both	condition assessment → defects have an impact on the element function → evaluation of the impact of the each element on the bridge regarding traffic safety, structural safety and durability
Czech Republic	substructure, superstructure	visual investigation, surface measurement, geometric shape surveying, bridge behaviour observation and comparison with previous bridge data
Estonia	both	Pontis - bridge Health Index and Condition Index
France	both	IQOA (Image quality of structures) scoring system
Germany	individual elements	the method is based on BASt-report B22 “Algorithmen zur Zustandsbewertung von Ingenieurbauwerken” (Algorithms for the assessment of the condition of civil engineering structures)
Hungary	individual elements	further developed Pontis system
Italy	both	condition states are associated to specific observed defects
Latvia	whole bridge	LatBrutus - bridge condition index BCI
Serbia	whole bridge	every element, according to the value, has its own coefficient, which is multiplied, depending on the rank of damage, rank high = big damage of bridge
Slovakia	both	weighted coefficient method
Slovenia	for individual elements and damages	Slovene method developed in 1989
UK	defects are recorded against individual components; a method for calculating the overall condition of a structure is under development but not yet in use	condition indicator is used under development but not yet in use; it uses an algorithm to calculate a condition score for the structure based upon the extent and severity of defects and the significance of the components against which they are assigned
Ukraine	both	there are 5 level of bridge technical conditions: 1 - perfect, 2 - good, 3 - satisfactory, 4 - bad, 5 - critical

Within ASCAM, focus was on the background of the existing Bridge Management Systems. The Austrian evaluation system of the maintenance condition, implemented in the new guidelines for the condition assessment of road bridges is based on the rating system with 5 condition levels, presented in Table 18. The evaluation of the object is performed according to the Table 19. The evaluation of components is based on Table 20, which also includes exemplary defects. [RVS 13.03.11]

There is no clear correlation between component (element) condition rating and object (structure as a whole) condition rating, which means in the end, there is no objective way of checking the final condition grade of the object. The weight of a certain component on structural stability, safety and durability is not defined. This means the final evaluation of the object as a whole needs to be performed by experienced bridge engineers, who can justify his decision about a certain rating.

Table 18: General rating for the condition in Austria [RVS 13.03.11]

Grade	Condition
1	Very good
2	Good
3	Satisfactory
4	Faulty
5	Bad

Table 19: Object (structure as whole) evaluation system [RVS 13.03.11]

Grade	Description
1	No or very minor damages. Faults stem from the construction phase, e.g. from discrepancies in dimensions, aesthetic flaws. No reduction in load bearing capacity, serviceability or durability. No maintenance measures required.
2	Minor, light damages; faults stem from the construction phase and show no signs of deterioration. No reduction in load bearing capacity and serviceability. In case of no intervention, limitations to the serviceability/durability will only arise in the long-term. Corrections recommended in the course of regular maintenance or repair works.
3	Medium damages which do not affect the load-bearing capacity. Signs of a reduction in serviceability and durability can be found. Maintenance should take place in the mid-term in order to raise the serviceability and durability back to desired level.
4	Heavy damages which currently do not affect the load-bearing capacity. A reduction in serviceability and durability is clearly noticeable. Repair measures should be planned in the short-term in order to raise the serviceability and durability to the desired level. Maintenance interventions can be substituted by another assessment/special assessment within a prescribed deadline (shortening the inspection interval).
5	Very heavy damages which result in a reduced load-bearing capacity and/or serviceability unless renewal/repair takes place. Repair/renewal works should be initiated immediately.

Table 20: Component evaluation system [RVS 13.03.11]

Grade	Description
1	No or very minor damages. Faults stem from the construction phase, e.g. discrepancies in the dimensions, aesthetic flaws. No reduction in load bearing capacity, serviceability or durability. No maintenance measures required.
2	Minor, light damages; faults stem from the construction phase and show no signs of deterioration. No reduction in load bearing capacity and serviceability. In case of no intervention, limitations to the serviceability/durability will only arise in the long-term. Corrections recommended in the course of regular maintenance or repair works.
3	Medium damages to the components or several smaller damages. No reduction in load-bearing capacity. Signs of a reduction in serviceability and durability can be found. Maintenance should take place in the mid-term in order to raise the serviceability and durability back to desired level. *Examples of failure modes:* Substructure: twists, compressions, chipping with exposed rebars, voids, damaging cracks with/without efflorescence, initial scouring, etc. Superstructure: Chipping with exposed rebars, voids, damaging cracks with/without efflorescence, initial surface corrosion, initial damages to steel/timber connections, open coupling joints without efflorescence, etc. Pavement: Light rutting, starting alligator cracks, small compressions, light settlement of walkways/bicycle paths, etc. Bearing: Harmless malposition, slight cracks of the elastomer, corrosion etc. Expansion joints: Leakage, problems with the attachment to the deck plate, surface corrosion on the underside, harmless malposition, etc. Seals, dewatering: Light lateral infiltration, corrosion of the drains, etc. Edge beams: Chipping with exposed rebars, open joints, frost/de-icing salt damages, etc. Other fittings: Surface corrosion, minor mechanical damage, starting decay on timber components, etc.
4	Heavy damages to the components. Currently no effect on the load-bearing capacity, but reduction in serviceability and durability are clearly noticeable. Repair measures should be planned in the short-term in order to raise the serviceability and durability to the desired level. *Examples of failure modes:* Substructure: Large-scale chipping with exposed rebars, serious crack formations with/without efflorescence, extensive scouring, etc. Superstructure: Large-scale chipping with exposed rebars, serious crack formations with/without efflorescence, surface corrosion reducing the cross section area, damaged steel/timber connections, cracked welding seams, dents, etc. Pavement: Extensive rutting, compressions and break-offs, settlement
5	Very heavy damages to components. Missing fittings. Reduced load-bearing capacity and/or serviceability. Repair/renewal works should be initiated immediately.

In the new version of the Austrian guideline RVS 13.03.11there is no defined relation between element and object rating, or quantitative evaluation of the detected damages. Nevertheless, in the BRIME project, deliverable D2, “Review of current practice for assessment of structural condition and classification of defects” (1999), the Austrian condition assessment procedure was presented in detail. The summary is as follows:
The assessed condition of the bridge structure is expressed by the condition rating, S, which in general form is given by the following function:

$$S = \sum_{1}^{32} G_i \times k_{1i} \times k_{2i} \times k_{3i} \times k_{4i}$$

where individual numerical attributes refer to:

- G_i - Type of damage. There are 32 types of damages. The value of Gi is in the range of 1 to 5 and depends on the severity of the damage. For each type of damage a description of its extent, intensity and urgency of the intervention on particular structural member is given.
- K_{1i} - Extent of damage. It is expressed as a numerical value between 0 and 1. It can be described in words: few or some, frequent and very frequent or large. The description usually refers to one or more components of the bridge or to the whole bridge structure. The extent is never quantified by the measured sizes (length, area, etc.) of the damage.
- K_{2i} - Intensity of damage. It is expressed as a numerical value between 0 and 1. It can be also described in words: little or insignificant, medium, heavy and very heavy. The description of intensity is usually associated with the description of damage (e.g. width of the cracks, etc.).
- K_{3i} - Importance of the structural component or member. Values range between 0 and 1. The structural components are classified as primary, secondary and other parts.
- K_{4i} - Urgency of intervention. Values range between 0 and 10 and depend on the type, seriousness and risk of the collapse of the structure or its part.

According to the obtained value of condition rating *S* bridge structures can be ranked into one of six classes, which are defined in table 21.

Table 21: Condition rating of the bridge based on the value *S* [BRIME D02, 1999]

Damage class	Definition	Condition rating value S
1	No or very little deterioration	0-3
2	Little deterioration	2-8
3	Medium to severe deterioration	6-13
4	Severe deterioration	10-25
5	Very severe deterioration	20-70 (k_4=10)
6	Very severe or total deterioration	>50 (k_4=10)

The Croatian asset rating system is based on degradation categorization given in Table 22. Final categorization is expressed in percentage of the entire surface area of a certain element, and indicates how much surface of the concerned element should be repaired and to what extent, as shown in an example from a case study in Table 23, based mainly on the visual inspection and no quantitative assessment of the bridge condition as a whole.

Table 22: Croatian condition rating system

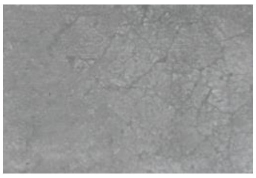
Damage category	Type of damage	Main performance indicators	Example
0	No damage.		
I	Smaller defects resulting from the construction process.	- Surface imperfections - Small cracks (shrinkage cracks	
II	Smaller defects resulting from the exploitation.	- Surface cracks - Delamination of surface cement paste film - Evaporation of Ca(OH)2	 
III	Defects that in the long term decrease durability of the structure. Repair is needed.	- Network of cracks in concrete cover - Contamination of concrete cover (chloride, pH) - Concrete loss due to frost and de-icing salts damage	 
IV	Defects that can, in the foreseeable future, decrease the reliability of the structure. Repair is needed now.	- Delamination, spalling of concrete cover (partially) - Honeycombs in concrete - Corrosion of steel visible - Loss of steel cross section due to corrosion	 
V	Defects that present a serious danger for safety of the structure. Intervention is needed immediately, and if necessary limitation or shutdown of traffic.	- Delamination and spalling of concrete cover (full) - Advanced corrosion of steel, - Significant loss of steel cross section	

Table 23: Categories of defects for certain structural elements from a Croatian case study [Skaric et al. 2008]

Parts of structure	Category of defects				
	I	II	III	IV	V
Superstructure					
Main girders		70%	20%	7%	3%
Head beams		45%	35%	15%	5%
Cross girders		40%	30%	20%	10%
Precast slabs			90%	5%	5%
Transverse joints between slabs			75%	25%	
Longitudinal joints between slabs			85%	15%	
Substructure					
Columns		60%	25%	10%	5%
Abutments		40%	25%	25%	10%

The Slovenian National Building and Civil Engineering Institute started to develop BMS (named MOST) at the beginning of the 90s, and the system was in operation from 1996. Beside the manual and guideline for the usage of MOST, Slovenia has no official regulation for carrying out the inspections and procedures for the assessment of the condition of existing bridges.
The condition rating of the bridge is performed in a quantitative form. The final assessment code is given in Table 24. The bridge condition is calculated as a sum of individual elements' damage rating:

$$R = \Sigma RF_i \qquad (1)$$

Table 24: Bridge condition rating [MOST, Slovenia]

Condition class	Definition	Condition rating R
5	Very good	0 < R < 5
4	Good	1 < R < 15
3	Satisfactory	10 < R < 30
2	Bad	20 < R < 50
1	Critical	R > 40

The individual elements' damage rating is calculated as follows:

$$RF_i = B*K_1*K_2*K_3*K_4 \qquad (2)$$

Where individual factors mean:

- B - type of damage, in the range of 1 to 5
- K_1 - importance of the defect for the particular element (0.3, 0.7, 1.0)
- K_2 - damage level (0.4, 0.6, 0.8, 1.0) corresponding to (I, II, III, IV)
- K_3 - damage extend (0.5, 0.8, 1.0) corresponding to (A, B, C)
- K_4 - seriousness (threat) of the damage to the element (1, 3, 5, 10)

Examples for (K_2)

- cracks in concrete

Crack width (mm)	0.1-0.2	0.2-0.5	0.4-1.0	>1.0
K_2	0.4	0.6	0.8	1.0

- reinforcement corrosion

Corrosion (%)	0-2	2-10	10-20	>20
K_2	0.4	0.6	0.8	1.0

Defect extend (K_3)

(%)	do 10	10-40	>40
K_3	0.5	0.8	1.0

In Norwegian BMS, there are 4 levels (from 1 to 4) of condition rating and this does not include “no damage”.

Defects are categorized by using a system of letters and numbers, meaning:

M=Environment

B=Load capacity

T=Traffic safety

V=Maintenance cost

This is combined with a number, meaning:

1=Small damage, no repair needed

2=Medium damage, repair needed in 4-10 years

3=Large damage, repair needed in 1-3 years

4=Critical damage, repair now

Then these two are combined for all the bridge elements. An example: V3 means damage with consequence for maintenance cost need repair within 1-3 years.

The element condition is related to the number of years before maintenance is needed, and the condition rating is not levelled. The structure condition is quantified by using the element condition.

In French BMS, there are 5 levels in condition rating on the element level: 1, 2, 2E, 3 and 3U. Each element's part is evaluated and classified (1,2,2E,3 or 3U). During the inspection of an element all defects are listed and each of them includes a classification of the element. The final class is the maximum of all the defects. For the structure level condition rating, the number of levels and categories are the same as for the element level: 5 levels (1, 2, 2E, 3 and 3U) and the structure level is the maximum out of all element levels.

There is a catalogue of defects for each kind of bridge, and defects are defined according to the IQOA Methodology. Depending on the nature of the defect and of the structure, the defect is appointed according to either the material or the structure.

In Table 25 information gathered in ASCAM about bridge condition rating is summarized.

Table 25: Bridge condition rating in different countries

Different bridge condition rating in different countries									
Austria		**Croatia**		**Slovenia (MOST)**		**Norway**		**France**	
Grade	***Condition***	***Class***	***Condition***	***Class***	***Condition***	***Class***	***Condition***	***Class***	***Condition***
1	Very good	0	No damage	5	Very good	1	Small damage	1	Good overall state
2	Good	I	Smaller defects from construction period.	4	Good	2	Medium damage	2	Minor structural damage. Non urgent maintenance needed
3	Satisfactory	II	Smaller defects from exploitation period.	3	Satisfactory	3	Large damage	2E	Minor structural damage. Urgent maintenance needed.
4	Faulty	III	Defects that in long term decrease durability	2	Bad	4	Critical damage	3	Structure deterioration. Non urgent maintenance needed
5	Bad	IV	Defects that in foreseeable future can decrease reliability	1	Critical	Defects are categorized by using the following system of letters and numbers and combined with the above classes: M=Environment, B=Load capacity, T=Traffic safety, V=Maintenance cost.		3U	Serious structure deterioration. Urgent maintenance needed.
		V	Defects that present serious danger to safety of traffic						
No clear correlation		Structure level condition is		Bridge condition is		The element condition is		For the structure level	

Different bridge condition rating in different countries				
Austria	**Croatia**	**Slovenia (MOST)**	**Norway**	**France**
between component (element) condition rating and object (structure as a whole) condition rating.	not determined from the above classes but from the influence of each elements' functionality on traffic safety, mechanical resistivity, stability, durability and general condition of element. Structural level is then determined by combining maximum elements level grades.	calculated as a sum of individual elements' damage rating.	related to the number of years before maintenance is needed, and the condition rating is not levelled. The structure condition is quantified by calculating a character using condition from the element condition.	condition. rating number of levels and categories are the same as for element level: 5 levels, 1, 2, 2E, 3 and 3U, and the structure level is the maximum of all element levels.
PREDICTION OF BRIDGE AGEING				
Probabilistic (details given in Task 1 report).	None	None	None	Probabilistic in nature (Poisson's function is used)
Grades/Classes and conditions are not comparable between themselves for different countries in this table.				

4 Deterioration models / prediction

Prediction of deterioration is an important aspect of bridge management in order to estimate the remaining service life and plan future maintenance tasks. When providing decision support for long term management planning, a number of prediction models are required and the BMS should offer basic analytic capabilities. The functional requirements for the BMS in predicting future demand, condition, and performance have to be defined by the owner and the society. The process of converting the inputs into the required outputs requires complicated mathematical relations and it is therefore suggested that detailed technical models for forecasting traffic growth and deterioration of components and structures as a whole are kept outside the BMS.

Bridge deterioration is the process of decline in the condition of the bridge resulting from normal operating conditions [Abed-Al-Rahim and Johnston, 1995], excluding damage from such events as earthquakes, accidents, or fire. The deterioration process exhibits the complex phenomena of physical and chemical changes that occur in different bridge components. What makes the problem more complicated is that each element has its own unique deterioration rate. Accurately predicting the rate of deterioration for each bridge element is, therefore, crucial to the success of any BMS.

In the late 1980s, deterioration models for bridge components were introduced in order to predict the future condition of infrastructure assets as a function of their expected service condition. Deterioration models in Infrastructure Management Systems (IMS) were first developed for Pavement Management Systems (PMS). Deterioration models in PMS differ from those in BMS because of the differences in construction materials, structural functionality, and the types of loads. In addition, safety is widely perceived more important in bridges than in pavements.

Despite the dissimilarities in the deterioration models for pavement and bridges, the approaches to developing pavement deterioration models have been employed in the development of bridge deterioration models.

In a study conducted at the transportation systems center (TSC), Busa et al. [1985] examined the factors affecting the deterioration of a bridge's condition. The study concluded that the topranking factors that affect deterioration include age, average daily traffic, the environment, the bridge design parameters, and the quality of the construction and materials used.

According to the FHWA's Bridge Management System report [1989a], most studies of deterioration rates tend to predict slower declines in condition ratings after 15 years. The report included results from a regression analysis of NBI data for the deterioration of structural conditions. For example, the results suggest that the average deck condition rating declines at the rate of 0.104 points per year for approximately the first 10 years and 0.025 points per year for the remaining years. In addition, the overall structural condition declines at a value of 0.094 per year for 10 years and 0.025 per year thereafter. These results suggest that the condition will not fall below 6 until after 60 years, which is not the case in real life: bridges deteriorate at a much higher rate. In another study, the estimated average deterioration of decks was about 1 point in 8 years and 1 point in 10 years for the superstructure and substructure. A simple description of the deterioration process over time is given in Figure 8. In general, deterioration models can be grouped into four main categories: mechanistic models, deterministic models, stochastic models, and artificial intelligence (AI) models. [Elbehairy, 2007]

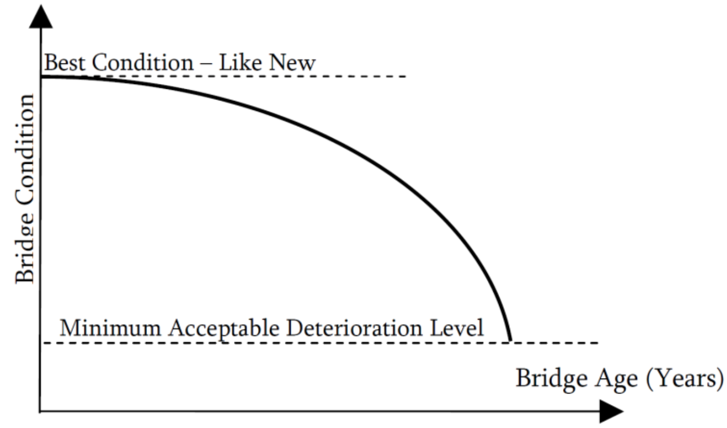


Figure 8: Bridge deterioration [Elbehairy, 2007]

From the IABMAS Bridge Management Committee survey the following was reported with respect to predictive capabilities, including deterioration, improvement and cost modelling (Table 26):

- Nine of the systems can predict deterioration. Five of these systems use probabilistic methods.
- Nine of the systems are reported to predict improvement, i.e. the improvement due to future interventions, of which two are reported to use probabilistic methods.
- Thirteen of the systems are reported to predict costs. As there are only nine systems that predict future deterioration and improvements due to future interventions, it is assumed that the additional four systems that predict costs do so only on an operational basis, i.e. taking into consideration only the existing condition state and likely intervention costs for the objects in those condition states. [IABMAS BMC, 2010]

Table 26: Predictive capabilities of existing BMSs [IABMAS BMC, 2010]

No.	Country	Name	Deterioration				Improvement				Cost	
			Yes	Yes		No	Yes	Yes		No	Yes	No
				Prob.	Det.			Prob.	Det.			
1	Canada	QBMS	+	+			+	+			+	
2	Canada	QBMS	+	+			+	+			+	
3	Denmark	DANBRO				+				+	+	
4	Finland	FBMS	+				+				+	
5	Germany	GBMS	+				+				+	
6	Ireland	Eirspan				+				+		+
7	Italy	APTBMS	+	+			+	+			+	
8	Japan	RPIBMS	+				+					+
9	Korea	KRBMS				+				+		+
10	Latvia	Lat Brutus				+				+	+	
11	Netherlands	DISK				+				+	+	
12	Poland	SMOK				+				+	+	
13	Poland	SZOK				+				+	+	
14	Spain	SGP				+				+		+
15	Sweden	BaTMan	+		+		+		+		+	
16	Switzerland	KUBA	+	+			+	+			+	
17	USA	ABMS				+				+	+	
18	USA	Pontis	+	+			+	+			+	
Total			9	4	1	9	9	2	1	9	13	5

In respect to the survey performed within ASCAM, Slovenia, Norway and Croatia do not have deterioration models embedded in their BMS.

In the Austrian BMS, the prediction of bridge ageing takes place on a **probabilistic** basis (bridges are grouped into **condition classes 1 – 5**, where 1 is a good condition and 5 is bad condition, Table 15, 16). For each class, the bridge age is plotted against the relative number of bridges in that class, giving a probability density function. At the same time, ageing is described through a **hazard function**, which defines the probability of a bridge in one condition class migrating to another condition class:

$$\lambda(t) = \frac{f(t)}{1-F(t)} = h(t) \tag{3}$$

which describes the hazard rate of elements per condition class (based on the procedure of Cohort Survival Method, CSM).
State transition function (survival function) is defined as

$$R(x)=1-F(t) \tag{4}$$

The **failure rate** is calculated by the integration of the Hazard function over the time until the current date in simulation:

$$H(x) = \int_0^T h(t)dt \tag{5}$$

The reliability data is not found in usual databases; parameters for the reliability analysis are formed by complex interacting components. The most common distribution used in stochastic ageing prediction is the Herz distribution, as it fits well with the hazard function. If data cannot be fitted or is not available, “left” or “right censored” data analysis (see CSM) is used from two inspection cycles, typically in 6 year-periods. From this analysis migration rates from one condition class to the other are being observed. [Questionnaire Petschacher, 2011; Petschacher & Gragger 2008]
In the Norwegian BMS, the deterioration model is probabilistic in nature (Poisson’s function is used). Each bridge has a grade (1, 2, 2E, 3 or 3U). Not the BMS, but the manager of the BMS uses a deterioration model on the whole state property of bridges to predict future conditions and the evolution of bridge number in each class. For a single bridge, it relies on the evolution of condition data, experience and, if necessary, the opinion of an expert. Statistical models are introduced to build predictive tools such as risk analysis or “inspections ciblées” (targeted inspections) whose purpose is to define the time a homogeneous population of bridges with an asset maintenance would remain operational.

4.1 Case study – Slovenia

Historical data of bridge assessment performed on seven bridges of different age, structure, traffic load etc. were collected and evaluated. The assessments included in the study were performed during the years 1993 to 2011, and bridge rating was performed in Slovenian BMS “MOST”. During this time the quality of the inspections has increased due to increased experience. On the other hand, the personnel involved in the assessment of the bridges have widened. Both facts, as shown in this survey, have influenced the assessment results, as summarised in the conclusions. A detailed report in which the main bridge data for each of the seven bridges are given first is presented in ANNEX A. Further, main or typical defects and damages are listed shortly for each year of inspection, followed by the rankings of individual defects. At the end, the rankings for substructure, superstructure, bridge deck, accessories and bridges as a whole are given for each year of inspection. Rankings are also presented in graphs. Photos of defects are put on view, where possible in such a way that the evolution of the defect over the years can be followed.
In Table 27, general information about analyzed bridges us given.

Table 27: General information about analyzed bridges

No.	Bridge No.	Year of construction	Length (m)	Width (m)
1	VA 0038	1980	72.40	10.70
2	VA 0226	1980	46.40	3.40
3	VA 0228	1980	44.02	3.40
4	VA 0133	/	72.00	8.80
5	VA 0134	/	218.60	8.80
6	VA 0137	/	230.60	9.80
7	CE 126	1961	17.60	6.90

Ratings of bridges as whole are presented in figure 9. They can be commented as follows:

- For the last 11 to 15 years, very fast degradation of bridges VA 0134 and VA 0137 was observed, which is in line with the on-site observations.
- A similar degradation rate was observed in the case of bridges VA 0038, VA 0226, VA 0228, VA 0133 and CE 126, both on-site and according to the ratings.
- The lower rating, i.e. improvement of the bridge state recorded for the bridges VA 0226 and VA 0228 is unrealistic, as the two bridges were not repaired during the years 1993 to 1995. The discrepancies can be explained by the ongoing development and implementation of the BMS system and by the related educational process of the personnel.
- Slight fluctuations in rating for the bridge CE 126 in the years 1996 to 2000 is of minor importance and is probably due to different inspectors performing the check-up.

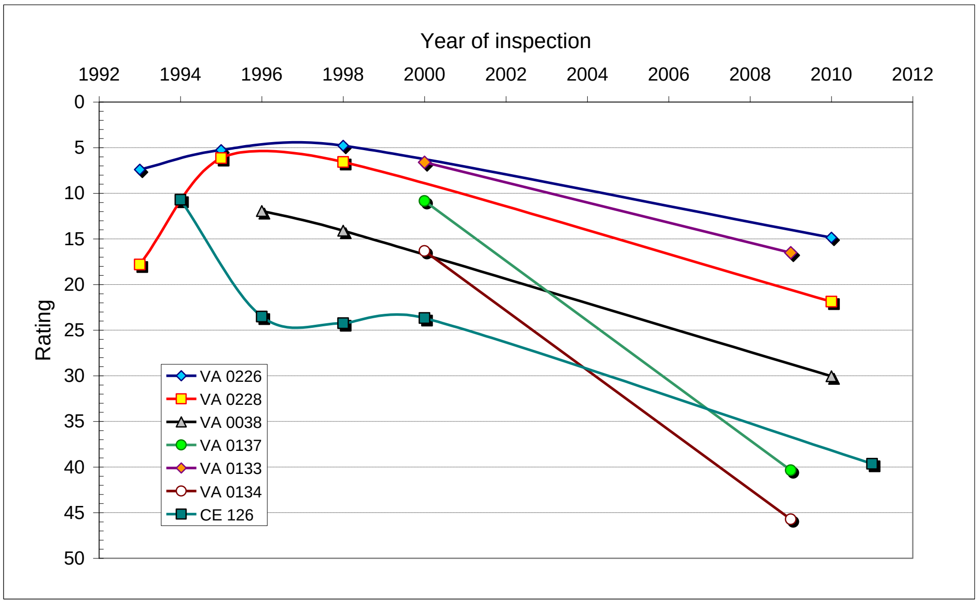


Figure 9: Assessment results for all bridges (overall structure)

The Slovenian National Building and Civil Engineering Institute (ZAG) started to develop its own bridge management system (BMS) at the beginning of the 90s. The current system (MOST) has been operational since 1996.

For the purposes of ASCAM, the Slovenian BMS was evaluated based on evaluation reports of the seven bridges compiled during the years 1993 to 2011.

Based on this review, it can be concluded that the Slovenian BMS delivers fair information about the bridge state, if the assessment is performed by a skilled personnel.

Deviations or unexpected ratings were assigned to the damages observed in two cases: First, during the initiation period of the BMS system, in the years 1993 to 1996 (see VA 0226 and VA 0228). Second, when new personnel was assigned to evaluate the bridges, as in the case of CE 126, where each evaluation was performed by a different person. The main discrepancy was observed in the allocation of value of the K4 factor, which gives an information about the seriousness (threat) of the damage to the element. This factor can take on a value of 1, 3, 5 or 10 and is usually too low, as probably in the case 2011 assessment of the bridge CE 126.

As the qualification of the personnel plays an important role in the assessment of the bridges, the following improvements in the education process are recommended:

- A catalogue of defects, possibly the handbook of damages developed in the SAMARIS project, should be implemented in the Slovenian BMS.
- Additional guidelines, including examples, should be prepared to give new inspectors instructions for assigning values to factors K1 – importance of the defect, K2 – damage level and K4 - seriousness (threat) of the damage to the element.
- More effort should be put on on-site education, both for new and expert inspectors. This will result in more unified evaluation criteria among inspectors.

5 Maintenance / intervention

A BMS should represent a tool for transportation agencies and decision makers to optimize bridge maintenance and repair strategies over a number of years within the given budget limits and other constraints, so that feasible and practical plans can be determined.

Extensive literature can be found on condition assessment and modelling future deterioration but only few studies have been directed at optimizing the decisions of maintenance or repair of bridges, especially on the material level [Elbehairy 2007]. Frangopol et al. [2001] stated that additional research is required in order to develop a better life cycle cost analysis (LCCA) whereby the costs and benefits can be quantified. Moreover, costs and effects of the interventions should be assessed more accurately based on real data [Bocchini et al., 2010]. The best practice in LCCA calls for including all costs incurred throughout the life of a bridge. There are two types of costs that need to be considered: agency costs – direct costs (maintenance and repair costs) and user costs – indirect costs (costs incurred by the public) [FHWA 2002]. The indirect costs may be regarded as more or less abstract but they are real, just as direct costs, the difference is that they are paid by society, not the owner [BRIME 2000, Externe 2005].

The maintenance module of the BMS should store information about planned and realized maintenance, repair and other types of activities in hierarchical order. It should contain the information about activities required for maintenance, repair, etc. and to register presumed costs. For this purpose, cost catalogue is sometimes used which can be incorporated in the BMS. Once the activity is complete, the module allows the real data to be entered, including actual costs incurred. The module enables some statistical evaluations (e.g. summary of the costs according to type of activity, for stock of bridges, etc.). [ARCHES D09, 2009]
Each record should contain:

- type of activity (diagnostics, maintenance, repair, reconstruction, etc.),
- element (part) of the bridge involved,
- cost of activity (presumed/real),
- date of realisation (planned term based on degree of urgency/date of finishing),
- who performed it,
- which parameter was improved,
- what is the warranty period, etc.

5.1 Trigger degradation levels

In most BMSs, maintenance planning is completely deterministic and the times for maintenance are determined by fixed deterioration levels at which the structural condition is no longer sufficient or the decision is made exclusively by an expert. Results of maintenance actions in terms of the condition of the object can also be considered deterministic.
Two similar approaches from the ASCAM survey are based on these principles. For example, in France, bridge administrators decide when the maintenance works should be planned. They are usually planned when bridges are classified 2E or higher. The model does not generate an optimal maintenance strategy but the Inter-departmental Road Divisions have to ensure a specific proportion in each class by the year 2020 (under 30 % of bridges in class 2E, 15% in class 3 and 1% in class 3U). Costs of repair are simply compared to the costs of replacement. If repair costs are more than 50% of replacement, then replacement has to be considered. If repair costs are more than e.g. 20% of replacement, alternatives must be considered. All kinds of intervention can be applied up to maximum cost compared to new bridges. Maintenance measures that can be applied are generic (applicable to any

kind of structure), and the best maintenance option is chosen based upon engineering evaluation and cost/benefit analysis.
Future prediction theories regarding deterioration should incorporate prediction of trigger deterioration aspects (points in time where certain major decisions about measures/interventions are made, as well as decisions themselves) and incorporate probabilistic theory.

5.2 Maintenance plan

The maintenance plan should be based on a decision-making system which chooses the best repair option considering safety, durability, functionality and economy.
Figure 10 presents the general framework for concrete structure maintenance, with the application of repair performance indicators (RPI). The method was developed in the CONREPNET project, for the monitoring of the post-repair period. The strategy of intervention developed in the project consists of: (1) defining the set of requirements to be fulfilled by the repaired structure; (2) performing a technical and economic analysis through the use of appropriate requirements and performance indicators, or through a rigorous life-cycle cost analysis (LCCA); and (3) selecting among the identified options the optimal repair or strengthening method. Finally, the repair has to be executed and its maintenance needs established. Although it seems that an LCCA would be the most suitable methodology for comparing different repair options, it is very often not feasible because of a lack of experience or reliable data. [Andrade & Martinez, 2009; CONREPNET 2007, Andrade & Izquierdo 2005; Frangopol et al. 2001]

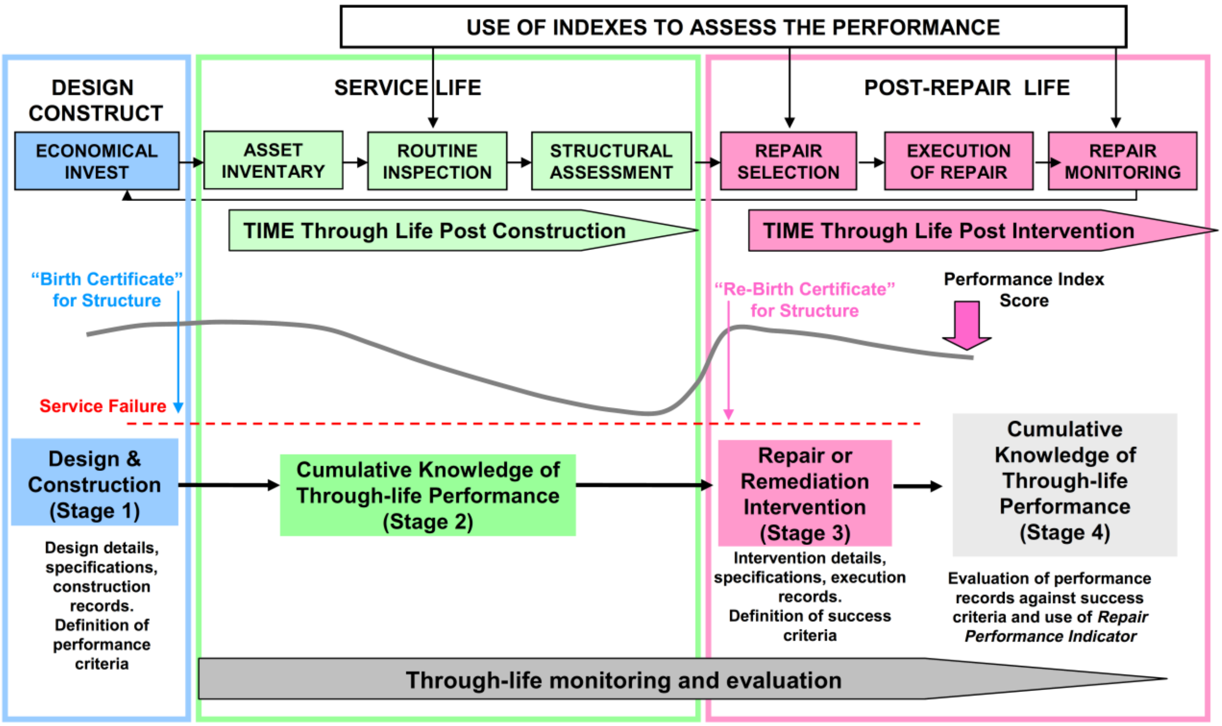


Figure 10: General framework for concrete structure maintenance [Andrade & Martinez, 2009]

The chart given in Figure 11 (based on Humphreys M. et al. 2007) presents part of the decision-making process in managing an infrastructural asset. The diagram presents a project level decision making process and should be implemented into the network level decision making process.

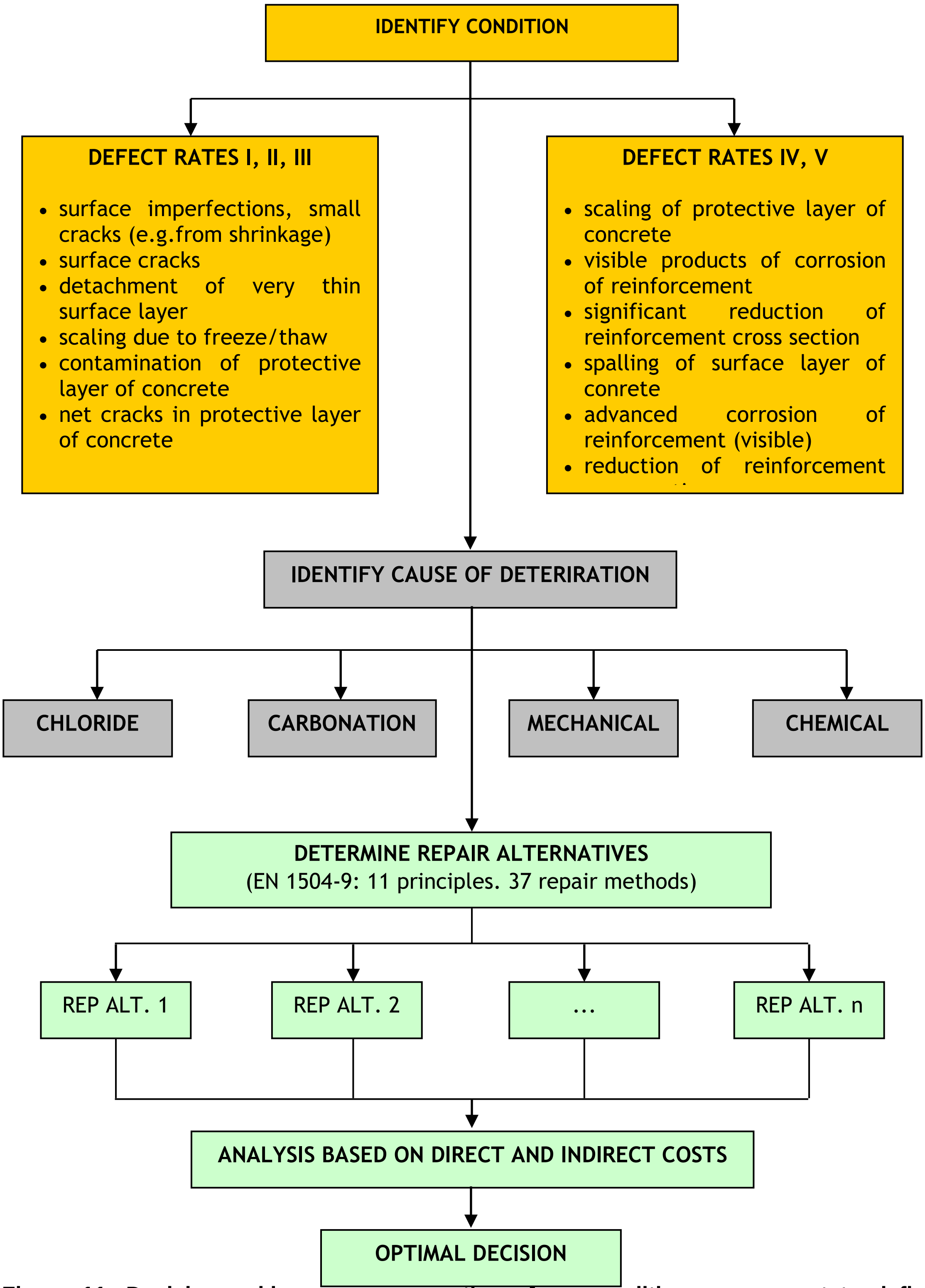


Figure 11: Decision-making process – actions from condition assessment to definition of possible repair alternatives

In the ASCAM survey, the maintenance planning for the Norwegian BMS is performed according to the following equation. Cost of repair is simply compared with the cost of replacement. If the repair costs are more than 50% of replacement, then replacement has to be considered. If the repair costs are more than e.g. 20% of replacement or more than € 250.000, alternatives must be considered. All kinds of intervention can be applied up to maximum cost compared to new bridges. Maintenance measures that can be applied are generic (applicable to any kind of structure), and the best maintenance option is decided based upon engineering evaluation and cost/benefit analysis.

Maintenance planning in the French BMS, as collected through ASCAM, is as follows. There is a daily maintenance, which consists of current works, with neither technical specification, materials or engines, and a specialised maintenance which is decided by the administrators. They rely on knowledge of bridge management concerning each bridge they are in charge of, their conditions and evolutions and make decisions depending on local management policy, the works needed for the whole infrastructure system to be maintained and the financial capacity of the service. Bridge administrators decide when they want to plan maintenance works. They are usually planned when bridges are classified 2E or higher. Model does not generate an optimal maintenance strategy but the Inter-departmental Road Divisions have to ensure a specific proportion in each class by the year 2020 (under 30 % of bridges in class 2E, 15% in class 3 and 1% in class 3U). A method which uses socio-economic parameters is under development. These parameters include the bridge costs (construction and destruction costs) balanced with their significance in the local infrastructure and traffic organisation.

Common maintenance measures do not need structural design and are generic. They are correlated to the type of elements concerning bridge equipment (joints, bearing …) or the type of material concerning other elements. More important maintenance measures like external pre-stress, are correlated to each type of bridge. According to the rules of the public command, there is also a generic maintenance which allows access to the cheapest prices and/or, at the same time, better maintenance quality than in specific contracts' cases. The best maintenance option is decided by the chief-administrator, in close cooperation with the administrator in charge of the bridges who establishes a plan over several years based on the condition of its bridges and their development, the advantages and risks of the different scenarios in the programming of the works. Interventions on a bridge's element decrease the element's classification to 1 but not the classification of the entire bridge (the classification of the bridge is the maximum of the element's classifications).

5.3 Maintenance options

In the report from IABMAS BMC [2010] information about interventions on the element, structure and project level were collected. Most of the systems use user-defined intervention options and 8 out of 17 systems use predefined intervention standards (Table 28).

Table 28: Intervention information on element-, structure- and project level [IABMAS BMC, 2010]

No.	Country	Name	Element level			Structure level			Project level		
			Predefined standard	User defined/ custom	Intervention strategy	Predefined standard	User defined/ custom	Intervention strategy	Predefined standard	User defined/ custom	Intervention strategy
1	Canada	QBMS	+	+	+	+	+	+		+	
2	Canada	QBMS	+	+	+	+	+	+		+	
3	Denmark	DANBRO	+	+	+	+		+	+	+	+
4	Finland	FBMS	+	+	+	+	+	+		+	+
5	Germany	GBMS									
6	Ireland	Eirspan	+	+	+		+	+			
7	Italy	APTBMS		+	+					+	+
8	Japan	RPIBMS	+	+	+	+	+				
9	Korea	KRBMS									
10	Latvia	Lat Brutus	+	+	+		+			+	+
11	Netherlands	DISK	+	+	+		+				
12	Poland	SMOK		+	+		+			+	
13	Poland	SZOK		+	+		+			+	
14	Spain	SGP	+	+		+	+				
15	Sweden	BaTMan		+			+	+			
16	Switzerland	KUBA	+	+	+		+	+			
17	USA	ABMS	+	+		+	+				
18	USA	Pontis	+	+	+	+	+	+	+	+	+
Total			12	16	13	8	14	8	2	9	5

Over the past 30 to 40 years, the industry's understanding of the technical performance requirements of concrete repair and protection products has increased significantly. The new European standard EN 1504 represents the culmination of over 15 years of consultation and committee work by professionals from all sectors of the concrete repair industry. The series of CEN standards under EN 1504 defines the principles of rehabilitation of concrete structures. Furthermore, these standards specify guidelines for the choice of repair materials and systems that are appropriate for rehabilitation and maintenance of concrete structures:

• Assessment of the registered state of a concrete structure
• Determination of the courses of damage
• Determination of the objective of the rehabilitation of a deteriorated concrete structure
• Choice of relevant principles for rehabilitation of a deteriorated concrete structure
• Choice of methods for rehabilitation of a deteriorated concrete structure
• Definition of the properties for repair materials and systems for rehabilitation of a deteriorated concrete structure or its members
• Specification of requirements for the maintenance that should always follow rehabilitation of a deteriorated concrete structure or its members.

It is significant to note that the EN 1504 standards do not exclude other methods than those mentioned in EN 1504-9. However, application of such methods is limited to situations in which their application is justified. However, documentation of the properties of the considered repair materials and systems and their characteristics is mandatory.

According to EN1504-9, the owner has six different maintenance strategies, see Table 29.

Table 29: Maintenance strategies

OPTIONS FOR PROTECTION AND REPAIR	
1	Do nothing for a certain time Postpone the repair work, but monitor the degradation process
2	Re-analysis of structural capacity, possibly leading to downgrading of the function of the concrete structure
3	Prevention or reduction of further deterioration, without improvement of the concrete structure
4	Improvement, strengthening or refurbishment of all or part of the concrete structure
5	Reconstruction of part or all of the concrete structure
6	Demolition of all or part of the concrete structure

Table 29 indicates the six main strategies that should be evaluated in a process when deciding on the right maintenance for the actual structure. It should be emphasised that more than one strategy may be applicable and each structural part should be given a separate evaluation. The selection of the right maintenance strategy and repair method should, as a minimum, be based on the owner's requirements, built documentation, evaluation of the bearing capacity, cost benefit analyses and a detailed condition assessment.

The owner himself or a qualified consultant should document the selection process. This documentation should, as a minimum, contain the following main aspects:

- Documentation, showing that the selected maintenance strategy, or repair method, satisfies the owner's requirements.
- Cost benefit analyses comparing different strategies
- Final evaluation and a short conclusion to explain why the actual strategy and/or method are selected.

In Table 30, a relation is established between degradation rate (with some characteristic performance indicators) and possible repair methods. Methods and principles used in Table 30 are some of the repair methods from standard EN 1504-9:2001, which overall includes 11 principles and 37 methods.

Table 30: Possible repair methods for some characteristic defects

Deg. rate	Characteristic performance indicators	Possible repair methods (principle; method) (HRN EN 1504-9:2001)
0	-	-
I	Surface imperfections	Surface coating (1 [PI], 2 [MC], 5 [PR], 6 [RC]; 1.2, 2.2, 5.1, 6.1)
	Small cracks (e.g.from shrinkage)	
II	Surface cracks	Surface coating (1 [PI], 2 [MC], 5 [PR], 6 [RC]; 1.2, 2.2, 5.1, 6.1)
	Detachment of very thin	

Deg. rate	Characteristic performance indicators	Possible repair methods (principle; method) (HRN EN 1504-9:2001)
	surface layer	
III	Net cracks in protective layer of concrete	Reprofilation of concrete depth depending on depth of penetration, cost given for 2 cm (3 [CR]; 3.1, 3.3) – applying mortar by hand or spraying
	Contamination of protective layer of concrete (chloride penetration, dealkalisation)	
	Scaling due to freeze/thaw cycles	
IV	Scaling of protective layer of concrete	Reprofilation of concrete 8 cm in depth (behind reinforcement), replacement of part of reinforcement (3 [CR]; 3.1, 3.2, 3.3) - applying mortar/concrete by hand or spraying or recasting
	Visible products of corrosion of reinforcement	
	Reduction of reinforcement cross section	
V	Spalling of surface layer of concrete	Reprofilation of concrete 8 cm or more in depth (behind reinforcement), replacement of part of reinforcement (3 [CR]; 3.1, 3.2, 3.3) - applying mortar/concrete by hand or spraying or recasting
	Advanced corrosion of reinforcement (visible)	Replacement of element (3 [CR]; 3.4)
	Significant reduction of reinforcement cross section	

5.4 Condition and maintenance

After an intervention or maintenance measure has been applied to a structure, the resulting condition of the bridge is not always that of the new structure. Therefore it is important that the impact of each repair option on the bridge condition is determined.
Bridge condition before and after repair is usually monitored through regular inspections, but in most cases this is not enough, since the deterioration is very often not fully suppressed.
The repair index methodology developed in the projects REHABCON and CONREPNET suggests monitoring the performance of concrete repaired structures based on measured technical parameters. When monitoring the post-repair phase, it is necessary to establish the performance indicators mentioned in stage 4 of Fig. 10, and to choose appropriate procedures and test methods to assess the performance of repair or remediation intervention(s) on concrete structures.
During the post-repair period, the objective is to devise a methodology to monitor the performance of the selected repair option and of the repaired structure as a whole. The methodology is based on the same principles as the RIM for selecting the best repair option, but some improvements have been made to accommodate the new objectives. The process must start with the requirements definition (R) of the repair material or repaired structure, which are qualified by the performance indicators (PI). These performance indicators must be determined by different tests or evaluation methods, which are scored in accordance with a certain set of evaluation criteria. The evaluation criteria represent the test results on a four-level scale, from 4 (very bad) to 1 (very good). A high score indicates poor performance. In this way, it is possible to calculate an index for each performance indicator (PI), as indicated in Eq. (6)

$$\mathrm{PI} = \frac{\Sigma\,\mathrm{EC}}{\text{number of EC}}. \quad (6)$$

The requirements (R) are calculated for each specific case using Eq. (7):

$$R = \Sigma\,\mathrm{PI} \cdot \mathrm{Im}_{\mathrm{PI}}, \quad (7)$$

where Im_{PI} is the importance assigned to each performance indicator, *PI*. The final assessment is made through the calculation of a Repair index (*RI*) which is obtained by summing the requirement indices, each multiplied by its relative importance, Im_R:

$$\mathrm{RI} = \sum_{1}^{n} R \cdot \mathrm{Im}_R, \quad (8)$$

where *n* is the number of requirements used to qualify each repair and remediation intervention method.

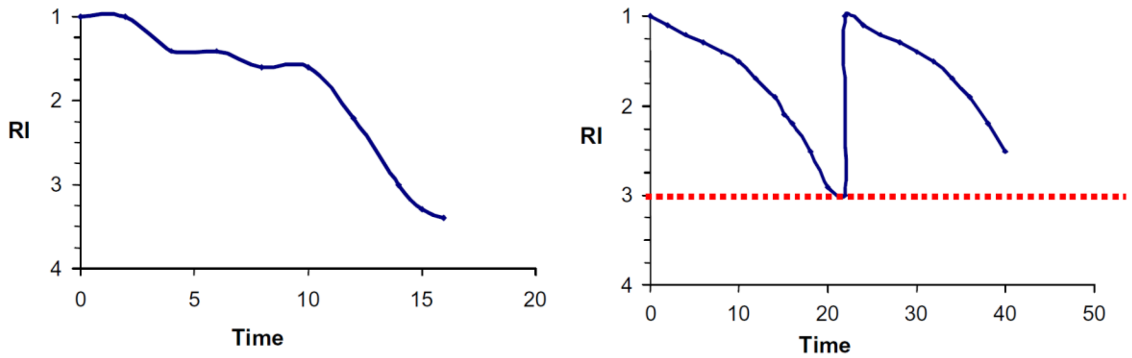


Figure 12: Development of RPI over time (left). Hypothetical threshold value (dotted line) (right)

Figure 12 shows a hypothetical plot of the variation over time of *RI* for a particular structure as a result of its evaluation in periodical inspections. The sum of the importance Im_R of all requirements must be 1, as indicated in Eq. (9), and the sum of the importance Im_{PI} of all the performance indicators that characterize a given requirement must be equal to the importance of that requirement, Im_R (see Eq. (10))

$$1 = \sum_{1}^{n} \mathrm{Im}_R. \quad (9)$$

$$\mathrm{Im}_R = \sum_{1}^{n} \mathrm{Im}_{\mathrm{PI}} \quad (10)$$

The values of RI can also be expressed on a scale from 1 to 4 or can be normalized as a percentage by dividing the actual value of RI by a predefined success threshold value. [Andrade & Martinez, 2009]

6 Maintenance Costs

One of the main disadvantages in most bridge management practices is that repair planning is most often approached from a short-term financial aspect, taking into consideration only the direct costs of a certain maintenance solution. All other influences, such as durability, impact on the environment, social costs such as traffic delays, noise produced during repair process, which are not as transparent as direct costs, are more or less neglected [*fib Bulletin* 44 2008, ISO 15686-7]. This is the reason why results from analyses should be easily understood by residents, stakeholders and decision makers [NCHRP 2001].

It is stated in literature that experience with evaluation regarding environment and health is relativelly limited and under development but it can serve as a useful tool for comparing different repair methods. [REHABCON 2004, Austroads 2006].

From the survey performed in the BRIME project it was reported that most countries store maintenance, repair and, in some cases, inspection costs on their BMS. The BMSs used in most countries do not calculate the financial consequences of traffic disruption caused by maintenance work and the associated traffic management. In the UK, delay costs are calculated using either the computer programme QUADRO or look-up tables derived from the programme. Ireland also uses QUADRO, and Sweden has its own model for the calculation of user costs. [BRIME, Final report, 2001]

From the survey performed by IABMAS BMC in 2010 (see Table 31) it is obvious that the majority of cost information used in BMS is still based on direct intervention cost. The usage of inspection costs is limited but, nevertheless, the implementation of traffic delay and indirect costs is increasing.

Table 31: Cost and prioritization information [IABMAS BMC, 2010]

No.	Country	Name	Cost information					Prioritization	
			Inspection cost	Intervention cost	Traffic delay cost	Indirect user cost	Life-cycle costing	Yes	No
1	Canada	QBMS		+	+	+	+	+	
2	Canada	QBMS		+	+	+	+	+	
3	Denmark	DANBRO	+	+	+	+	+	+	
4	Finland	FBMS		+				+	
5	Germany	GBMS		+	+	+	+		+
6	Ireland	Eirspan		+	+	+	+	+	
7	Italy	APTBMS	+	+			+	+	
8	Japan	RPIBMS		+		+	+	+	
9	Korea	KRBMS							+
10	Latvia	Lat Brutus		+					+
11	Netherlands	DISK	+	+			+	+	
12	Poland	SMOK		+					+
13	Poland	SZOK		+					+
14	Spain	SGP		+	+	+		+	
15	Sweden	BaTMan	+	+	+		+	+	
16	Switzerland	KUBA	+	+	+	+	+	+	
17	USA	ABMS	+	+					+
18	USA	Pontis		+	+	+	+	+	
Total			6	17	9	9	11	12	6

6.1 Direct costs

The direct costs of maintenance, repair and rehabilitation in BMS can be expressed either as a unit cost or as a percentage of the initial or replacement costs of the bridge. An example of MR&R unit costs for some frequently performed interventions on deteriorating reinforced concrete structures based on the case studies analysed in Croatia is given in Table 32.

Table 32: Direct costs of maintenance interventions

No	Description	Croatia
1	Replacing concrete with mortar 4 cm thick (without waterjetting)	50-65 €/m^2
2	Recasting concrete (concrete + instalment, without waterjetting and without new reinforcement)	250 €/m^3
3	Coating horizontal surface	15 €/m^2
4	Coating soffit	27 €/m^2
5	Waterjetting (cost depending on concrete class)	400-800 €/m^3

In Table 33 data about bridge management costs in some European countries are presented, showing the relationship between the cost of annual maintenance and the replacement value.

Table 33: Global data on bridge management in Europe [BRIME Final report, 2001]

Owner	Number of bridges	Maintenance: annual cost (MEuro)	Replacement value of stock (MEuro)	Ratio (%)
Belgium Roads of Wallonnie	5 000	10	3 800	**0.3**
Finland Road Network	15 000	30	2 900	**1.0**
France National Road Network	22 000	50	10 800	**0.5**
France National conceded motorways	6 000	23	4 100	**0.6**
Germany National Road Network	34 600	318	30 000	**1.0**
Great Britain National Road Network	9 500	225	22 500	**1.0**
Ireland National Road Network	> 1 800	2.5	450	**0.6**
Norway Road Network	17 000	37	6 000	**0.6**
Spain National Road Network	13 600	13	4 100	**0.3**
Sweden National Road Network	15 000	92	5 300	**1.7**

6.2 Case study – Croatia

Table 34 is an expanded version of Table 30 presented in chapter 6.3, in which a relation between degradation category (with some characteristic performance indicators) and direct cost of repair method from the Croatian case studies has been established. For example, the cost for category IV and V is the same but risks are different because category V means that the stability of the element or the whole structure is endangered. Direct costs included in the analysis present current costs on the Croatian market and were collected directly from manufacturers and contractors.

Table 34: Possible repair methods for some characteristic defects

Deg. cat.	Characteristic performance indicators	Possible repair methods (principle; method) (HRN EN 1504-9:2001)	Direct cost €/unit
0	-	-	-
I	Surface imperfections	Surface coating (1 [PI], 2 [MC], 5 [PR], 6 [RC]; 1.2, 2.2, 5.1, 6.1)	25 €/m²
	Small cracks (e.g. from shrinkage)		
II	Surface cracks	Surface coating (1 [PI], 2 [MC], 5 [PR], 6 [RC]; 1.2, 2.2, 5.1, 6.1)	25 €/m²
	Detachment of very thin surface layer		
III	Net cracks in protective layer of concrete	Reprofilation of concrete depth depending on depth of penetration, cost given for 2 cm (3 [CR]; 3.1, 3.3) – applying mortar by hand or spraying	90-130€/m²
	Contamination of protective layer of concrete (chloride penetration, dealkalisation)		
	Scaling due to freeze/thaw cycles		
IV	Scaling of protective layer of concrete	Reprofilation of concrete 8 cm in depth (behind reinforcement), replacement of part of reinforcement (3 [CR]; 3.1, 3.2, 3.3) - applying mortar/concrete by hand or spraying or recasting	180-230€/m²
	Visible products of corrosion of reinforcement		
	Reduction of reinforcement cross section		
V	Spalling of surface layer of concrete	Reprofilation of concrete 8 cm or more in depth (behind reinforcement), replacement of part of reinforcement (3 [CR]; 3.1, 3.2, 3.3) - applying mortar/concrete by hand or spraying or recasting	180-230€/m²
	Advanced corrosion of reinforcement (visible)		
	Significant reduction of reinforcement cross section	Replacement of element (3 [CR]; 3.4)	-

In Table 35 an example of analysing two repair options, concrete recasting or mortar repair, is presented. It is a brief and simple example of two different repair methods which can be equally applied based on their technical characteristics. Usually, the decision is primarily based on the direct costs, disregarding other impacts (social, environmental, life cycle).

Table 35: Direct costs of two repair options regarding degradation type - porous concrete (segregation, mechanical damage, nests in concrete) – 4 cm

Repair option	1 (3 [CR]; 3.1, 3.3)	2 (3 [CR]; 3.2)
Definition	Reprofilation, applying mortar by hand or spraying mortar.	Recasting concrete.
Steps	Removal of concrete by waterjetting – 4 cm	Removal of concrete by waterjetting – 8 cm (concrete to be installed properly needs larger thickness)
	60 €/m^2	120 €/m^2
	Repair of reinforcement, adding new bars (up to app 25%) Protection of reinforcement (coating)	
	Reprofilation of concrete with mortars class R3 or R4 (depending on the structural element, cost for R4) – 4 cm	Reprofilation of concrete with concrete, class depending on structural element and environmental condition (cost for C35/45) – 8 cm
	50 €/m^2	35 €/m^2

In Table 36, the direct costs are expanded further into manual labour, mechanization, material itself and other direct costs. In this way, a method becomes more transparent and other influences are easier to recognize. Indirect costs (impact on the environment - IE, social cost -SC) can be recognized and should be further analysed based on material (production, compound, transport would determine IE value) and installment procedure (duration and energy consumption would determine SC (traffic jams) and IE (CO_2 emission)). [Habert G., 2009; Škarić Palić S. & Stipanović Oslaković I., 2010]:

Table 36: Analysis of direst costs

Repair option	1 (3 [CR]; 3.1, 3.3)	2 (3 [CR]; 3.2)
Definition	Reprofilation, applying mortar by hand or spraying mortar	Recasting concrete.
Manual labour	8,1 €/m^2	15,4 €/m^2
Mechanization (e.g. aggregate, pumps, compressor...)	7,6 €/m^2	2,2 €/m^2
Material (e.g. concrete, mortar, fuel, formwork...)	34,3 €/m^2	17,4 €/m^2

When choosing an optimal repair alternative, the whole life cycle after the performed option should be taken into consideration. For this a net present value (NPV) for each method should be analyzed taking into consideration discount rates due to the fact that money is spent during a long period of time. A targeted service life needs to be established for this purpose. Costs can then be combined separately from material, equipment and labour costs (establish from current market). Durability (i.e. degradation after repair), performance, effect on deterioration rate are parameters needed for life cycle cost analysis.

A case study was performed on 12 bridges (viaducts) inspected in 1998 and in 2010. A list of analysed viaducts is shown in Table 37, with the year of construction, length and technical characteristics. Only routine maintenance was performed on viaducts from the year of construction until the final inspection in year 2010.

In 1998 and 2010 visual inspection was performed on all structural elements (bridge equipment, substructure and superstructure elements), and all defects (delamination, spalling, segregation, corrosion of reinforcement, wet areas, mechanical defects, cracks) were recorded and categorized accordingly. Upon the performed condition assessment a list of repair works needed to get structural elements (substructure and superstructure in this analysis) into their original condition was made with direct costs of all activities. A detailed report about the performed analysis in this case study is given in ANNEX B.

Table 37: Analyzed viaducts

Nr	Year	Length (m)	Technical characteristics
1	1988	186 (6 spans)	• 4 precast prestressed "T" girders (H=1,70m, L=29,85m) + continuity slab 24 cm (precast slabs 6 cm + in-situ concrete 18 cm) • Cantilever head beam • 2xO column • Precast curbs and cornices
2	1988	189 (6 spans)	
3	1988	186 (6 spans)	
4	1988	186 (6 spans)	
5	1988	127 (4 spans)	
6	1988	480 (16 spans)	• 4 precast prestressed "I" girders (H=1,70m, L=29,85m) + continuity slab 24 cm (precast slabs 6 cm + in-situ concrete 18 cm) • Cantilever head beam • column • Precast curbs and cornice
7	1981	377 (14 spans)	• 6 precast prestressed box girders (H=1,50m, L=29,10m) • Cantilever head beam • 2xO column
8	1981	74 (4 spans)	• 6 precast prestressed box girders (H=1,10m, L=17,30m) • Cantilever head beam • column
9	1981	240 (8 spans)	• 4 precast prestressed "I" girders (H=1,86m, L=29,75m) + continuity precast slab 17 cm • Cantilever head beam • Octagonal column • Monolithic pedestrian ways
10	1981	122 (6 spans)	• 4 precast prestressed "I" girders + continuity precast slab • Cantilever head beam • 2xO column • Precast curbs and cornices
11	1981	150 (5 spans)	• 4 precast prestressed "I" girders (H=1,86m, L=29,75m) + continuity precast slab 17 cm • Cantilever head beam • Octagonal column • Monolithic pedestrian ways
12	1981	50 (1 span)	• 4 precast prestressed "T" girders (H=1,70m, L=29,85m) + monolithic continuity slab 17 cm • Monolithic pedestrian ways

In Tables 38 and 39, the direct costs for repairs performed in 1998 and 2010 are presented. They are compared and also transformed into the unit value €/m^2.

Table 38: Direct repair costs in 1998 and 2010

Bridge No	Total repair cost in 1998 (€)	Total repair cost in 2010 (€)
1	7.175,81	293.802,97

Bridge No	Total repair cost in 1998 (€)	Total repair cost in 2010 (€)
2	6.725,48	63.884,60
3	6.263,68	134.067,02
4	8.824,86	29.596,75
5	4.538,51	21.595,51
6	35.095,21	137.722,17
7	791,35	219.654,19
8	375,24	31.916,48
9	50.641,70	421.073,11
10	3.594,60	33.774,90
11	41.135,98	248.705,54
12	13.973,0	91.618,9

Table 39: Repair unit costs from the Croatian case study

Nr	Year	Bridge area (m^2)	Total repair cost in 1998 (€/m^2)		Total repair cost in 2010 (€/m^2)	
1	1988	1971,6	3,7	Av. vlaue.= 4,2	149,0	Av. vlaue.= 51,2
2		2003,4	3,4		31,9	
3		1971,6	3,2		68,0	
4		1971,6	4,5		15,2	
5		1346,2	3,4		16,0	
6		5088,0	6,9		27,1	
7	1981	4410,9	0,2	Av. vlaue.= 11,6	49,8	Av. vlaue.= 93,9
8		843,6	0,5		37,8	
9		2760,0	18,4		152,6	
10		1725,0	2,1		19,6	
11		1342	23,9		144,2	
12		575,0	24,3		159,3	

The averaged value of direct repair costs in relation to the age of the bridge is presented in Figure 13. It is obvious that after approx. 17 years of usage, the direct repair costs increase rapidly.

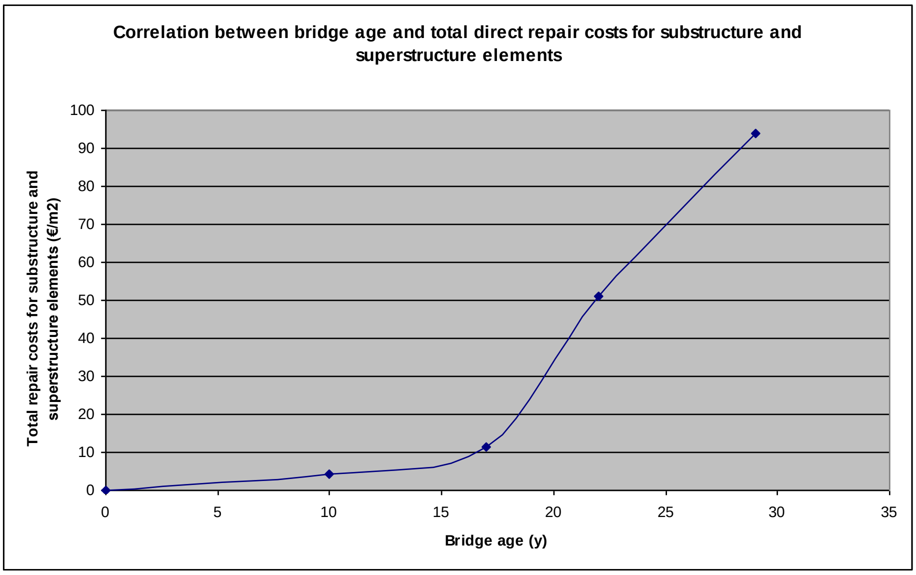


Figure 13: Direct costs established on a case study of 12 viaducts

6.3 Indirect costs

Indirect costs can be evaluated in monetary terms but this can be quite difficult and sometimes misleading. Perhaps a better solution would be – especially when the optimization process is correlative (meaning the decision is made by correlating few repair alternatives) - to establish a grading system and rate indirect costs accordingly.
In order to qualify and quantify indirect costs of different maintenance interventions, the following information about disruption of traffic, traffic restrictions, duration of repair woks, noise, CO_2 pollution and any other induced costs should be collected.
In analysing indirect costs the crucial step is to establish all indirect costs. Each analysed method/alternative/solution has to be described in detail with all the associated activities (define resources, identify work tasks in the process, determine the logic of the process, build a model/chart/diagram of the process) [Hong et al. 2007].

For the purpose of establishing indirect costs, the potential environmental and social impacts should be highlighted first and afterwards analysed. The list of possible social and environmental impacts is given in Table 40. [Austroads, 2006].

Table 40: Overview of potential social and environmental impacts

Social impacts	Environmental impacts
Health and well-being – air pollution, water pollution and noise exposure Safety effects – higher accidents rate Travel time changes Accessibility – closely linked to travel time changes Noise Choice – restriction in transport choice Community cohesion – ability of people to undertake desired activities or access facilities Community perception – ride quality, aesthetics, changes in visual landscape Vehicle operating costs – alteration in personal travel costs Economic development – changes in land value	Resource use Air quality Waste management Heritage Water quality Biodiversity

6.4 Case study – Slovenia

Indirect costs of bridge repair were evaluated during the ARCHES project, using improved Ultra High Performance Fibre Reinforced Concrete (UHPFRC) for the repair of the Log Čezsoški bridge, in the NW of Slovenia. Both, social and environmental impacts were estimated.

6.4.1 Social impacts

During the presentation of the innovative repair material and associated procedure to the designer, contractor and owner, the social impacts were thoroughly analysed. The Log Čezsoški bridge is a 1-lane bridge. As it is the only one crossing river Soča within 7.5 km, its closure has a major social impact on the users. The mayor of municipally of Bovec, in which the bridge is located, pointed out two restrictions: the bridge shall not be closed before the end of the school year (25th June) as the bridge is used daily by the school children on their way to school, and it should be reopened as soon as possible, as it represents an important connection to tourist attractions. Thus, the reduction of the construction site duration from three months to just one was an important advantage of the proposed solution. By implementing innovative UHPFRC and keeping the deadline, the social impact was reduced to a minimum to the great satisfaction of all users.

6.4.2 Environmental impact

The environmental impact of the bridge repair using UHPFRC was evaluated based on an LCCA analysis, calculating the emission of CO2. Four different scenarios were taken into consideration: the traditional repair using “ordinary” concrete, the traditional repair using “green” concrete, the innovative repair using “ordinary” UHPFRC and the innovative repair using “green” UHPFRC. The environmental impact was evaluated for a unit of material produced, for the repair itself, taking into consideration the amount of material applied and all worksincluding necessary additional detour kilometres, and for the (longer) service life of the repair. The main conclusion was that if the impact of the traffic deviation caused by the bridge closure is considered, the global warming impact of this eco-UHPFRC rehabilitation solution is significantly lower than the impact of the traditional rehabilitation (Figure 14).

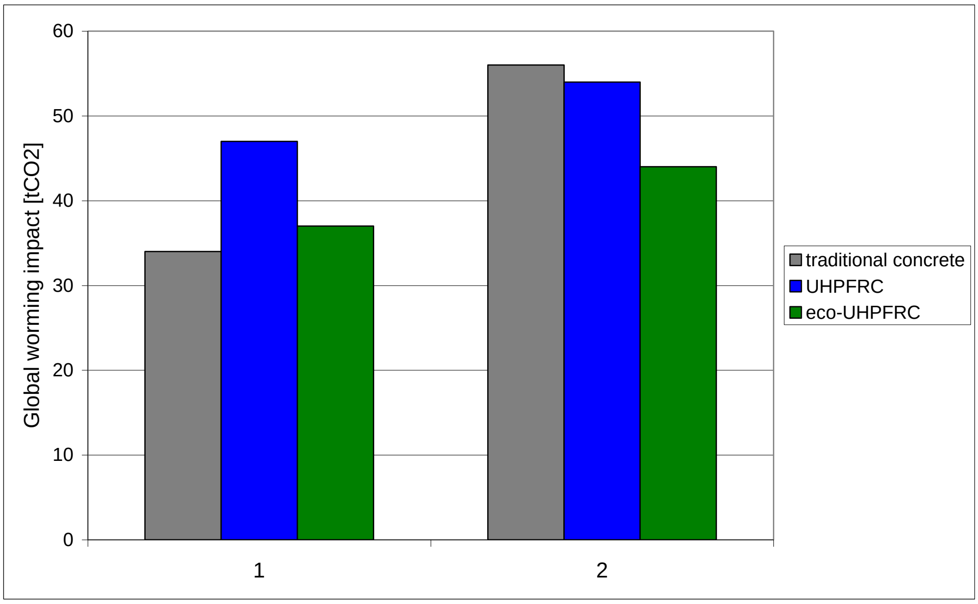


Figure 14: Global warming impact for rehabilitation works (1) and rehabilitation works + CO2 emission due to traffic detour (2), both for Log Čezsoški bridge

7 Key performance indicators

In this chapter an initial search for relations between technical KPI (Key performance Indicators) and EUSL (End User Service Level) is performed. In current practice, the need for this is widely recognized but direct relations are still missing. Basic requirements for bridges are as follows:

- Safety (capability of structure to overcome influences from the environment)
- Stability (capability of structure to contravene shape changing)
- Functionality demands (traffic condition)
- Comfort
- Consistency (durability) – (ability of structure to maintain capacity of safety and serviceability)

Additional requirements:

- Aesthetics (also in regard to the surroundings)
- Originality
- Ease of construction
- Economics
- Ease of maintenance

Economic requirements

- Prodigality of cheap construction (reactive)
- Optimum of durability according to the cost
- LCC

When designing a new bridge, but also when planning measures/interventions and managing a bridge through its whole life cycle, the optimum of all the above requirements should be aimed for. These requirements lead to the definition of key performance indicators for bridges.

Management of road infrastructure networks recently started recognizing the end user as a very important link in upgrading the network itself, with the increased need for expert analysis (life-cycle analyses).
So far, analyses regarding KPIs emphasised parameters which describe the condition of the structure and road itself, and have direct influence on financial activities of the investor i.e. authorities responsible for managing existing road networks. On the other hand, parameters which would describe the infrastructure condition influence on different end user service levels have not been researched yet. However, defining these indicators which are important for the end user of road structures as well as roads, and for the society as a whole, is the key precondition for effective designing, construction and maintenance of infrastructure, beneficial for the society and the environment. Their definition is important also because of mutual harmonization between different European countries and the definition of a uniform model for improved and more effective performance.
These KPIs would be used within an advanced management process to monitor performance of the management strategy. The information is required on service level KPIs and their evolution over time, the development of environmental and socio-economic KPIs and interaction between different KPIs. [FHWA, 2011]

Key Performance Indicators (KPIs) can generally be divided into:

- Service level KPI
- Environmental KPI
- Socio-economic KPI

In Table 41 some of the possible single key performance indicators for bridges which affect the end users are suggested, categorized into three groups as previously described.
End users may be divided in two groups:

- directly influenced ends users (bridge users, drivers etc.) and
- indirectly influenced end users (residents in the area, workers in the immediate vicinity etc.)

End users can also be in both groups at the same time. Once all key performance indicators are established for a certain structure in a certain situation, the required measures/interventions can be established, ,leading to the total costs of influence on the end user.

Table 41 Key performance indicators for bridges

SINGLE KEY PERFORMANCE INDICATORS FOR BRIDGES WHICH AFFECT THE END USER (TECHNICAL AND NON-TECHNICAL PERFORMANCE INDICATORS)		
SERVICE LEVEL KPIs	***ENVIRONMENTAL KPIs***	***SOCIO AND ECONOMIC KPIs***
Everything that causes any kind of distress for the end user	***Everything that effects the environment***	***Everything that has social and economic influence on the end user***
MEASURABLE PARAMETERS		
VIBRATION while crossing the bridge which can be caused by one or more of the following: • **Unbalance of static systems of bridge** • **Design deficiencies** • **Mistakes during construction** • **Bearings** • **Maintenance problems** **Measurable parameter ISO2372 - m/s, km/h**	***Influence on the AIR QUALITY (toxicity):*** • **Global effect (CO_2 emission, SO_4 greenhouse effect, acid rain)** • **Local effect (CO, NO_2, CH)**	***Influence on the AADT – average annual daily traffic:*** • **Reduced speed due to condition, or inspections and maintenance works** • **Closed traffic for inspections or maintenance works**
NOISE while crossing the bridge which can be caused by one or more of the following: • **Inadequate or misinstalled rail expansion joints** • **Transition from embankment to the bridge and vice versa** **Measurable parameter – decibel**	***VIOLATION OF NATURAL SURROUNDINGS (depletion of natural resources, habitat alteration)***	***ECONOMICAL DEVELOPMENT OF THE AREA***
DEGRADATION OF CONCRETE which can cause problems in traffic which and can be caused by one or more of the following: • **Design deficiencies** • **Mistakes during construction**	***ENERGY CONSUMPTION (production of materials, transport, installation)***	***LIFE CYCLE COST***

SINGLE KEY PERFORMANCE INDICATORS FOR BRIDGES WHICH AFFECT THE END USER (TECHNICAL AND NON-TECHNICAL PERFORMANCE INDICATORS)		
SERVICE LEVEL KPIs	*ENVIRONMENTAL KPIs*	*SOCIO AND ECONOMIC KPIs*
• **Ageing** • **Maintenance problems** **Measurable parameters depending on the type of degradation**		
UNMEASURABLE PARAMETERS OR PARAMETERS THAT ARE DIFFICULT TO MEASURE		
PSYCHOLOGICAL INDICATORS OF DISTRESS caused by: • **Wrong design of grade level of a bridge** • **Dissallowed deformation (deflection)** • **Uneven crossing from embankment to the rigid structure (bridge) and vice versa** • **Unproperly installed rail expansion joints (dilatation)** • **Bad foundation** • **“peak travel time”**	***VIOLATION OF FLORA AND FAUNA*** ***EFFECT ON SURFACE AND GROUND WATER*** ***EUTROPHICATION***	***RELEVANT TRAFFIC LOAD*** ***TRANSPORT COST (direct)*** ***LIFE OF TREATMENT*** ***TRAVELLING TIME*** ***INTENSIFYING OF INVESTMENTS IN MAINTAINING ROAD INFRASTRUCTURE*** ***MIGRATION (goods, population)*** ***INFLUENCE ON CULTURAL HERITAGE***
PSYCHOLOGICAL INDICATORS OF INSECURITY: • **Insufficient load carrying capacity** • **Lack of emergency lane on a bridge**		***TRAFFIC SAFETY***
REPAIR METHODS ⇒ TOTAL COSTS		

Some conventional definitions of several concepts (e.g. safety) were (only for the moment) disregarded in order to gain the freedom to come up with these new and innovative relations.

8 Condition and maintenance measures in relation to the EUSL

Condition of a structure as well as maintenance activities affect the end users in different ways. In the service life of a structure there are several important stages related to the condition, as can be seen in Figure 15. Hereafter, two stages are recognized as most important for determining the influence on direct and indirect end-users: 1) damaged condition, defined through categories of damage, and 2) the stage when repair is undertaken, i.e. during the execution of the maintenance measure.

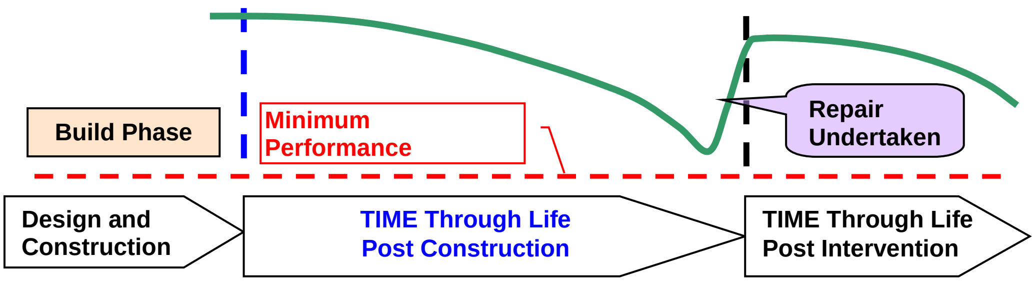


Figure 15: Phases of the structure within the service life [fib Bulletin 44]

In Figure 16 the relationship between damage (degradation) categories three levels of key performance indicators affecting end user is presented.
Figure 17 presents the influence of a certain possible maintenance intervention needed to repair a certain damage (degradation) category, on different end users service levels.

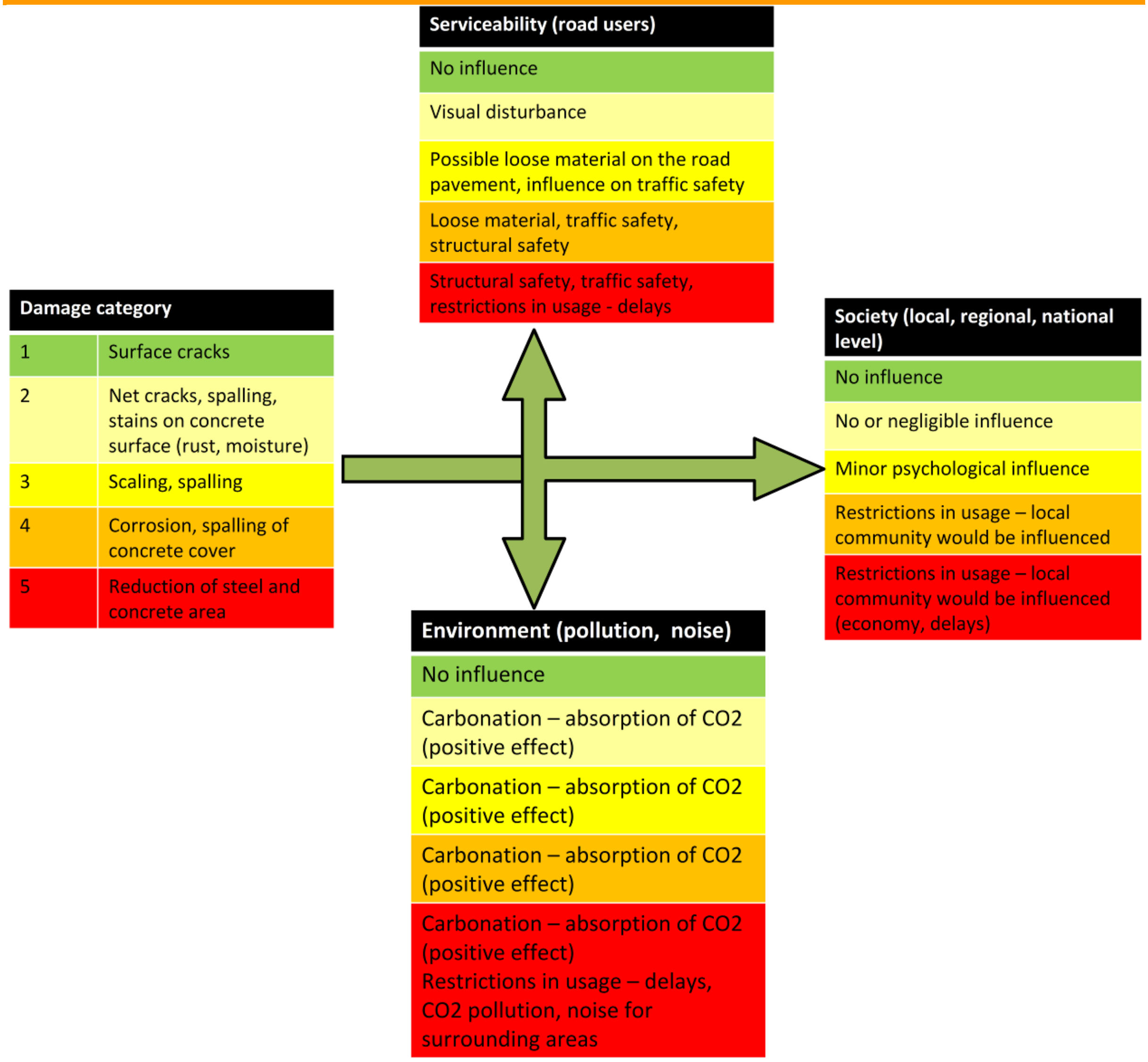


Figure 16 Relationship between damage categories and three categories of EUSL – qualitative description of possible effects

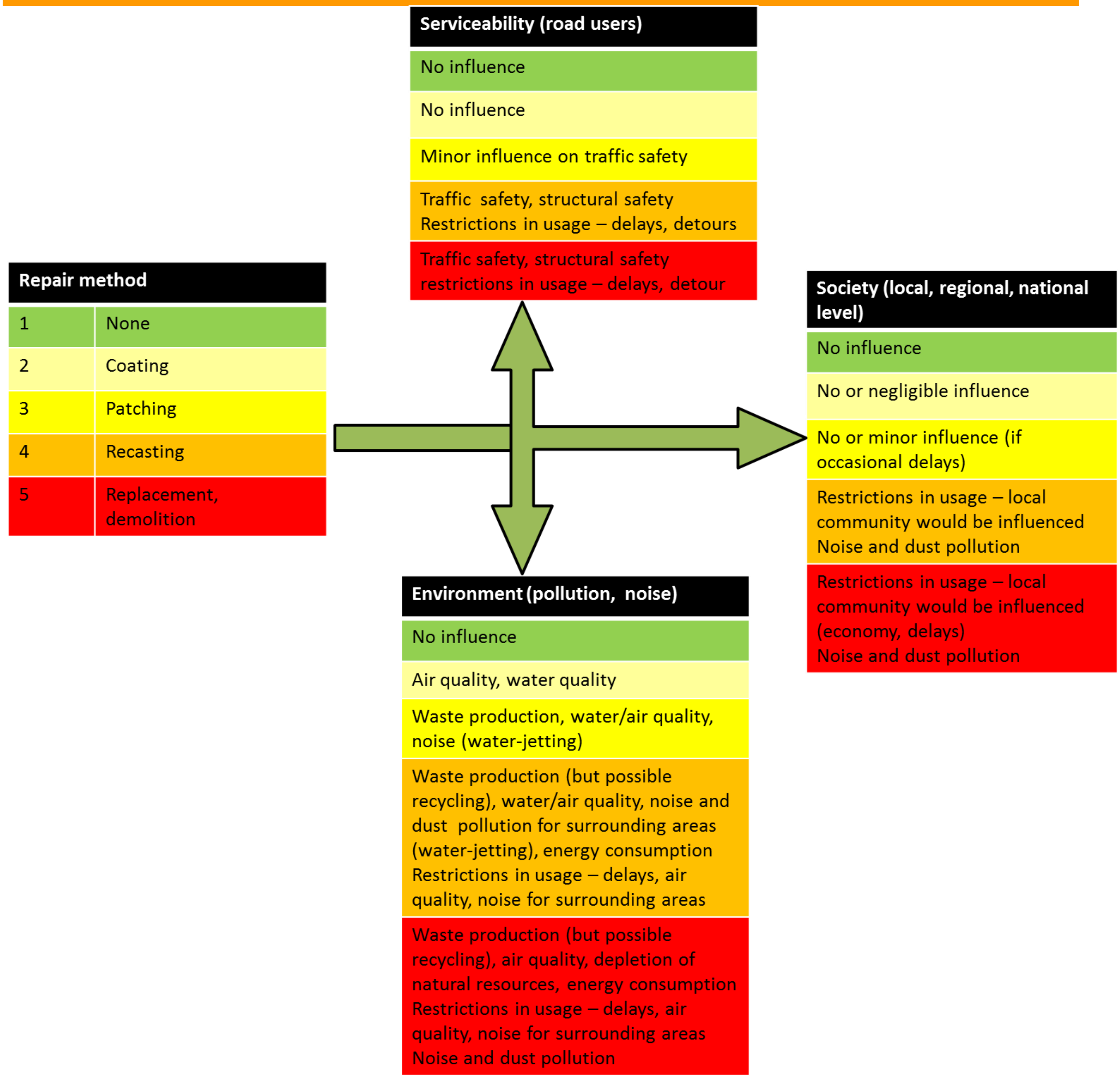


Figure 17 Relationship between repair method for a certain damage category and three categories of EUSL – qualitative description of possible effects

9 Conclusion

The main objective of this report was to give an overview of the existing management systems for structures, with the main focus on bridges. From the collected information and literature review, it can be concluded that the management of the network is usually object-oriented, which means that the amount of money allocated to each network asset is determined through object-oriented management systems (pavement management systems, bridge management systems, etc.) working independently to optimise the financial allocations. Over the last decade, a new network management philosophy has emerged, which puts the customer - the traffic user - at the centre, and looks at methods to allocate an optimal amount of money to each specific asset (roads, bridges, tunnels, lighting, signs, guard rails, etc.) in terms of socio-economic requirements.

Condition assessments vary in frequency of performance, in condition rating levels and in decision-making about the final condition of the structure as a whole. The influence of individual component ratings on the overall bridge is not clearly defined in many countries.

Based on the experience of the authors and case studies analysed within ASCAM, one of the main conclusions about condition assessment is that they are still largely based on subjective observations of the person who performs the assessment. Usually, this is done without objective support of testing and monitoring results. In order to prevent future mistakes and loss of data, the simplest way would be to record the assessed defects of a certain structure/element in drawings or photographs with percentage (surface area) of the element belonging to a certain damage category. That would enable future examiners to compare progress of defects with an objective record of previous inspections.

Although BMSs have been used for some years, the experience from these management practices (data about condition in relation to MR&R costs) is typically not used for prediction of future performance. In this respect it is necessary to state again the importance of credible and reliable data especially about condition assessments performed over the years because this is the basis for all further analysis in a certain BMS.

Performance indicators are not uniquely defined but can normally be classified in three categories: structural safety (load-bearing capacity), serviceability (traffic safety), and durability.

Prioritising bridges for repair employs a range of methods, from subjective decisions based on expert judgement to complex optimization techniques. Although optimization techniques may be on a high level (probabilistic approach), the fact remains that they still rely on very subjective condition assessment data.

Relationships between maintenance measures, bridge condition and end-user service levels are not yet established in current practice and need to be further researched. Some of the possible applicable single key performance indicators for bridges which affect end users and were developed in ASCAM related to three categories of KPIs: service level, environmental and socio-economic.

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