Universität für Bodenkultur Wien
Department für Bautechnik +
Naturgefahren

Winter School Zell am See
Performance-based assessment of Existing Road Bridges

Schriftenreihe des Departments
Nr. 25 – August 2018

18th – 21st December, 2017
Hotel St. Hubertushof Zell am See Zell am See,
Salzburg, Austria

Organisers:
Alfred Strauss
Jose Matos
Helmut Wenzel
Konrad Bergmeister
within the COST Action TU1406 "Quality specifications for roadway bridges, standardization at a European level (BridgeSpec)"
(http://www.cost.eu/COST_Actions/tud/TU1406)
University of Natural Resources and Life Sciences,

Gregor Mendel Strasse 33 A 1180 Wien , Austria
ISSN 1811-8747

OBJECTIVES

The objective of the COST TU1406 Winter School – Zell am See is to spread the latest knowledge and developments acquired by the action in the topic of performance-based assessment of existing road bridges. The school aims at teaching the most recent developments of COST Action TU1406 on performance indicators and performance goals, focusing on the findings of WG1, WG2 and WG3.

In the first year of COST Action TU1406 the main focus was on the screening process of existing European documents and establishing a database for PIs. The goal was to explore performance indicators of bridge structures, in the course of international research cooperation, which capture the mechanical and technical properties and its degradation behaviour, already partly covered by code specifications. Considerations also include: natural aging, quality of the material; service life design methods; sustainable indicators; environmental, economic and social based indicators, performance profiles. The findings of this process are incorporated in a PI-KPI database which will be available to the user for its practical use.

The second year focused on technical and non-technical bridge performance goals. The aim was to identify existing performance goals (where the term goal pertains to quantifiable requirement and/or threshold value) for the indicators previously indicated in WG1. The performance goals vary according to technical, environmental, economic and social factors. These goals are already in a report which is now the basis for the objective performance assessment.

The third year of COST TU1406 is focused on establishing a quality control (QC) plan for different types of bridges. The goal is to create a procedure, based on heuristic rules and on WG1 and WG2 findings, which will allow bridge owners to define a QC plan for each individual bridge.

The objective of the Winter School is to spread the latest knowledge and developments acquired by the action in the topic of performance-based assessment of existing road bridges, and has the aim to teach the most recent developments of COST Action TU1406 on performance indicators, performance goals and quality control plans, focusing on the findings of WG1, WG2 and WG3. In this winter school participants will be familiarized with the developed tools and database. The application of the tools to defined bridge structures will be worked out in form of an interactive workshop. Participants will be able to use the tools in their daily practice after attending this training school.

SCOPE

The event is co-organised with the University of Natural Resources and Life Sciences in Vienna. It will cover WG1, WG2 and WG3 topics of COST Action TU1406, which are ”the assessment of road bridges through Key Performance Indicators (KPIs)”, ”the establishment of Performance Thresholds/Goals” and “recommendations for the establishment of QC plans”.

Venue: Hotel St. Hubertushof Zell am See, Zell am See, Salzburg. Room: to be assigned Time: 18 – 21 December 2017

Organisers:

COST Action TU1406 ”Quality specifications for roadway bridges, standardization at a European level (BridgeSpec)” (http://www.cost.eu/COST_Actions/tud/TU1406)
University of Natural Resources and Life Sciences
Gregor Mendel Strasse 33, A-1180 Wien, Austria

Trainers list of experts:

- Prof. José C. Matos, Civil Engineering Department, School of Engineering, University of Minho (UMinho), Portugal.
- Prof. Alfred Strauss, University of Natural Resources and Life Sciences (BOKU), Institute of Structural Engineering, Austria.
- Prof. Irina Stipanovic, University of Twente (UTwente), Faculty of Engineering Technology Construction Management and Engineering Department, The Netherlands.
- Prof. Rade Hajdin, Faculty of Civil Engineering, University of Belgrade, Serbia.
- Prof. Helmut Wenzel, VCE – Vienna Consulting EngineersZT GmbH, Vienna, Austria.

Content

TU1406

COST ACTION

QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

ESF provides the COST Office through a European Commission contract

COST is supported by the EU Framework Programme

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Winter School – Zell am See

Performance-based assessment of Existing Road Bridges

18th – 21st December, 2017
Hotel St. Hubertushof Zell am See
Zell am See, Salzburg, Austria

ACTION CONTACTS

Chair of the Action	Prof. José C. Matos	chair@tu1406.eu
Vice Chair of the Action	Prof. Joan R. Casas	vicechair@tu1406.eu
School Co-Organizer	Prof. Alfred Strauss	alfred.strauss@boku.ac.at
Local organizers	Dr. Alfred Strauss	alfred.strauss@boku.ac.at
	Dr. Helmut Wenzel	wenzel@vce.at
Action websites	http://www.tu1406.eu	http://www.cost.eu
School webpage	http://www.tu1406.eu/zellamsee	

CONTENTS

1. WINTER SCHOOL – ZELL AM SEE

1.1. OBJECTIVES

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Venue: Hotel St. Hubertushof Zell am See, Zell am See, Salzburg.
Room: to be assigned
Time: 18 – 21 December 2017

Local Organizer	Co-Organizer
Prof. Alfred Strauss *BOKU, Austria.*	**Prof. José C. Matos** *Minho University, School of Engineering, Civil Engineering Department, Guimarães, Portugal.*
Dr. Helmut Wenzel *VCE – Vienna Consulting Engineers ZT GmbH, Austria.*	

Organisers: COST Action TU1406 ”Quality specifications for roadway bridges, standardization at a European level (BridgeSpec)” (http://www.cost.eu/COST_Actions/tud/TU1406)

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- Prof. Rade Hajdin, Faculty of Civil Engineering, University of Belgrade, Serbia.
- Dr. Helmut Wenzel, VCE – Vienna Consulting EngineersZT GmbH, Vienna, Austria.

1.3. PROGRAMME

Monday, 18 December 2017

When	What
09:00 – 10:00	Transfer from Vienna to Zell am See

Tuesday, 19 December 2017

When	What
09:00 – 10:00	Opening
10:00 – 10:15	Coffee-break
10:15 – 12:00	Lecture
12:00 – 13:00	Lunch
13:00 – 15:00	Interactive Workshops and World Cafe
15:00 – 15:15	Coffee-break
15:15 – 16:00	Example cases and reflection

Wednesday, 20 December 2017

When	What
09:00 – 10:00	Lecture
10:00 – 10:15	Coffee-break
10:15 – 12:00	Lecture

12:00 – 13:00	Lunch
13:00 – 15:00	Interactive Workshops and World Cafe
15:00 – 15:15	Coffee-break
15:15 – 16:00	Example cases and reflection

Thursday, 21 December 2017

When	What
09:00 – 10:00	Lecture
10:00 – 10:15	Coffee-break
10:15 – 12:00	Lecture
12:00 – 13:00	Lunch
13:00 – 15:00	Interactive Workshops and World Cafe
15:00 – 15:15	Coffee-break
15:15 – 16:00	Example cases and reflection
18:30 –	Social event

Friday, 22 December 2017

When	What
10:00 – 11:00	Transfer from Zell am See to Vienna

1.4. LOCATION, DATES AND TRAVELLING

1.4.1. LOCATION AND DATE

The training school is hosted by Hotel St. Hubertushof Zell am See, Salzburg, Austria and it will be held between the 18th and 21st December 2017. The venue is located in a superb location by the edge of the woods, just a few minutes' walk away from Lake Zell.

Characterised by Lake Zell, the region is picturesquely nestled between the Grasberg Mountains in Kitzbühl in the west, the Central Alps in the south and the Limestone Alps in the north.

Zell am See is a region where are available three top ski resorts with a total of 138 kilometres of slopes: Kitzsteinhorn, Schmittenhöhe and Maiskogel. The region also offers a lot of fun, variety and a large number of alternative sports off-piste. Without a lift or a cable car you can also experience nature in all its variety while winter and snowshoe hiking, tobogganing, curling, cross-country skiing, ice skating and on skiing trips. In order to set out for the most beautiful places, walkers, Nordic walkers and sun worshippers meet on the many winter hiking trails which, amongst other places, pass by the lake promenade.

Hotel St. Hubertushof Zell am See
Seeuferstrasse 7
A-5700 Zell am See
Tel.: +43 (0)6542 767
Fax: +43 (0)6542 767-71
E-Mail: hubertushof@zellamsee.co

Zell am See has been in existence for centuries. Only a market in the 19th century, the town was originally called "Zelle im Pinzgau", probably because it spreads along the shores of Lake Zell and is the indisputable centre of the entire region; today, especially in terms of tourism. The triumph of tourism in Zell am See was marked by the building of the railway through Zell am See in 1875. This transport connection opened an important link between the town and the region, widely known as a gem of relaxation between mountain and lake. The town has been bearing the name "Zell am See" since 1810 and is home to approx. 9.900 habitants today. Many more "temporary" habitants are accommodated by the town during the touristic seasons in summer and in winter. For a long time, winter sport and especially ski holidays were the main reasons for travelling to Zell am See. The clear air and in particular the crystal-clear water of Lake Zell and the quality of the drinking water made the town at Lake Zell more and more popular with summer holiday makers.

More information: https://www.zellamsee-kaprun.com/en

1.4.2.HOW TO GET TO ZELL AM SEE

The venue of our Winter School is in the middle of the Alps. Major airports are only available at some distance. The closest airport is Salzburg, which has limited international connections.

There are the following options for travel:

1. By Plane

The closest airport is Salzburg (75 km), then Innsbruck (150 km) and Munich (250 km). All airports offer public transportation (rail and bus) as well as rent a car facility.

2. By Rail

Zell am See has a main railway station. It can be reached from Salzburg (1.5 hours), from Innsbruck (2.5 hours) and Munich (4 hours). Please have a look at the following web sites for your rail connection.
http://fahrplan.oebb.at/bin/query.exe/en?

3. By Bus

There is a direct bus service from Salzburg Airport to Zell/See (travel time 2 hours). (Bus 260).
http://www.postbus.at/de/Flughafenbus/Flughafenbus_Salzburg/index.jsp
http://www.postbus.at/en/index.jsp

4. By Car

Zell/See is well connected and situated in an attractive area for excursions. To rent a car or to drive on your own might be interesting. The distance to Salzburg is 75 km (1 hour 15 minutes), to Innsbruck 150 km (2 hours) and to Munich 250 km (3 hours).

5. By Taxi

The taxi charge from the Salzburg airport to Zell/See is approximately 130 € per car. In case of several persons travelling in 1 taxi this might be an option. We are also able to send a taxi or a minibus to the airport where the price reduces with the number of travellers. Driving time is 1 hour 15 minutes.

6. Local Travel

The venue is situated on the other side of the lake. To reach it from the town of Zell/See there is a bus shuttle (6 – 19 h) around the lake. Please exit at Thumersbach Centre where the venue is placed.

1.5. ACCOMMODATION

Local organizers suggest using the hotel where the training school will be lectured.

Hotel St. Hubertushof Zell am See
Seeuferstrasse 7
A-5700 Zell am See
Tel.:+43 (0)6542 767
Fax: +43 (0)6542 767-71
E-Mail: hubertushof@zellamsee.co
https://www.hotel-zellamsee.info/en/

In case that you have a plan and would like to get the best options please let us know. I am sure we will be able to help.

1.6. COMMITTEES

An executive scientific committee as well an organizing committee were defined.

1.6.1. SCIENTIFIC COMMITTEE

Name	*TU1406 Position*	*E-mail*
José C. Matos	Chair	chair@tu1406.eu
Alfred Strauss	WG1 Leader	wg1@tu1406.eu
Irina Stipanovic	WG2 Leader	wg2@tu1406.eu
Rade Hajdin	WG3 Leader	wg3@tu1406.eu
Helmut Wenzel	MC member	wenzel@vce.at

1.6.2. ORGANIZING COMMITTEE

Name	*TU1406 Position*	*E-mail*
José C. Matos	Chair	chair@tu1406.eu
Alfred Strauss	WG1 Leader	wg1@tu1406.eu
Irina Stipanovic	WG2 Leader	wg2@tu1406.eu
Helmut Wenzel	MC member	wenzel@vce.at

1.6.3. SECRETARIAT

Name	*TU1406 Position*	*E-mail*
Eleni Chatzi	Technical Secretariat	tecsec@tu1406.eu
Lara Leite	Administrative Secretariat	adminsec@tu1406.eu

1.6.4. LOCAL ORGANIZERS

Name	*TU1406 Position*	*E-mail*
Alfred Strauss	WG1 Leader	wg1@tu1406.eu
Helmut Wenzel	MC member	wenzel@vce.at

2. HOW TO APPLY

2.1. APPLICATION

Interested applicants should submit their personal information and a short Curriculum Vitae through the form available for this purpose and available at https://goo.gl/aq7cjj.

Registrations should be submitted until the 15th October 2017.

Communication of Acceptance will be sent by the 22nd October 2017.

2.2. FUNDING AND REIMBURSEMENT

COST supports the participation of Trainees for their attendance at approved Training Schools. 15 Trainees approved by Organization/Management Committee, based on technical curriculum and on the COST policies on ESR (early stage researcher), gender and inclusiveness country, are entitled to receive a fixed Grant of 650,00 € and free registration.

Trainee grants do not necessarily cover all expenses related to attending the Training School. The Trainee Grant is a contribution to the overall travel, accommodation and meal expenses of the Grantee. Different grants amount can be attributed to each trainee.

The grant will be paid up to one month after the training school and no proof of expenses will be required to make the payment. The only requirement is to sign the attendance list.

WWW.TU1406.EU

TU1406
COST ACTION

COST ACTION TU1406
QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Training School on Bridge Quality Control
19^{th} December, 2017
Zel Am See, Austria

Overview on COST Action TU 1406
Performance-based Assessment of Existing Road Bridges

Jose C. Matos - Chair
Minho University (Uminho) - Portugal

European Science Foundation
ESF provides the COST Office through a European Commission contract

COST is supported by the EU Framework Programme

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

OUTLINES

- Motivation
- COST Action TU1406
  - Objectives
  - Organization
  - Scientific Program
  - Members
  - Dissemination
- WG1
  - Performance Indicators
  - From PI to KPI
  - Milestone
- WG2
  - Interaction of PI with PG
  - Performance Goals
  - Milestone
- WG3
  - Quality Control for Bridges
- WG4
  - Preliminary Work
  - On-Site Inspection
  - Maintenance Scenarios
  - Comparing Scenarios
- Closing

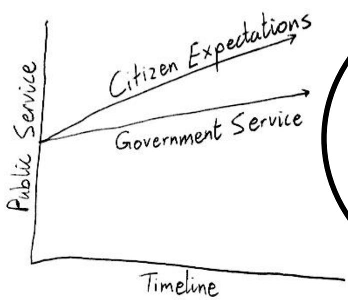
Motivation

Decay Process

Public Demands

Efficient Management

Limited Resources



Public Expectations

Motivation

Visual Inspection

NDT Testing

Monitoring System

Performance Indicator

Performance Goal

Quality Control Plan

Motivation

There is a **REAL NEED** to standardize the quality assessment of roadway bridges at an European Level

COST Action TU1406. Objectives

The overall intention of the Action is to

develop a guideline for the establishment of Quality Control (QC) plans in roadway bridges

reachable by pursuing the following 5 objectives:

(i) **Systematize knowledge on QC plans for bridges**, which will help to achieve a state-of-art report that includes performance indicators and respective goals;

(ii) **Collect** and contribute to **up-to-date knowledge on performance indicators**, including technical, environmental, economic and social indicators;

(iii) **Establish a wide set of quality specifications** through the definition of performance goals, aiming to assure an expected performance level;

(iv) **Develop detailed examples for practicing engineers** on the assessment of performance indicators as well as in the establishment of performance goals, to be integrated in the developed guideline;

(v) **Create a database from COST countries** with performance indicator values and respective goals, that can be useful for future purposes.

COST Action TU1406. Organization

Management Committee

Including:
- MC Chair
- MC Vice-Chair
- WG's Leaders and Vice-Leaders
- General Secretariat
- STSM Leader and Vice-Leader
- M&E Leader and Vice-Leader
- Innovation Leader and Vice-Leader
- R&D Leader and Vice-Leader

Core Group

- MC Chair
- MC Vice-Chair
- WG's Leaders
- General Secretariat
- STSM Leader
- M&E Leader *
- Innovation Leader *
- R&D Leader *

Advisory Board

- Industry/Owners/ Operators
- External Advisors (MC Observers)

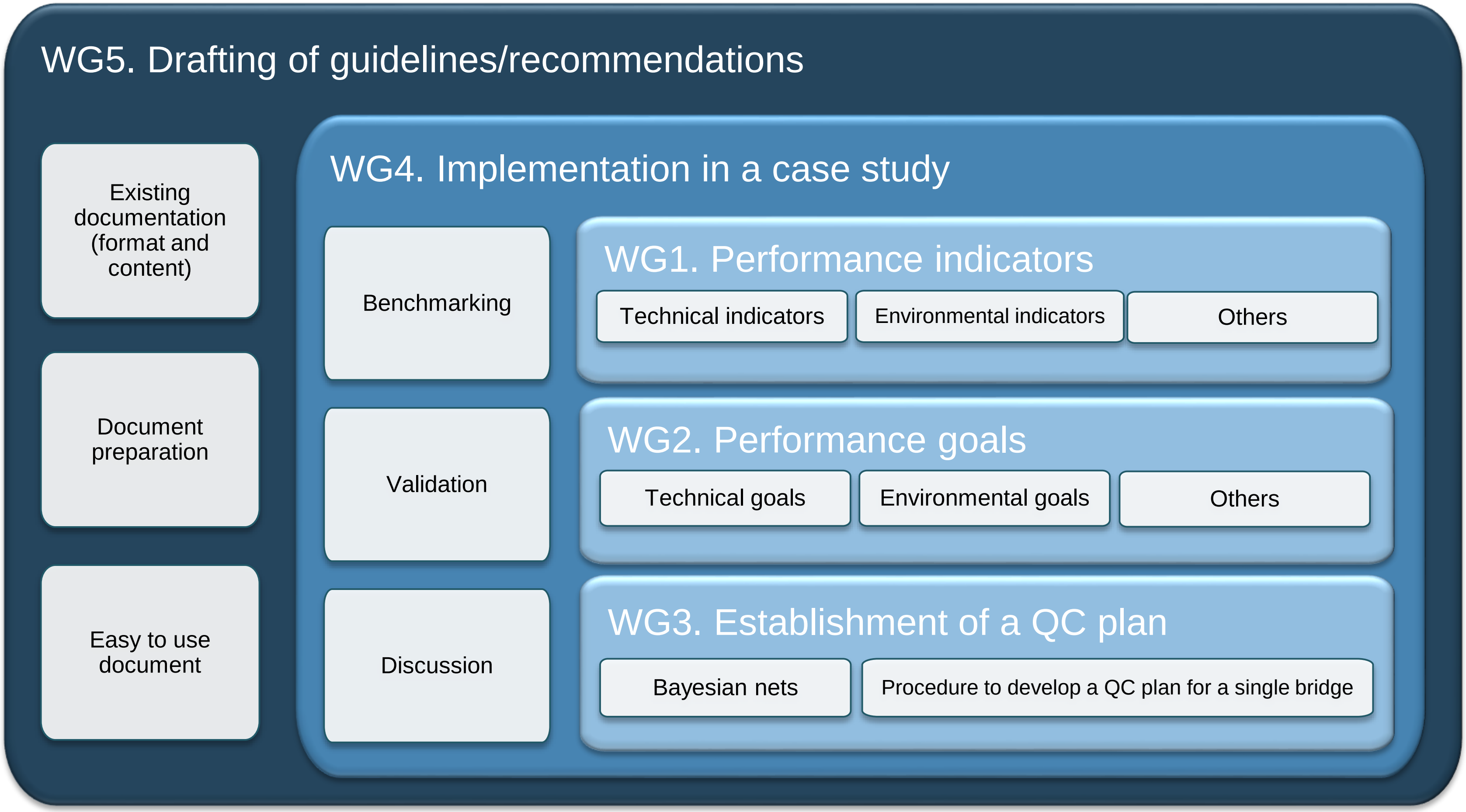
MC Observers

- Australia
- Chile
- Japan
- South Africa
- United States of America

An MC Observer per Continent

* under an "ad-hoc" basis

COST Action TU1406. Scientific Program



COST Action TU1406. Scientific Program

Activity/Months	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
Milestone				M1				M2		M3				M4		M5

M1: WG1 – Performance indicators
Elaborate a report of performance indicators

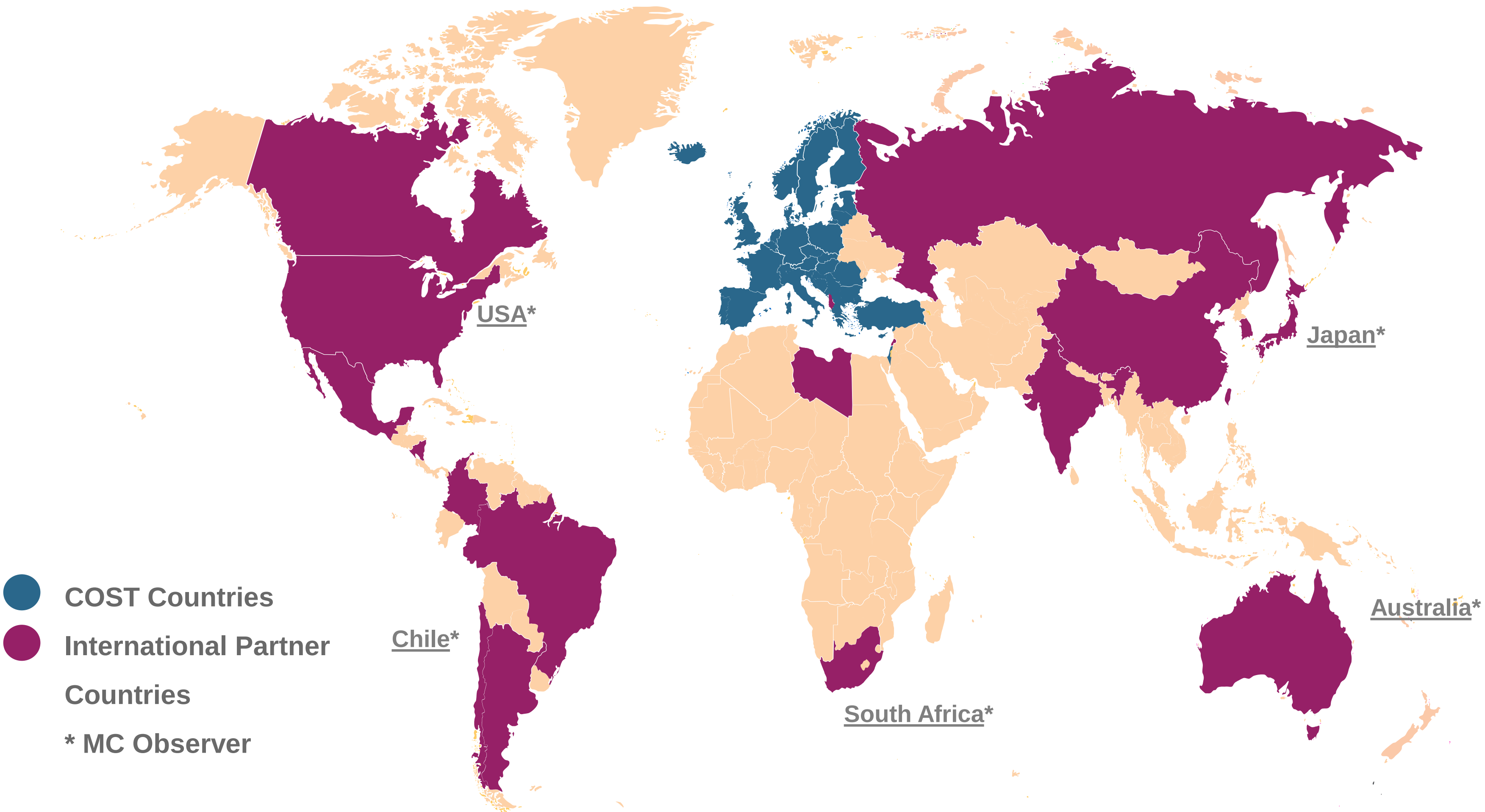
M2: WG2 – Performance goals
Elaborate a report of performance goals

M3: WG3 – Establishment of a QC plan
Prepare recommendations for the establishment of Quality Control plan

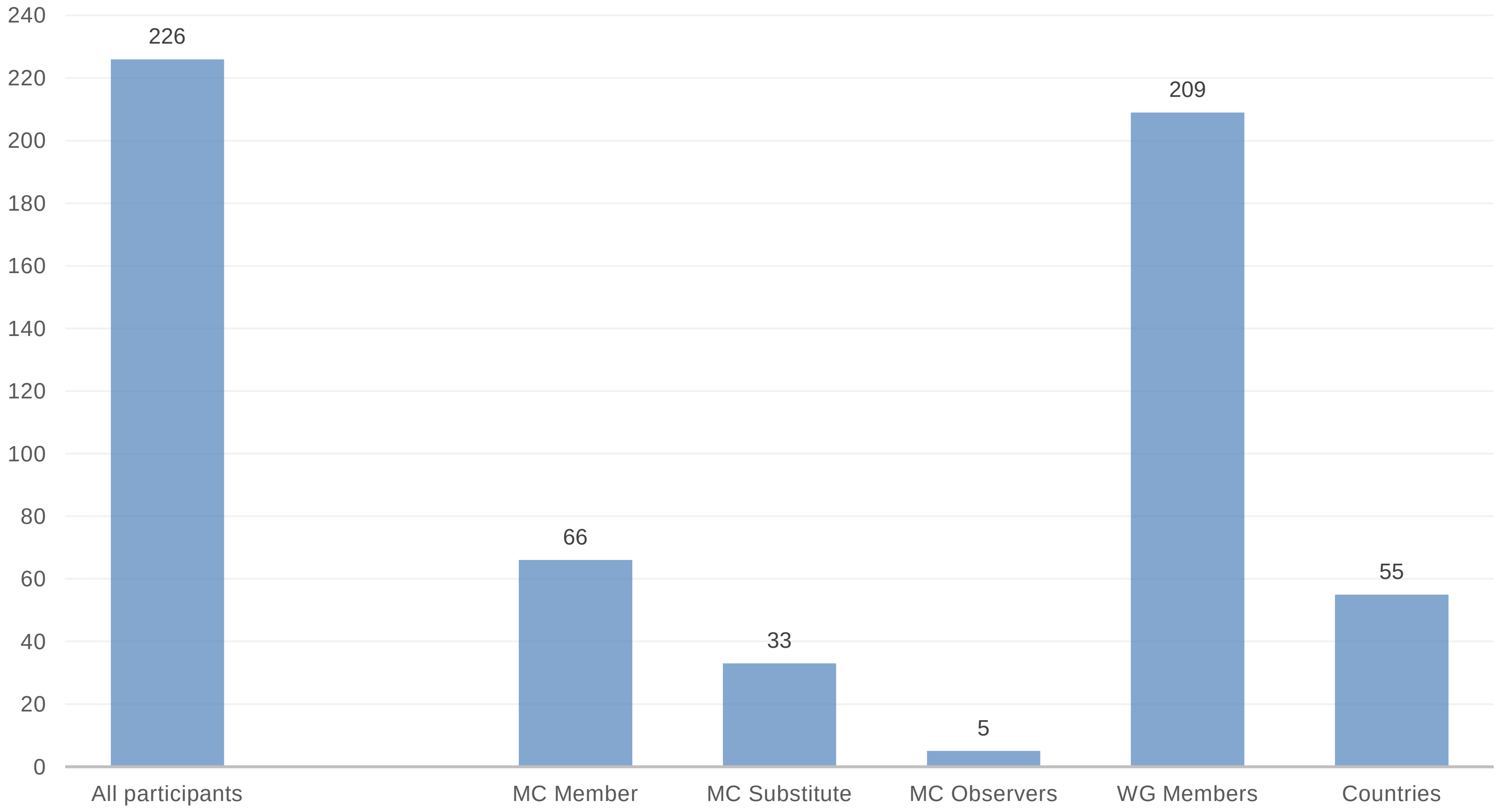
M4: WG4 – Implementation in a Case Study
Prepare database from benchmarking

M5: WG5 – Drafting of guideline/recommendations
Prepare guideline/recommendations for the establishment of QC plan

COST Action TU1406. Members



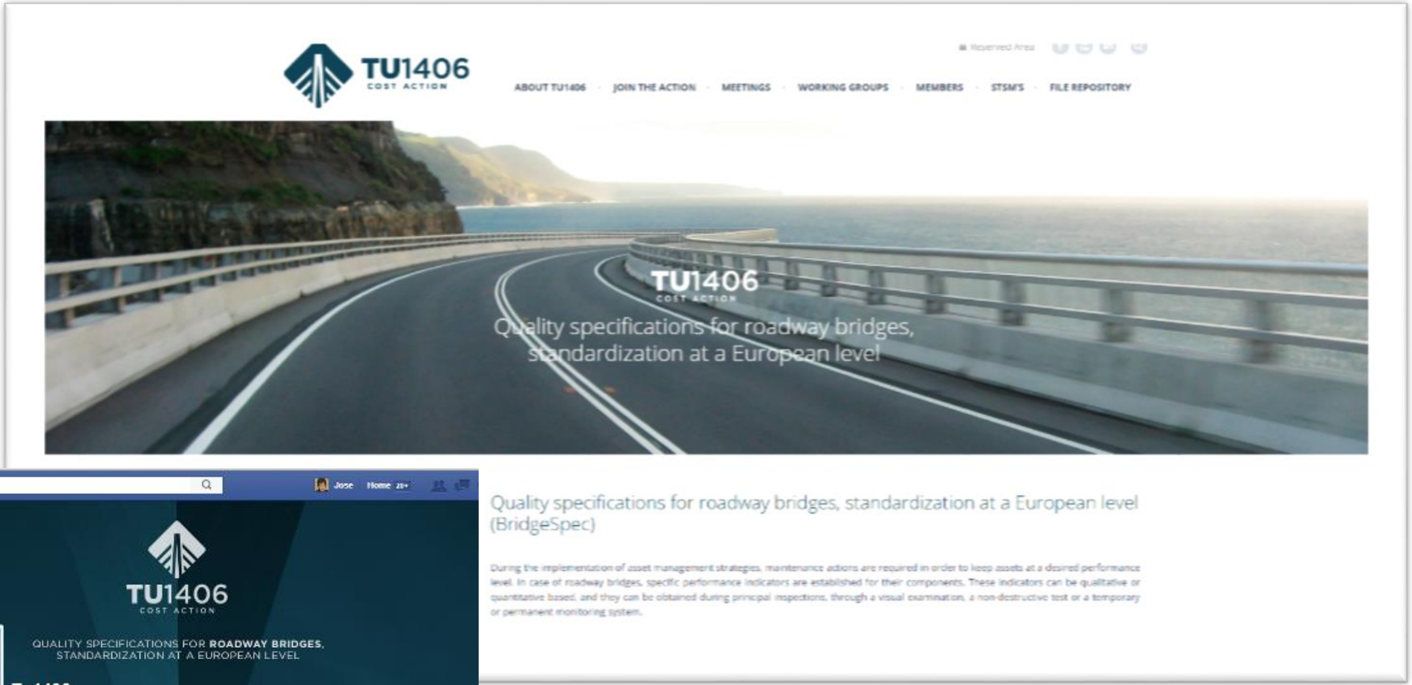
COST Action TU1406. Members

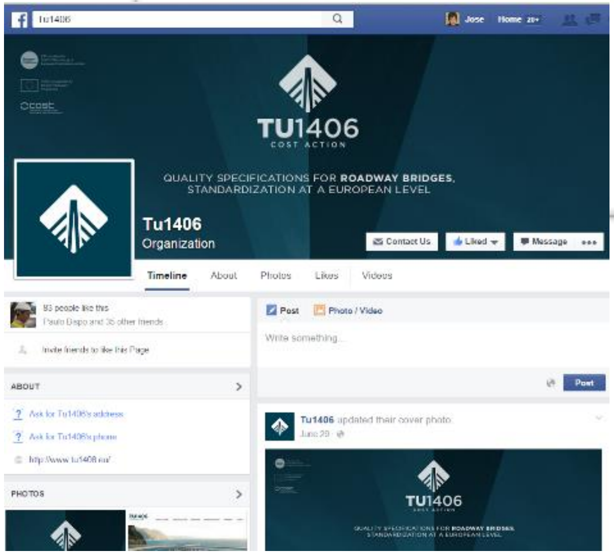


COST Action TU1406. Dissemination

Website

www.tu1406.eu





Facebook page

https://www.facebook.com/tu1406ca

COST Action TU1406. Dissemination

GUIMARÃES 2019
IABSE CONFERENCE

SAVE THE DATE 27-29 MARCH 2019

**TOWARDS A RESILIENT BUILT ENVIRONMENT
RISK AND ASSET MANAGEMENT**

-
27 to 29 March 2019
Vila Flor Cultural Centre, Guimarães, Portugal
-

Innovative Themes
1. Novel Management Tools for the Built Environment
2. Lifecycle Quality Control of new and existing Infrastructures
3. Advanced Frameworks for a Sustainable Built Environment
4. Risk Analysis Procedures, from Theory to Practice
5. Future trends in Structural Engineering

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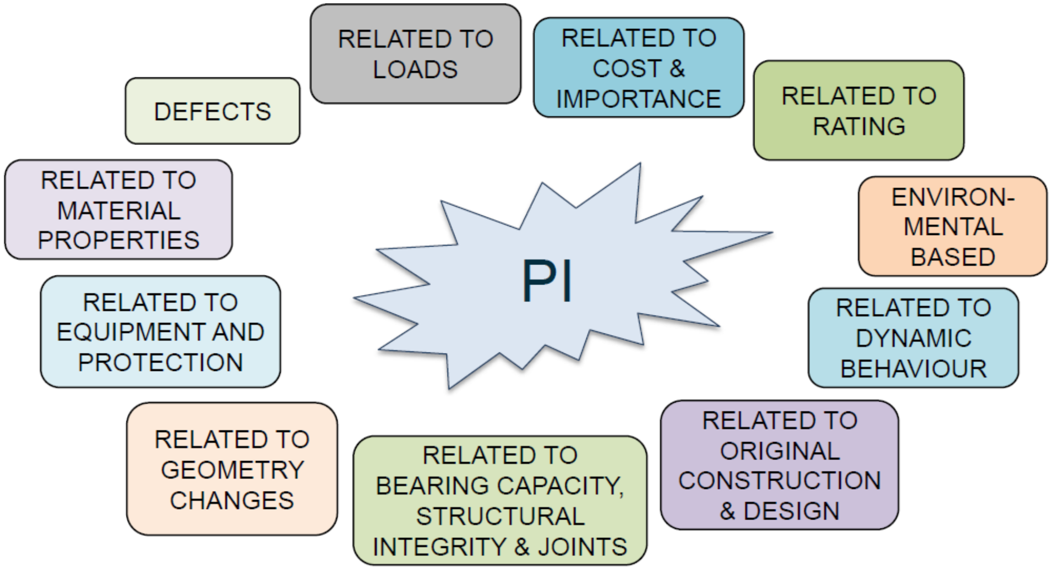
WG1. Performance Indicators

What is an “Indicator”?

- Something measurable, quantifiable?
- For which there is a target value / goal, available?
- Which is valid for ranking / decision purposes?

And what is a “Performance Indicator”?



WG1. Performance Indicators

Performance Indicator is a …

Measurable and **quantifiable** parameter, related to the bridge performance, that can be directly compared with a **target measure** of a **performance goal** (absolute measure of performance) or can be used for **ranking** purposes, among a bridge population (relative measure of performance), in the framework of a **Quality Control Plan** or life-cycle management (**decisions, actions involving economic resources**)

WG1. From PI to KPI

1. Survey phase

   Screening of national documents

2. Clustering and homogenization of PI (from more than 700 to 385 PI)

   WG 1 – Categorization of the PI in clusters

   NR – Verifying the PI inputs by comparing it with the homogenized and categorized terms

3. From PI to KPI (from 385 to 108 PI)

   In order to move on with the reduction of the list of Performance Indicators, an Expert Group was asked to specify a reduced list of 108 PIs according to the following points:

- **Level** (Component Level, System Level or Network Level)
- Is the **PI measureable**? (Technical, Socio Economical or Sustainable)
- PI **belongs to the Key Performance Indicator(s)**? (Reliability, Availability, Maintainability, Safety, Security, Environment, Costs, Health, Politics, Rating/Inspection)
- **Assessment** (Threshold, Goal, Rating)

WG1. From PI to KPI

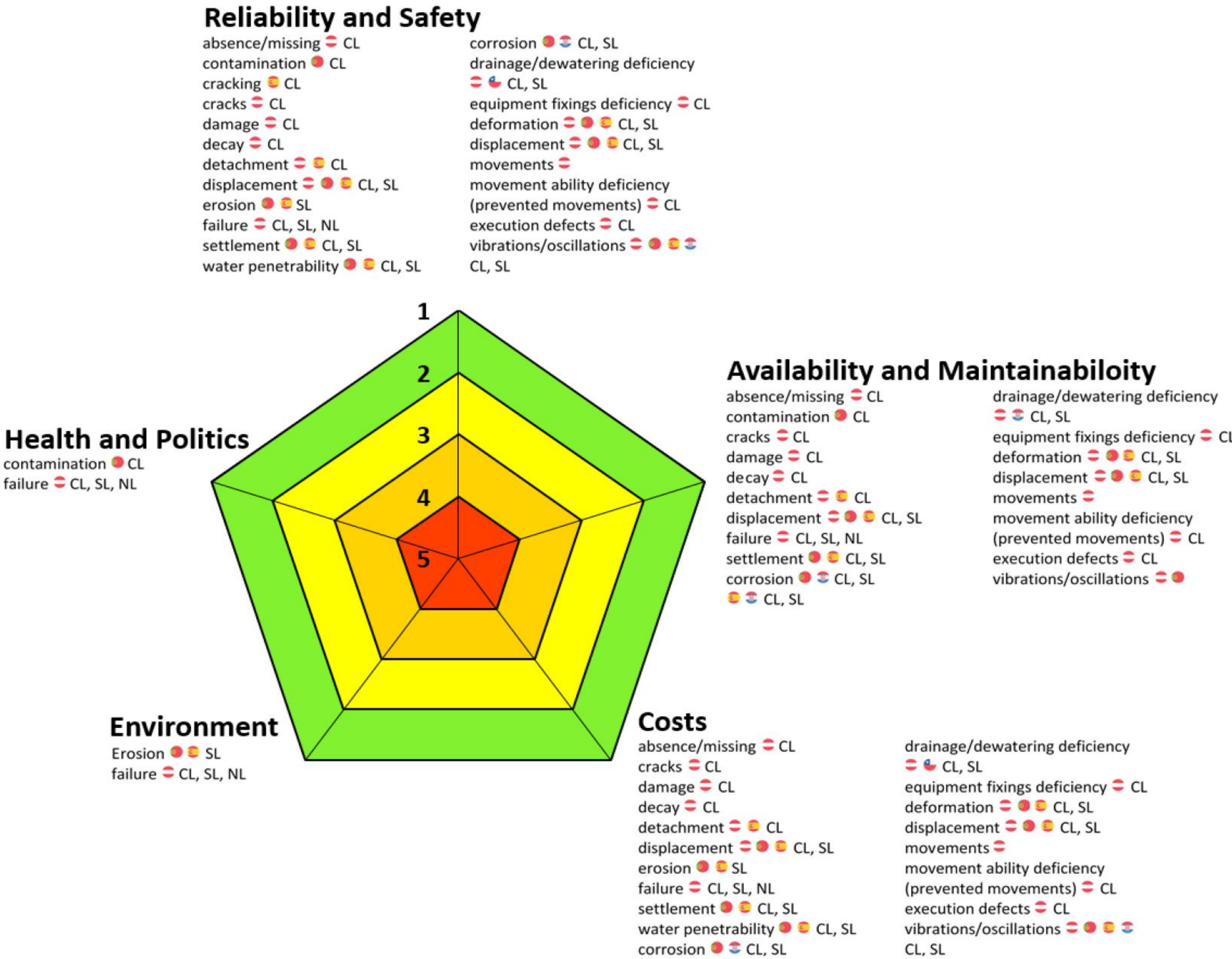
abrasion [DP], absence/missing [PI], aggradation (alluviation) [DP], blistering [OBS], blocking [DP], bulging [OBS], cavitation [OBS], clogged [OBS], coating loss [OBS], contamination [PI], corrosion (state) [OBS], crack length [OBS], crack orientation [OBS], crack width [OBS], cracking [PI], cracks [PI], cracks - Alligator cracks [OBS], cracks - drying cracks [DP], cracks - temperature cracks [DP], cracks distance [OBS], cracks related to material [OBS], cracks related to origin (e.g. due to loading, due to settlement, due to crumbling of concrete,... [DP], cracks related to position in a component [OBS], cracks related to sintering [DP], cracks -structural cracks [DP], crumbling [OBS], crumbling of concrete cover [OBS], crushing [DP], damage [PI], debonding [DP], debris [OBS], decay [PI], decomposition/disintegration [OBS], deepening [OBS], deficiency [OBS], degradation [PI], delamination [OBS], destroyed [OBS], detachment [PI], deterioration [PI], differential settlement [OBS], displacement [PI], distance between cracks [OBS], efflorescence/crypto-florescence [OBS], erosion [PI], erosion magnitude [OBS], exposure of element [OBS], failure [PI], falling out of units [OBS], fatigue cracking [DP], fire damage [OBS], foundation deficiency [OBS], gap [OBS], holes [OBS], humidification [OBS], hydraulic inadequacy [DP], impact damage [OBS], insufficient concrete cover [OBS], layering [OBS], leaking [OBS], nests [OBS], obstruction/impending (e.g. of water flow) [OBS], oval wholes [OBS], patching [OBS], peeling of [OBS], pitting [DP], potholes [OBS], ravelling [OBS], rupture [OBS], scaling [OBS], scaling of cement crust [OBS], scaling of treated layer [OBS], scour [DP], scour criticality [OBS], scour depth [OBS], secretion [OBS], segregation [OBS], separation [OBS], settlement [PI], shear [OBS], shoving ? [OBS], silting and vegetation [OBS], sliding [OBS], soil Failure [DP], spalling [OBS], splitting [OBS], staining [OBS], stratification [OBS], structural damage [PI], surface corrosion [OBS], surface damage/deficiency [OBS], surface discoloration [OBS], surface flaking due salting [DP], swelling of structural steel surface [OBS], tearing [OBS], timber splitting [OBS], transverse compression cracks (crushing) [OBS], undermined stability (e.g. of river bank) [OBS], undermining [OBS], undesirable paintings, graffiti [OBS], uneven [OBS], unlevelled components [OBS], water leakage [OBS], water penetrability [PI], wearing and tearing [OBS], weathering [DP], wet spots [OBS], wet spots with corrosive edges [OBS], worn out [OBS], yield [OBS], acids attacks [DP], aggregate segregation [OBS], aging of material [DP], alkali aggregate reaction (alkali-silica reaction) [DP], alkali aluminium reaction [DP], bad concrete compaction [OBS], bedding mortar failure [OBS], bituminous binder emersion [OBS], calcification [DP], carbonation [DP], chemical attack [DP], chemical parameter [OBS], chloride action [DP], chloride content [OBS], chloride ions penetration [OBS], concrete quality insufficient [OBS], corrosion [PI], corrosion fatigue [DP], corrosion related to prestressing steel [OBS], corrosion related to protective coating [OBS], corrosion related to reinforcement steel [OBS], corrosion related to structural steel [OBS], cracks due to shrinkage [DP], fatigue [DP], galvanization deficiency [OBS], gel exudation [OBS], hydroxide calcium exudation [OBS], material characteristics [OBS], material quality insufficient [OBS], oxidation [DP], pitted corrosion [DP], porous concrete [OBS], red colour areas [OBS], reinforcement bar yielding [OBS], reinforcement corrosion [DP], rot fungi attack [OBS] , shrinkage/creep [DP], sintering [DP], sulphate action [DP], termite infestation [OBS], wear out [DP], white colour areas [OBS], woodworm infestation [OBS], xylophagous attack [OBS], absence (missing) of equipment component [OBS], approach slab settlement [OBS], asphalt pavement cracking [OBS], asphalt pavement wearing and tearing (rutting, ravelling) [OBS], asphalt pavement wheel tracking and wrinkling and undulation [OBS], blistering paint [OBS], cladding damages [OBS], cladding deformations [OBS], clogged collector [OBS], clogged drain [OBS], clogged manhole [OBS], clogged pipe [OBS], cornicles and curbs defects [OBS], corrosion related to equipment made of steel [OBS], crack over the buried expansion joint [OBS], cracks in covering [OBS], damage of protective coating [OBS], debonding of elastomeric surface [OBS], deterioration of protective coatings (e.g. corrosion protection, impregnate...) [OBS], deviator deficiency [OBS], drainage/dewatering deficiency [PI], elastomeric leakage [OBS], equipment fixings deficiency [PI], expansion joint pavement crack [OBS], functionality of device [PI], hydro-insulation defects [OBS], incorrect position [OBS], leaking at seepage water tube [OBS], maintenance equipment defects [OBS], oiling system deficiency [OBS], pavement lateral displacement [OBS], protection (cover) deficiency [OBS], protection duct damage (of prestreesed cable) [OBS], reduction of embankment cone [OBS], rollers condition (e.g. sliding, fixed, broken,...) [2ºPI], sliding interface insufficient [OBS], sliding path failure/blocking [OBS], slip of bearing [OBS], special inspection requisite [2ºPI], step in transition slab [OBS], waterproofing deterioration [OBS], buckling [OBS], cross incline of road [OBS], deformation [PI], denivelation [OBS], differential movement [OBS], displacement [PI], distortion [OBS], flattening [OBS], height difference [OBS], inclinations [OBS], misalignment [OBS], movements [PI], rotations [OBS], sag [OBS], torsion

2º Level PIs, 2ºPI; Damage Process, DP_; Non-interceptable processes, NIP; Observation, OBS; Other data, OD; Performance Indicator, PI

defects; related to material properties; related to equipment & protection; geometry changes

; Austria; Chile; Croatia; Portugal; Spain

WG1. From PI to KPI



WG1. Milestone

WG1

Technical Report

Performance Indicators for Roadway Bridges of Cost Action TU 1406

General

Performance Indicators terms after surveying

Operators

Operators list of documents and database per country

Research

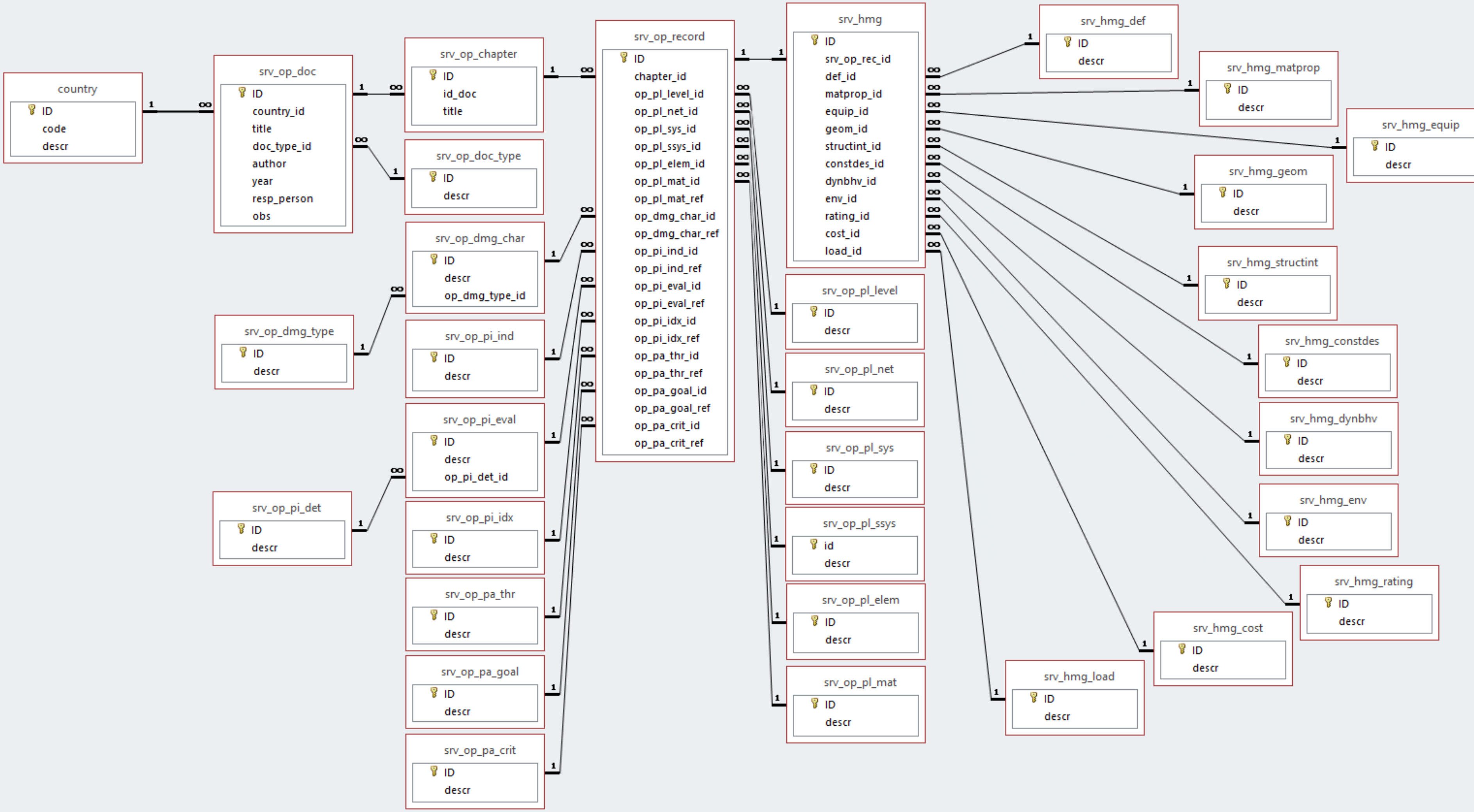
Research list of documents and database per country

Glossary

Glossary and specific term sheet per country

available on website: www.tu1406.eu

WG1. Milestone



WG1. Milestone

Operators Survey | Research Survey | Spider Survey

Documents

Show 10 entries

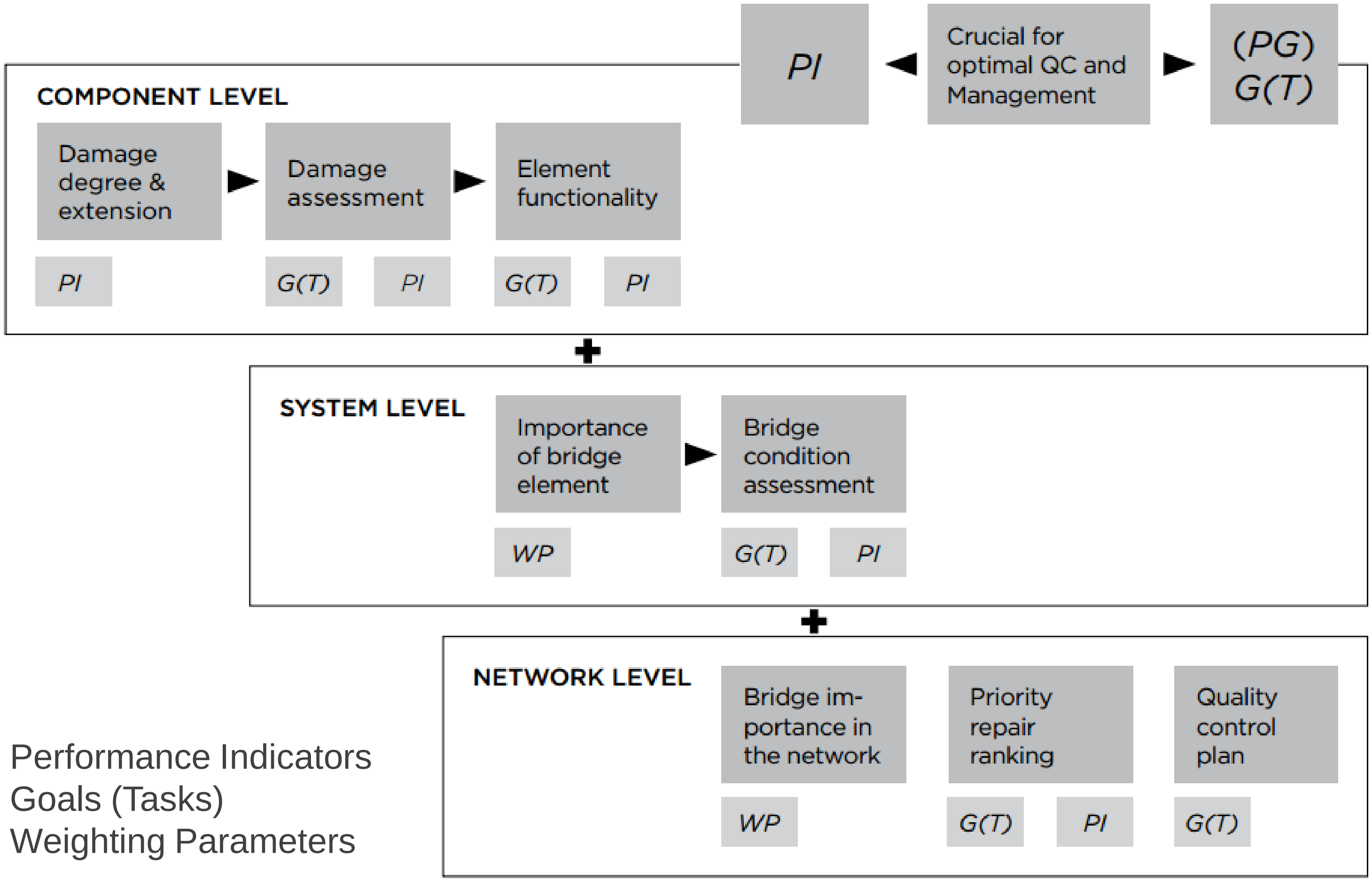
Search:

Country	Title	Type	Author	Year	RespPerson	Obs
AT	Repair of concrete structures - National specifica...	Inspection	Austrian Standards Instit...	2015		
AT	Repair of concrete structures - National specifica...	Inspection	Austrian Standards Instit...	2015		
AT	Quality Assurance for Structural Maintenance, Stru...	Evaluation	FSV	2009		
AT	Evaluation of load capacity of existing railway an...	Evaluation	Austrian Standards Instit...	2014		
AT	Quality Assurance for Structural Maintenance - Suv...	Inspection	BMVIT	2011		
BA	UPUTSTVO ZA INSPEKTORE MOSTOVA / INSTRUCTIONS FOR ...	Evaluation	BCEOM Societe Francaise D...	2004	Neven Pavlinovic	
BA	UPUTSTVO ZA INSPEKTORE MOSTOVA / INSTRUCTIONS FOR ...	Evaluation	BCEOM Societe Francaise D...	2004	Neven Pavlinovic	
CZ	TP72 Diagnostics of road bridges	Inspection	Pontex spol. s r.o.	2008	Pavel Ryjácek	
CZ	TP120 Maintenance, repairs and refurbishment of co...	Inspection	Pontex spol. s r.o.	2010	Pavel Ryjácek	
CZ	SŽDC S5 management of bridges(railway)	Inspection	SŽDC TÚDC	2012	Pavel Ryjácek	
All	All	All	All		All	All

Showing 1 to 10 of 74 entries

Previous 1 2 3 4 5 … 8 Next

WG2. Interaction of PI with PG



PI – Performance Indicators
G(T) – Goals (Tasks)
WP – Weighting Parameters

WG2. Performance Goals

- The goal of road users is simple: to get from A to B safely in expected time.
- The road connection has to be reliable.
- Operational reliability -> not directly considered
- Structural **reliability!**
  - EN 1990:

    "Ability of a structure or a structural member to fulfil the specified requirements, including the design working life, for which it has been designed. Reliability is usually expressed in probabilistic terms
    NOTE: Reliability covers **safety, serviceability** and durability of a structure."

    Durability: The structure shall be **designed** such that deterioration over its design working life does not impair the **performance** of the structure below that intended, having due regard to its environment and the anticipated level of maintenance.
  - EN 1992:

    A design using the partial factors given in this Eurocode (see 2.4) and the partial factors given in the EN 1990 annexes is considered to lead to a structure associated with reliability Class RC2 -> $\beta_{safety} = 3.8$, $\beta_{serviceability}=1.5$ for 50years

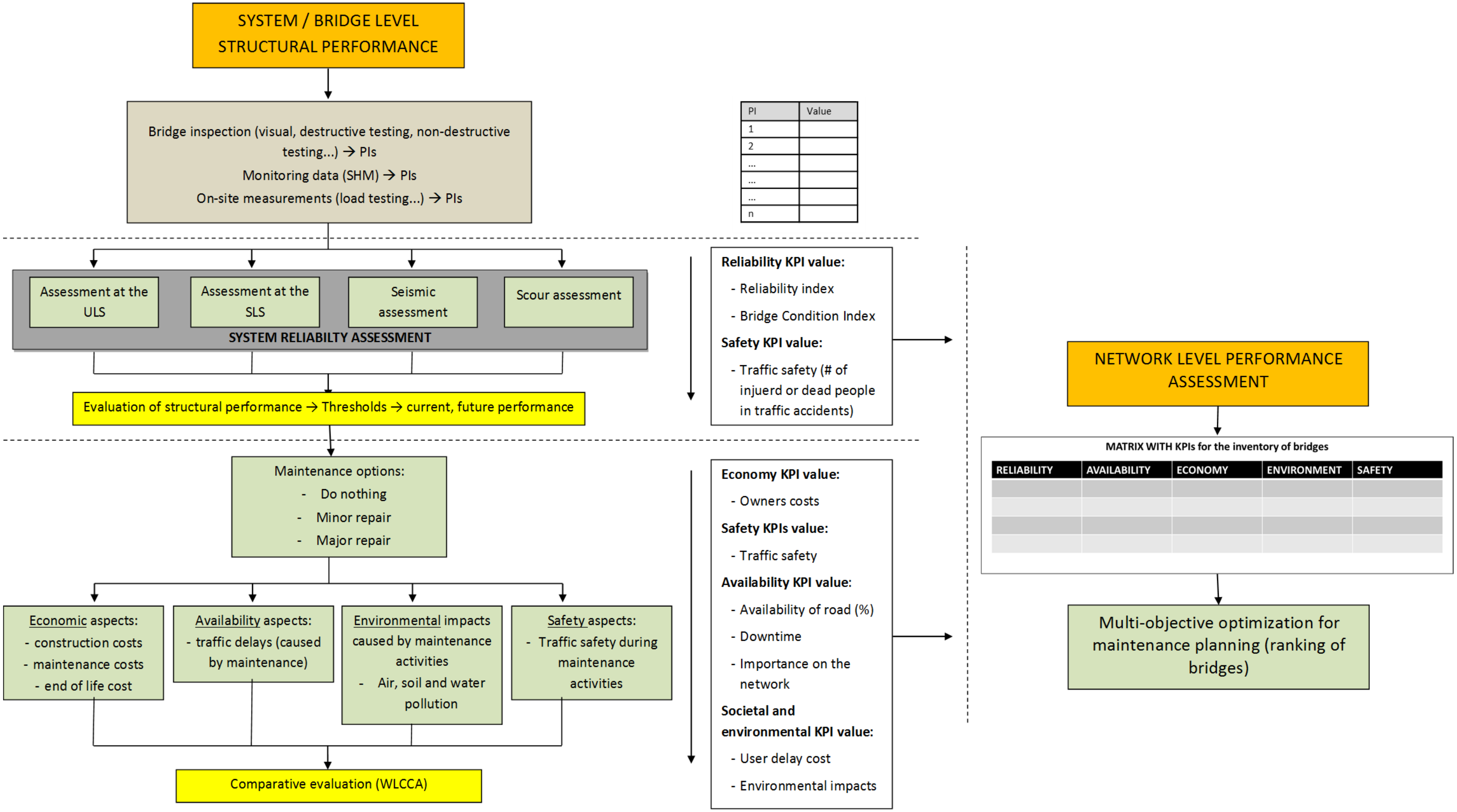
WG2. Performance Goals

- **Reliability** include the probability of structural failure (safety) or operational failure (serviceability).
- **Availability** is the proportion of time a system is in a functioning condition.
  - Somewhat critical: Meet object specific requirements with regard to the fulfilment of object function.
  - For our purposes: Additional travel time due to imposed traffic regime on bridge.
  - ***Not reliability-related disruption of bridge users***
- **Economic efficiency** -> minimizing long term cost
- **Safety** (not structural safety) minimize (eliminate) the **harm people** during the service life of a bridge. Loss of life and limb due to structural failure is normally not included!
- **Environmental friendliness** -> minimize the **harm to environment** during the service life of a bridge.

WG2. Performance Goals

- **Maintainability** is the ease with which a product can be maintained in order to correct defects or their cause, repair or replace faulty components without having to replace still working parts and prevent unexpected working condition -> *design aspect and is covered with economic efficiency*.
- **Security** is degree of protection against vandalism -> *similar to maintainability is design aspect included in economic efficiency*
- **Health** is absence of non-failure causes of illnesses (e.g. asbestos) -> *regulated*
- **Environment** -> *regulated*
- **Politics** include elimination of causes for public outcry, image protection etc. -> downstream performance goal, i.e., fulfilled if RAS€E (Reliability; Availability; Safety; Economic Efficiency; Environmental Friendliness) goals are met.

WG2. Performance Goals



WG2. Milestone

WG2

Technical Report

Performance Goals for Roadway Bridges
OF COST ACTION TU 1406

Performance Goals

Reliability Performance Assessment

Economy, Societal and Environmental Assessment

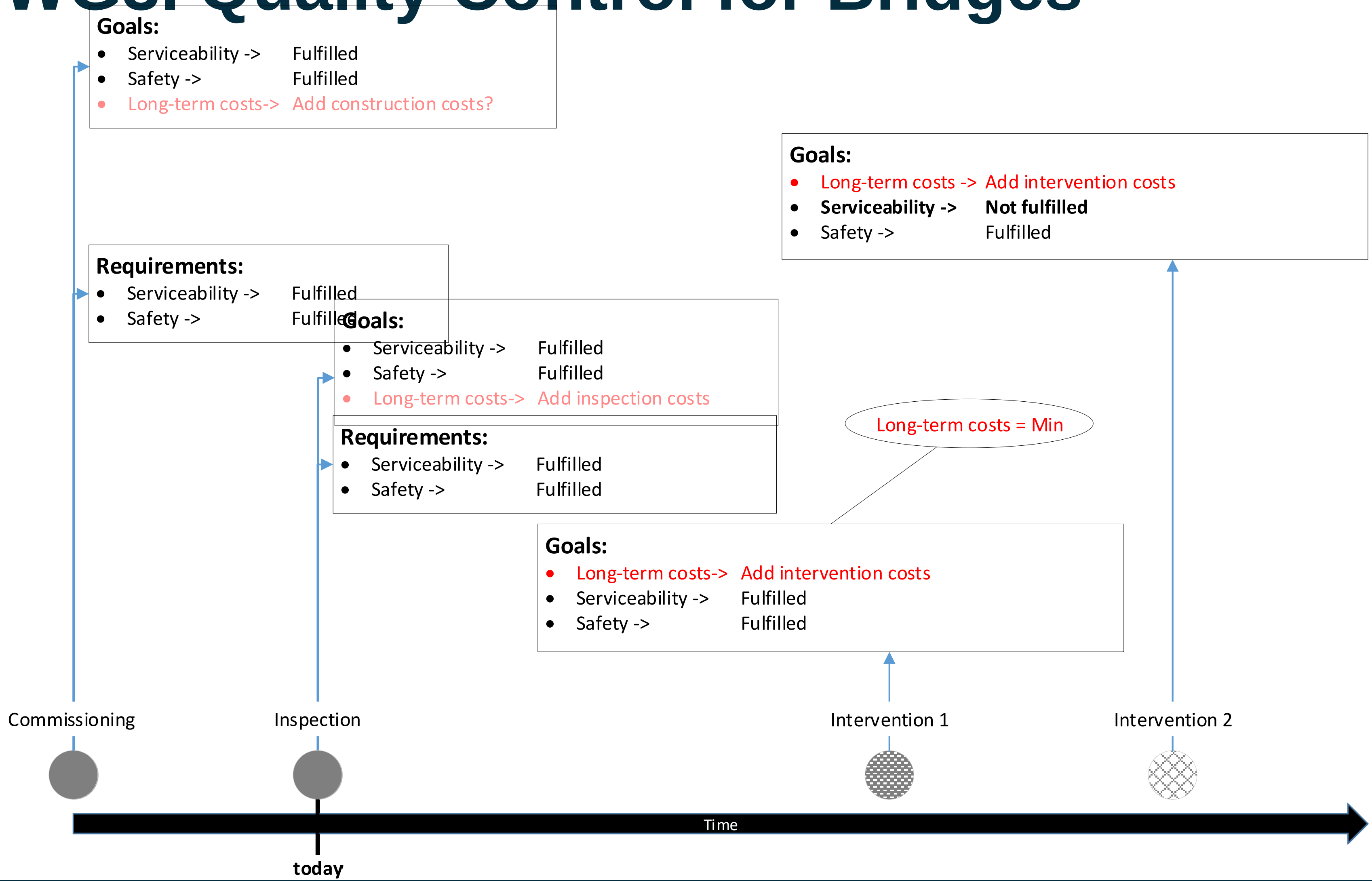
Glossary
Multi-Objective Optimization Models

available soon on website: www.tu1406.eu

WG3. Quality Control for Bridges

- **Static (snap shot) quality control**: Inspect and investigate a bridge and determine whether the **reliability** and **safety** goals are met.
  - Basis for the decision making on actions
- **Dynamic quality control**: Static + Plan and execute actions to **ensure long term fulfillment of safety and serviceability goals. -> Bridge Management**
- There are different ways to ensure that goals are met on the long-term:
  - Preventive action
  - Corrective actions
  - Operational actions
- Maintenance scenarios, which define **costs (economics)** and **availability**
- Assess economics and availability at the time of inspection is not meaningful!

WG3. Quality Control for Bridges

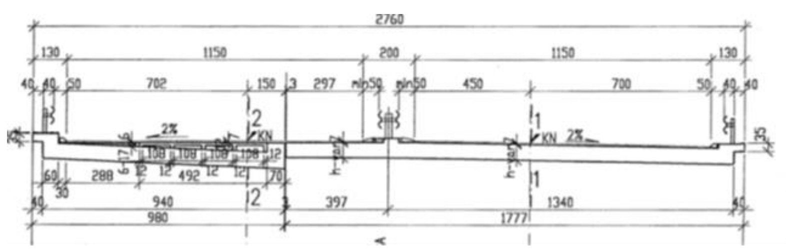


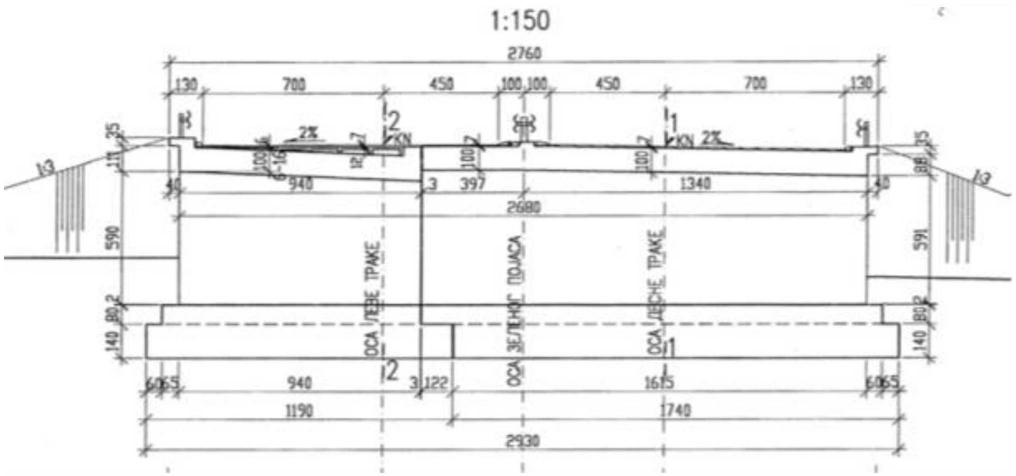
WG3. Quality Control for Bridges

- Within the QC Framework
  - Reliability
  - Availability
  - Safety
  - €conomics

  will be assessed for different maintenance scenarios
- Environment is mostly regulated, but in some cases can be also included.
- **Snapshot or static quality control** includes
  - **Reliability** (structural safety and serviceability) and **Safety** (not structural safety) regarding loss of life and limb
- **Dynamic quality control** (bridge management) include feasible maintenance scenarios that define **Costs** and **Availability** over certain time frame **Reliability** and **Safety** forecasts

WG4. Preliminary Work





RC Frame

ADT 10’000

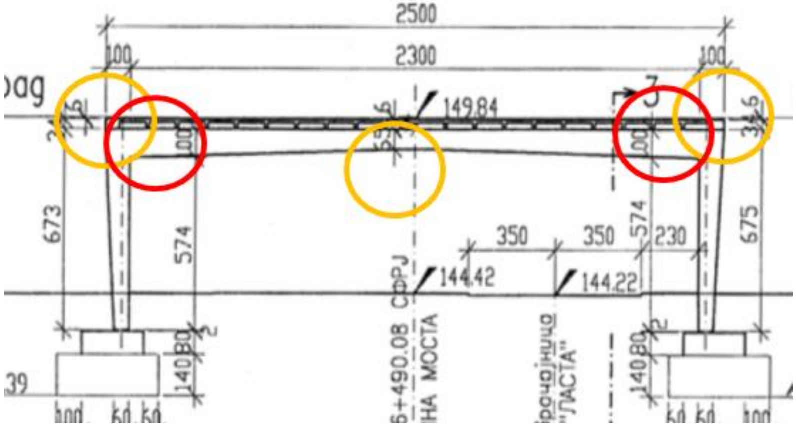
Construction year 1963

Widened in 1977

No natural hazards

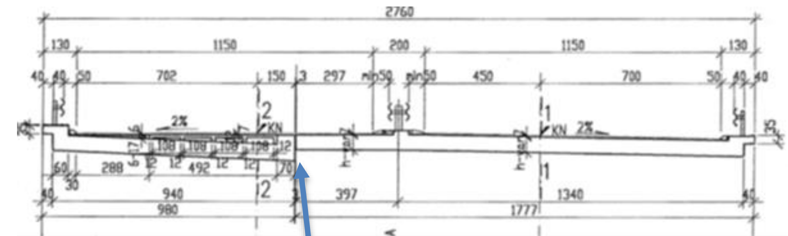
WG4. Preliminary Work

- No particular weaknesses of original design
- The obvious weakness is longitudinal joint connecting the old and the new parts of bridge
- No particular material weaknesses are known – steel bars didn't have any ductility problems
- The traffic load in code of practice did increase since 1963, but the bridge was recalculated in 1977.
- Prior reliability index (safety) is 3.8



HMS-high suging moment zone	orange circle	ductile
HMH - high hoging moment zone		
HSS - high shear zone	red circle	britle

WG4. On-Site Inspection



WG4. On-Site Inspection

- There is a road beneath the bridge
- It is rural road with low traffic volume
- There is however a danger of falling concrete on vehicles or persons
- Railings can’t performed as designed

WG4. Maintenance Scenarios - Reliability

- There are some indication of diminished resistance:
  - Spalling at the width of (in average) 1.5 meters over the whole span.
  - Uncertain bonding
  - Significant corrosion ~10% section loss (old structure)
  - Corrosion to ~5% section loss in vulnerable zone (new structure)
  - Based on the symptoms there is probably corrosion over the piers, which is a vulnerable zone belonging to same failure mechanism
  - Redistribution in perpendicular sense has positive effects.
  - Uncertain cause and development of the diagonal crack.
- Based on experience and elementary statics the resistance reduction has been assessed to 10% (probably conservative)
- There is no urgent necessity to perform in depth investigation.
- Clearly, the assessment is rather rough and based on inspector’s experience but so is condition rating.

WG4. Maintenance Scenarios - Reliability

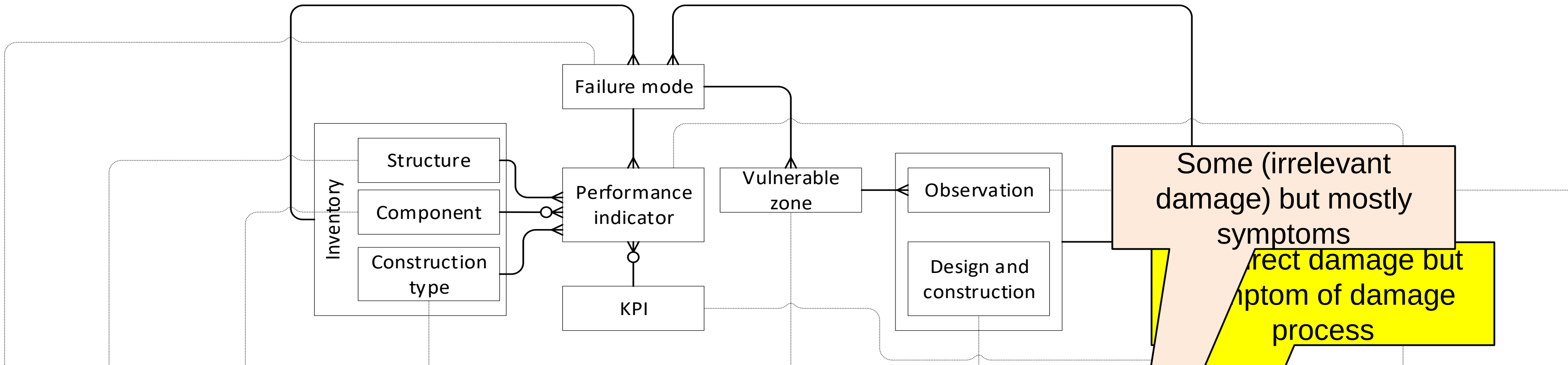
WG4. Maintenance Scenarios - Reliability

- The value of virgin reliability due to current loading is critical!
- It is advisable for old bridges to estimate the real loading by means of axle load measurements. The real traffic loading can be sometimes higher but sometimes significantly lower (less aggressive).
- In this particular case the traffic loading increased from 1977.
- The assessment od reliability is similar to the condition assessment with two crucial differences:
  - It takes into account virgin reliability,
  - focuses on failure modes and
  - related vulnerable zones.
- Most inspection practices focus implicitly on the latter two, but not explicitly.
- Hint: Thinking in failure mechanisms helps since it allows one to estimate the reduction of dissipation work due to damages.
- The example bridge will probably not fail catastrophically but rather experience a warping deformation.

WG4. Maintenance Scenarios - Safety

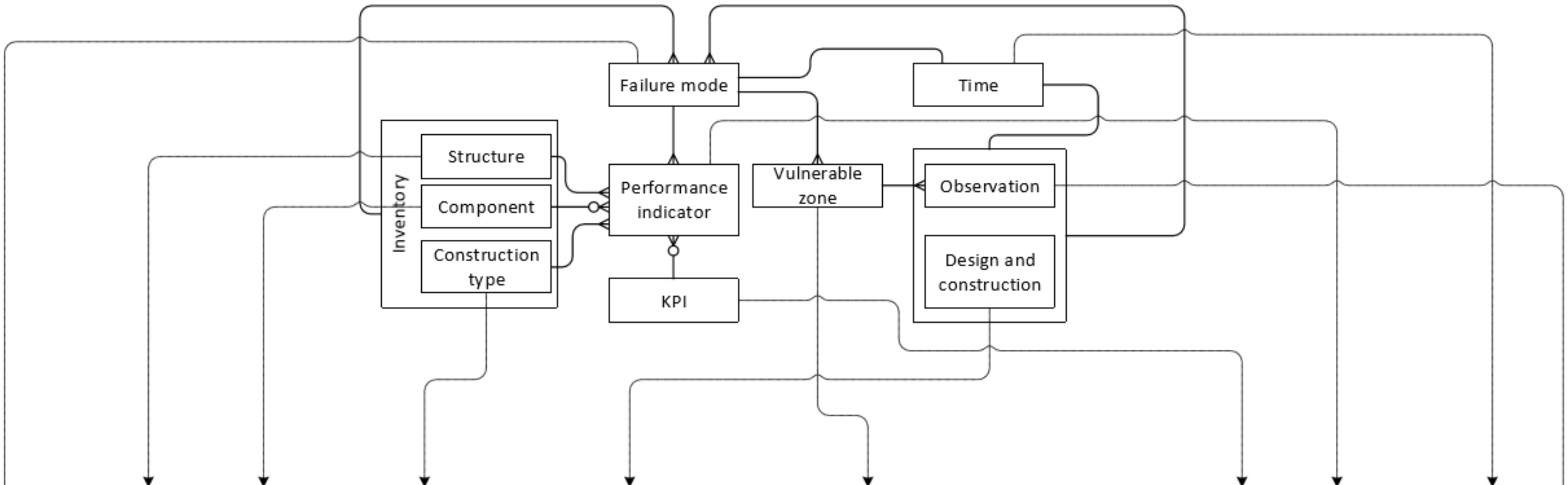
- The loss and life and limb due to structural failure is **not included**.
- Falling concrete cover can endanger persons in and outside the vehicles.
- It is very unlikely that large chunks are going to fall down.
- The chunks that are found on the street were maximum 10x10x2 cm.
- The traffic volume is very low both pedestrian and vehicles.
- The capacity for spalling has also diminishes as water cannot reach reinforced bars that are still covered with concrete.
- The falling height is relatively small.
- The damaged railings jeopardize traffic safety
- Taking the observations into account and the above reasoning the danger for life and limb is relatively small i.e. 2.
- The performance indicator of 1 is no danger (injury return period > 100 years) and performance indicator of 5 characterizes immediate danger (injury return period < 10 years)

WG4. Maintenance Scenarios



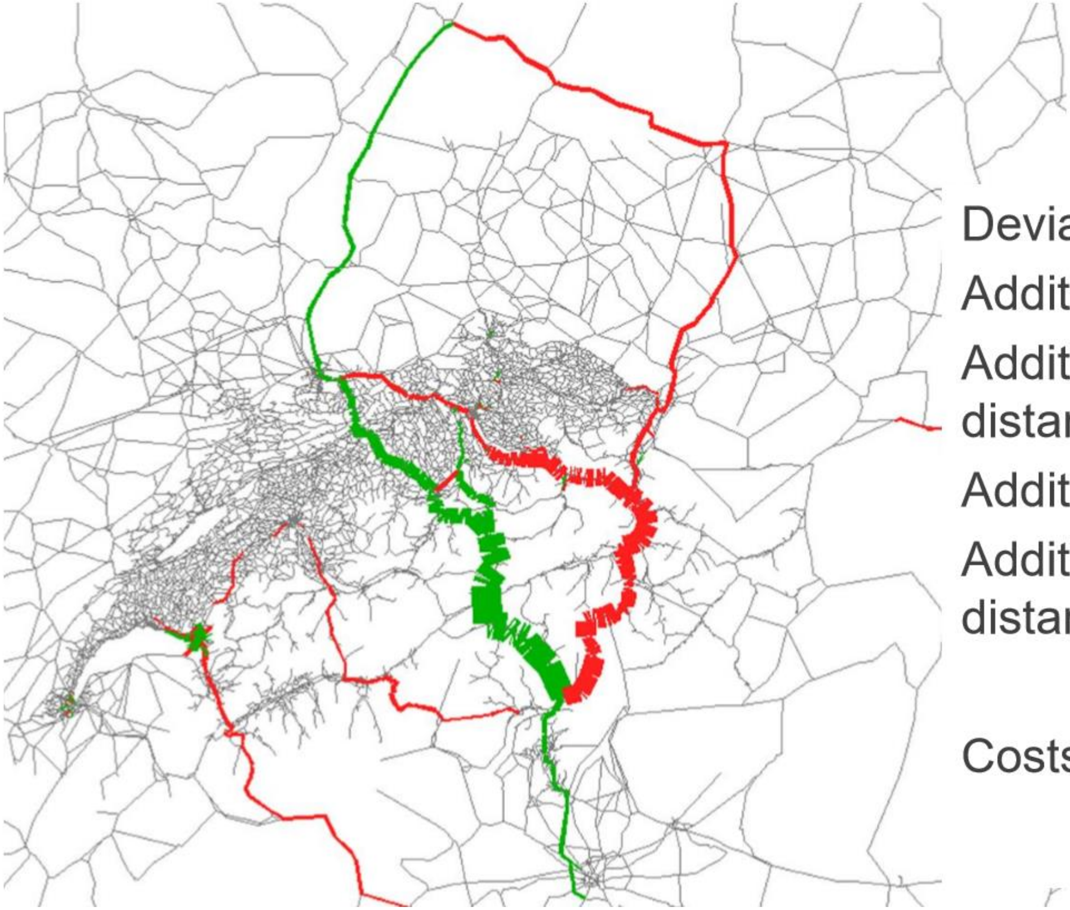
Frame bridge	Deck (old)	Reinforced concrete	1963	Bending failure mode	HMS	Corroded reinforcement	Reliability (Structure safety)	3	3
	Deck (new)	Reinforced concrete	1977			Corroded reinforcement			
	Deck (old)	Reinforced concrete	1963			Spalling			
	Deck (new)	Reinforced concrete	1977			Spalling			
	Deck (new)	Reinforced concrete	1977		HMH	Corroded reinforcement			
	Deck (old)	Reinforced concrete	1963			Corroded reinforcement			
	Deck (new)	Reinforced concrete	1977			Spalling			
	Deck (old)	Reinforced concrete	1963			Spalling			
	Deck (new)	Reinforced concrete	1977			Efflorecences			
	Deck (old)	Reinforced concrete	1963			Efflorecences			
	Deck (old)	Reinforced concrete	1963	Shear failure mode	HSS	Crack		2	
	Deck (old)	Reinforced concrete	1963	Falling chunks		Spalling	Safety (Life and limb)	2	2
	Deck (new)	Reinforced concrete	1977			Spalling		2	
	Railings	Steel	1977	Falling of the bridge		Broken		2	

WG4. Maintenance Scenarios – Forecasts



Frame bridge	Deck (old)	Reinforced concrete	1963	Bending failure mode	HMS	Corroded reinforcement	Reliability (Structure safety)	3	3	15 years
	Deck (new)	Reinforced concrete	1977			Corroded reinforcement				
	Deck (old)	Reinforced concrete	1963			Spalling				
	Deck (new)	Reinforced concrete	1977			Spalling				
	Deck (new)	Reinforced concrete	1977		HMH	Corroded reinforcement				
	Deck (old)	Reinforced concrete	1963			Corroded reinforcement				
	Deck (new)	Reinforced concrete	1977			Spalling				
	Deck (old)	Reinforced concrete	1963			Spalling				
	Deck (new)	Reinforced concrete	1977			Efflorecences				
	Deck (old)	Reinforced concrete	1963			Efflorecences				
	Deck (old)	Reinforced concrete	1963	Shear failure mode	HSS	Crack		2		
	Deck (old)	Reinforced concrete	1963	Falling chunks		Spalling	Safety (Life and limb)	2	2	40 years
	Deck (new)	Reinforced concrete	1977			Spalling				
	Railings	Steel	1977	Falling of the bridge		Broken		2		

WG4. Maintenance Scenarios - Availability

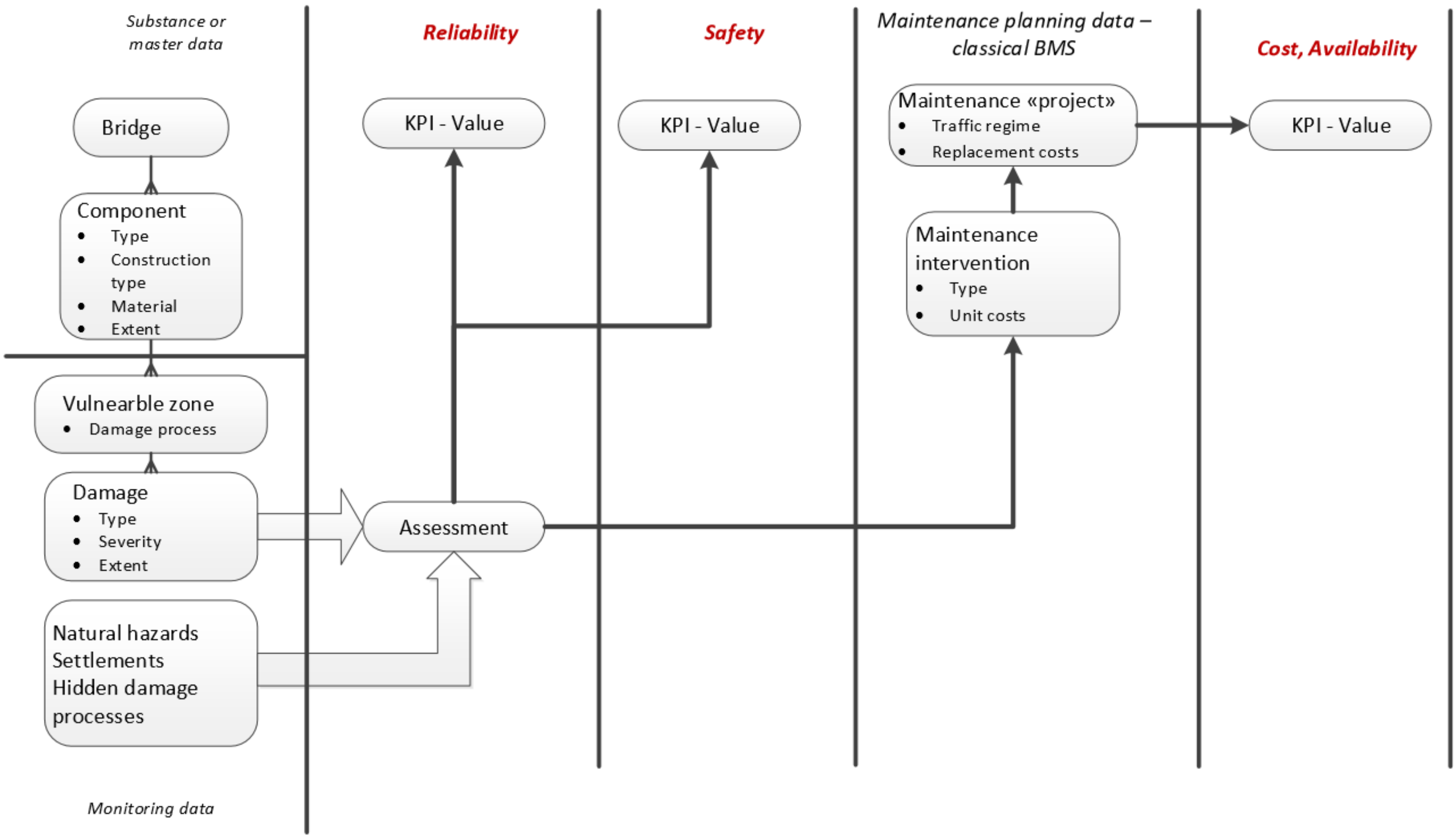


Deviated vehicles:	18’053/d
Additional travel time:	15’673 h/d
Additional travel distance:	1.3 Mio. Km
Additional travel time:	55 min./veh.
Additional travel distance:	57 km/veh.
Costs:	652’000 CHF

WG4. Maintenance Scenarios - Costs

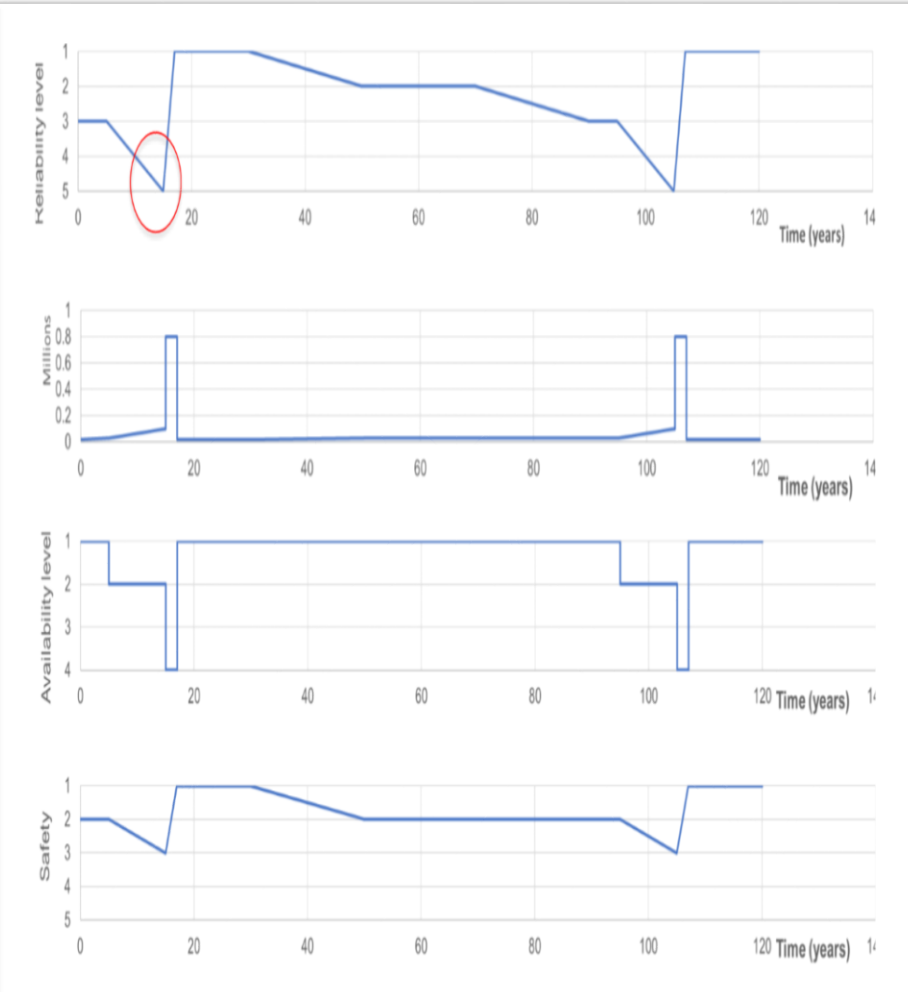
- “Classical” BMS
- Inspection results:
  - Severity of damage
  - Extent of damage
  - Location (Component)
- Unit costs
- Mobilization costs
- Damage forecast
- Generation of “Maintenance Intevention”
  - Type (Repair, Rehabilitation, Replacement)
  - Estimated costs

WG4. Maintenance Scenarios - Resume

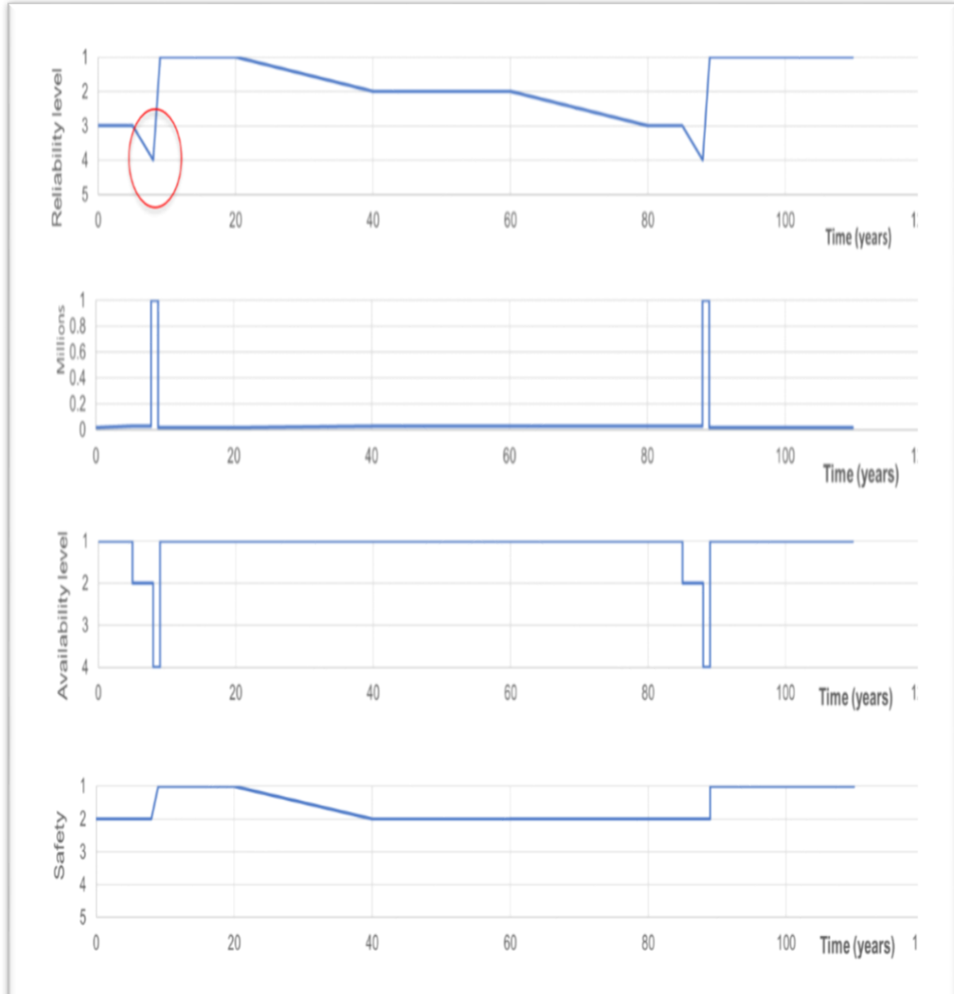


WG4. Comparing Scenarios

Reference Scenario



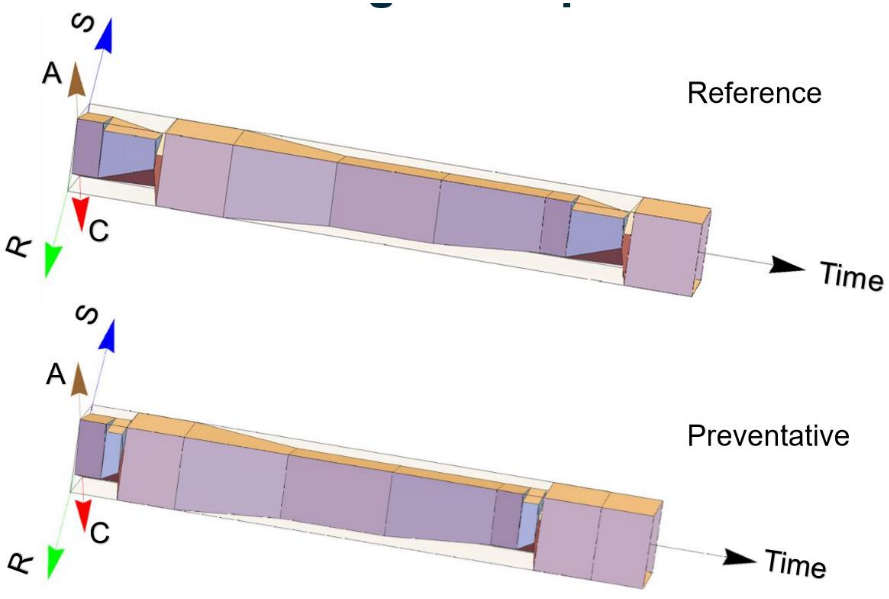
Preventative Scenario

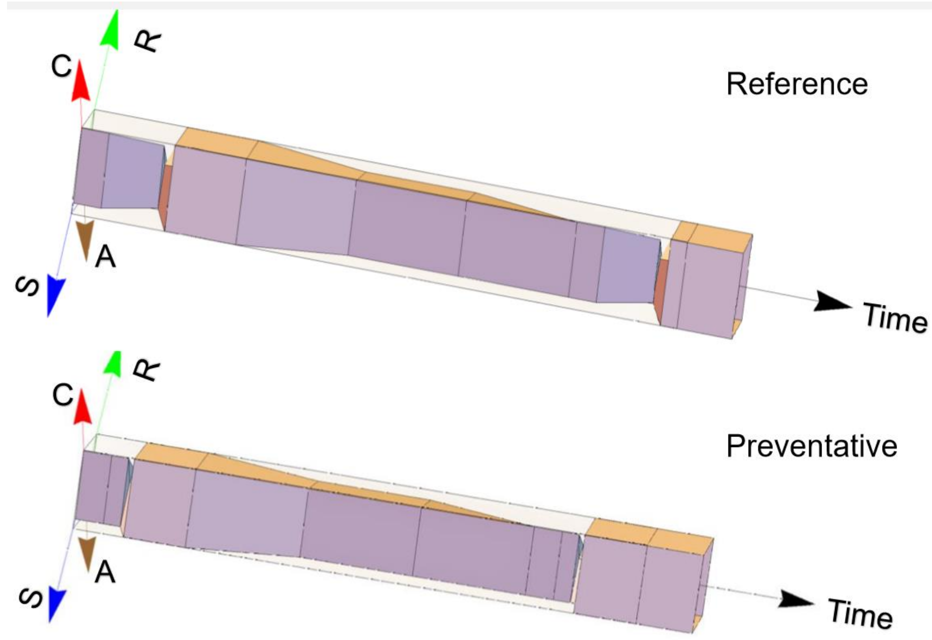


WG4. Comparing Scenarios

- All relevant KPI are to be expressed on the scale from 1 to 5.
- Rating 1 is the best and 5 is the worst.
- Reliability and Safety is already expressed in this manner.
- Availability will be transformed from the 1 to 4 scale into 1 to 5 scale.
- Zero costs are expressed with 0 and the highest costs/year are expressed as 5
- The highest costs/year in both scenarios are 1Mio/year -> rating 5
- In this manner a 3D spider diagram for both scenarios can be generated.

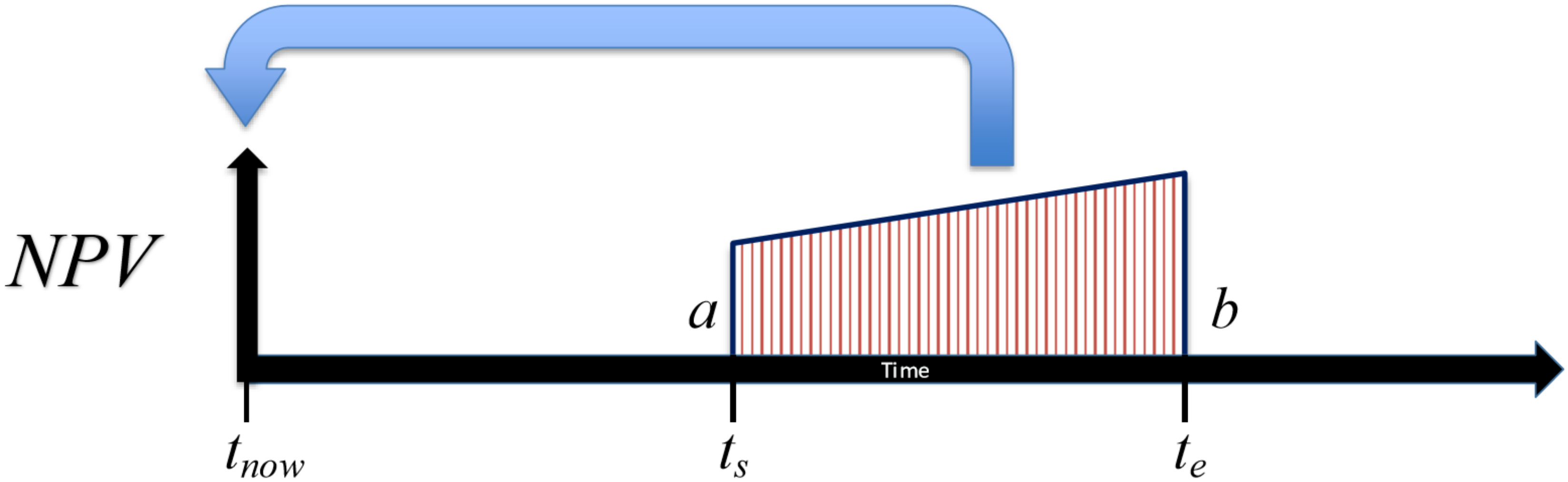
WG4. Comparing Scenarios





WG4. Comparing Scenarios

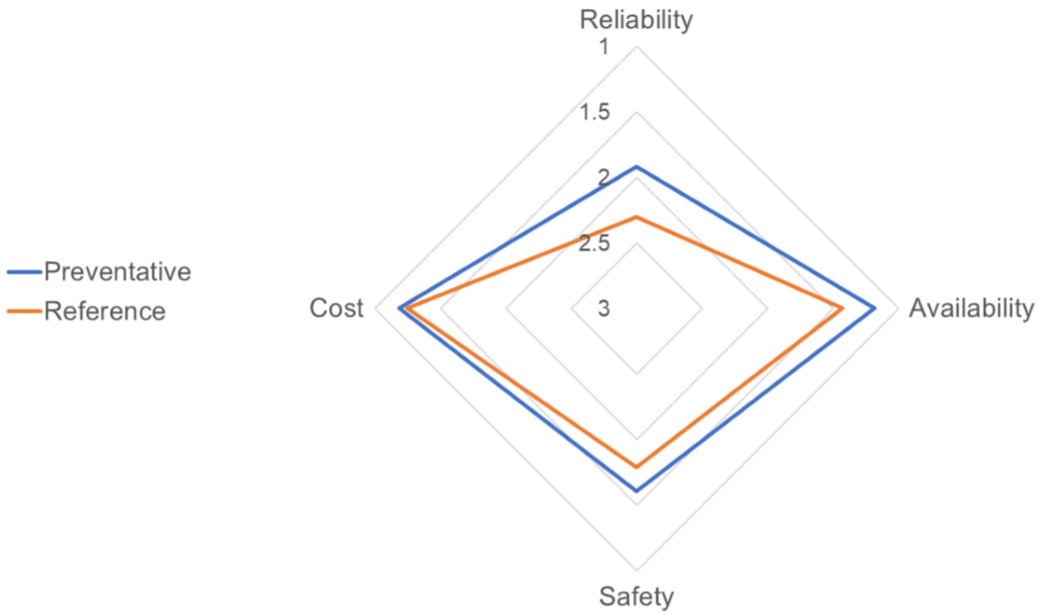
$$NPV = \frac{\left\{\left[r\cdot(t_e - t_s) - 1\right]\cdot b + a\right\}\cdot e^{-rt_e} + \left\{\left[r\cdot(t_s - t_e) - 1\right]\cdot a + b\right\}\cdot e^{-rt_s}}{r^2\cdot\left(t_e - t_s\right)}$$



r = continuous discount rate

WG4. Comparing Scenarios

- Net present value of all KPIs is already directly comparable due to the same scale.
- In order to reduce the KPIs to the same scale as for any time instance the NPV is divided with NPV which is calculated if all KPI were 1 over the whole investigation period.
- These value can be regarded as “average” long term KPIs.



TU1406

COST ACTION

WENZEL Consult

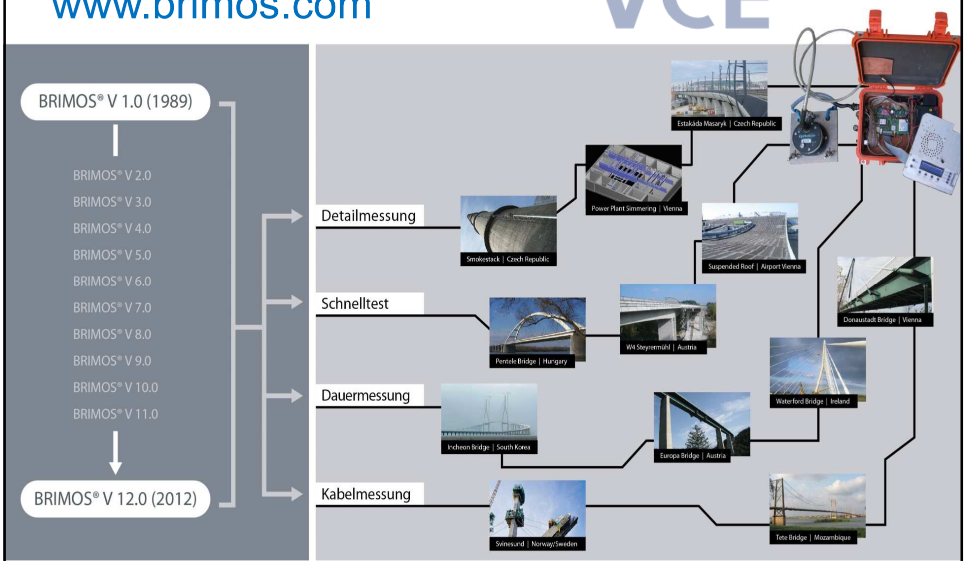
Objectives for Structural Health Monitoring and Asset Management of Bridges

Helmut WENZEL // Zell am See, December 2017

WENZEL Consult

BRIMOS SHM methodology

www.brimos.com



References

WENZEL Consult

- » Bridge design
- » Civil engineering
- » Project management
- » Research & Development
- » Railway design
- » Tunneling
- » Structural health Monitoring (BRIMOS®)
- » Life Cycle Engineering
- » Asset Management

Monitoring and Assessment Work done

WENZEL Consult

- ■ AVM since 1995
- ■ Brands: BRIMOS, SHManager, Seismid

Focus:

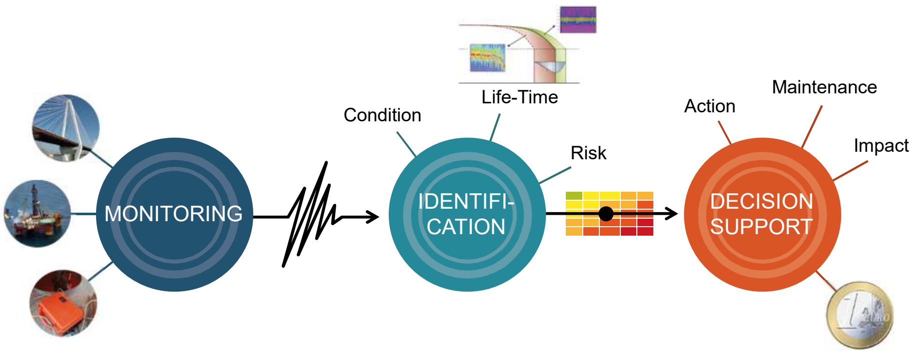
- ■ Bridges, Underground Structures, Railways, Offshore Assets

Monitoring Projects:

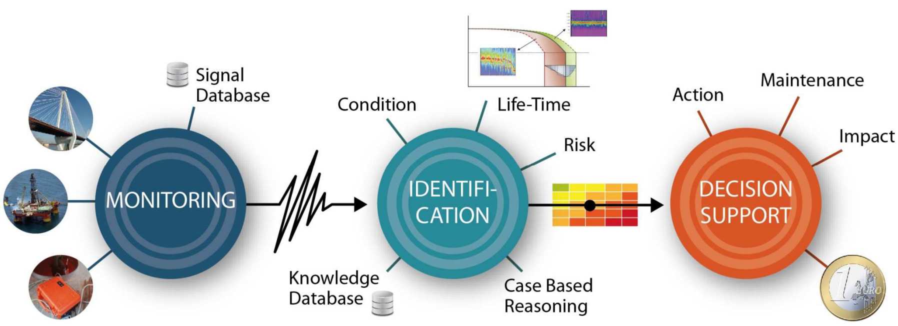
- ■ Total 9000 structures monitored (15TB database)
- ■ 1100 Buildings
- ■ 1800 Bridges
- ■ 2200 Cables
- ■ 40 permanent systems in operation

VCE

BRIMOS® Process

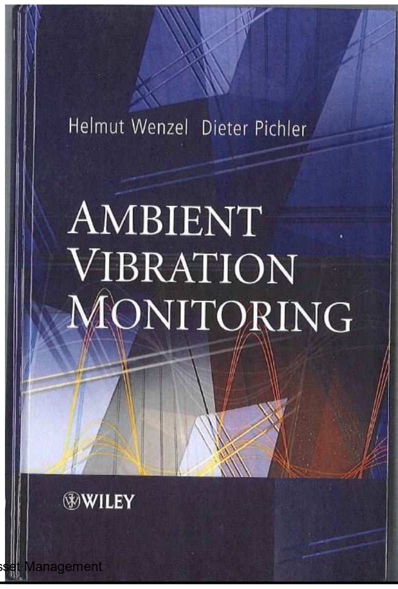


BRIMOS® Process with Data Management



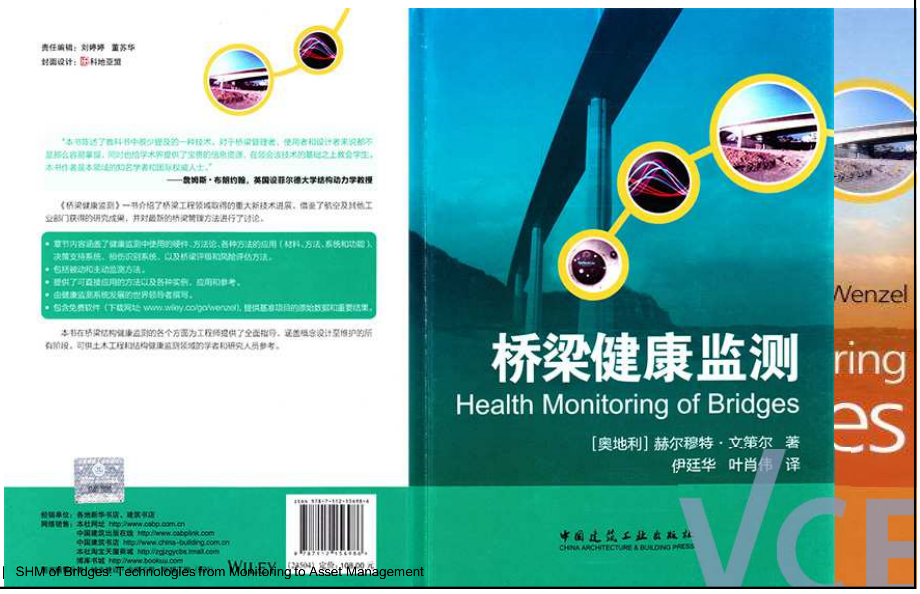
Best Practice Document (SAMCO 2005)

2. Edition in progress



Bridge Monitoring and Assessment (2009)

Available also in Chinese



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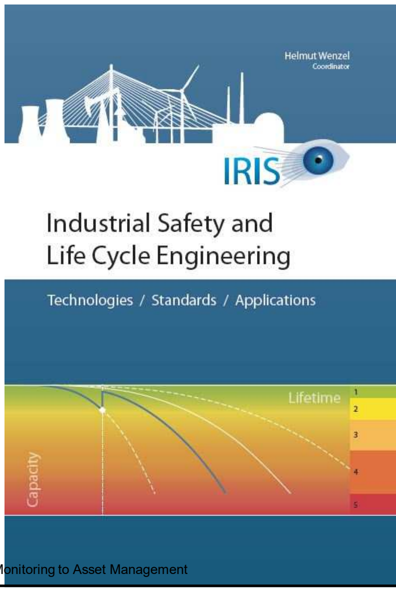
SHM Standardization Activities in Europe (IRIS 2012) Free Copies available!



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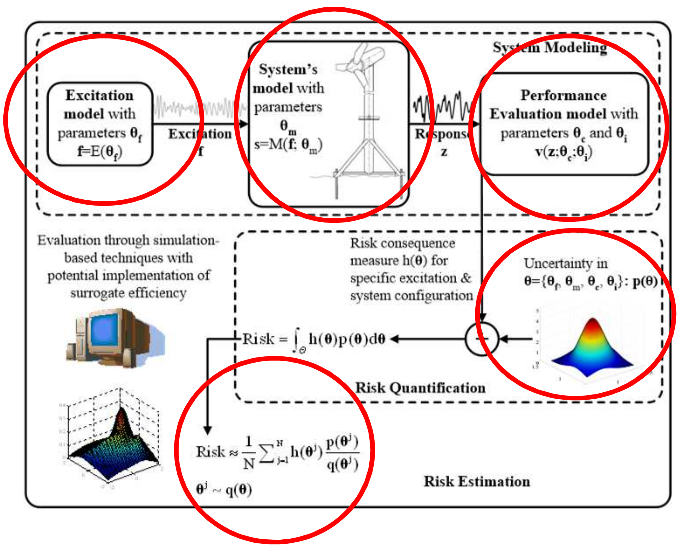
The **IRIS** Risk Paradigm Example



Life Time Performance

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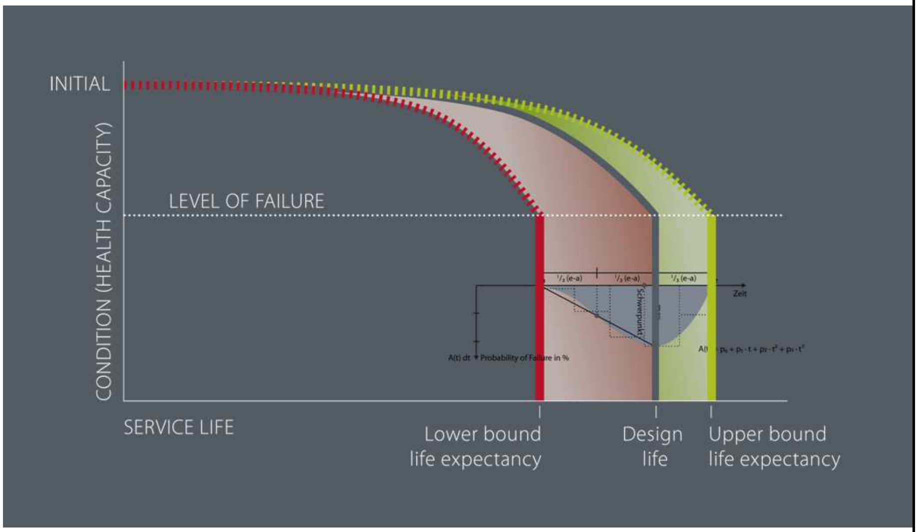

11 |

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» Industrielle Normen im Risikoumfeld

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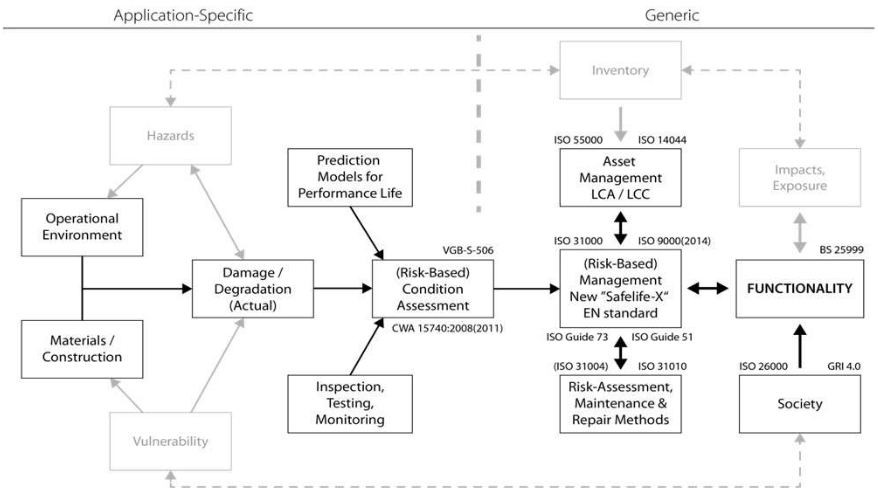

Version 3

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Risikodarstellung

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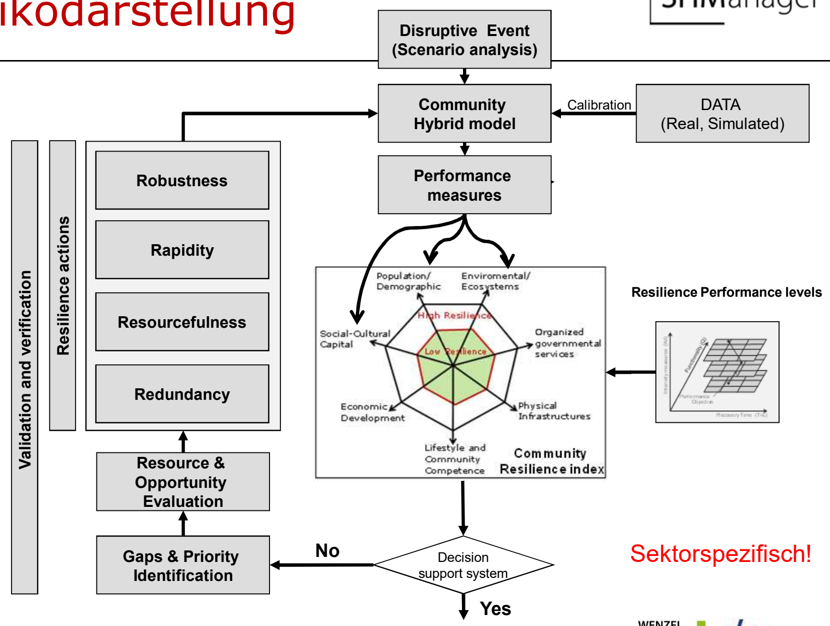

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NBI Parameter

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National Bridge Inventory [NBI] - Data Dictionary

NBI Elements

Item #	Description	Item #	Description
1	State Code	55	Minimum Lateral Underclearance on Right
2	Highway Agency District	56	Minimum Lateral Underclearance on Left
3	County (Parish) Code	58	Deck Condition Rating
4	Place Code	59	Superstructure Condition Ratings
5	Inventory Route	60	Substructure Condition Ratings
6	Features Intersected	61	Channel and Channel Protection
7	Facility Carried by Structure	62	Culverts Condition Ratings
8	Structure Number	63	Method used to Determine Operating Rating
9	Location	64	Operating Rating
10	Inventory Route, Minimum Vertical Clearance	65	Method used to Determine Inventory Rating
11	Kilometer Point	66	Inventory Rating
12	Base Highway Network	67	Structural Evaluation Appraisal Ratings
13	LRS Inventory Route, Subroute Number	68	Deck Geometry Appraisal Ratings
19	Bypass, Detour Length	69	Underclearances, Vertical and Horizontal Appraisal Ratings
20	Toll	70	Bridge Posting
21	Maintenance Responsibility	71	Waterway Adequacy Appraisal Ratings
22	Owner	72	Approach Roadway Alignment Appraisal Ratings
26	Functional Classification of Inventory Route	75	Type of Work
27	Year Built	76	Length of Structure Improvement
28	Lanes On and Under the Structure	90	Inspection Date
29	Average Daily Traffic	91	Designated Inspection Frequency
30	Year of Average Daily Traffic	92	Critical Feature Inspection
31	Design Load	93	Critical Feature Inspection Date
32	Approach Roadway Width	94	Bridge Improvement Cost
33	Bridge Median	95	Roadway Improvement Cost
34	Skew	96	Total Project Cost
35	Structure Flared	97	Year of Improvement Cost Estimate
36	Traffic Safety Features	98	Border Bridge
37	Historical Significance	99	Border Bridge Structure Number
38	Navigation Control	100	STRAHNET Highway Designation
39	Navigation Vertical Clearance	101	Parallel Structure Designation
40	Navigation Horizontal Clearance	102	Direction of Traffic
41	Structure Open, Posted or Closed to Traffic	103	Temporary Structure Designation
42	Type of Service	104	Highway System of the Inventory Route
43	Structure Type, Main	105	Federal Lands Highways
44	Structure Type, Approach Spans	106	Year Reconstructed
45	Number of Spans in Main Unit	107	Deck Structure Type
46	Number of Approach Spans	108	Wearing Surface/Protective System
47	Inventory Route, Total Horizontal Clearance	109	Average Daily Truck Traffic
48	Length of Maximum Span	110	Designated National Network
49	Structure Length	111	Pier or Abutment Protection [for navigation]
50	Curb or Sidewalk Widths	112	NBIS Bridge Length
51	Bridge Roadway Width, Curb-to-Curb	113	Scour Critical Bridges
52	Deck Width, Out-to-Out	114	Future Average Daily Traffic
53	Minimum Vertical Clearance Over Bridge Roadway	115	Year of Future Average Daily Traffic
54	Minimum Vertical Underclearance	116	Minimum Navigation Vertical Clearance

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NBI Parameter

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NBI Elements > ITEMS 70 - Bridge Posting

Code	Description
5	Equal to or above legal loads
4	00.1 - 09.9 % below
3	10.0 - 19.9 % below
2	20.0 - 29.9 % below
1	30.0 - 39.9 % below
0	> 39.9% below
99	Miscoded data

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Content

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- Facts and Figures in Bridge Management
- Learning from Cases and Events
- Monitoring and Assessment
- Standards and Guidelines
- Monitoring Control Centres
- Conclusions

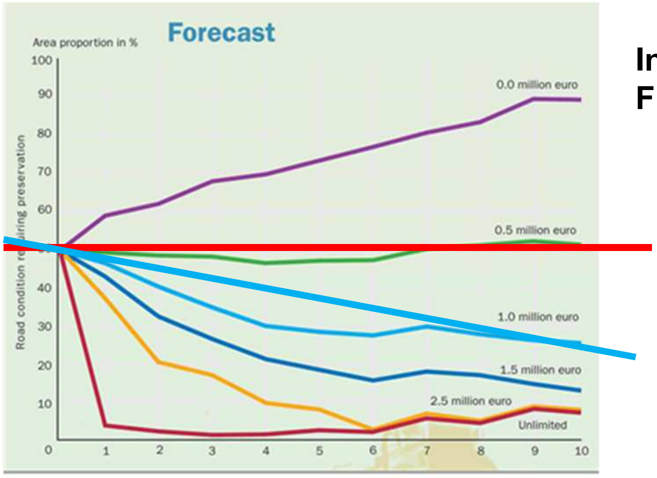
Content

- **Facts and Figures in Bridge Management**
- Learning from Cases and Events
- Monitoring and Assessment
- Standards and Guidelines
- Monitoring Control Centres
- Conclusions

Specific Issues of Bridge Management (Basics)

- Ageing is a steady process comprising every asset on earth.
- To keep functionalities investment into maintenance is necessary.
- Studies have shown that an average investment of **0,87% of the replacement value** is required to keep functionality
- In most in the cases only half of this budget is made available.
- This results in a loss of functionality over time.

Specific Issues of Asset Management
(cost vs condition)



Investment vs Functionality

Status in Germany till 2012

Decision in Germany 2012

Content

eRISK
AGENDA

Zitat BP Offshore

„ If you think safety is expensive, try an accident“

eRISK
MODUL 2

TGV Accident 14. 11. 2015

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Collapse Events

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Understanding Technologies

Misconceptions

WENZEL Consult

Understanding Interrelations

Loading Problems

China
Scour

Understanding Hazards

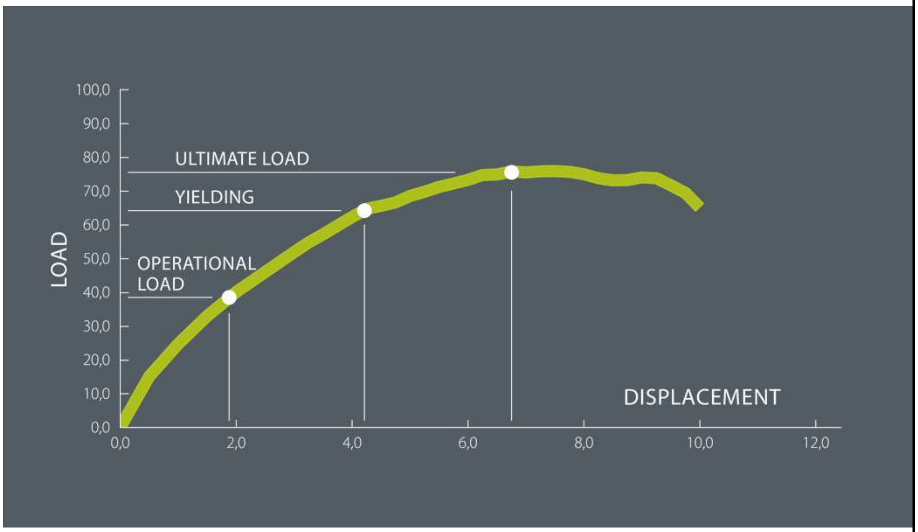
29 | SHM of Bridges: Technologies from Monitoring to Asset Management

Famous I-35 Collapse

30 | SHM of Bridges: Technologies from Monitoring to Asset Management

Content

Ultimate Load



Fatigue Status

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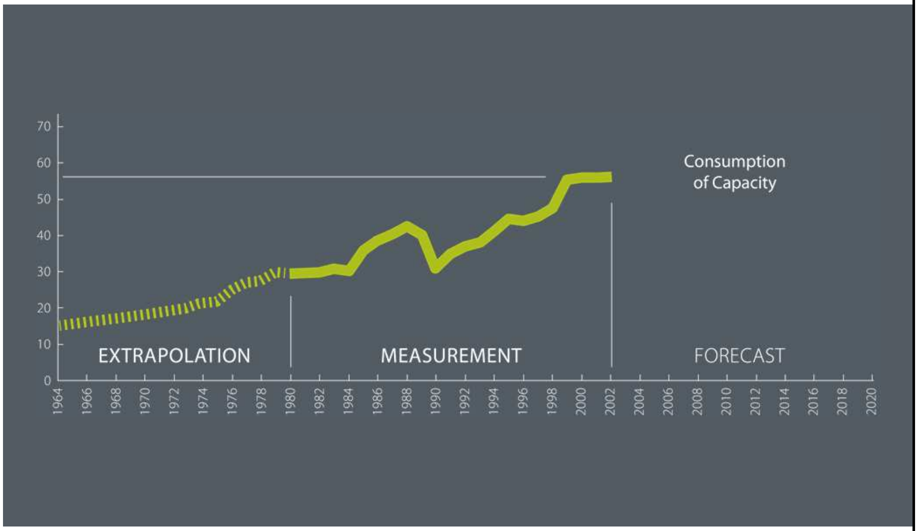

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Targeted Inspection

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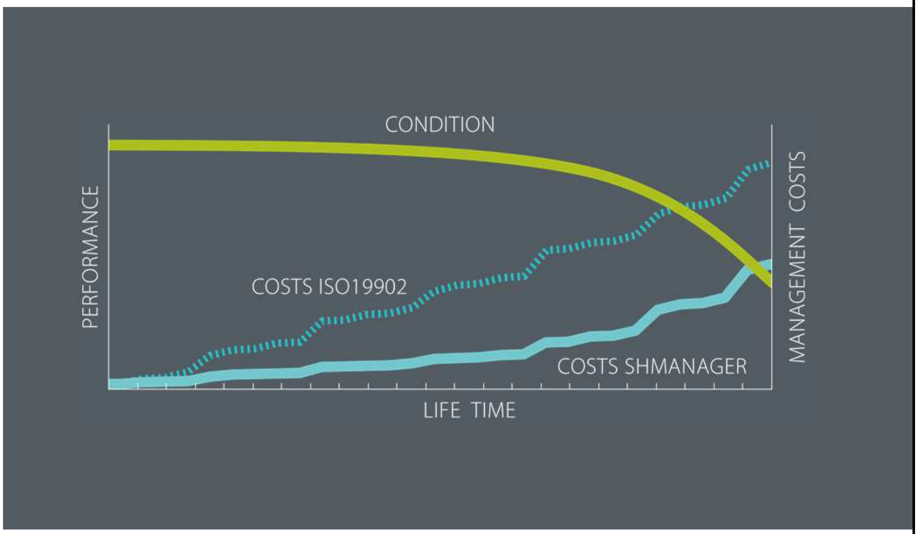

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Targeted Inspection

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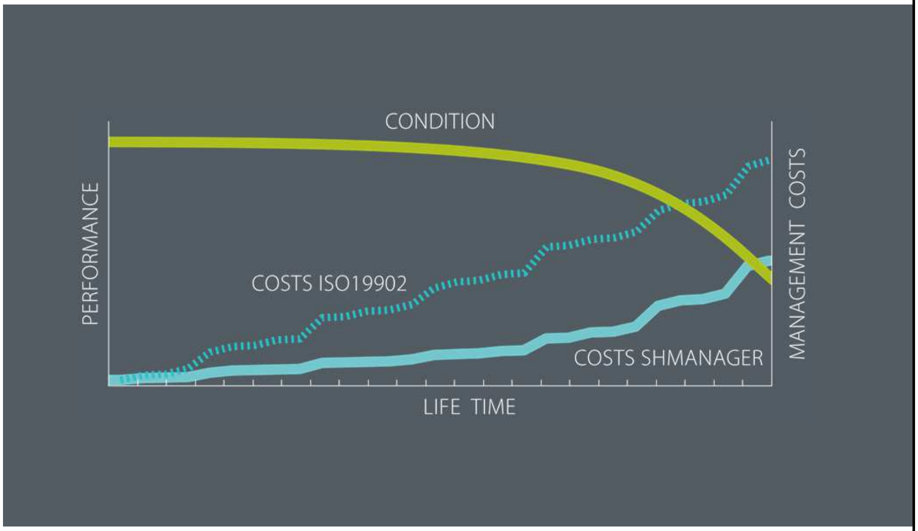

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Extension of Life

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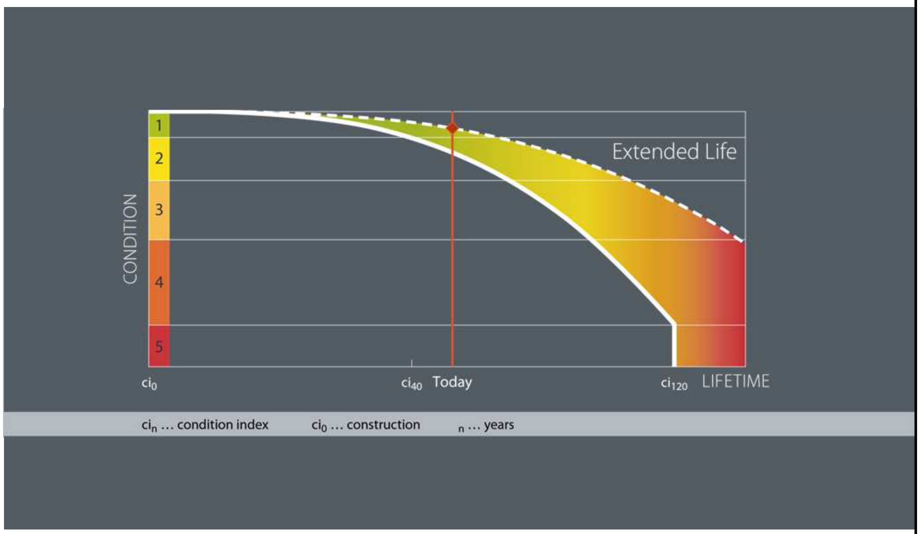

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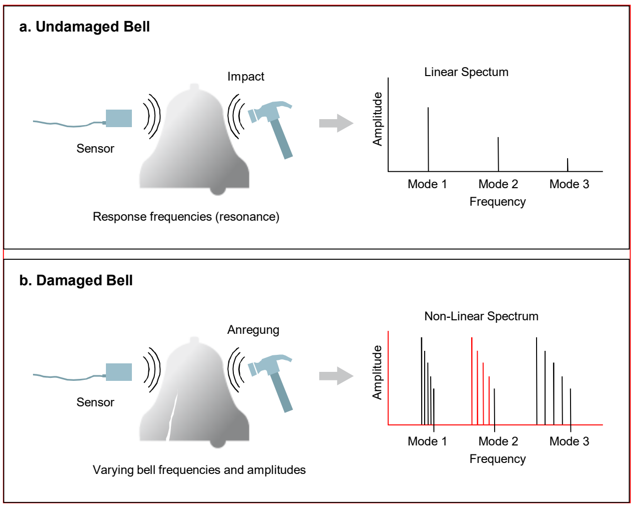
Background: Why Dynamic Monitoring ?



Shadow Frequencies

Indicate Damage

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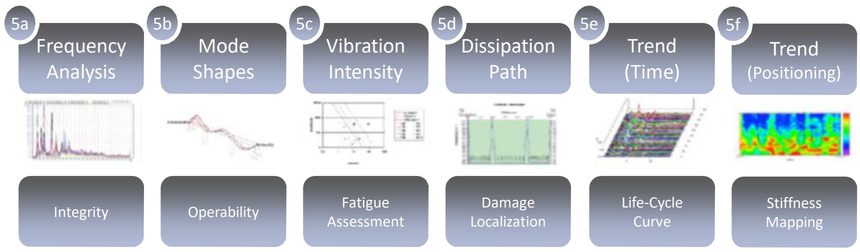
Damage Identification
(from Parameters to Key Performance Indicators KPIs)

Damage Parameters and Indicators:

1. Displacements (kinematics)
2. Natural frequencies (shift and character)
3. Mode shapes
4. Damping
5. Energy Dissipation (leaks, transfers)
6. Power spectral density:
   » cumulative sum
   » shift of the cumulative sum

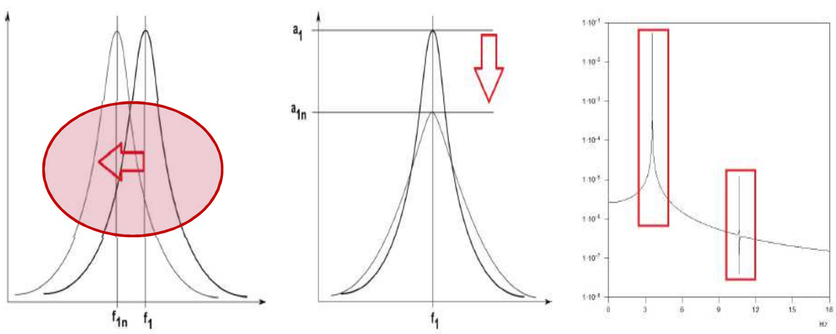
Data Analysis

- Key Performance Indicators (KPIs) obtained from analysis of measurement data

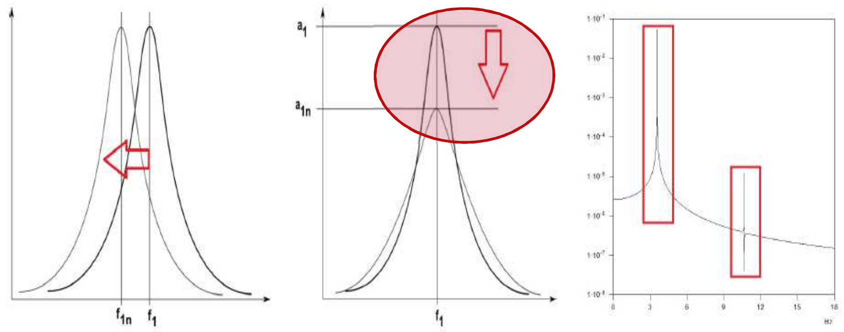


- KPIs are used in the analysis to determine the current **condition of a structure**

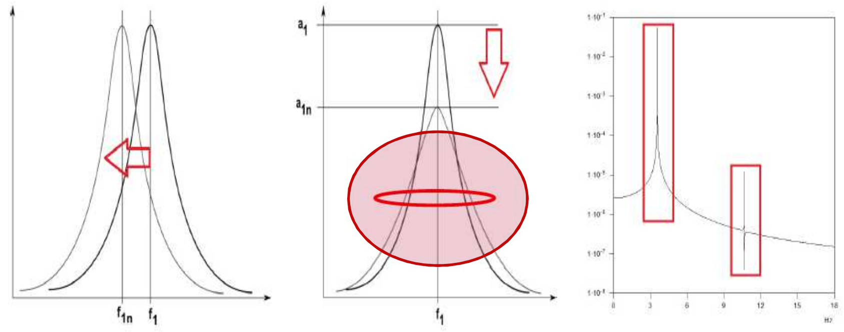
Parameter vs Key Performance Indicators



Parameter vs Key Performance Indicators



Parameter vs Key Performance Indicators



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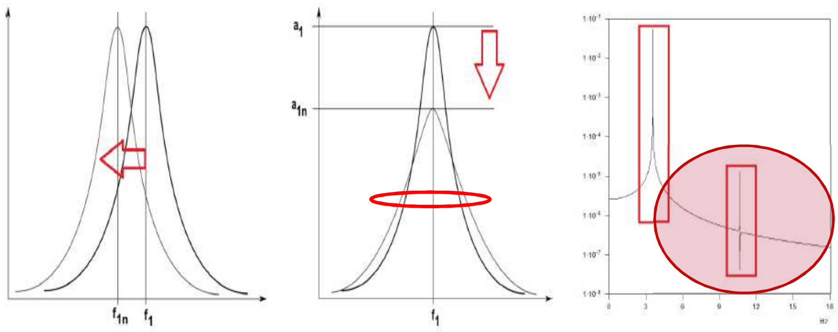
Parameter vs Key Performance Indicators



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Aging

IRIS Aging Formulation (CEN)

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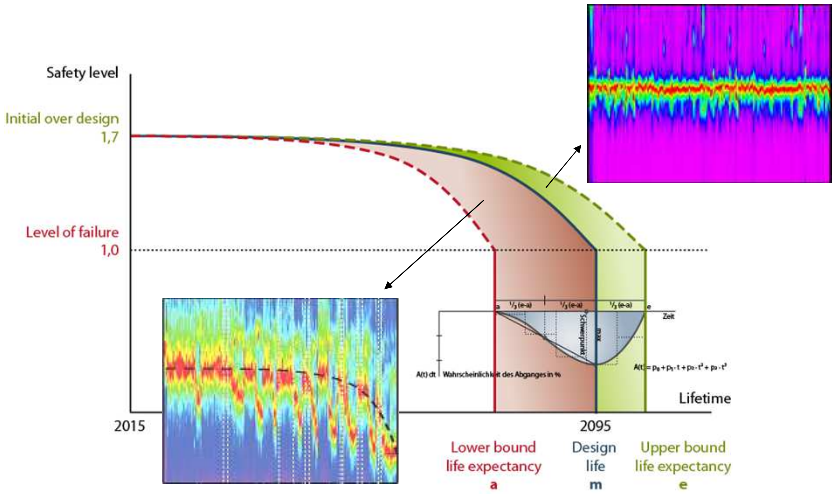
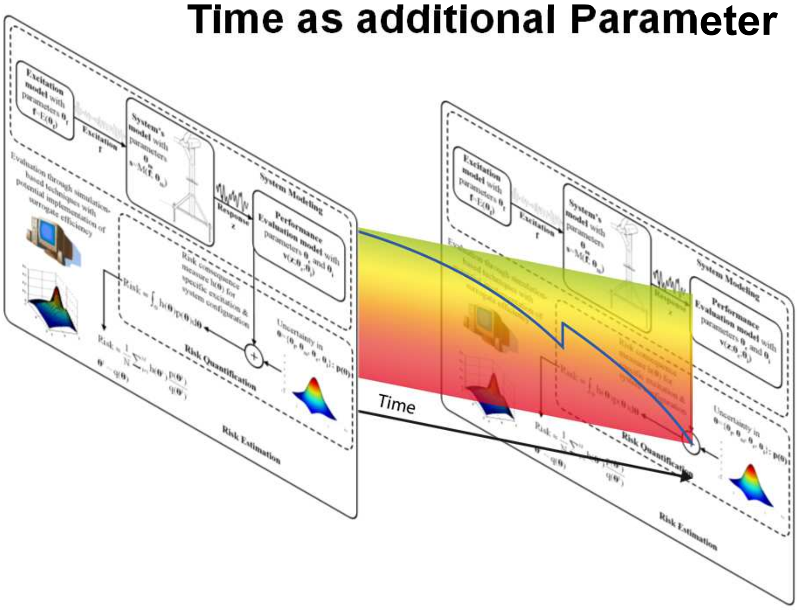


IRIS Risk Paradigm
Time as additional Parameter



Life Cycle and Event Management Concept

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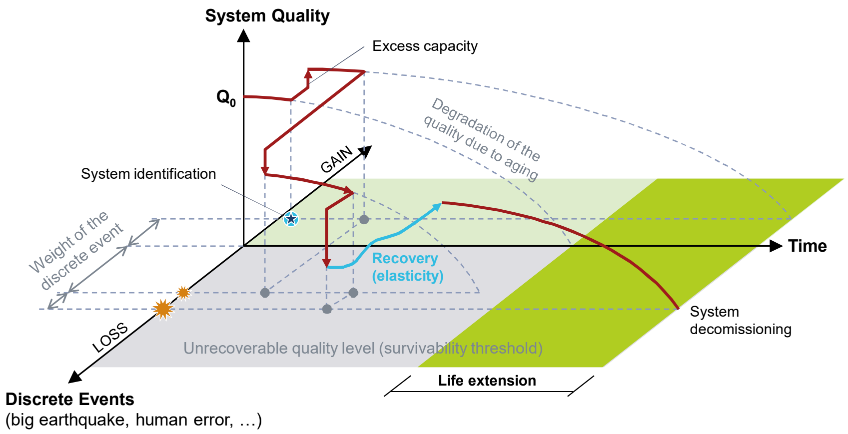

Rating: International Comparison

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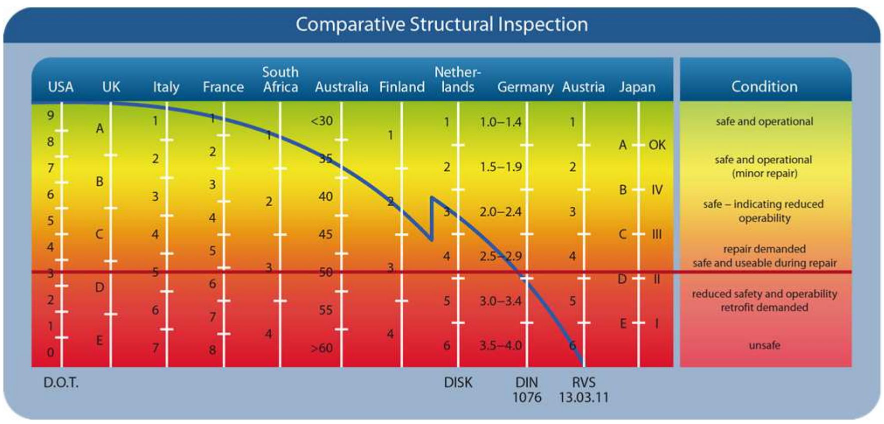

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Performance, Risk and Safety

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Proposed Procedure (from IRIS 2012)

- **Risk = Hazard * Vulnerability * Consequences**
- Hazard and trends are known (Climate Change)
- Introduce **aging** into the vulnerability model
- Introduce **functionality** in the performance model
- Compute and **normalize risk**
- Fix **individual inspection period and procedures**
- **Improve information by monitoring**

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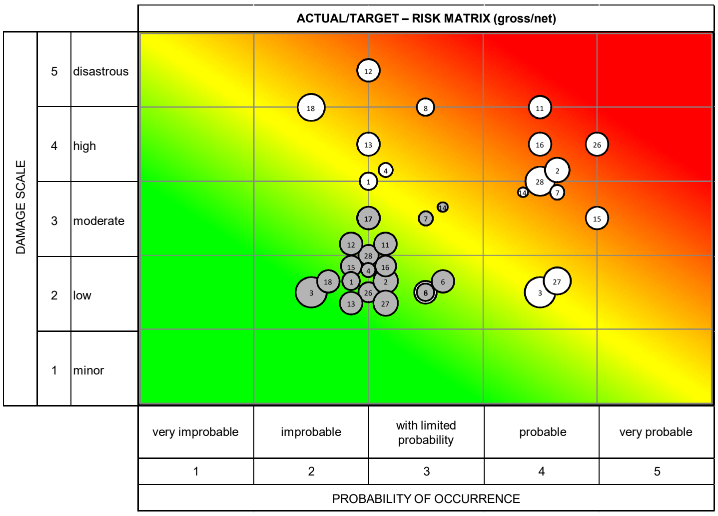
Representation of Risk (Example)



Targeted Inspection Programme

Risk Quantification

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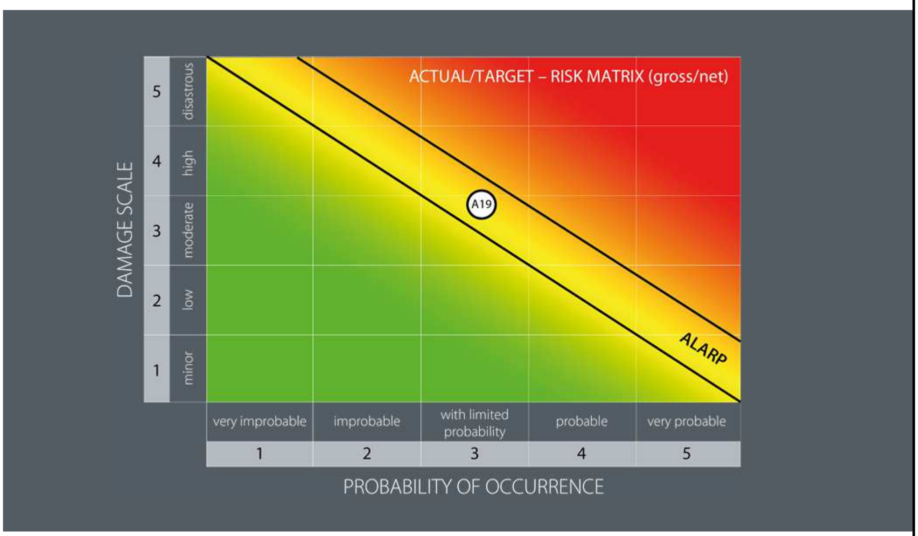

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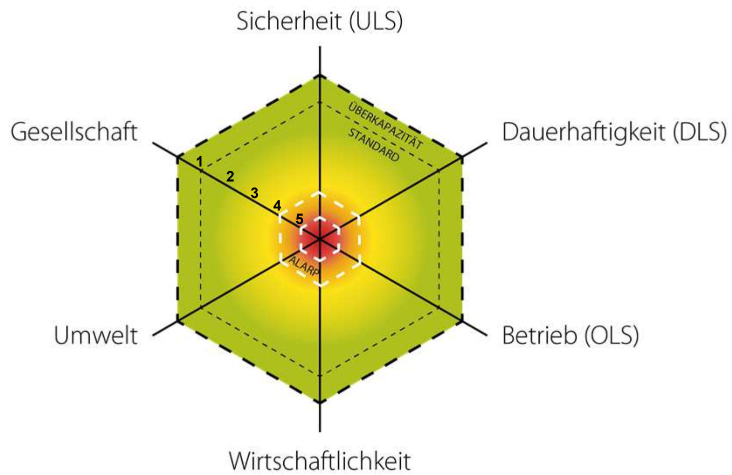
eRISK
AGENDA

Bestimmung von Risken (Hausarbeit)



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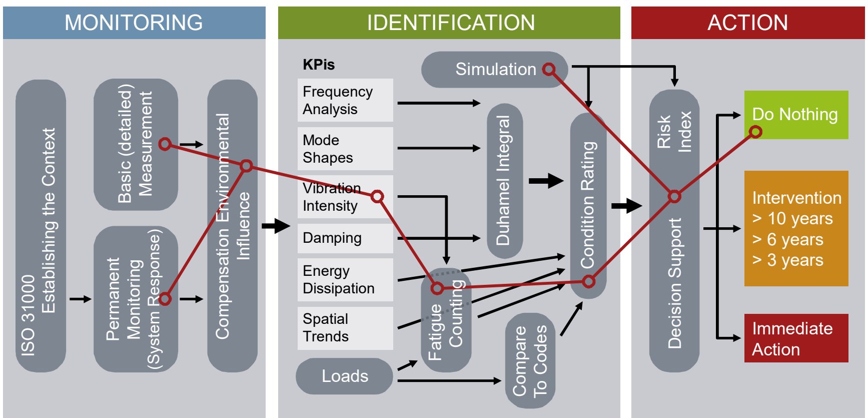
IRIS

Monitoring – Identification – Action

Determination of Fatigue Life



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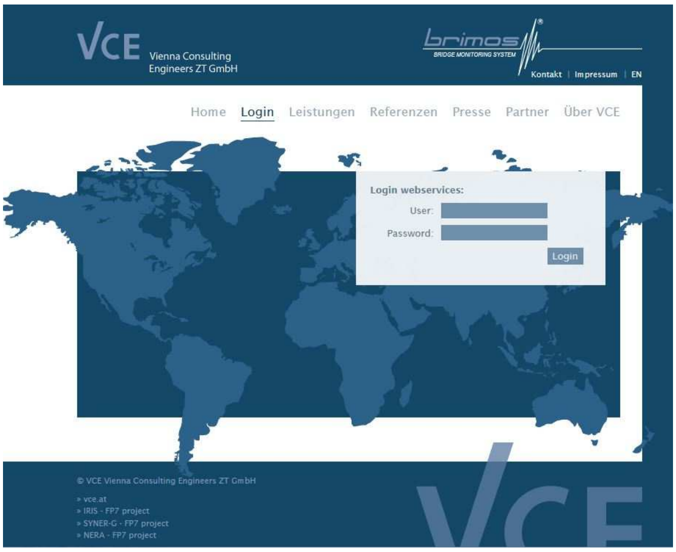
Multi functional Web-Interface

www.brimos.com



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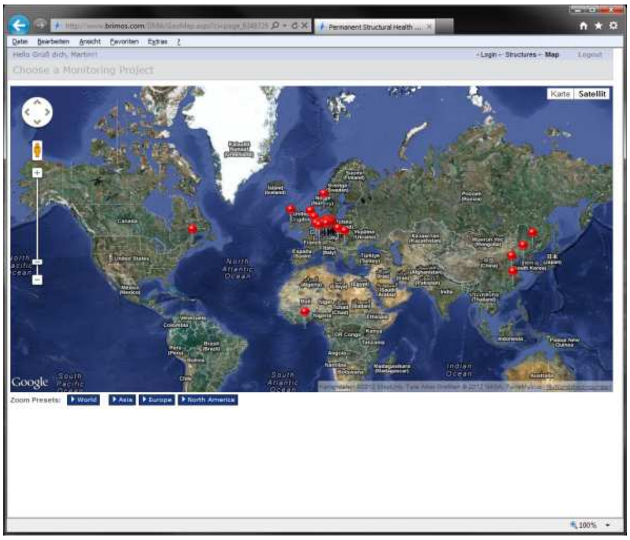
Multi functional Web-Interface

Overview and interactive data management (>9000 cases)

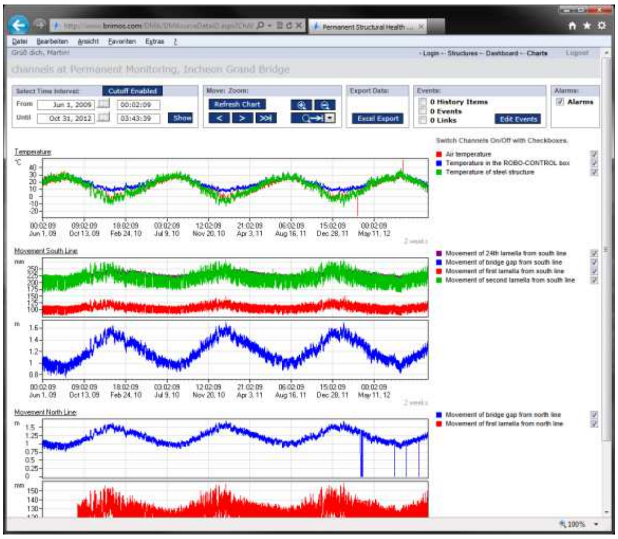


> 9000 cases

Incheon Monitoring of Critical Joints

Multi functional Web-Interface

Inchon Bridge (Korea): Life Cycle counting and performance



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Example: New Structures

Tai Zhou, China

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Multi functional Web-Interface

Tai Zhou Bridge (China): Performance Alarm

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Inspections, how precise?

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Standardization?
Aswan Bridge / Jan. 2013

Pier Condition after Ship Impact ?

Halifax – Joint Performance

Two Suspension Bridges

65 | SHM of Bridges: Technologies from Monitoring to Asset Management

Typical Monitoring Cabinet

66 | SHM of Bridges: Technologies from Monitoring to Asset Management

Un-typical Monitoring Conditions

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Alarm from outliers in correlation functions

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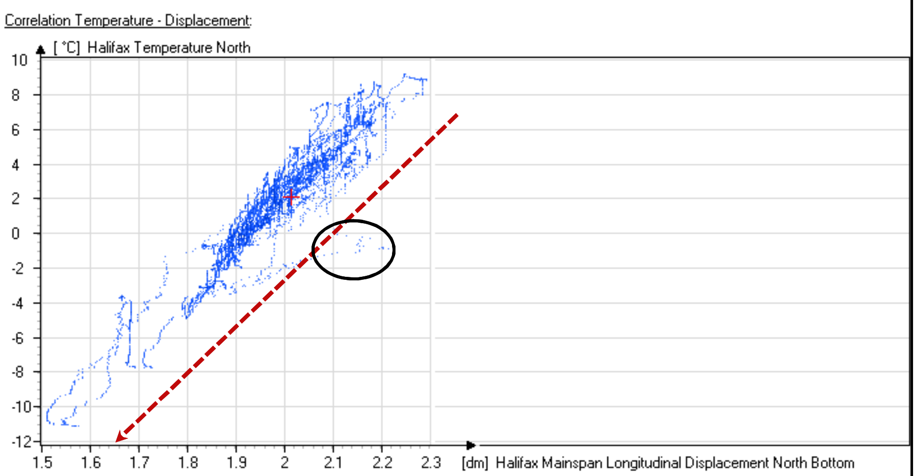


Content

■ Facts and Figures in Bridge Management

■ Learning from Cases and Events

■ Monitoring and Assessment

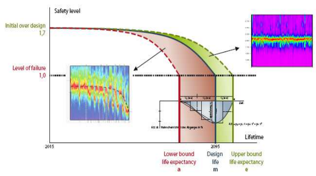
■ **Standards and Guidelines**

■ Monitoring Control Centres

■ Conclusions

SHM Standardization Activities in Europe

- DIN 91298
- USA (Nist)
- UK (BS 16663)
- Japan
- Canada
- Netherlands
- New Zealand
- Russia
- Turkey
- Switzerland
- +7



/TC

Date: 2012-06

prCWA 63:2012

/TC

Secretariat: ON

Ageing behaviour of Structural Components with regard to Integrated Lifetime Assessment and subsequent Asset Management of Constructed Facilities —

Alterungsverhalten von Bauteilen in Bezug auf ganzheitliche Lebenszyklusbewertungen und weiterführendes Erhaltungsmanagement von Infrastrukturbauten —

ICS:

Descriptors: Draft version May 16th, 2012

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A new EUROCODE

Date: 2014-01
CEN/TC 319
Secretariat: NEN UNI

Risk-Based Inspection Framework

Document type: European Standard
Document subtype:
Document stage: CEN Enquiry
Document language: E

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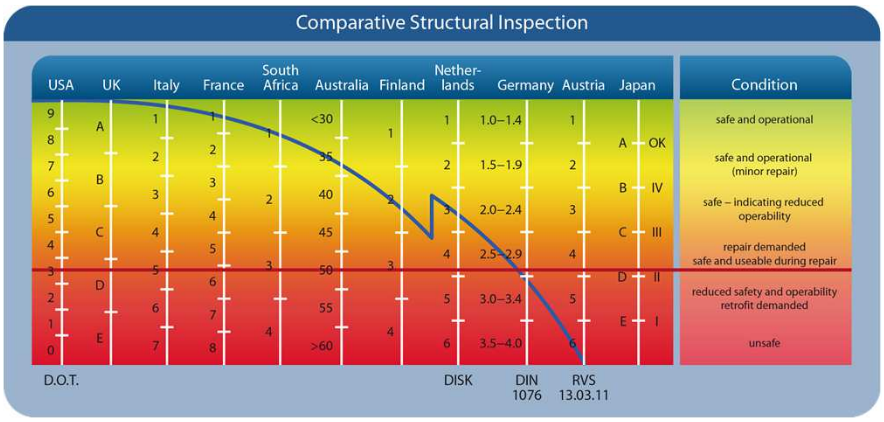
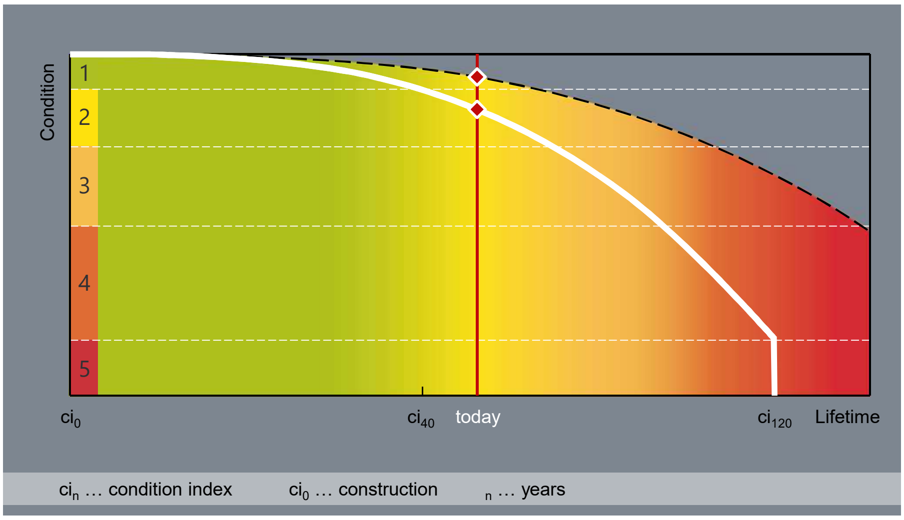
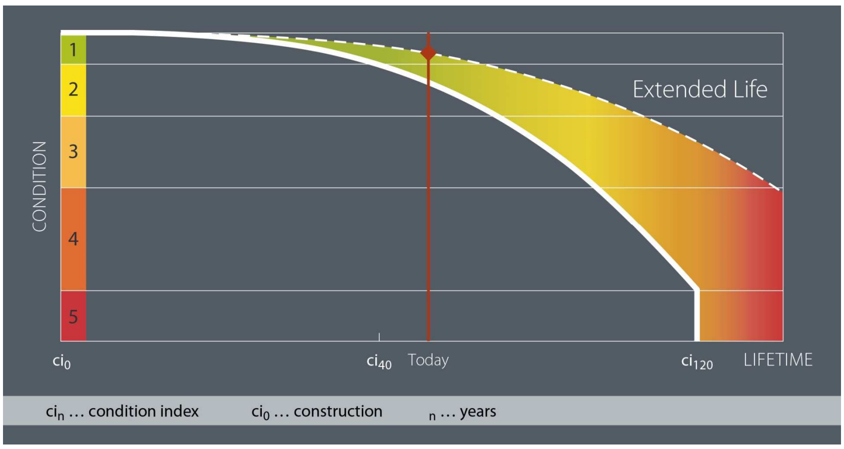
Rating: International Comparison



The NEW Colour Scheme with Uncertainty



Representation of extended Life



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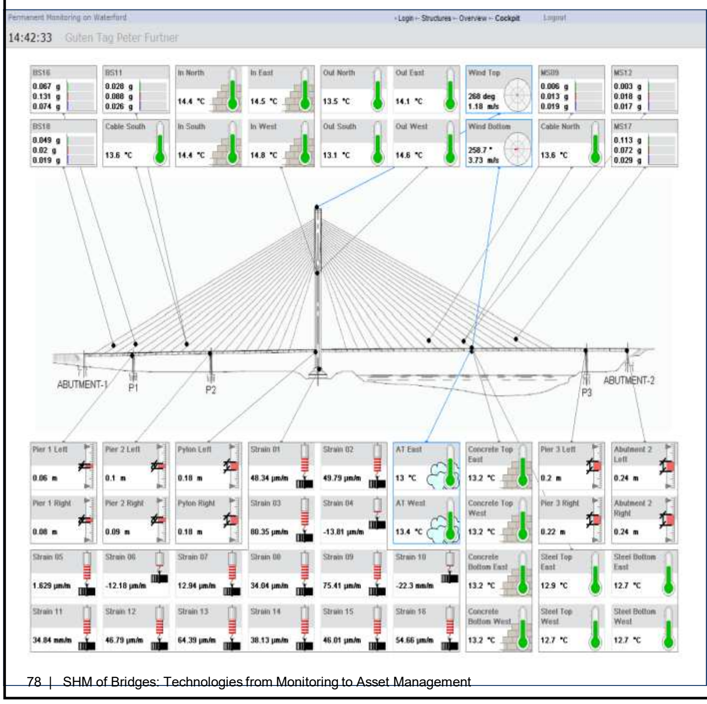
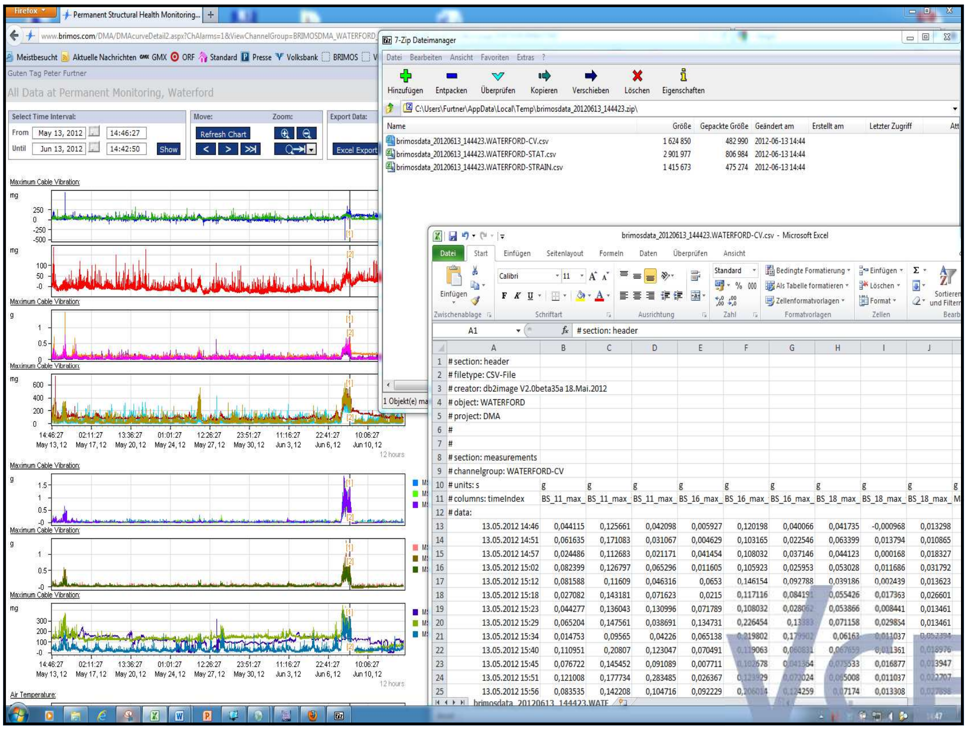
Content

PPP Management (design built), Irland





Incheon Monitoring of Critical Joints

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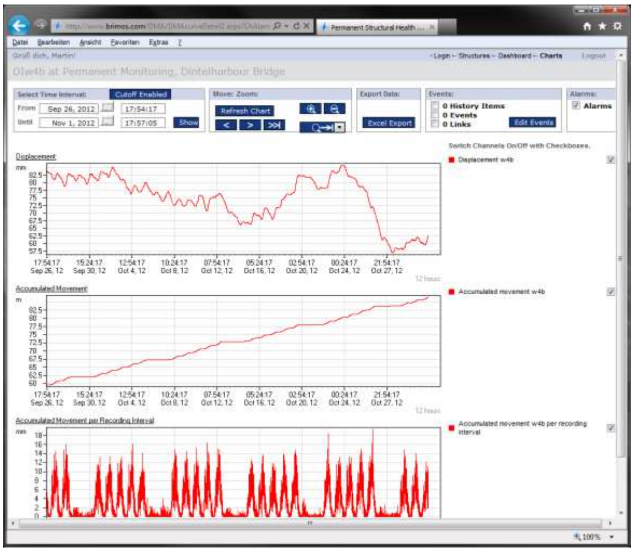
Incheon (KR) Monitoring: Displacement Collectives



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Dintelhaven Monitoring: Load Collectives

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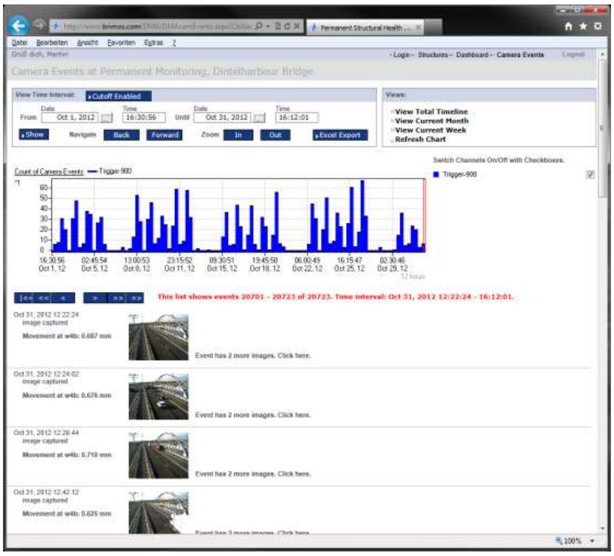
Dintelhaven Monitoring: Load Collectives



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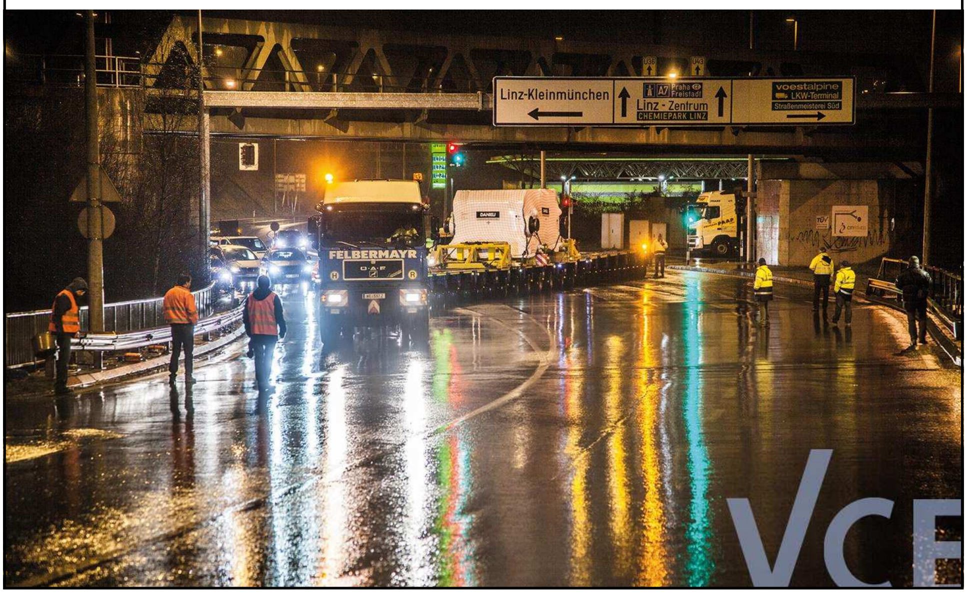
Heavy Loads (350t) – Real-time Assessment



Heavy Loads (350t) – Real-time Assessment

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Vergleich der durchgeführten Sondertransporte hinsichtlich Gewicht, dessen Verteilung und Lage am Tieflader

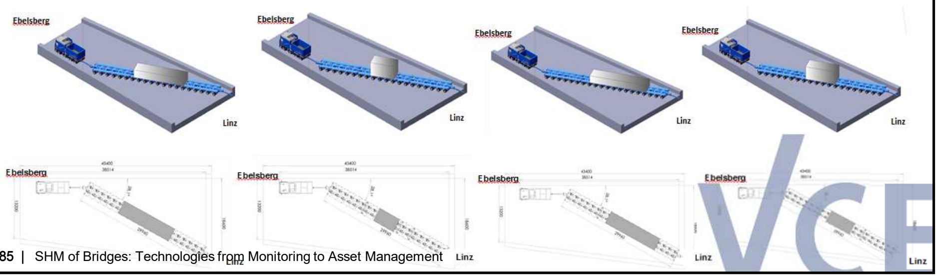
1.Uberfahrtsserie 2.Uberfahrtsserie 3.Uberfahrtsserie 4.Uberfahrtsserie

	1. Überfahrtsserie	
	16.12.2013	
	Überfahrt 1	Überfahrt 2
Tonnage	305	305
Achsanzahl Tieflader	20	20
Gewichtsverteilung	Achse 7-15	Achse 7-15

	2. Überfahrtsserie	
	21.01.2014	
	Überfahrt 1	Überfahrt 2
Tonnage	280	295
Achsanzahl Tieflader	20	20
Gewichtsverteilung	Achse 9-11	Achse 9-12

	3. Überfahrtsserie	
	17.02.2014	
	Überfahrt 1	Überfahrt 2
Tonnage	295	295
Achsanzahl Tieflader	20	20
Gewichtsverteilung	Achse 8-17	Achse 8-17

	4. Überfahrtsserie	
	20.03.2014	
	Überfahrt 1	Überfahrt 2
Tonnage	295	280
Achsanzahl Tieflader	20	20
Gewichtsverteilung	Achse 9-13	Achse 8-13



Heavy Loads (350t) – Real-time Assessment

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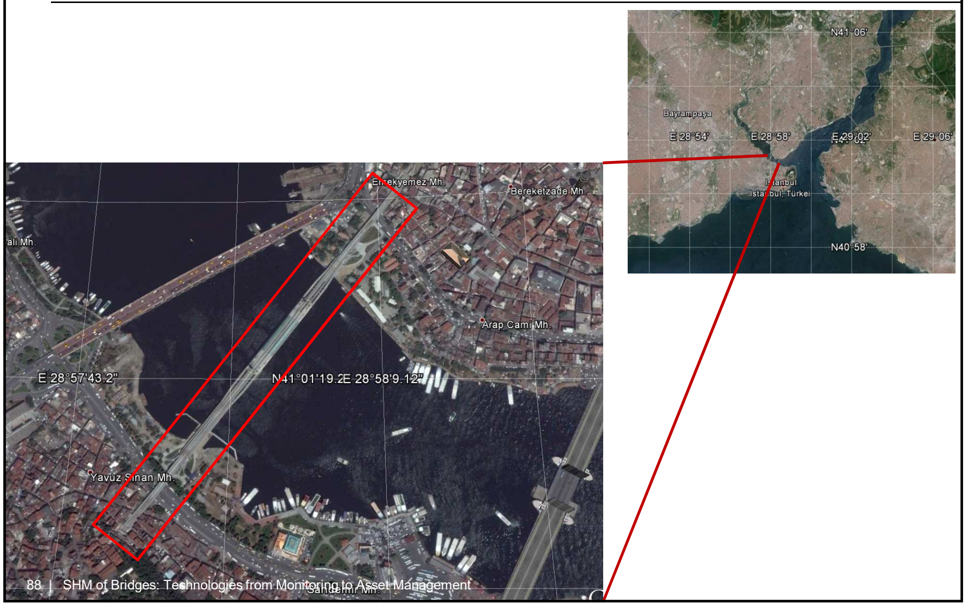
Bridge Location

Istanbul – Golden Horn



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Halic Metro Bridge
Operation and Rotation Tests

89 | SHM of Bridges: Technologies from Monitoring to Asset Management

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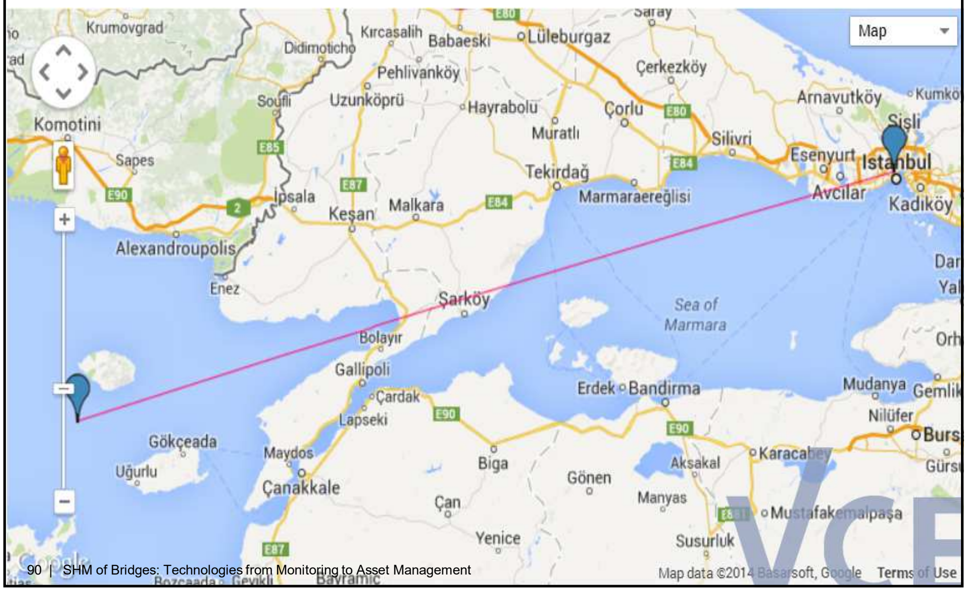
Halic Metro Bridge
Monitoring Facts and Figures



90 | SHM of Bridges: Technologies from Monitoring to Asset Management

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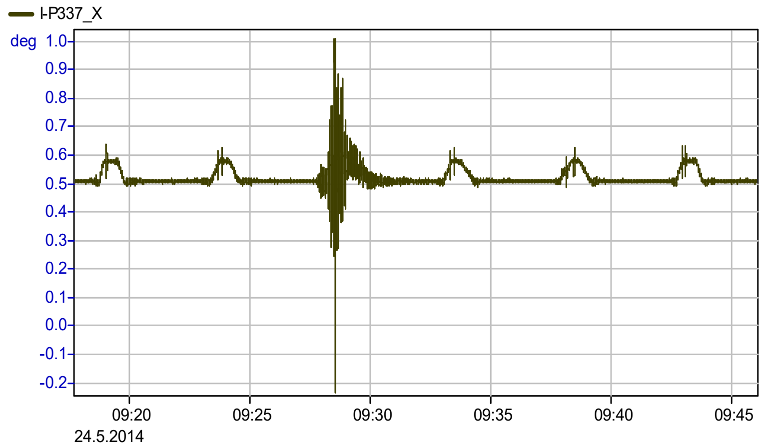
Halic Metro Bridge

Monitoring Facts and Figures



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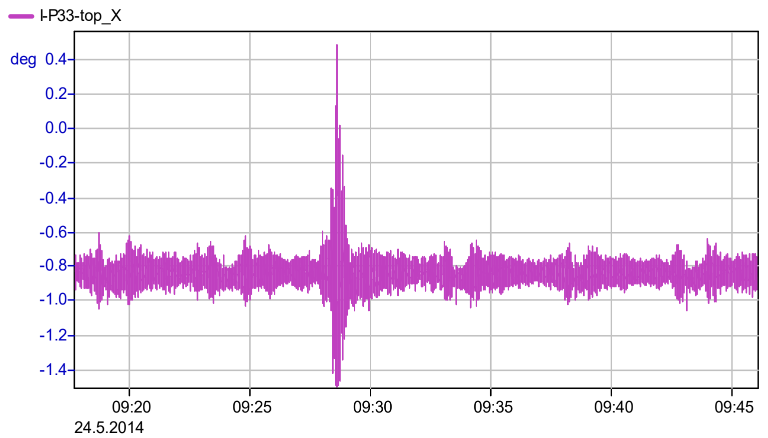
Halic Metro Bridge

Monitoring Facts and Figures



Halic Metro Bridge

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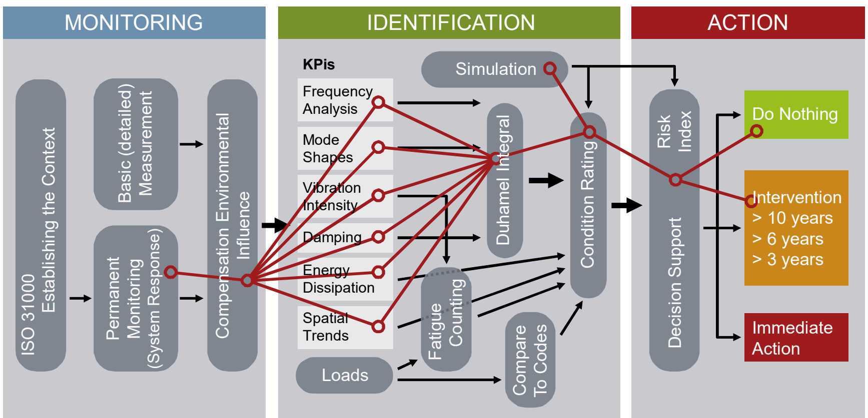
Monitoring – Identification – Action

Performance of Joints at Infrastructures

IRIS



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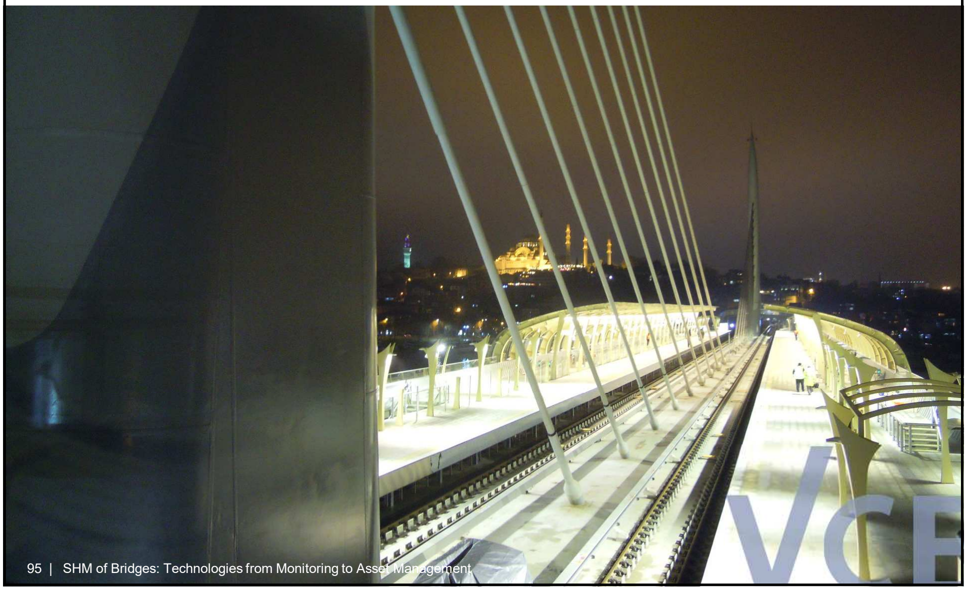
Halic Metro Bridge



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3. Bosporus Bridge Monitoring

European Side

Content

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- Monitoring and Assessment
- Standards and Guidelines
- Monitoring Control Centres
- **Conclusions**

Izmit Bay Bridge, Turkey

WENZEL Consult

Decision Support

WENZEL Consult

Summary

- Asset Management is changing
- **Risk based Inspection and Monitoring** are applied to optimise Costs and Availability
- Life Cycle Models are applied
- Accurate Condition rating is feasible
- **Risk, Functionality** and **Availability** are key
- Asset Management becomes more effective

Thank You !

helmut.wenzel@wenzel-consult.com

TU1406
COST ACTION

COST TU1406 – An overview of European Standardization on Quality Control of Road Bridges

Performance-based assessment of Existing Road Bridges
WG1 Performance Indicators

18th – 21st December,
2017 Hotel St. Hubertushof Zell am See,
Salzburg, Austria

Alfred Strauss– Chair WG1

European Science Foundation
ESF provides the COST Office through a European Commission contract

COST is supported by the EU Framework Programme

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Winterschool Zell am See

Tuesday, 19 December 2017	
09:00 – 10:00	Opening by Helmut Wenzel
10:00 – 10:15	Coffee-break
10:15 – 12:00	Risk based bridge assessment and management – best practice by Helmut Wenzel
12:00 – 13:00	Lunch
13:00 – 15:00	Performance based assessment of existing road bridges WG1 Performance indicators / Workshop by Alfred Strauss
15:00 – 15:15	Coffee-break
15:15 – 16:00	Performance based assessment of existing road bridges WG1 Performance indicators / Workshop reflection by Alfred Strauss

Winterschool Zell am See

Wednesday, 20 December 2017	
09:00 – 10:00	WG2 Performance goals / Workshop by Irina Stipanovic
10:00 – 10:15	Coffee-break
10:15 – 12:00	WG2 Performance goals – best practice by Irina Stipanovic
12:00 – 13:00	Lunch
13:00 – 15:00	Application of quality control framework by Rade Hajdin
15:00 – 15:15	Coffee-break
15:15 – 16:00	Application of quality control framework – best practice by Rade Hajdin

Winterschool Zell am See

Thursday, 21 December 2017	
09:00 – 10:00	Application of quality control framework – best practice by Rade Hajdin
10:00 – 10:15	Coffee-break
10:15 – 12:00	WG2 Performance goals – best practice by Irina Stipanovic
12:00 – 13:00	Lunch
13:00 – 15:00	International aspects by Helmut Wenzel
15:00 – 15:15	Coffee-break
15:15 – 16:00	International aspects by Helmut Wenzel
18:30 – 22:00	Social event

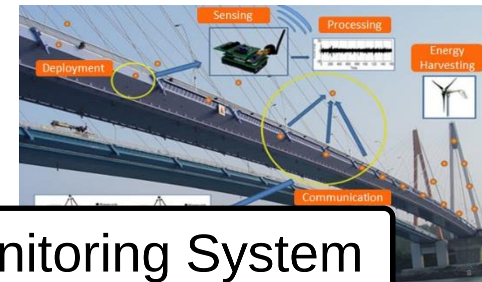
Winterschool Zell am See

Friday, 22 December 2017	
10:00 – 11:00	Transfer from Zell am See to Vienna

BACKGROUND

Visual Inspection

NDT Testing



Monitoring System

Performance Indicator

Performance Goal

Quality Control Plan

REASONS FOR THE ACTION

There is a **REAL NEED** to standardize the quality assessment of roadway bridges at an European Level

REASONS FOR THE ACTION

CSO Approval: 13-11-2014

Start of the Action: 16-04-2015

End of Action: 15-04-2019

Total Number of COST countries accepting MoU: **37**

Total Number of COST countries intending to accept MoU: 0

AIM & OBJECTIVES

The overall intention of the Action is to

develop a guideline for the establishment of Quality Control (QC) plans in roadway bridges

reachable by pursuing the following 5 objectives:

(i) Systematize knowledge on QC plans for bridges, which will help to achieve a state-of-art report that includes performance indicators and respective goals;

(ii) Collect and contribute to up-to-date knowledge on performance indicators, including technical, environmental, economic and social indicators;

(iii) Establish a wide set of quality specifications through the definition of performance goals, aiming to assure an expected performance level;

(iv) Develop detailed examples for practicing engineers on the assessment of performance indicators as well as in the establishment of performance goals, to be integrated in the developed guideline;

(v) Create a database from COST countries with performance indicator values and respective goals, that can be useful for future purposes.

SCIENTIFIC PROGRAM

WG5. Drafting of guidelines/recommendations

- Existing documentation (format and content)
- Document preparation
- Easy to use document

WG4. Implementation in a case study

- Benchmarking
- Validation
- Discussion

WG1. Performance indicators

- Technical indicators
- Environmental indicators
- Others

WG2. Performance goals

- Technical goals
- Environmental goals
- Others

WG3. Establishment of a QC plan

- Bayesian nets
- Procedure to develop a QC plan for a single bridge

WG1. MILESTONE: *Report*

WG1

Technical Report

Performance Indicators for Roadway Bridges of Cost Action TU 1406

General

Performance Indicators terms after surveying

Operators

Operators list of documents and database per country

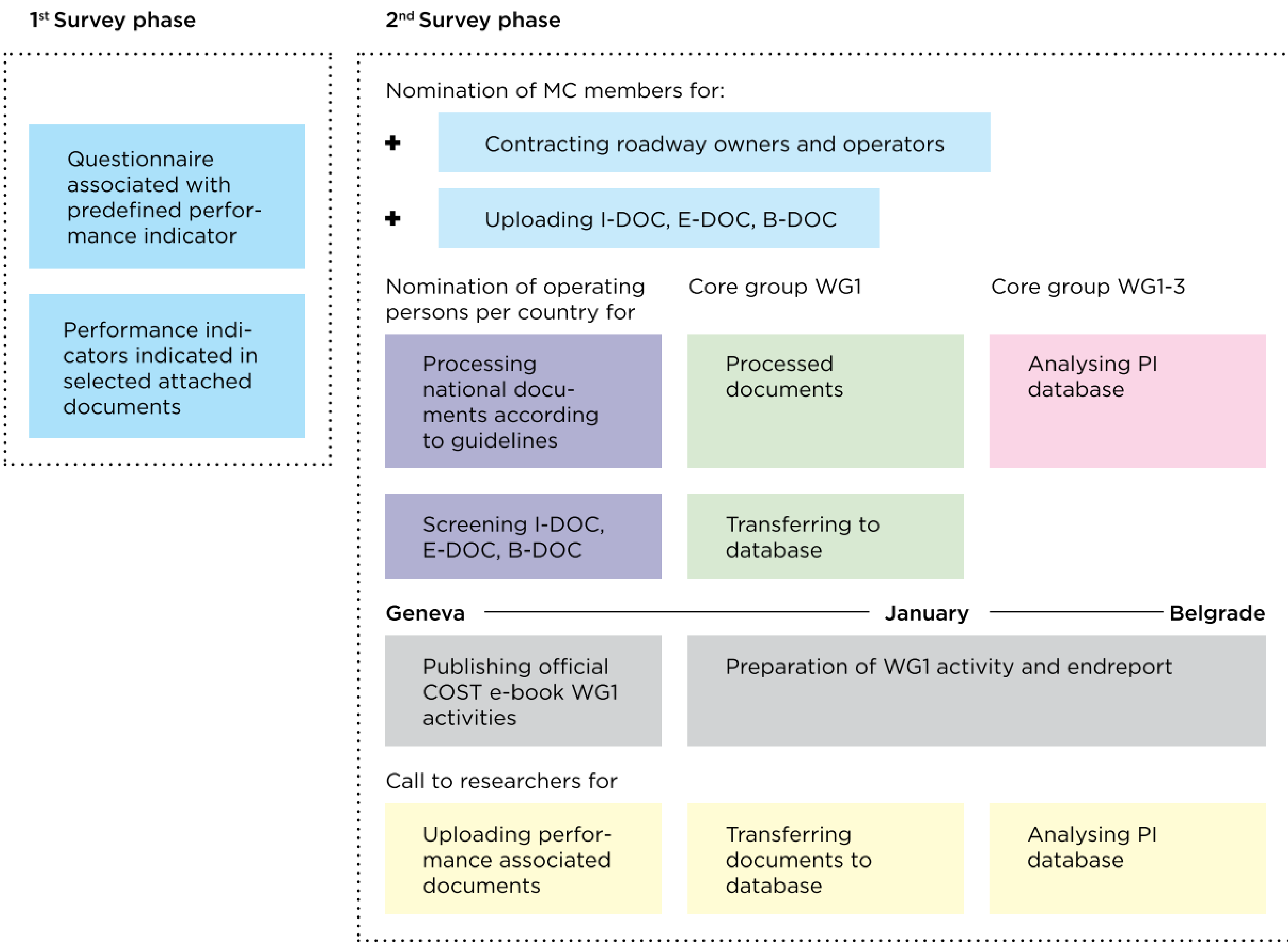
Research

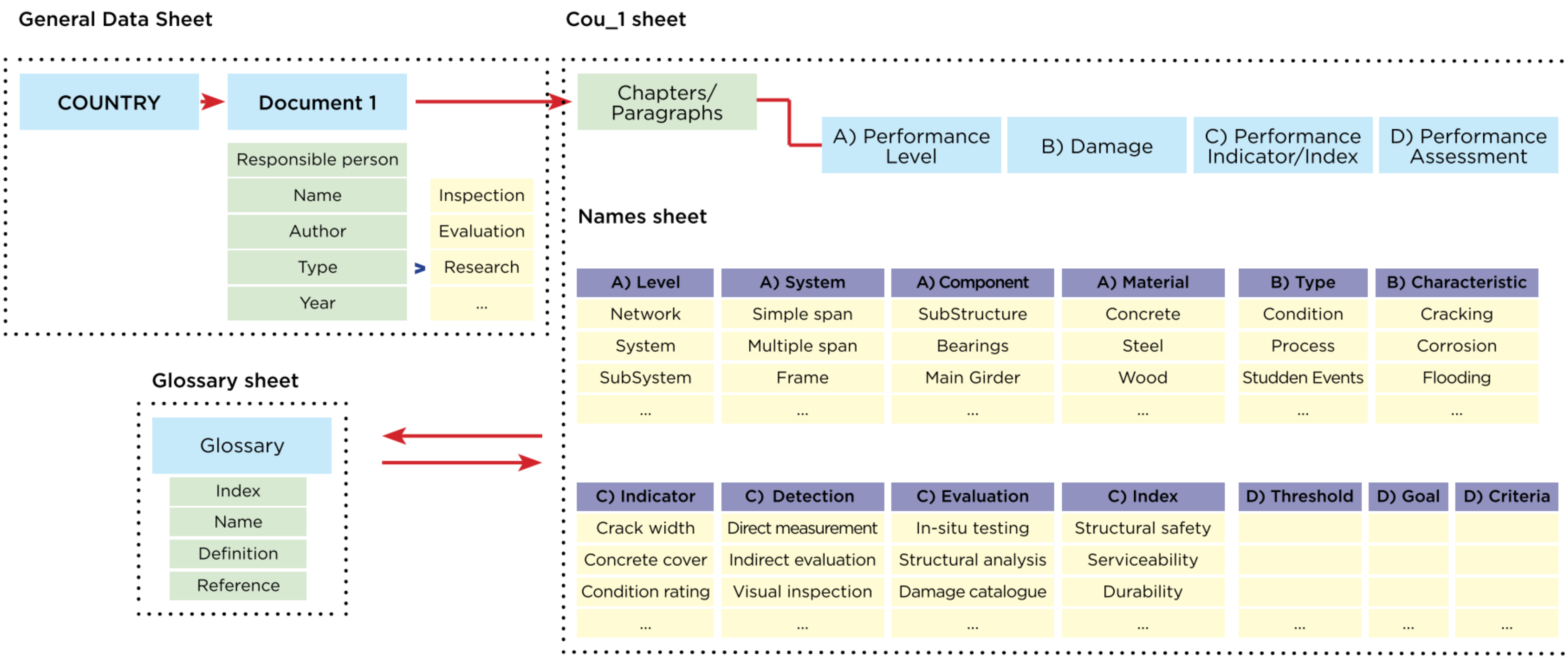
Research list of documents and database per country

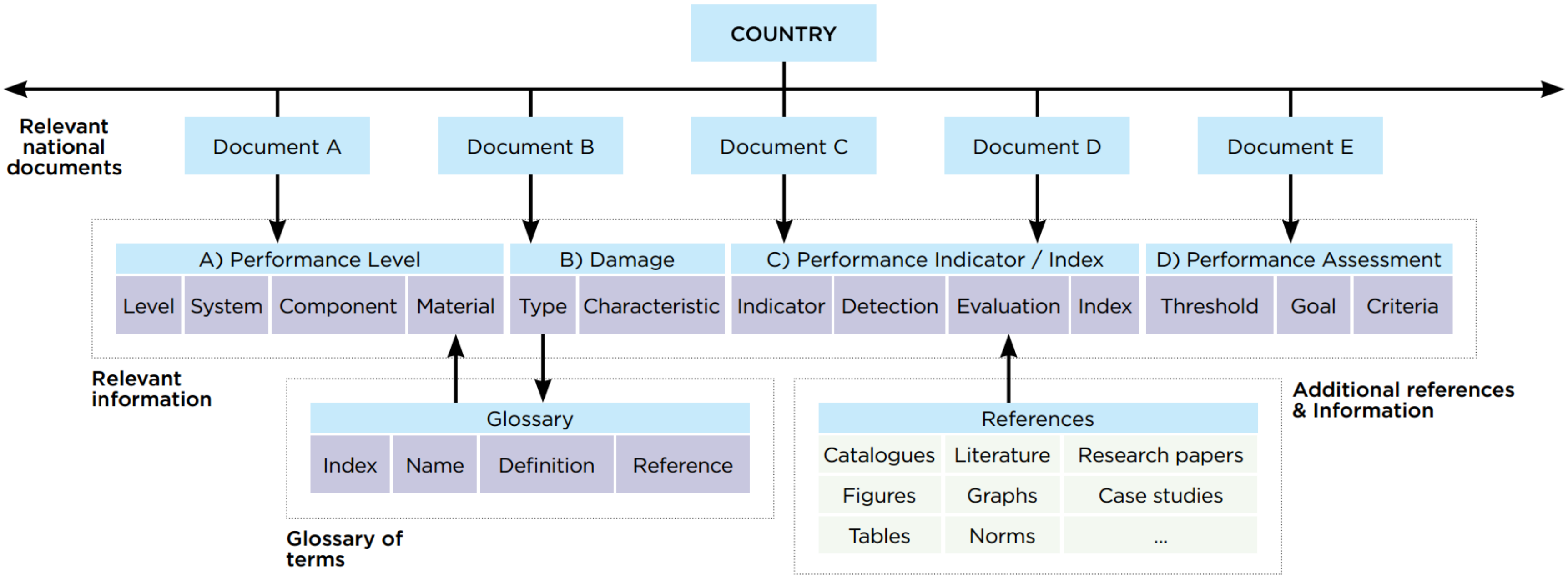
Glossary

Glossary and specific term sheet per country

available on website: www.tu1406.eu


1st Survey phase
Questionnaire associated with predefined performance indicator
Performance indicators indicated in selected attached documents
2nd Survey phase
Nomination of MC members for:
+ Contracting roadway owners and operators
+ Uploading I-DOC, E-DOC, B-DOC
Nomination of operating persons per country for
Core group WG1
Core group WG1-3
Processing national documents according to guidelines
Processed documents
Analysing PI database
Screening I-DOC, E-DOC, B-DOC
Transferring to database
Geneva
January
Belgrade
Publishing official COST e-book WG1 activities
Preparation of WG1 activity and endreport
Call to researchers for
Uploading performance associated documents
Transferring documents to database
Analysing PI database


General Data Sheet
COUNTRY
Document 1
Responsible person
Name
Author
Type
Year
Inspection
Evaluation
Research
...
Cou_1 sheet
Chapters/ Paragraphs
A) Performance Level
B) Damage
C) Performance Indicator/Index
D) Performance Assessment
Names sheet
A) Level
Network
System
SubSystem
A) System
Simple span
Multiple span
Frame
A) Component
SubStructure
Bearings
Main Girder
A) Material
Concrete
Steel
Wood
B) Type
Condition
Process
Studden Events
B) Characteristic
Cracking
Corrosion
Flooding
C) Indicator
Crack width
Concrete cover
Condition rating
C) Detection
Direct measurement
Indirect evaluation
Visual inspection
C) Evaluation
In-situ testing
Structural analysis
Damage catalogue
C) Index
Structural safety
Serviceability
Durability
D) Threshold
D) Goal
D) Criteria
Glossary sheet
Glossary
Index
Name
Definition
Reference


COUNTRY
Relevant national documents
Document A
Document B
Document C
Document D
Document E
A) Performance Level
Level
System
Component
Material
B) Damage
Type
Characteristic
C) Performance Indicator / Index
Indicator
Detection
Evaluation
Index
D) Performance Assessment
Threshold
Goal
Criteria
Relevant information
Glossary
Index
Name
Definition
Reference
Glossary of terms
References
Catalogues
Literature
Research papers
Figures
Graphs
Case studies
Tables
Norms
...
Additional references & Information

SCREENING RESULTS *OPERATOR* DOCUMENTS / *DATABASE*

SURVEY OF PERFORMANCE INDICATORS

Country	Croatia	New Document

num	Responsible Person	Document	Doc. Type	Author	Year
1	Ana Mandić Ivanković	*Handbook of damages on bridge elements*	Evaluation	Hrvatske ceste d.o.o., dr.sc. Danijel Tenžera	2014
2	Ana Mandić Ivanković	*Guidelines for bridge inspections*	Inspection	Hrvatske ceste d.o.o.	2014
3	Ana Mandić Ivanković	*HRMOS manual – Bridge management*	Inspection	Hrvatske ceste d.o.o.	1999
4	Dominik Skokandić	*HRMOS manual – Bridge management – General bridge inspection*	Inspection	Hrvatske ceste d.o.o.	1999
5	Dominik Skokandić	*Handbook of damages on bridges*	Inspection/ evaluation	Hrvatske Autocesete d.o.o.	2010
6	Ana Mandić Ivanković	*Guideline for bridge evaluation*	Evaluation	Hrvatske Autocesete d.o.o.	2010
7	Ana Mandić Ivanković	*Bridge Management Planning*	Background document	Hrvatske Autocesete d.o.o.	2008
8					
9					
10					
11					
12					

Blank | Names_Table | **GeneralData** | Cro_1 | Cro_2 | Cro_3 | Cro_4 | Cro_5 | Cro_6 | Cro_7

READY

C) Performance Indicator/Index				D) Performance Assessment		
indicator	detection	evaluation	index	threshold	goal	criteria
Damage degree	Direct_Measurement			affected area	Damage Assessment	
Damage degree	Direct_Measurement			crack width (	Damage Assessment	

	All bridge types				
Element	All bridge types	Foundations		Damage_State	Abrasion
Element	All bridge types	Foundations		Damage_State	Settlements
Element	All bridge types	Foundations		Damage_State	Degradation
Element	All bridge types	Foundations	Concrete	Damage_State	Spalling
Element	All bridge	Foundations	Concrete	Damage_State	Spalling

C) Performance Indicator/Index				D) Performance Assessment		
indicator	detection	evaluation	index	threshold	goal	criteria
Damage degree	Direct_Measurement			affected area	Damage Assessment	
Damage degree	Direct_Measurement			affected area	Damage Assessment	
Damage degree	Direct_Measurement			affected dep	Damage Assessment	
Damage degree	Direct_Measurement			sag (cm)	Damage Assessment	
Damage degree	Direct_Measurement			affected area	Damage Assessment	
Damage degree	Direct_Measurement			affected area	Damage Assessment	
Damage degree	Direct_Measurement			affected dep	Damage	

Blank | Names_Table | GeneralData | **Cro_1** | Cro_2 | Cro_3 | Cro_4 | Cro_5 | Cro_6 | Cro_7

READY

SCREENING RESULTS RESEARCH DOCUMENTS / DATABASE

SURVEY OF RESEARCH PERFORMANCE INDICATORS

Article	**Performance assessment of concrete s**
Author	Strauss, Zan
Year	
Abstract	An efficient evaluation and prediction of fundamental requirement for life-cycle a structures. Important tools and valuable methods. Unfortunately, due to their pra information gathered with inspection and monitoring methods need to be used in the most effective manner possible. The aim of this contribution is to present a framework performance indicators of concrete structures prone to fatigue, A theoretical background with selected indicators is presented t methods including inspection and monitoring information with i
Journal	IABSE Conference – Structural Engineering: Providing Solutions Geneva, Switzerlan
Keywords	life-cycle analysis; performance indicators; probabilistic perf

Performance Indicator	**Young modulus**
Type of Indicator	Material property
Mathematical Formulation	
Threshold	
Intentions (where to apply)	In order to evaluate the fatigue performance of the critical cross
Level of maturity	Research stage
Case study	STRABAG test foundation in Cuxhaven
Performance Indicator	**Reliability index**
Type of Indicator	Reliability
Mathematical Formulation	
Threshold	
Intentions (where to apply)	In order to evaluate the fatigue performance of the critical cross
Level of maturity	Research stage
Case study	STRABAG test foundation in Cuxhaven

References

[1] Zhao, Y.-G., Zhong, W.-Q., Ang, A.H.-S., 2007. Estimating joint failure probability of series structural systems. J. Eng. Mech. 133, 588–596.
[2] Strauss A, Vidovic A, Zambon I, Grossberger H, Bergmeister K. Monitoring information and probabilistic based prediction models for the
[3] Mark, P., Stangenberg, F., Bergmeister, K., Strauss, A., Ahrens, M.A., 2013. Lebensdauerorientierter Entwurf, Konstruktion, Nachrechnung

SURVEY OF PERFORMANCE INDICATORS

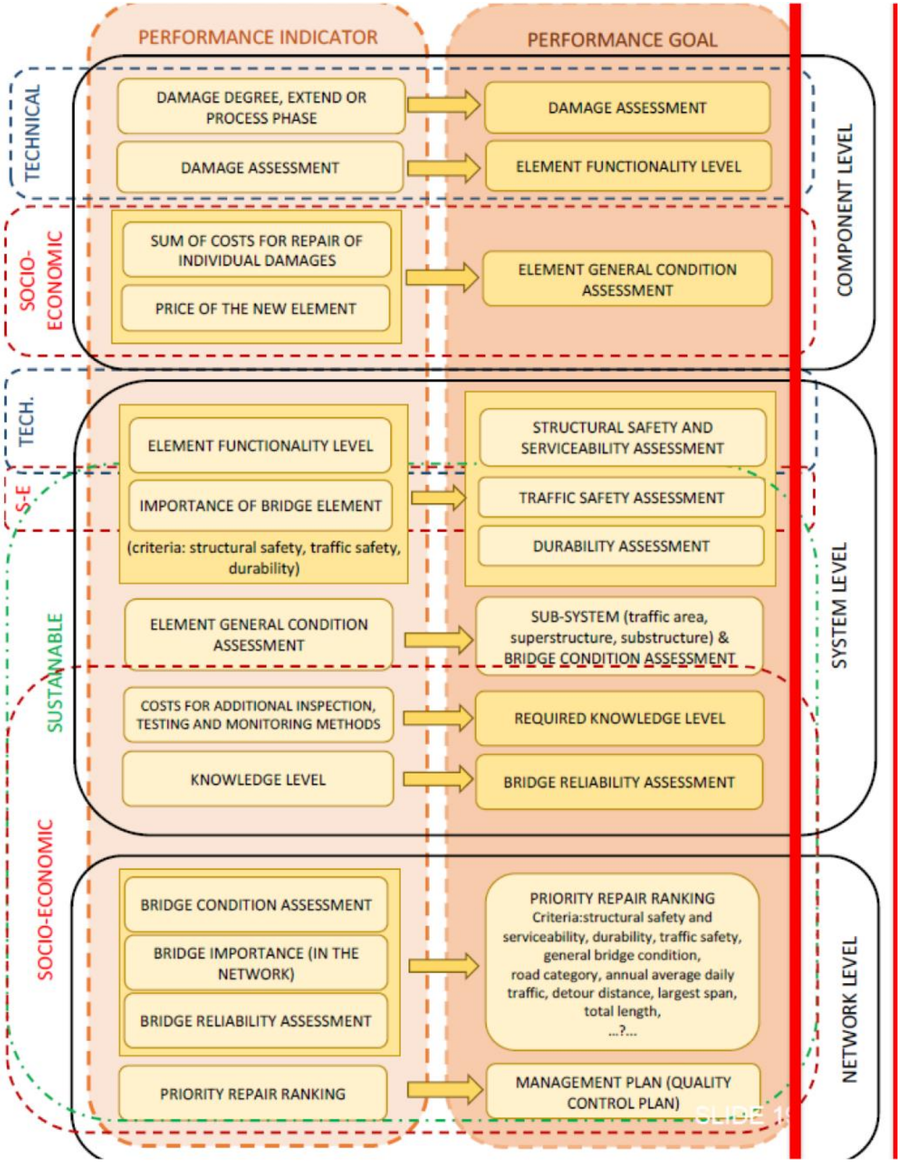
Country	Austria

Add Article

num	Responsible Person	Article	Author	Year
1	Ivan Zambon	*Performance assessment of concrete structures based on probabilistic prediction models and monitoring information*	Strauss, Zambon, Vidovic, Grossberger, Bergmeister	2015
2				
3				
4				

Indicators and goals

- Interactions between KPI and PG are contemplated, as they are crucial for optimal quality control and management of road bridges



Categorized

A) Performance Level				B) Damage		C) Performance Indicator/Index		D) Performance Assessment			
level	**system**	**compo-nent**	**material**	**type**	**character-istic**	**indicator**	**detection**	**threshold**	**goal**		
Sub-Sys-tem	All bridge types	Super Structure	Concrete	Damage State	Cracks	Damage degree	Direct Measure-ment	Crack width (mm)	Damage Assess-ment	>	**Defects** Crack width
Sub-Sys-tem	All bridge types	Super Structure	Concrete	Damage State	Hon-ey-comb-ing	Damage degree	Direct Measure-ment	Affected area (m2)	Damage Assess-ment	>	**Material prop-erties** bad concrete compaction
Sub-Sys-tem	All bridge types	Super Structure		Damage State	Freeze-thaw	Damage degree	Direct Measure-ment	Affected area (m2)	Damage Assess-ment	>	**Environmental based** Freeze-thaw
Sub-Sys-tem	All bridge types	Super Structure	Brick	Damage State	Disinte-gration of mortar	Damage	Visual Inspection		Damage Assess-ment	>	**Structural integ-rity & joints** Disintegration of mortar
Sub-Sys-tem	All bridge types	Railings	Steel	Damage State	Missing Parts	Damage degree	Visual Inspection		Damage Assess-ment	>	**Equipment and protection** Absence of equipment component
System	All bridge types			Damage State	Buckling	Damage degree	Visual Inspection		Damage Assess-ment	>	**Geometry changes** Buckling
System	All bridge types		Concrete	Damage State	Execution defects	Damage degree	Direct Measure-ment	Affected area (m2)	Damage Assess-ment	>	**Original construction & design** Execution/con-struction defects
Element				Damaging process	Low dam-age degree (first phase)	Damage degree	Visual Inspection	Upper limit + Duration of damage	Damage Assess-ment	>	**Rating** Damage degree +damage evo-lution
Element						Impor-tance of bridge element		Quantita-tive scale of values	Element impor-tance as-sessment	>	**Cost & impor-tance** Importance of bridge Element

Homogonized

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

Homogenized **Database**

Document	*Repair of concrete structures - National specifications for products and systems for the protection and repair of concrete structures according to ÖNORM EN 1504*
Chapter/ Paragraph / Section	4.3 Inspection

Add

Hide/Sho

A) Performance Level				B) Damage		C) Performance Indicator/Index				D) Performance Assessment		
level	system	component	material	type	characteristic	indicator	detection	evaluation	index	threshold	goal	criteria
Material	All bridge types		Concrete	Damage_ State	Cracks	Crack width	Visual_Inspect ion			Upper limit		
Material	All bridge types		Concrete	Damage_ State	Surface deficiency	Concrete cover	Visual_Inspect ion					
Material	All bridge types		Concrete	Damaging _Process	Corrosion	Chemical parameter	Visual_Inspect ion					
Element	All bridge types		Concrete	Damage_ State	Wet spots	Damage	Visual_Inspect ion					
Element	All bridge types		Concrete	Damage_ State	Efflorescence	Chemical parameter	Visual_Inspect ion					
Material	All bridge types		Concrete	Damage_ State	Concrete voids		Direct_Measu rement	In-situ testing				

Homogenized Indicators											
defects	related to material properties	related to equipment & protection	geometry changes	related to bearing capacity, structural integrity and joints	related to original construction and design	related to dynamic behaviour	environmental based (common appearance)	rating	cost and importance	loads	

02_385_PI_terms after_clustering - Excel

PRODUKTHINWEIS Excel wurde nicht aktiviert. Damit Sie Excel ohne Unterbrechung weiterhin verwenden können, führen Sie vor dem Mittwoch, 13. Juni 2018 die Aktivierung durch.

	A	B	C	D	E	F	G
1		**Level**	**Performance indicator PI if**	**PI belongs to the Key Peformance**	**Assessment**		**Level**
2		Component Level (CL) System Level (SL) Network Level (NL)	Measurable? {Quantifiable?; Target value available?; Valid for ranking purposes?; Allow decision with economic implications?} (YES/No) Technical (Tech), Socio Economical (SoEc), Sustainable (Sust)	Reliability (R), Availability (A), Maintainability (M), Safety (S), Security (Se), Environment (E), Costs (C), Health (H), Politics (P), Rating/Inspection (I)	Threshold (T = …..) Goal (G = ….) Rating (R = ….)		Component Level (CL) System Level (SL) Network Level (NL)
3	**defects**					**related to material properties**	
4	abrasion					acids attacks	
5	absence/missing					aggregate segregation	
6	aggradation (alluviation)					aging of material	
7	blistering					alkali aggregate reaction (alkali-silica reaction)	
8	blocking					alkali aluminium reaction	
9	bulging					bad concrete compaction	
10	cavitation					bedding mortar failure	
11	clogged					bituminous binder emersion	
12	coating loss					calcification	
13	contamination					carbonation	
14	corrosion (state)					chemical attack	
15	crack length					chemical parameter	
16	crack orientation					chloride action	
17	crack width					chloride content	
18	cracking					chloride ions penetration	
19	cracks					concrete quality insufficient	
20	cracks - Alligator cracks					corrosion	
21	cracks - drying cracks					corrosion fatigue	
22	cracks - temperature cracks					corrosion related to prestressing steel	
23	cracks distance					corrosion related to protective coating	
24	cracks related to material					corrosion related to reinforcement steel	
25	cracks related to origin (e.g. due to loading, due to settlement, due to crumbling of concrete,…					corrosion related to structural steel	
26	cracks related to position in a component					cracks due to shrinkage	
27	cracks related to sintering					fatigue	
28	cracks -structural cracks					galvanization deficiency	
29	crumbling					gel exudation	
30	crumbling of concrete cover					hydroxide calcium exudation	
31	crushing					material characteristics	
32	damage					material quality insufficient	
33	debonding					oxidation	
34	debris					pitted corrosion	
35	decay					porous concrete	
36	decomposition/disintegration					red colour areas	
37	deepening					reinforcement bar yielding	

Indicators after clustering_385

Assignment

- Analyses of Performance Terms
  - based on the Homogenised Country Specific Terms

- Performance Indicators and Performance Spider for the Assessment of a Structural Component or System
  - (work on your own Problem, or let us know if you need one)

Your results will be Analysed and Documented in the Master Thesis of Konrad Ciempiel – please provide us your approval

Your results and the results of the Master Thesis will be part of the WG1 Report Appendix

Assignment

				Safety, Reliability, Security
PI	**Level**	**Performance indicator PI if**	**PI belongs to the Key Peformance Indicator(s)**	**Assessm**
	Component Level (CL) System Level (SL)	Measurable? {Quantifiable?; Target value	Reliability (R), Availability (A), Maintainability (M), Safety (S),	Threshold (T Goal (G =
concrete cover (insufficient)	CL	Yes, Tech, Sust	R, A, (C, I)	T= thickness (mm), G=
cracks related to origin (e.g. due to loading, due to settlement, due to crumbling of concrete,…	CL, SL	Yes, Tech	R, A, S, (C, I)	T=width (mm), G=unde
fatigue cracking	CL, SL	Yes, Tech	R, A, S, (C, I)	T= number of cracks an
settlement	SL	Yes, Tech	R, A, S, (C, I)	T= dimension (mm) and
water penetrability	CL	Yes, Tech, Sust	R, (C, I)	T= area and affected co
wetting/leaking	CL	Yes, Tech, Sust	R, (C, I)	T= area and affected co
carbonation depth	CL	Yes, Tech, Sust	R, A, (C, I)	T= depth (mm) in relatio
cathodic protection defficiency	CL, SL	Yes, Tech, Sust	R, A, (C, I)	T= existence of deficienc
chloride depth profile	CL	Yes, Tech, Sust	R, A, (C, I)	T= depth (mm) in relatio
contamination (agent content)	CL	Yes, Tech, Sust	R, A, (C, E, H, I)	T= % of agent content,
corrosion	CL	Yes, Tech, Sust	R, A, S, (C, I)	T= % section loss; G= F
fatigue (remaining service life)	SL	Yes, Tech, SoEc	R, A, S, (C, I)	T= (Remaining SL / Tim
absence (missing) of equipment component	CL, SL	Yes, Tech	R, A, S, (C, I)	T= evidence of the defe
approach slab settlement	SL, NL	Yes, Tech	R, A, S, (C, I)	T= height (mm); G=ass
asphalt pavement cracking	CL, SL, NL	Yes, Tech, Sust	R, (C, I)	T= width (mm), length (
asphalt pavement wearing and tearing (rutting, ravelling)	CL, SL, NL	Yes, Tech, Sust, SoEc	R, A, S, (C, I)	T= affected area (m2),
asphalt pavement wheel tracking and wrinkling and undulation	CL, NL	Yes, Tech, SoEc	R, A, S, (C, I)	T= affected area (m2),
blistering of protective coating	CL	Yes, Tech, Sust	R, (C, I)	T= affected area (m2);

WG1. FROM PI TO KPI

abrasion [DP], absence/missing [PI], aggradation (alluviation) [DP], blistering [OBS], blocking [DP], bulging [OBS], cavitation [OBS], clogged [OBS], coating loss [OBS], contamination [PI], corrosion (state) [OBS], crack length [OBS], crack orientation [OBS], crack width [OBS], cracking [PI], cracks [PI], cracks - Alligator cracks [OBS], cracks - drying cracks [DP], cracks - temperature cracks [DP], cracks distance [OBS], cracks related to material [OBS], cracks related to origin (e.g. due to loading, due to settlement, due to crumbling of concrete,... [DP], cracks related to position in a component [OBS], cracks related to sintering [DP], cracks -structural cracks [DP], crumbling [OBS], crumbling of concrete cover [OBS], crushing [DP], damage [PI], debonding [DP], debris [OBS], decay [PI], decomposition/disintegration [OBS], deepening [OBS], deficiency [OBS], degradation [PI], delamination [OBS], destroyed [OBS],

detacl … magni … hydra … whole …

2º Level PIs, 2ºPI; Damage Process, DP_; Non-interceptable processes, NIP; Observation, OBS; Other data, OD; Performance Indica

defects; related to material properties; related to equipment & protection; geometry changes

; Austria; Chile; Croatia; Portugal; Spain

[DP], scour criticality [OBS], scour depth [OBS], secretion [OBS], segregation [OBS], separation [OBS], settlement [PI], shear [OBS], shoving ? [OBS], silting and vegetation [OBS], sliding [OBS], soil Failure [DP], spalling [OBS], splitting [OBS], staining [OBS], stratification [OBS], structural damage [PI], surface corrosion [OBS], surface damage/deficiency [OBS], surface discoloration [OBS], surface flaking due salting [DP], swelling of structural steel surface [OBS], tearing [OBS], timber s… …rmined stability (e.g. of river bank) [OBS], undermining [OBS], undesirable paintings, graffiti [OBS], uneven [OBS], unlevelled … wearing and tearing [OBS], weathering [DP], wet spots [OBS], wet spots with corrosive edges [OBS], worn out [OBS], yield … [DP], alkali aggregate reaction (alkali-silica reaction) [DP], alkali aluminium reaction [DP], bad concrete compaction [OBS], be… …alcification [DP], carbonation [DP], chemical attack [DP], chemical parameter [OBS], chloride action [DP], chloride content [OBS] … [OBS], corrosion [PI], corrosion fatigue [DP], corrosion related to prestressing steel [OBS], corrosion related to protec… …rrosion related to structural steel [OBS], cracks due to shrinkage [DP], fatigue [DP], galvanization deficiency [OBS], g… …acteristics [OBS], material quality insufficient [OBS], oxidation [DP], pitted corrosion [DP], porous concrete [OBS], red colour… …sion [DP], rot fungi attack [OBS], shrinkage/creep [DP], sintering [DP], sulphate action [DP], termite infestation [OBS], wear out [DP], whi… …tack [OBS], absence (missing) of equipment component [OBS], approach slab settlement [OBS], asphalt pave… (rutting, ravelling) [OBS], asphalt pavement wheel tracking and wrinkling and undulation [OBS], blistering paint… clogged collector [OBS], clogged drain [OBS], clogged manhole [OBS], clogged pipe [OBS], cornicles and curbs … [OBS], crack over the buried expansion joint [OBS], cracks in covering [OBS], damage of protective coating [OBS], de… …tive coatings (e.g. corrosion protection, impregnate...) [OBS], deviator deficiency [OBS], drainage/dewatering defici… …iciency [PI], expansion joint pavement crack [OBS], functionality of device [PI], hydro-insulation defects [OBS], incorrect … …equipment defects [OBS], oiling system deficiency [OBS], pavement lateral displacement [OBS], protection (cover) deficiency …, protection duct damage (of prestressed cable) …, reduction of embankment cone [OBS], rollers condition (e.g. sliding, fixed, broken,...) [2ºPI], sliding interface insufficient [OBS], sliding path failure/blocking [OBS], slip of bearing [OBS], special inspection requisite [2ºPI], step in transition slab [OBS], waterproofing deterioration [OBS], buckling [OBS], cross incline of road [OBS], deformation [PI], denivelation [OBS], differential movement [OBS], displacement [PI], distortion [OBS], flattening [OBS], height difference [OBS], inclinations [OBS], misalignment [OBS], movements [PI], rotations [OBS], sag [OBS], torsion

Kategorien:

2º Level PIs

Damage Process

Non-interceptable processes

Observation

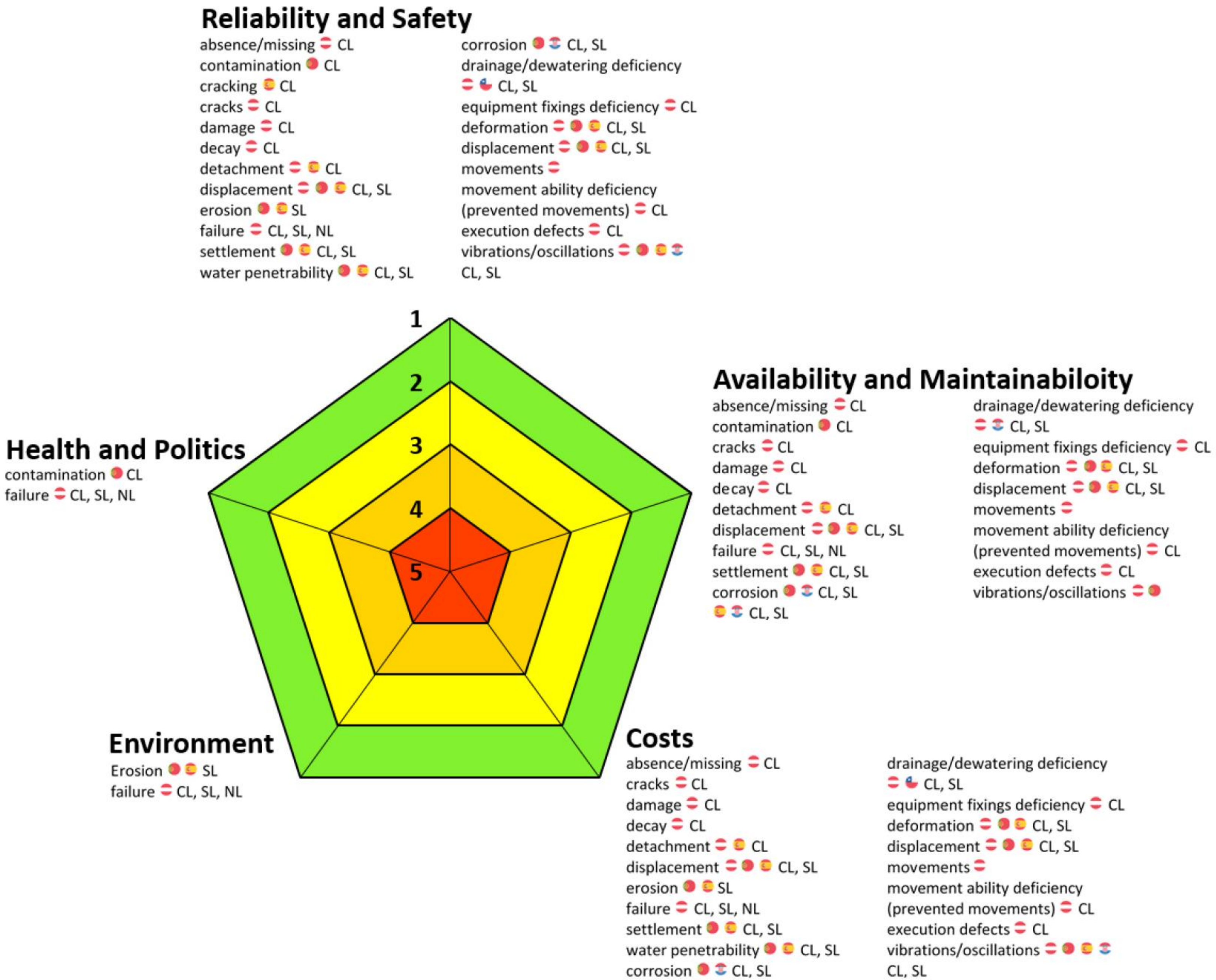
Other data

Performance Indicator

2º Level PIs, 2ºPI; Damage Process, DP_; Non-interceptable processes, NIP; Observation, OBS; Other data, OD; Performance Indicator, PI

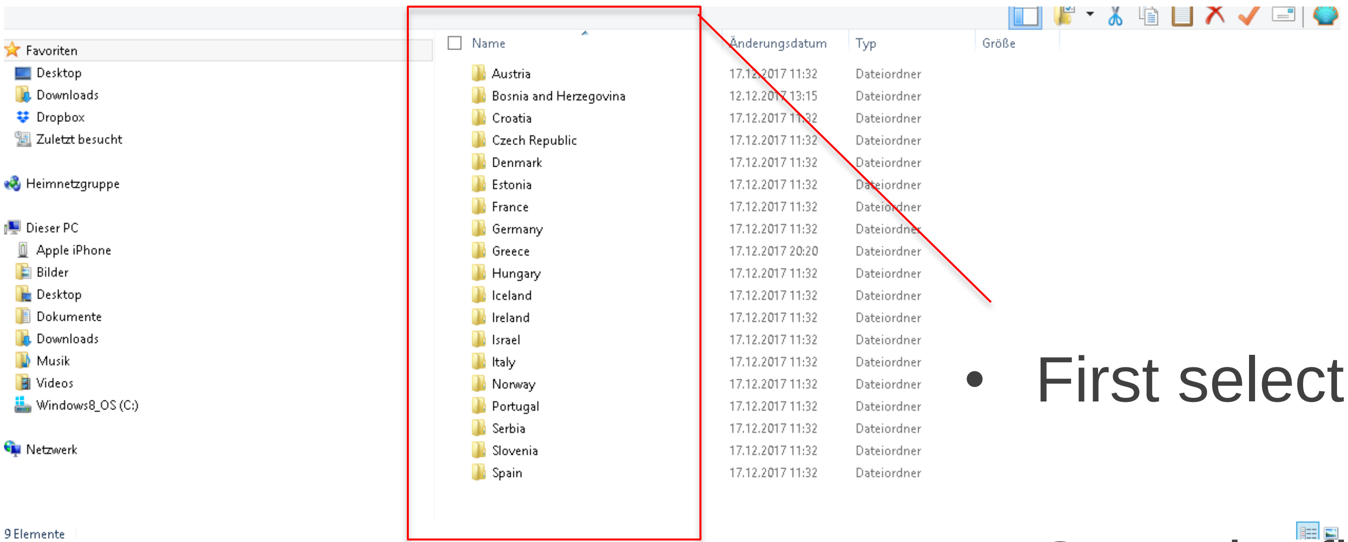
defects; related to material properties; related to equipment & protection; geometry changes

; Austria; Chile; Croatia; Portugal; Spain



Reliability and Safety
absence/missing CL
contamination CL
cracking CL
cracks CL
damage CL
decay CL
detachment CL
displacement CL, SL
erosion SL
failure CL, SL, NL
settlement CL, SL
water penetrability CL, SL
corrosion CL, SL
drainage/dewatering deficiency CL, SL
equipment fixings deficiency CL
deformation CL, SL
displacement CL, SL
movements
movement ability deficiency (prevented movements) CL
execution defects CL
vibrations/oscillations CL, SL
1
2
3
4
5
Availability and Maintainabiloity
absence/missing CL
contamination CL
cracks CL
damage CL
decay CL
detachment CL
displacement CL, SL
failure CL, SL, NL
settlement CL, SL
corrosion CL, SL
CL, SL
drainage/dewatering deficiency CL, SL
equipment fixings deficiency CL
deformation CL, SL
displacement CL, SL
movements
movement ability deficiency (prevented movements) CL
execution defects CL
vibrations/oscillations
Health and Politics
contamination CL
failure CL, SL, NL
Environment
Erosion SL
failure CL, SL, NL
Costs
absence/missing CL
cracks CL
damage CL
decay CL
detachment CL
displacement CL, SL
erosion SL
failure CL, SL, NL
settlement CL, SL
water penetrability CL, SL
corrosion CL, SL
drainage/dewatering deficiency CL, SL
equipment fixings deficiency CL
deformation CL, SL
displacement CL, SL
movements
movement ability deficiency (prevented movements) CL
execution defects CL
vibrations/oscillations CL, SL

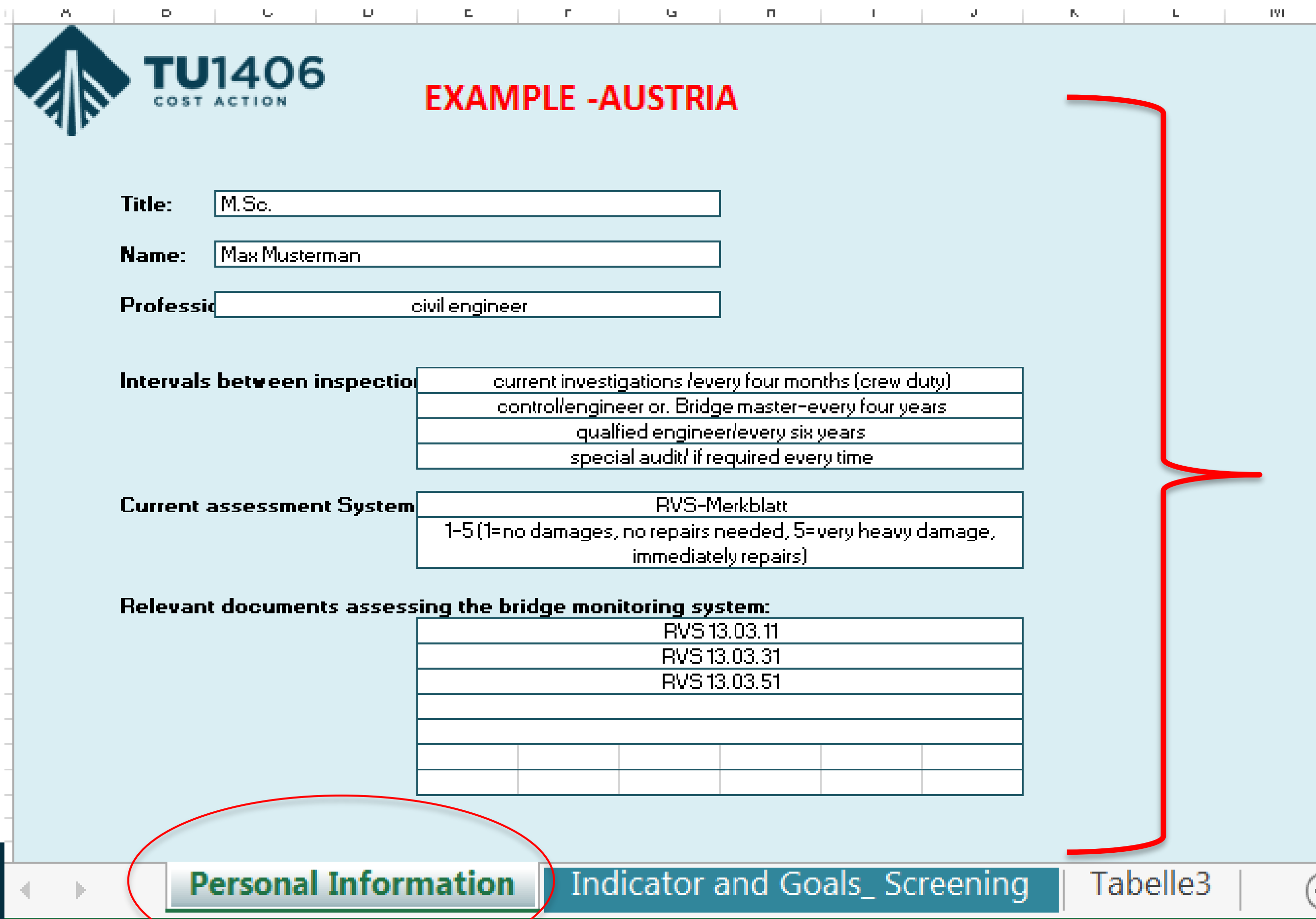
Survey- Step by Step



- First select your country
- Open the file named „19122017_Indicators&Goals_(country)-EXPERTS

Survey- Step by Step

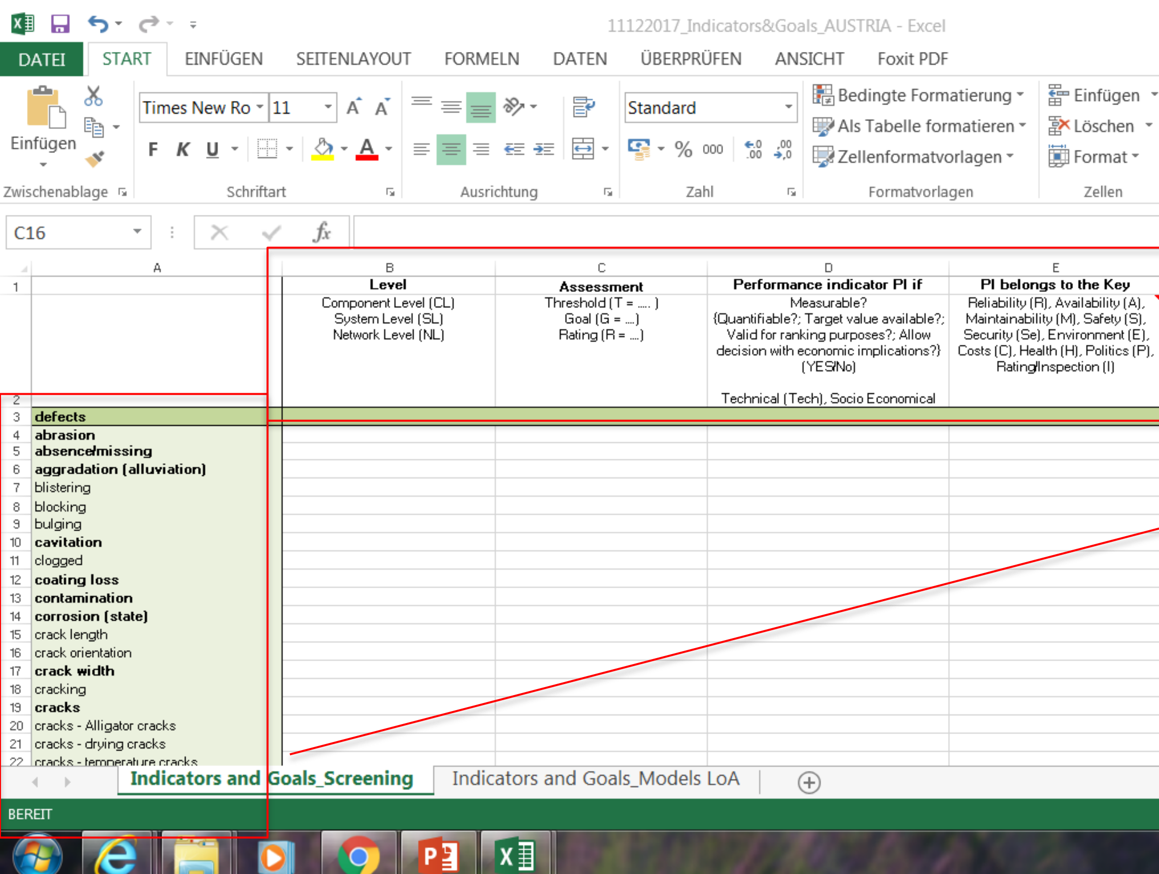
- Open the first data sheet called „Personal Information“ and fill in your personal data



Please fill in the empty cells

Survey- Step by Step

- If you are done with your personal informations, please open the „data sheet“ called „ Indicator and goals screening“
- Now we start with the main task



4 columns for each classification

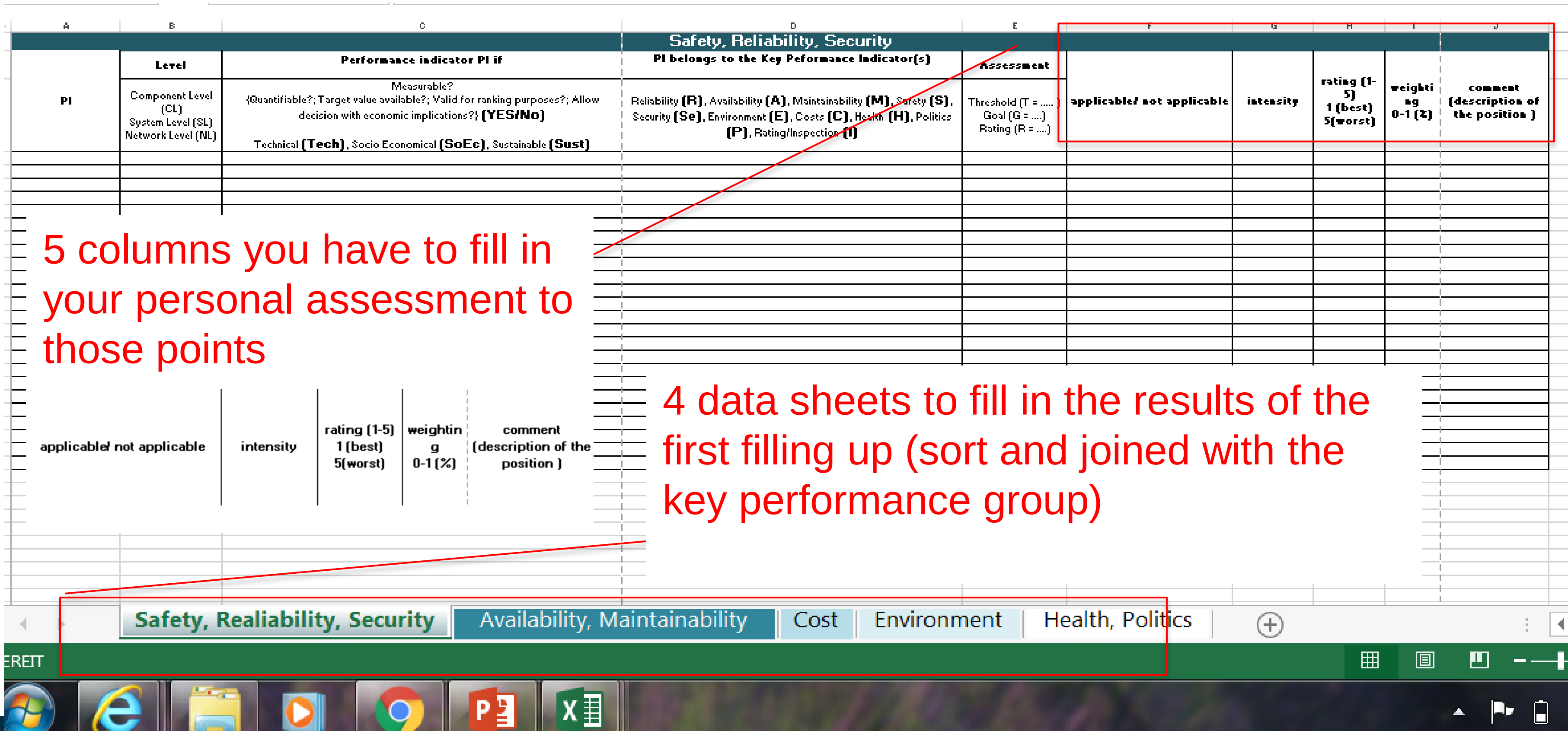
1. Level (CL, SL, NL)
2. Assessment (T, G, R)
3. Performance Indicator PI if (indicative questions)
4. PI belongs to the Key Performance Indicator(s)) (R, A, M, S, Se, C, H, P , I)

In this column are the PIs (Performance Indicators) and the homogenized PIs of each country (highlighted in bold)

Survey- Step by Step (Last step)

Preparation for plotting the „Spider-diagram“:

open den second file called „19122017_Spider_country_EXPERTS in your country folder



WG 1 REPORT

TU1406
COST ACTION

Quality specifications for roadway bridges, standardization at a European level

BASE

Estonia
- List of documents
- Homogenized database

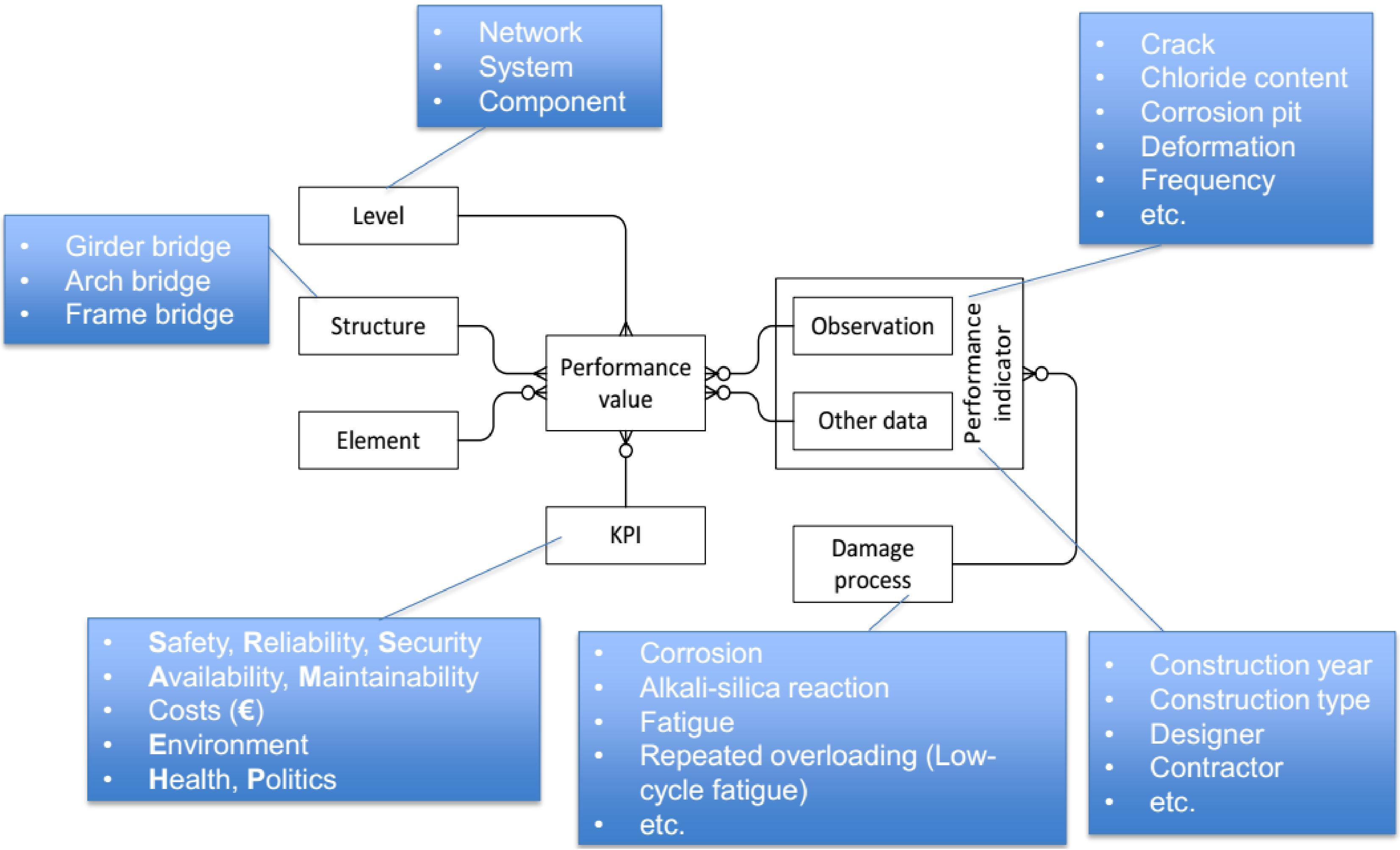
Finland
- List of documents
- Non-homogenized database

France
- List of documents
- Non-homogenized database

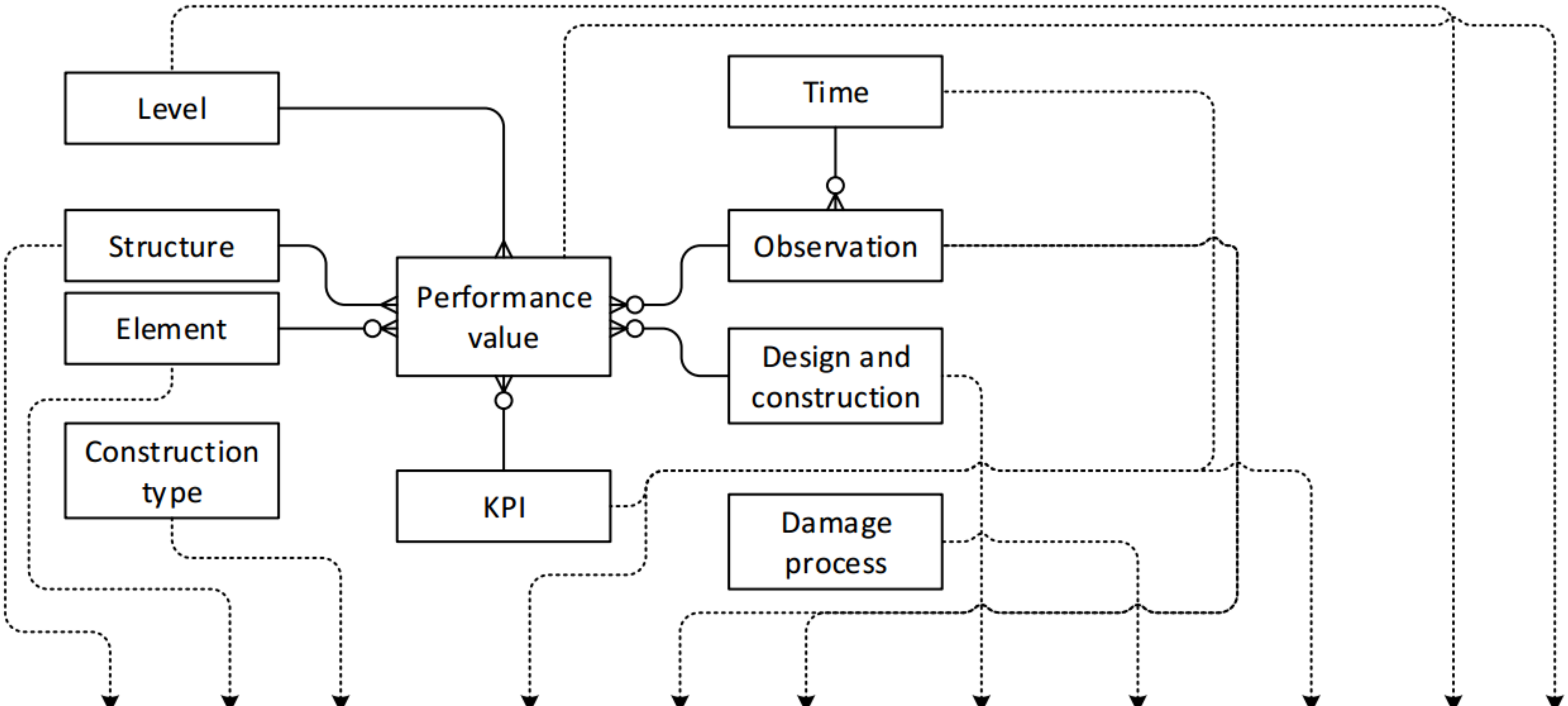
Germany
- List of documents
- Homogenized database

Greece
- List of documents
- Homogenized database

WG3. QUALITY CONTROL FRAMEWORK



WG3. QUALITY CONTROL FRAMEWORK



Single Girder Bridge	Beam	Reinforced concrete	*Time of the latest inspection*	Crack	0.4 mm	Construction year	Repeated overloading	Safety, Reliability, Security	Structure	2
Single Girder Bridge	Beam	Reinforced concrete	*Time of the latest inspection*	Spalling	1.0 m^2	Construction year	Corrosion of Reinforcement	Safety, Reliability, Security	Structure	3
Single Girder Bridge	Beam	Reinforced concrete	*Forecast in 10 years*	Spalling	2.0	Construction year	**Corrosion of Reinforcement**	Safety, Reliability, Security	Structure	4

WG4. CASE STUDIES

Girder Bridge
Strimonas River Bridge
Greece

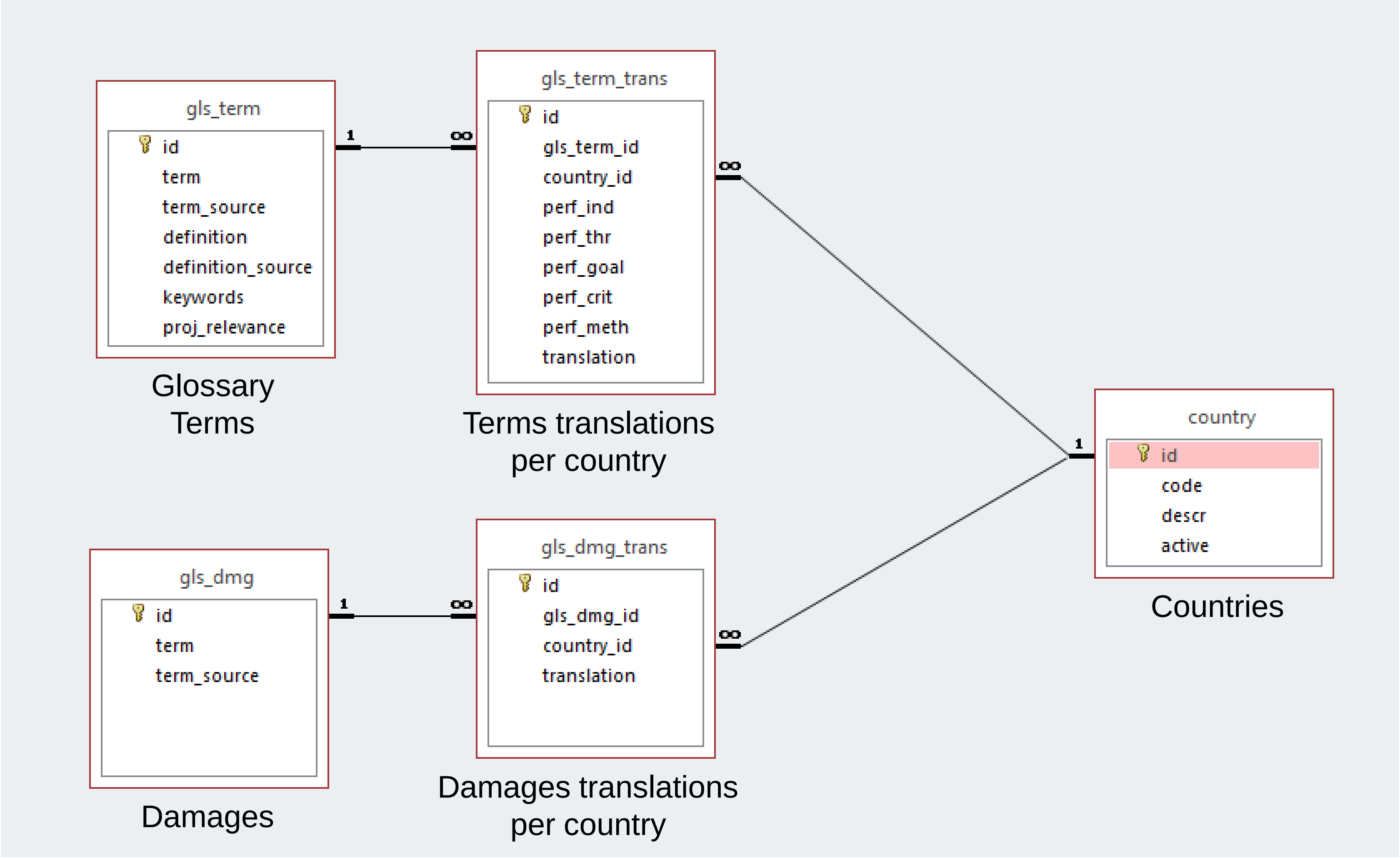
Arch Bridge
Carinski most, Mostar Bridge
Bosnia and Herzegovina

Frame Bridge
Unterführung SBB Bridge
Switzerland

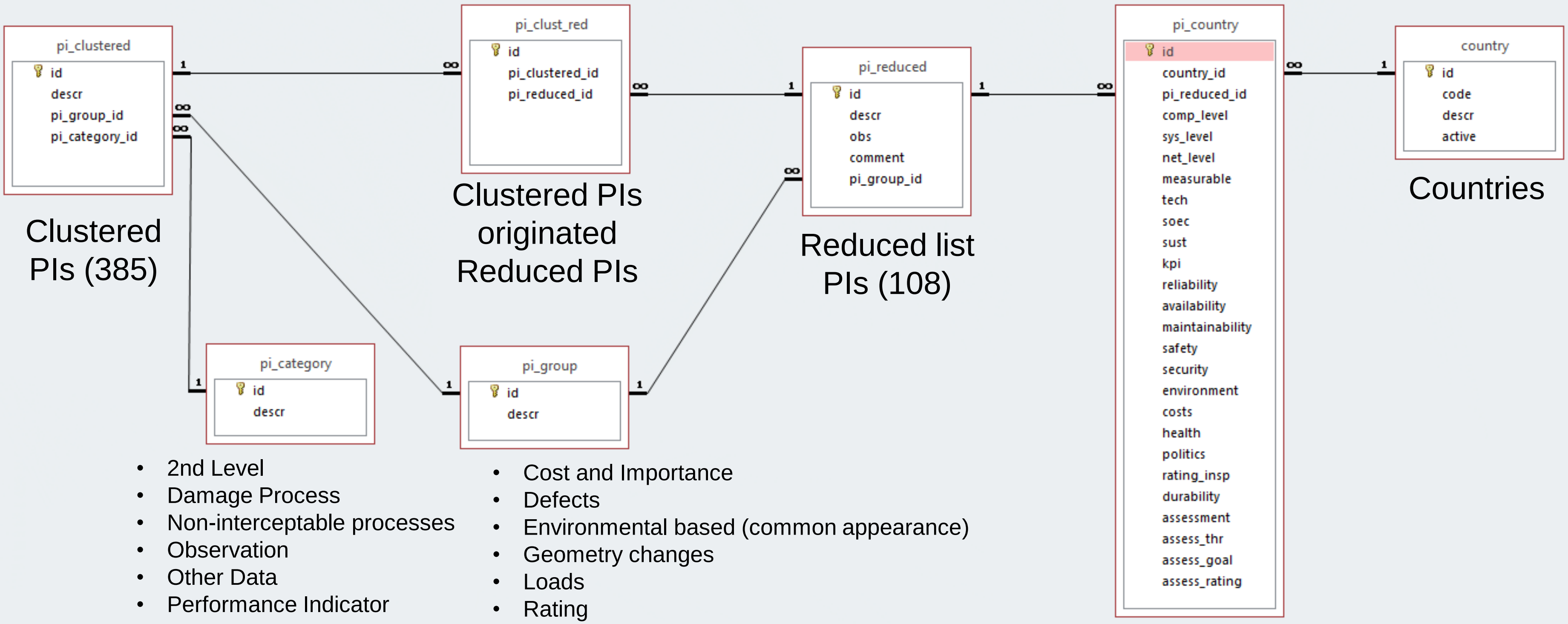
TU1406

COST ACTION

WG1 Database – Glossary



WG1 Database – Performance Indicators



- 2nd Level
- Damage Process
- Non-interceptable processes
- Observation
- Other Data
- Performance Indicator

- Cost and Importance
- Defects
- Environmental based (common appearance)
- Geometry changes
- Loads
- Rating
- Related to bearing capacity, structural integrity and joints
- Related to dynamic behaviour
- Related to equipment & protection
- Related to material properties
- Related to original construction and design
- Sudden events

PIs translations per country

Operators Survey | Research Survey | Glossary Terms | Glossary Damages | Perf. Indicators (Clustered) | Perf. Indicators (Reduced) | Perf. Indicators (Countries)

Operators Survey

Operators Survey | Research Survey | Glossary Terms | Glossary Damages | Perf. Indicators (Clustered) | Perf. Indicators (Reduced) | Perf. Indicators (Countries)

Documents

Show 10 entries

Search:

Country	Title	Type	Author	Year	Resp. Person	Obs.
All	All	All	All	All	All	All
AT	Repair of concrete structures - National specifica...	Inspection	Austrian Standards Instit...	2015		
AT	Repair of concrete structures - National specifica...	Inspection	Austrian Standards Instit...	2015		
AT	Quality Assurance for Structural Maintenance, Stru...	Evaluation	FSV	2009		
AT	Evaluation of load capacity of existing railway an...	Evaluation	Austrian Standards Instit...	2014		
AT	Quality Assurance for Structural Maintenance - Suv...	Inspection	BMVIT	2011		
BA	UPUTSTVO ZA INSPEKTORE MOSTOVA / INSTRUCTIONS FOR ...	Evaluation	BCEOM Societe Francaise D...	2004	Neven Pavlinovic	
BA	UPUTSTVO ZA INSPEKTORE MOSTOVA / INSTRUCTIONS FOR ...	Evaluation	BCEOM Societe Francaise D...	2004	Neven Pavlinovic	
CZ	TP215 The application of the modal analysis for th...	Evaluation	CTU in Prague, Faculty of...	2009	Pavel Ryjácek	
CZ	TP216 The design, maintenance, inspection, repairs...	Inspection	CTU in Prague, Faculty of...	2009	Pavel Ryjácek	
CZ	TP175 Evaluation of the remaining life of concrete...	Evaluation	SVÚOM s.r.o.	2006	Pavel Ryjácek	

Showing 1 to 10 of 74 entries

Previous 1 2 3 4 5 … 8 Next

Research Survey

TU1406 COST ACTION

Operators Survey | Research Survey | Glossary Terms | Glossary Damages | Perf. Indicators (Clustered) | Perf. Indicators (Reduced) | Perf. Indicators (Countries)

Articles

Show 10 entries

Search:

Country	Article Title	Author	Year	Resp. Person
All	All	All	All	All
CZ	Methodology for the quantitative risk assessment of road bridges exposed to accidental events	Sykora, M., Holicky, M., Manas, P.	2015	Pavel Ryjacek
CZ	BRIDGES EVALUATION FROM LCC ASPECT	Macek, D., Meštanová, D.	2009	Pavel Ryjacek
CZ	BRIDGE GIRDERS CONDITION EVALUATION BY ACOUSTIC EMISSION METHOD USE	Pospíšil, K., Korenská, M., Pazdera, M., Stryk, J.	2003	Pavel Ryjacek
CZ	Diagnostics of a Historical Bridge Using Measuring Methods and Inverse Analysis	KLUSÁCEK, L.; NECAS, R.; BUREŠ, J.	2015	Pavel Ryjacek
CZ	Reliability elements for assessment of existing bridges	Holický, M., Markova, J.	2010	Pavel Ryjacek
CZ	Optimum Reliability Levels for Structures	Holický, M.	2014	Pavel Ryjacek
CZ	Structural robustness as an innovative design concept	Sykora, M., Holicky, M.	2010	Pavel Ryjacek
CZ	Strength assessment of historic brick masonry	Witzany, J., Cejka, T., Sýkora, M., Holický, M....	2015	Pavel Ryjacek
CZ	Uncertainties in resistance models for sound and corrosion-damaged RC structures according to EN 1992-1-1	Sykora, M., Holicky, M., Prieto, M., Tanner, P. ...	2015	Pavel Ryjacek
CZ	The design value method and Adjusted Partial Factor Approach for existing structures	Caspeele, R., Sykora, M., Allaix, D.L., Steenber...	2013	Pavel Ryjacek

Showing 1 to 10 of 252 entries

Previous 1 2 3 4 5 … 26 Next

Glossary Terms

Operators Survey | Research Survey | Glossary Terms | Glossary Damages | Perf. Indicators (Clustered) | Perf. Indicators (Reduced) | Perf. Indicators (Countries)

Glossary

Definition

Search:

Country	Term (EN)	Source	Translation	Source	Keywords	Proj. Relevance	Perf. Indicator	Perf.
All	All	All	All	All	All	All	All	All
AU	? Failure path		Versagenspfad	[BFDW12]	Safety and Reliability, Modelling	FE 15.0538 (Systemanalyse)		
BA	? Failure path			[BFDW12]	Safety and Reliability, Modelling	FE 15.0538 (Systemanalyse)		
CZ	? Failure path			[BFDW12]	Safety and Reliability, Modelling	FE 15.0538 (Systemanalyse)	X	
DK	? Failure path			[BFDW12]	Safety and Reliability, Modelling	FE 15.0538 (Systemanalyse)		
EE	? Failure path			[BFDW12]	Safety and Reliability, Modelling	FE 15.0538 (Systemanalyse)		
ES	? Failure path			[BFDW12]	Safety and Reliability, Modelling	FE 15.0538 (Systemanalyse)		
FR	? Failure path		Chemin de défaillance	[BFDW12]	Safety and Reliability, Modelling	FE 15.0538 (Systemanalyse)		
GR	? Failure path			[BFDW12]	Safety and Reliability, Modelling	FE 15.0538 (Systemanalyse)		
HR	? Failure path			[BFDW12]	Safety and Reliability, Modelling	FE 15.0538 (Systemanalyse)		
IL	? Failure path			[BFDW12]	Safety and Reliability, Modelling	FE 15.0538 (Systemanalyse)		

Showing 1 to 10 of 6,279 entries

Previous 1 2 3 4 5 … 628 Next

Glossary Damages

Operators Survey | Research Survey | Glossary Terms | Glossary Damages | Perf. Indicators (Clustered) | Perf. Indicators (Reduced) | Perf. Indicators (Countries)

Glossary Damages

Show 10 entries — Search:

Country	Term (EN)	Translation	Source
All	All	All	All
AU	Abrasion	Abrieb	Qualitätssicherung bauliche Erhaltung Bauwerksdatenbank - RVS 13.04.11
ES	Abrasion	Daños producidos a causa de ciclos	
ES	abrasion	abrasión	
SI	Abrasion	Abrazija	
IL	Abrasion of Concrete Surface	????? (???? ??? ?????)	"Israeli bridges and road structures defects tables", ver-5-2015, Hebrew Edition
AU	Absence of a berm	Berme fehlt	Qualitätssicherung bauliche Erhaltung Bauwerksdatenbank - RVS 13.04.11
ES	Absence of anchorage protection elements	Ausencia de elementos de protección de anclaje	
ES	Absence of beacons and headrooms	Ausencia de balizamientos y galibos	
ES	Absence of defense elements	Ausencia de elementos de defensa	
AU	Absence of hollow box drainage	Fehlende Hohlkastenentwässerung	Qualitätssicherung bauliche Erhaltung Bauwerksdatenbank - RVS 13.04.11

Showing 1 to 10 of 966 entries

Previous 1 2 3 4 5 … 97 Next

Performance Indicators – Clustered

Operators Survey | Research Survey | Glossary Terms | Glossary Damages | Perf. Indicators (Clustered) | Perf. Indicators (Reduced) | Perf. Indicators (Countries)

Clustered List of Performance Indicators

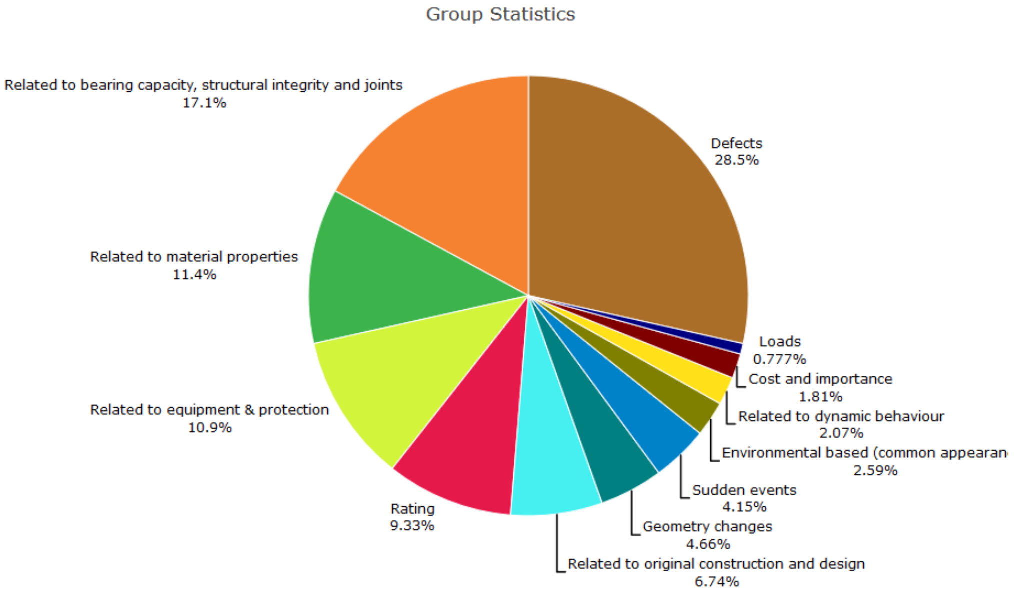
Show 10 entries | Search:

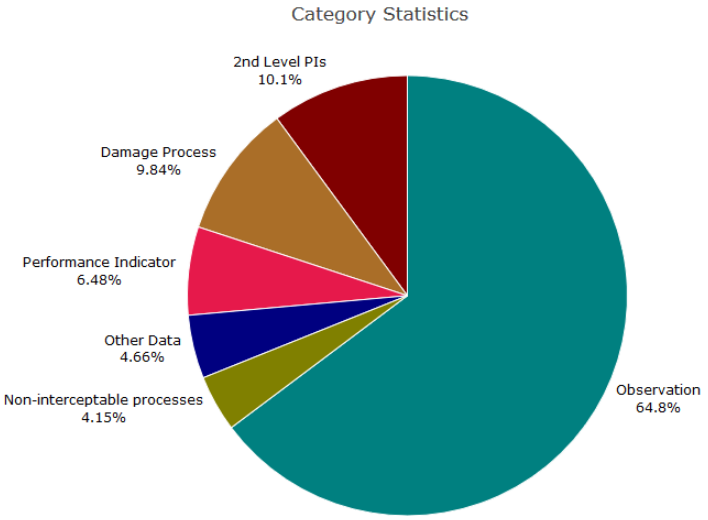
Perf. Indicator	Group	Category
All	All	All
element functionality level	Cost and importance	2nd Level PIs
sum of costs for repair of individual damages	Cost and importance	2nd Level PIs
traffic restrictions	Cost and importance	Observation
traffic volume	Cost and importance	Observation
bridge importance (size)	Cost and importance	Other Data
importance of bridge element	Cost and importance	Other Data
price of the new element	Cost and importance	Other Data
abrasion	Defects	Damage Process
aggradation (alluviation)	Defects	Damage Process
blocking	Defects	Damage Process

Showing 1 to 10 of 386 entries

Previous 1 2 3 4 5 … 39 Next

Performance Indicators Statistics – Clustered





Performance Indicators – Reduced

TU1406 COST ACTION

Operators Survey | Research Survey | Glossary Terms | Glossary Damages | Perf. Indicators (Clustered) | Perf. Indicators (Reduced) | Perf. Indicators (Countries)

Reduced List of Performance Indicators

Show 10 entries

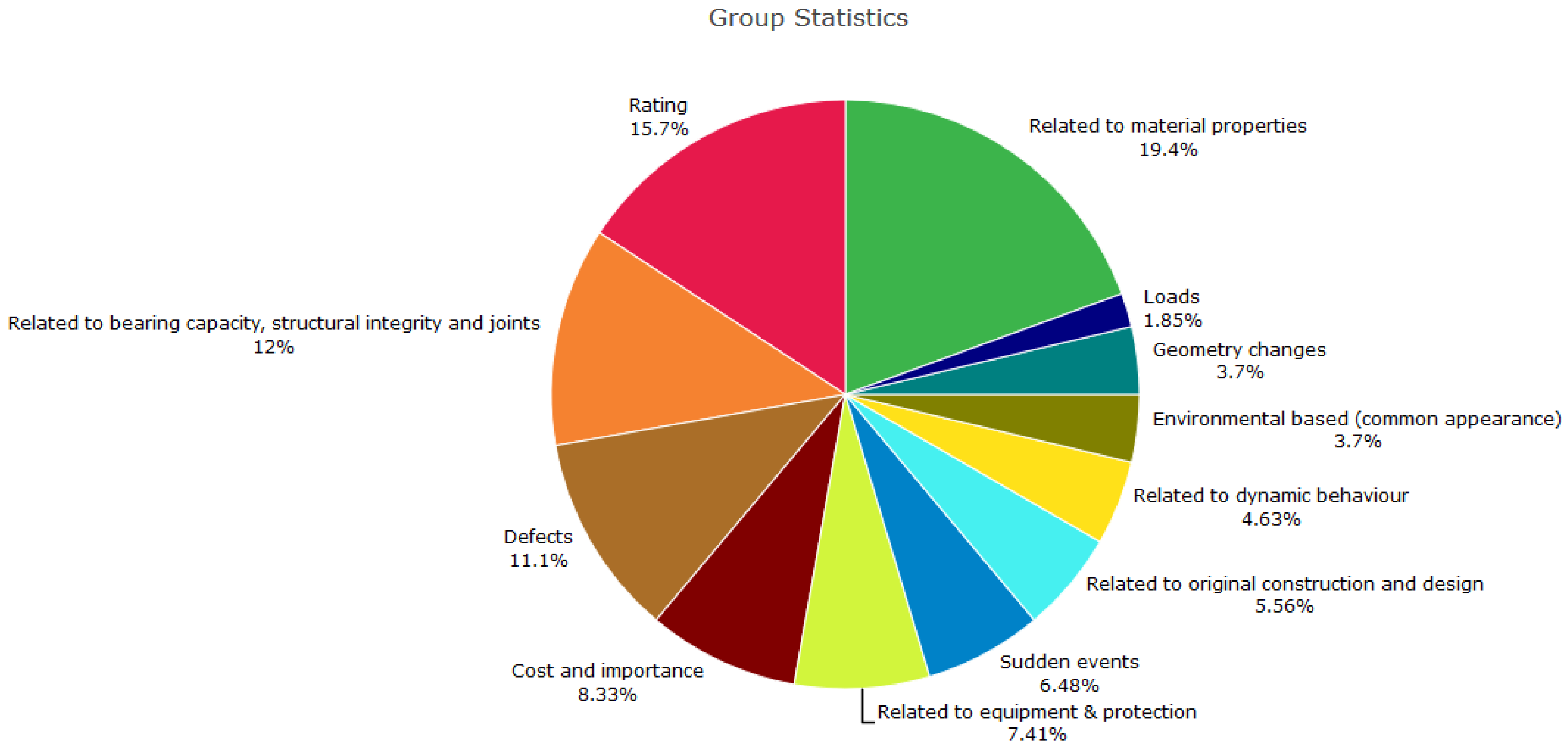
Search:

Perf. Indicator	Obs.	Group
All	All	All
Absence of equipment component	Components missing	Related to equipment & protection
Absent structural component	Components missing	Related to bearing capacity, structural integrity and joints
Advanced deterioration process		Rating
Approach slab settlement		Related to equipment & protection
Arch ring separation		Related to bearing capacity, structural integrity and joints
Asphalt pavement cracking		Related to equipment & protection
Asphalt pavement wearing and tearing	Rutting, ravelling	Related to equipment & protection
Asphalt pavement wheel tracking and wrinkling and undulation		Related to equipment & protection
Bearings deformation		Related to bearing capacity, structural integrity and joints
Bearings displacement		Related to bearing capacity, structural integrity and joints

Showing 1 to 10 of 108 entries

Previous 1 2 3 4 5 … 11 Next

Performance Indicators Statistics – Reduced



Country Performance Indicators

TU1406 COST ACTION

Operators Survey | Research Survey | Glossary Terms | Glossary Damages | Perf. Indicators (Clustered) | Perf. Indicators (Reduced) | Perf. Indicators (Countries)

Reduced List of Performance Indicators per Country

Show 10 entries

Search:

Country	Performance Indicator	Group	Component Level	System Level	Network Level	Measurable?	Technical	Socio-Economical	Sustainable	Belongs KPI?
All	All	All	All	All	All	All	All	All	All	All
ES	Sum of costs for repair of individual damages	Cost and importance		X		X		X		X
ES	Crack length	Defects	X			X	X			X
ES	Crack orientation	Defects	X			X	X			X
ES	Crack width	Defects	X			X	X		X	X
ES	Crack spacing	Defects								
ES	Cracks related to origin	Defects		X		X			X	X
ES	Fatigue cracking	Defects	X	X		X			X	X
ES	Concrete cover	Defects								
ES	Water penetrability	Defects	X	X		X	X			X
ES	Settlement	Defects	X	X		X	X			X

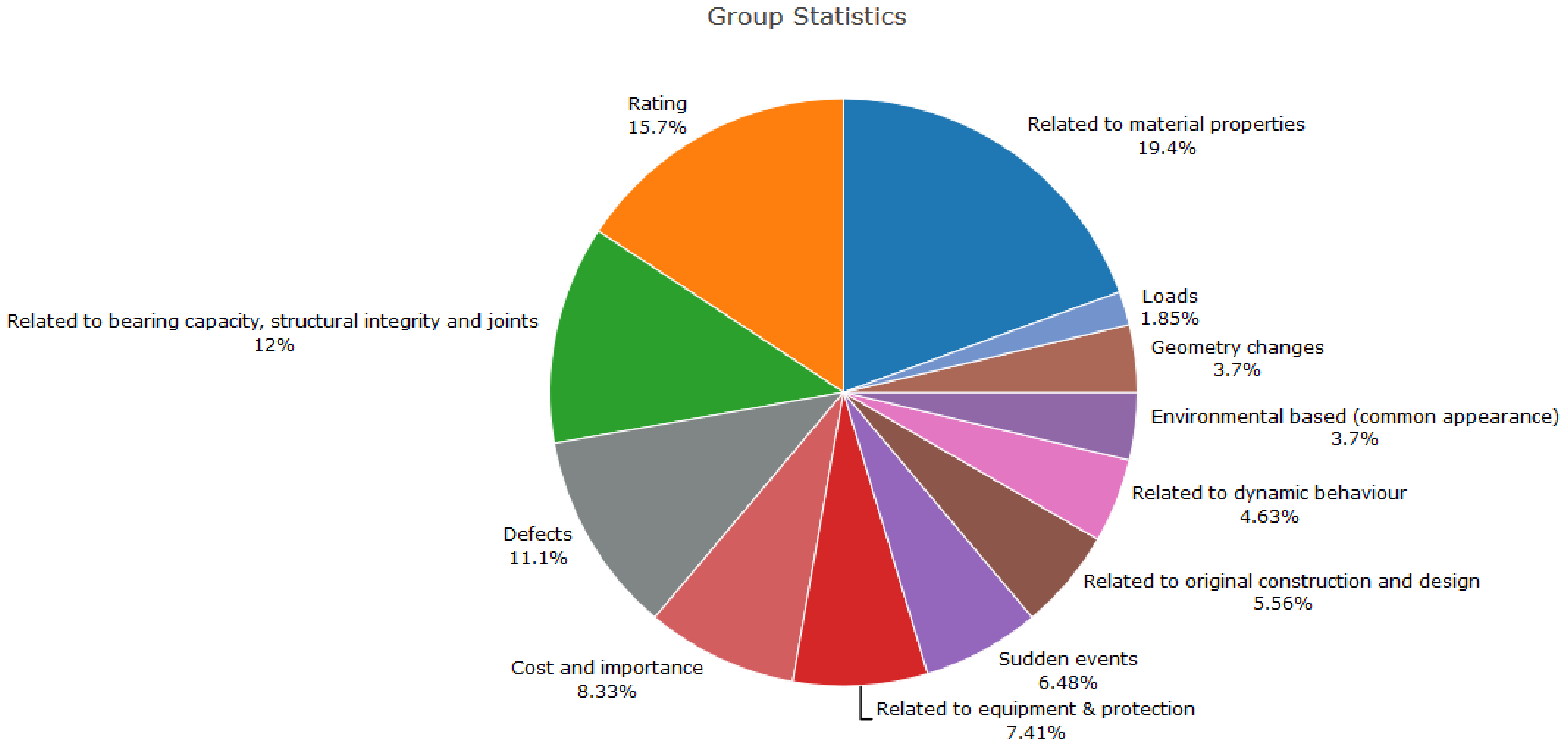
Showing 1 to 10 of 140 entries

Previous 1 2 3 4 5 … 14 Next

Country Performance Indicators

Group	ES	HR
Cost and importance	0	9
Defects	12	0
Environmental based (common appearance)	0	4
Geometry changes	4	0
Loads	0	2
Rating	0	17
Related to bearing capacity, structural integrity and joints	11	2
Related to dynamic behaviour	0	5
Related to equipment & protection	8	0
Related to material properties	21	0
Related to original construction and design	0	6
Sudden events	0	7

Country Performance Indicators Statistics



TU1406
COST ACTION

QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Framework for KPIs bridge assessment

Irina Stipanovic, University of Twente, Netherlands

UNIVERSITY OF TWENTE.

Winter training school, 18.-21. December 2018, Zell am See, Austria

Introduction

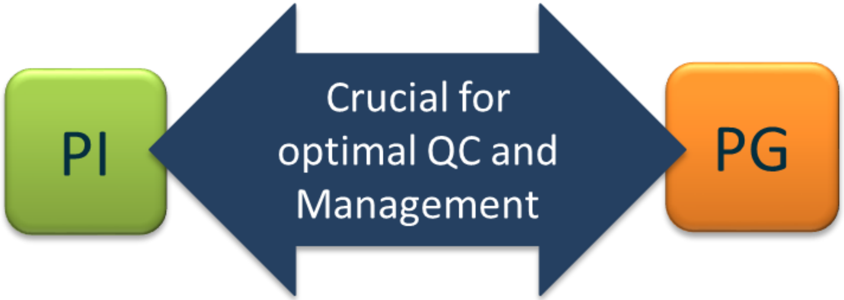
Main objective of WG 2 Performance Goals

- To provide an overview of existing performance goals based on the *performance indicators* previously identified in WG1.
- These goals will vary by technical, environmental, economic and social aspects, and on the component, system and network level.

- Deliver a Report which will specify the performance goals, linked to the Performance Indicators.

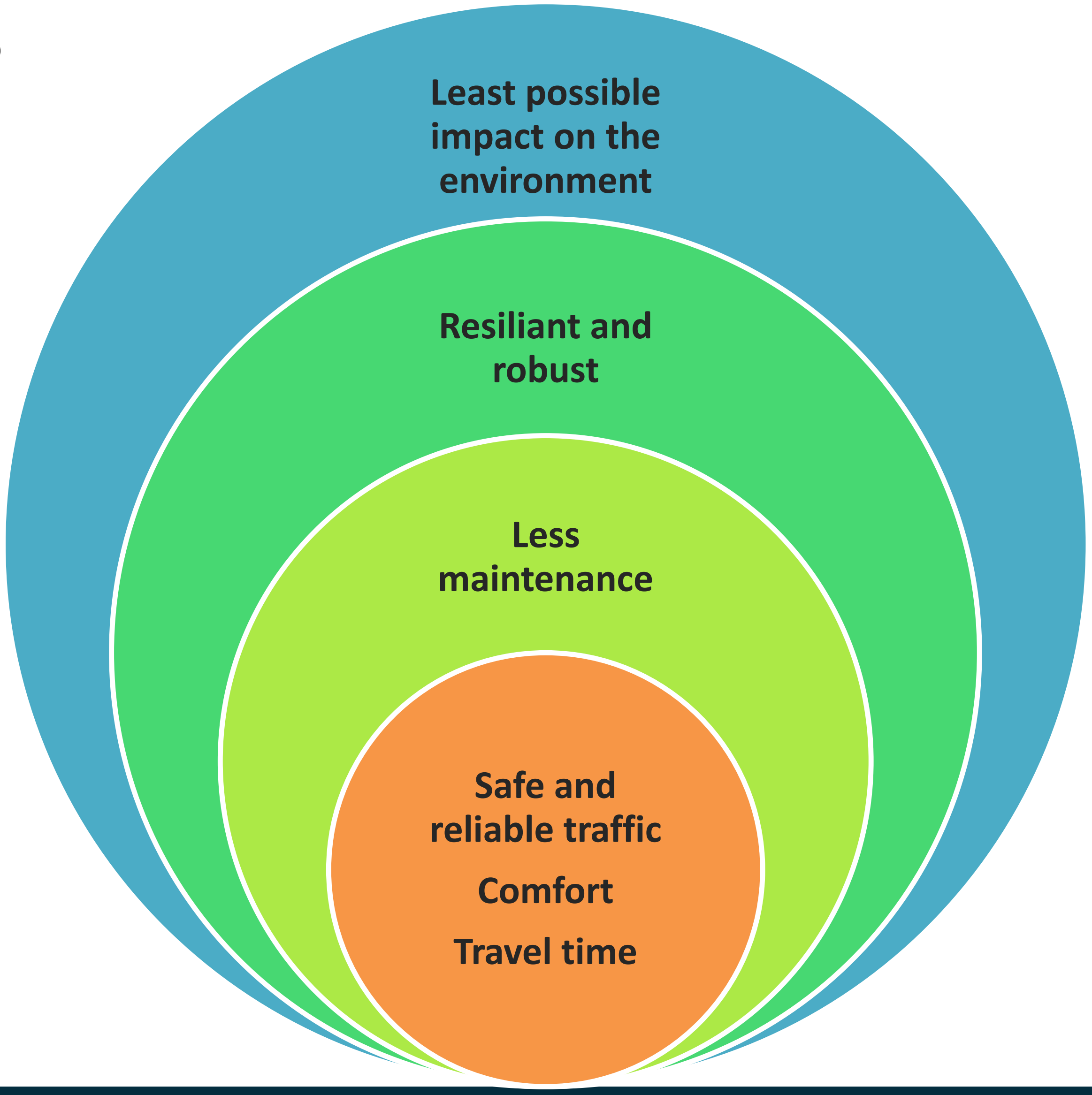
Definition of Performance Indicator

- Parameter **measurable** and **quantifiable** related to the bridge performance that can be compared with a **target measure** of a **performance goal** or can be used for **ranking** purposes among a bridge population in the framework of a **Quality Control Plan** or life-cycle management (**decisions, actions involving economic resources).**

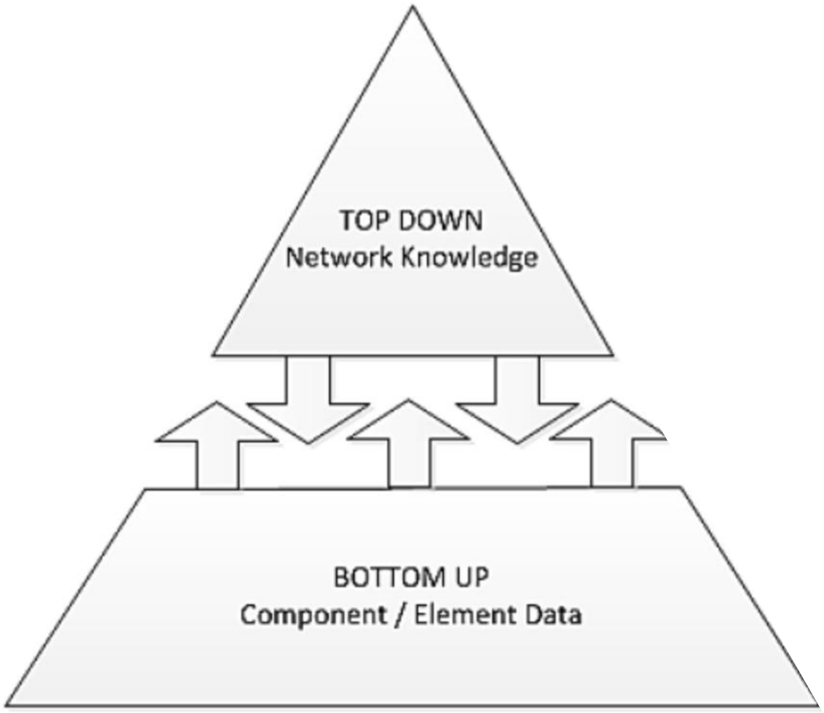


Performance goals
- society / users related

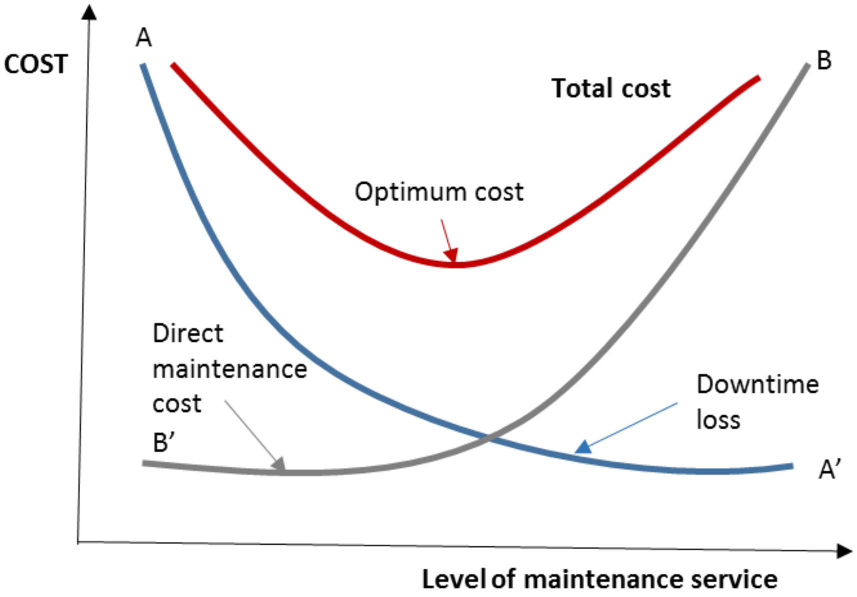
- Technical PGs
  - Reliability and safety related goals
- Sustainable PGs
  - Environmental impact related goals
- Other PGs
  - Economic and social based goals



Asset management approach



- LCC concept



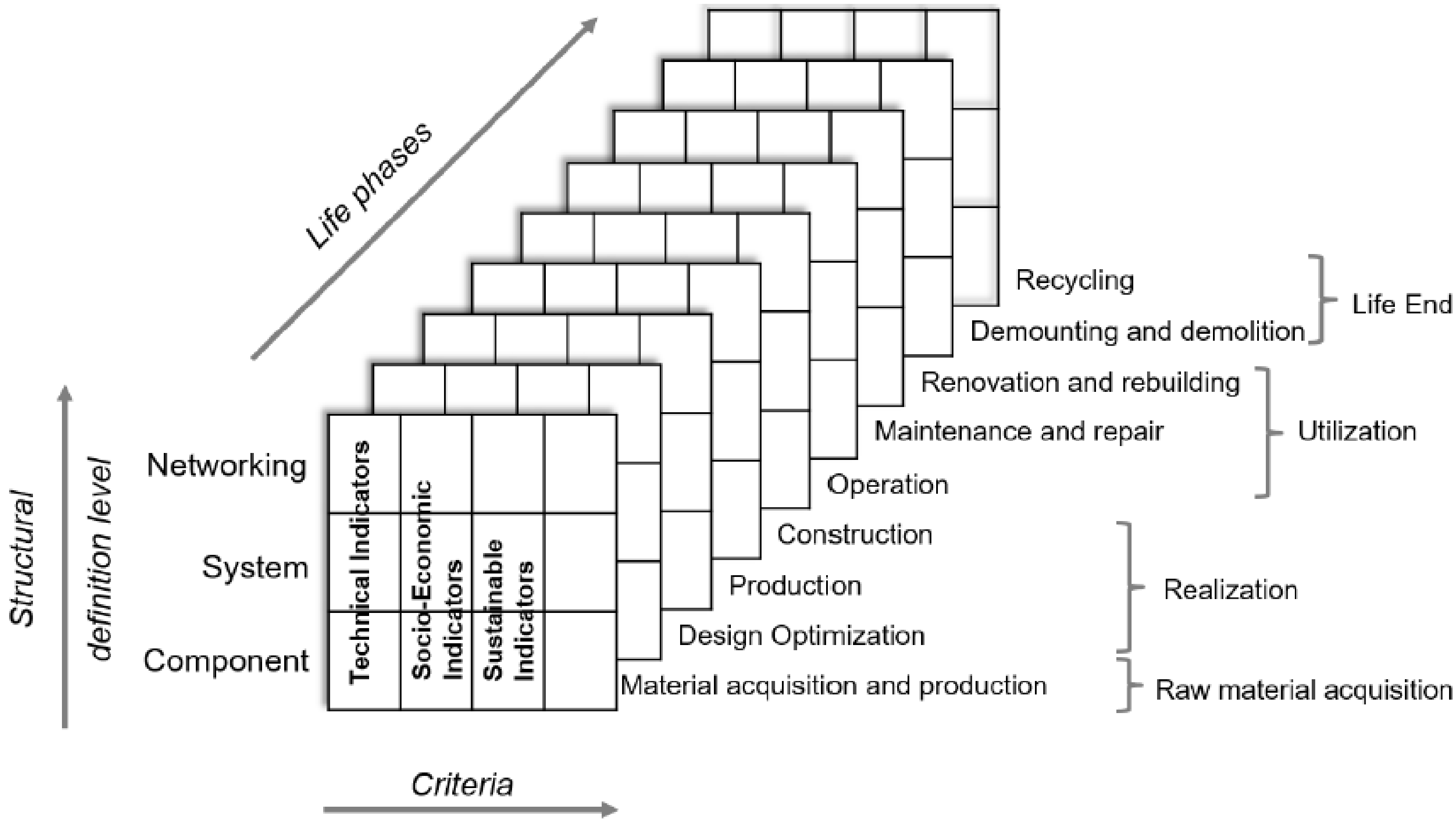
BRIDGE MANAGEMENT APPROACH

- Asset management considers physical assets in relation with other activities to deliver required performance
- Bridge management is to be part of the management of the network
- PAS55 (BSI, 2008) and ISO55000

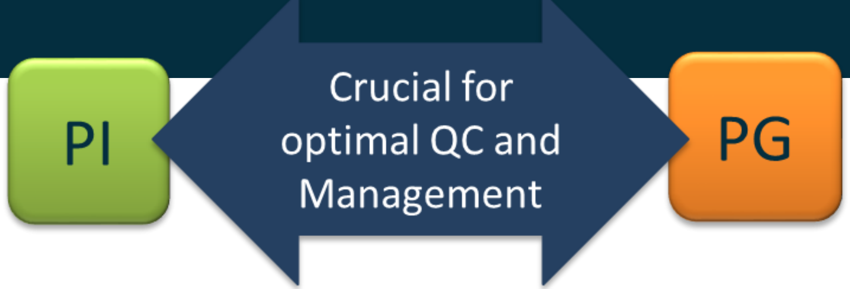
In the case of the Netherlands network performance is described using nine performance aspects (RAMS SHEEP):

- Reliability, Availability, Maintainability
- Safety
- Security, Health, Environment
- Life Cycle Costs
- Politics

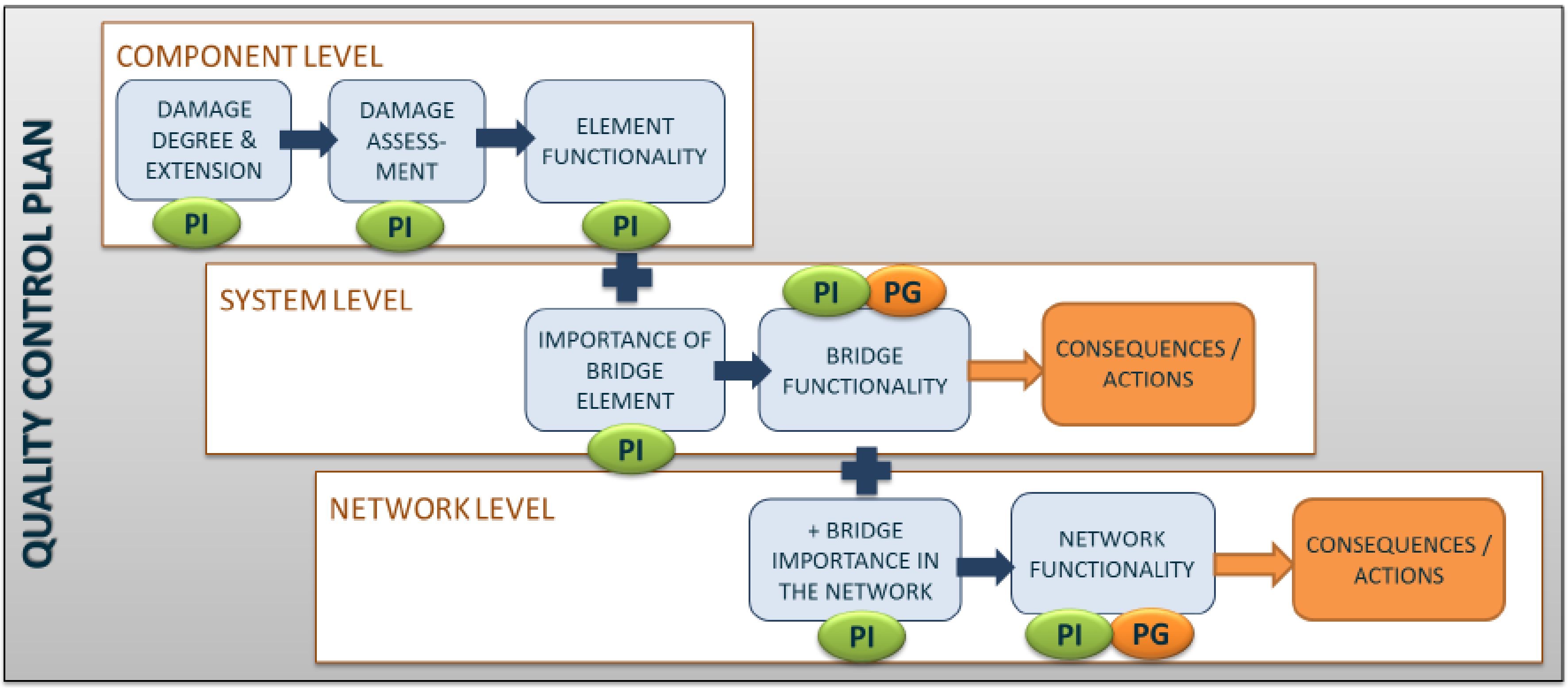
Complexity!


Life phases
Structural
definition level
Networking
System
Component
Technical Indicators
Socio-Economic Indicators
Sustainable Indicators
Criteria
Recycling
Demounting and demolition
Life End
Renovation and rebuilding
Maintenance and repair
Utilization
Operation
Construction
Production
Realization
Design Optimization
Material acquisition and production
Raw material acquisition

Framework

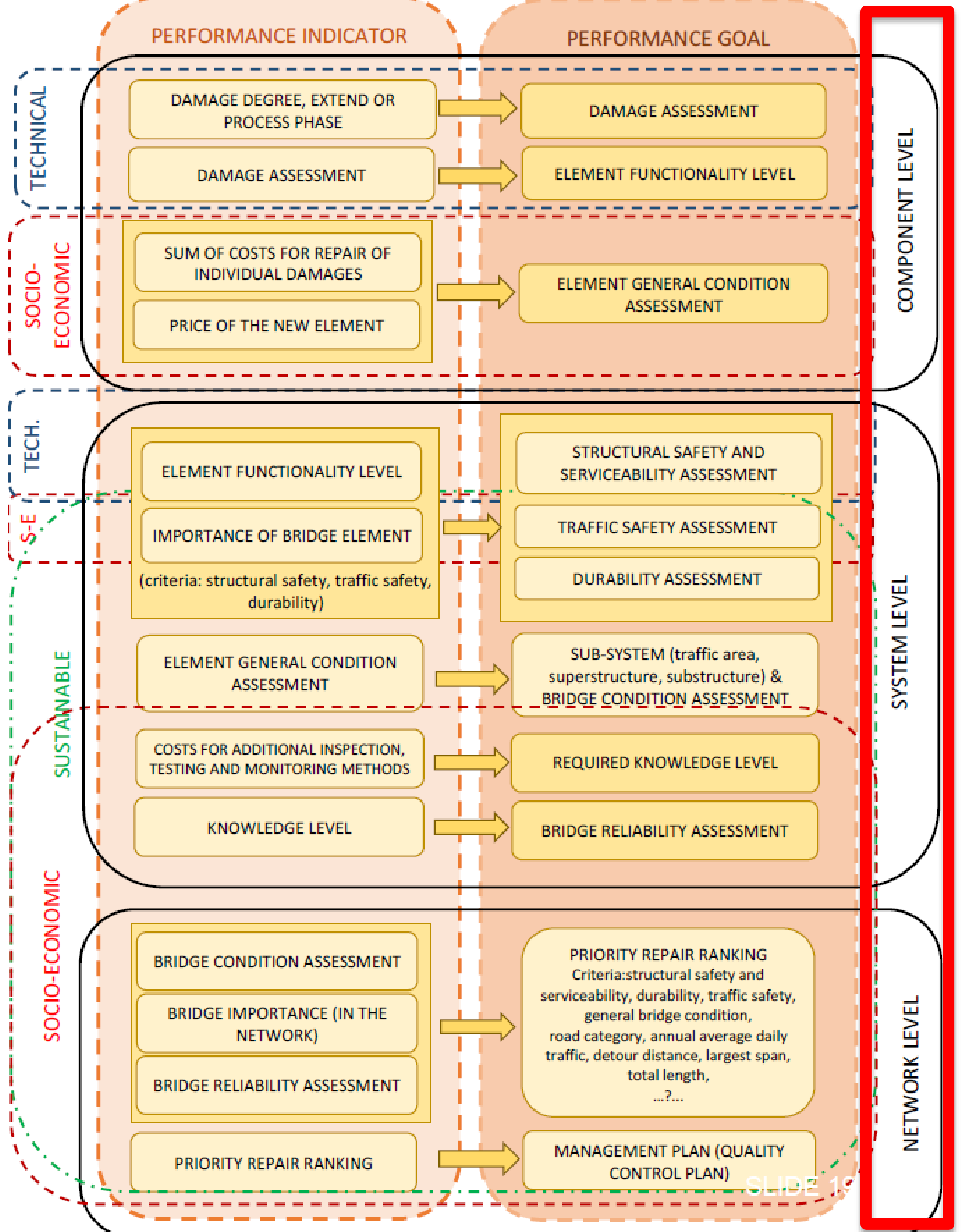


- Clustering the observations and the necessary actions based on the component, system and network level.



Indicators and goals

- Interactions between KPI and PG are contemplated, as they are crucial for optimal quality control and management of road bridges



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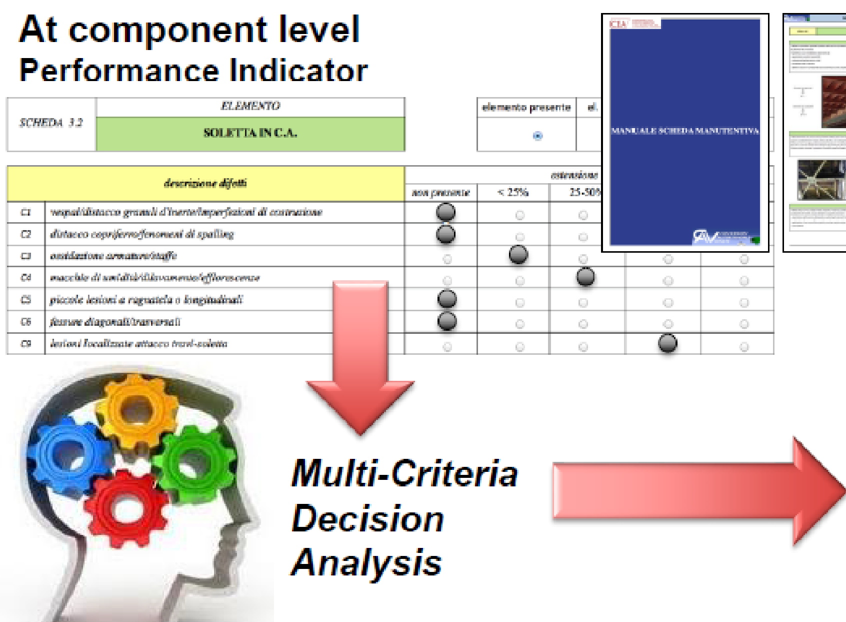
Transformation of performance indicators

- The multiple performance indicators cannot necessarily be directly compared;
- The PIs must be transformed in order to facilitate decision → KPIs as aggregated condition values → performance goals
- In order to do so, a “multi-criteria-analysis” or similar will have to be carried out



Performance Goal

CV - Condition Value	
No judgement	0
No meaningful defects	1
Minor defects that do not cause damage	2
Moderate defects that could cause damage	3
Severe defects that cause damage	4
Non-functional element	5

WG 2 Report

- Final report published in November 2017
- 13 Authors:

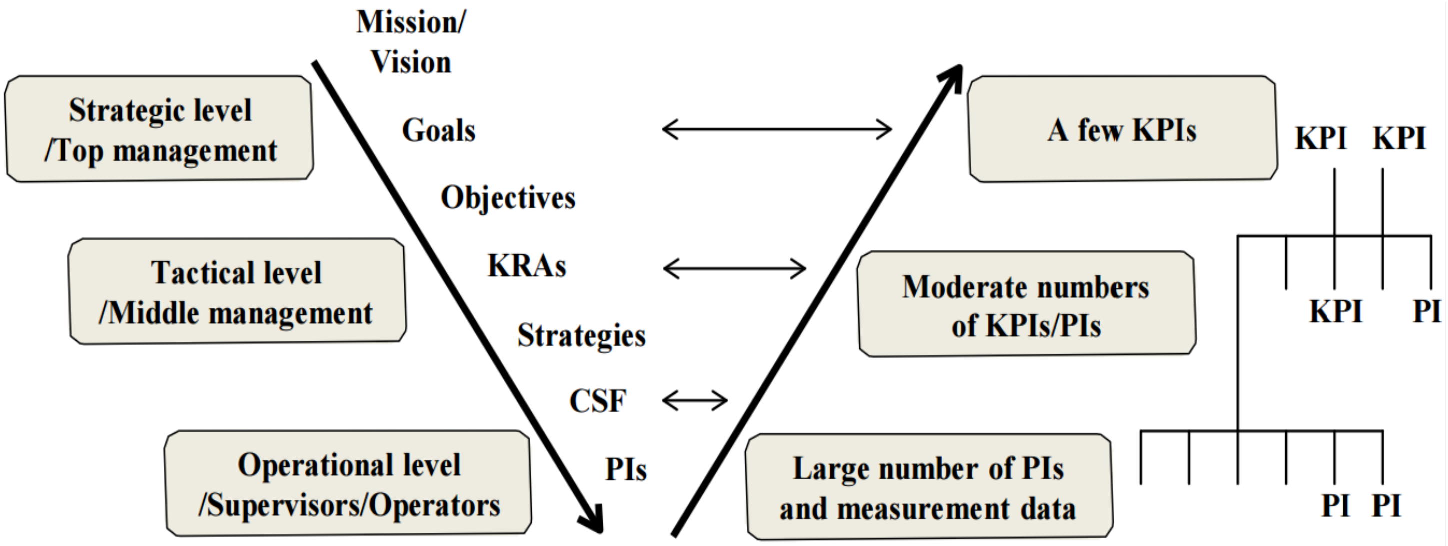
  I. Stipanovic, E. Chatzi, M. Limongelli, K. Gavin, Y. Xenidis,

  B. Imam, A. Anzlin, M. Zanini, Z. Allah, G. Klanker, N. Hoj, N. Ademovic, S. Skaric Palic
- 7 Chapters and 2 Appendices
- Additional online MAUT tool is developed
- In the final format report has about 80 pages

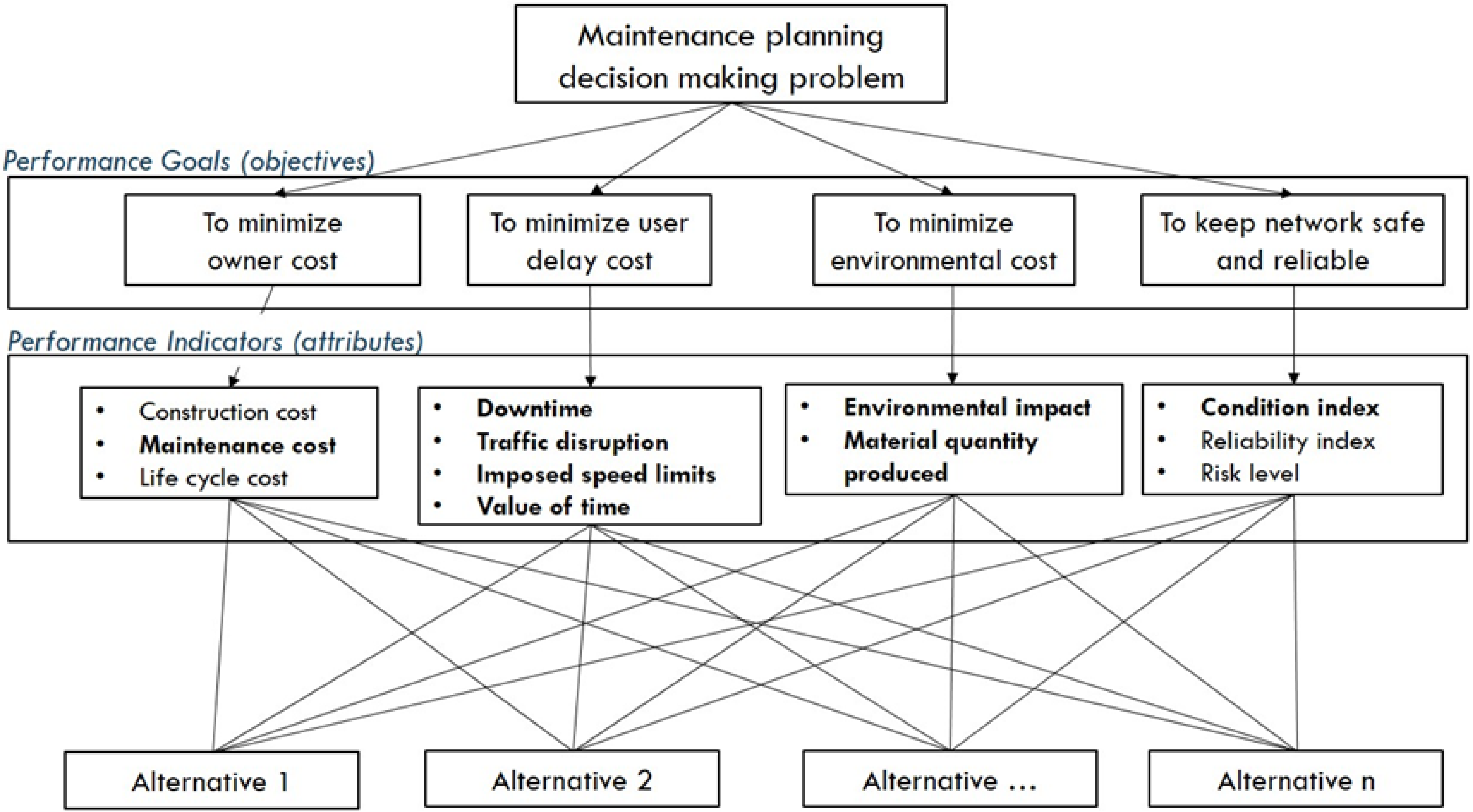
Content list

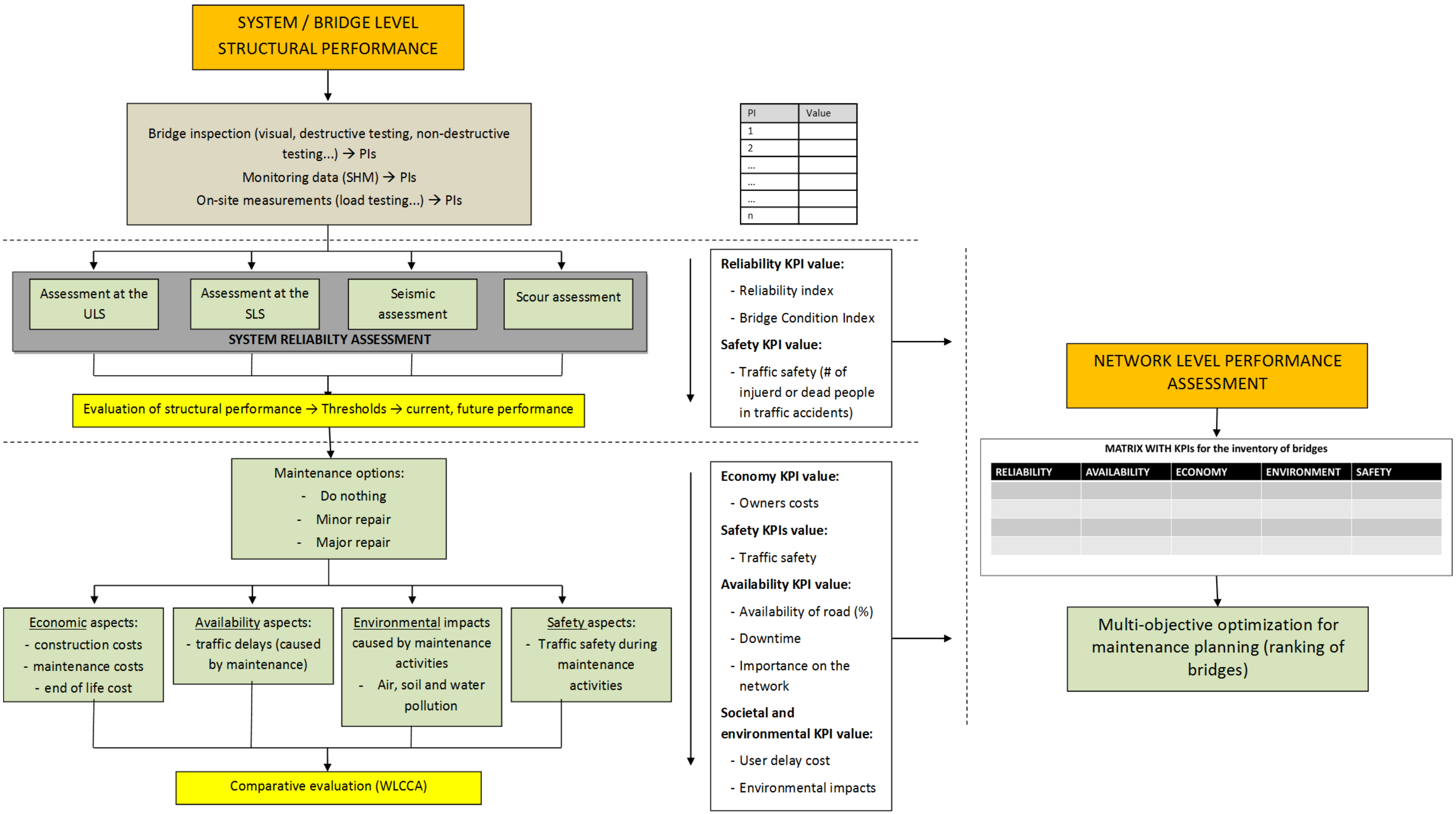
1 Introduction

2 Performance goals for roadway bridges



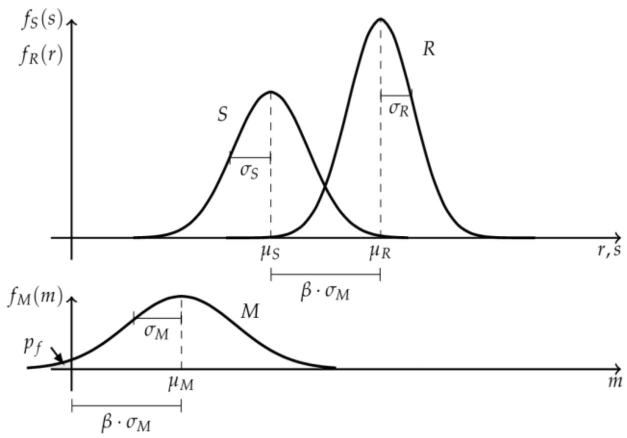
KRA = key result area; where the result and indicators are visualised
CSF = critical success factor; to succeed with set objectives
KPI = Key performance indicator (PI)

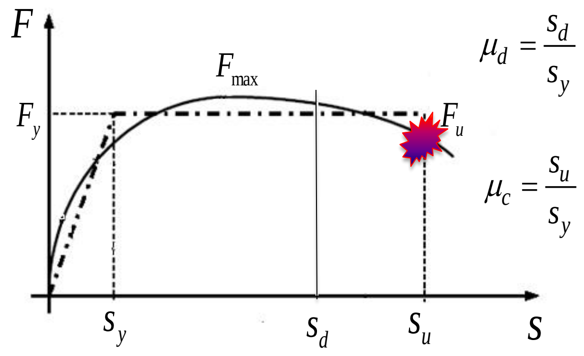

Maintenance planning decision making problem
Performance Goals (objectives)
To minimize owner cost
To minimize user delay cost
To minimize environmental cost
To keep network safe and reliable
Performance Indicators (attributes)
• Construction cost
• Maintenance cost
• Life cycle cost
• Downtime
• Traffic disruption
• Imposed speed limits
• Value of time
• Environmental impact
• Material quantity produced
• Condition index
• Reliability index
• Risk level
Alternative 1
Alternative 2
Alternative …
Alternative n

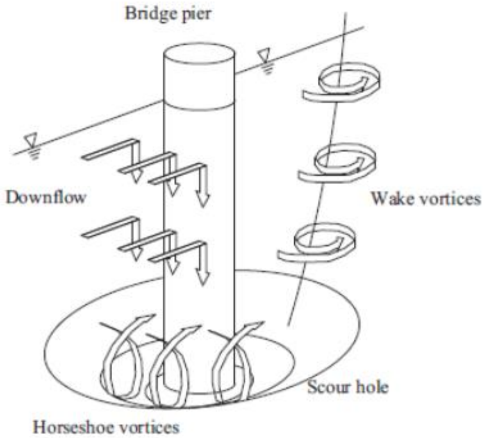

SYSTEM / BRIDGE LEVEL STRUCTURAL PERFORMANCE
Bridge inspection (visual, destructive testing, non-destructive testing...) → PIs
Monitoring data (SHM) → PIs
On-site measurements (load testing...) → PIs
PI
Value
1
2
...
...
...
n
Assessment at the ULS
Assessment at the SLS
Seismic assessment
Scour assessment
SYSTEM RELIABILTY ASSESSMENT
Evaluation of structural performance → Thresholds → current, future performance
Reliability KPI value:
- Reliability index
- Bridge Condition Index
Safety KPI value:
- Traffic safety (# of injuerd or dead people in traffic accidents)
NETWORK LEVEL PERFORMANCE ASSESSMENT
MATRIX WITH KPIs for the inventory of bridges
RELIABILITY
AVAILABILITY
ECONOMY
ENVIRONMENT
SAFETY
Maintenance options:
- Do nothing
- Minor repair
- Major repair
Economic aspects:
- construction costs
- maintenance costs
- end of life cost
Availability aspects:
- traffic delays (caused by maintenance)
Environmental impacts caused by maintenance activities
- Air, soil and water pollution
Safety aspects:
- Traffic safety during maintenance activities
Comparative evaluation (WLCCA)
Economy KPI value:
- Owners costs
Safety KPIs value:
- Traffic safety
Availability KPI value:
- Availability of road (%)
- Downtime
- Importance on the network
Societal and environmental KPI value:
- User delay cost
- Environmental impacts
Multi-objective optimization for maintenance planning (ranking of bridges)

3 Reliability

- 3.1 Structural Performance assessment
- 3.2 Seismic assessment
- 3.3 Scour assessment
- 3.4 Joint seismic and scour assessment: current research trends
- 3.5 Implementation of Structural Health Monitoring







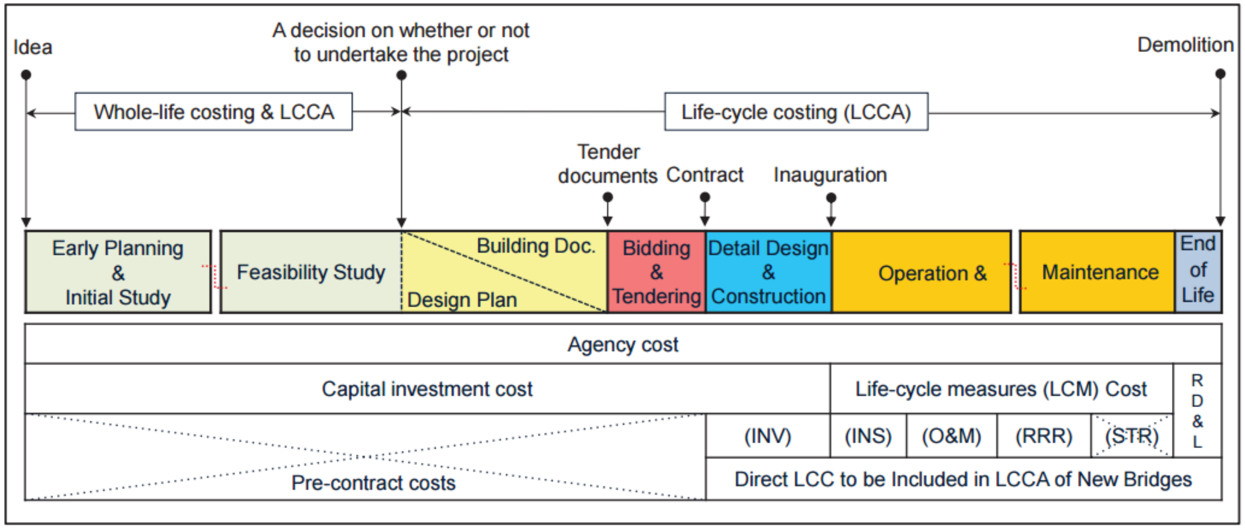
4 Economy, societal and environmental performance goals

4.1 Introduction

4.2 Economy performance assessment

4.3 Societal Performance Aspect

4.4 Combined Economic and Environmental Performance Analysis

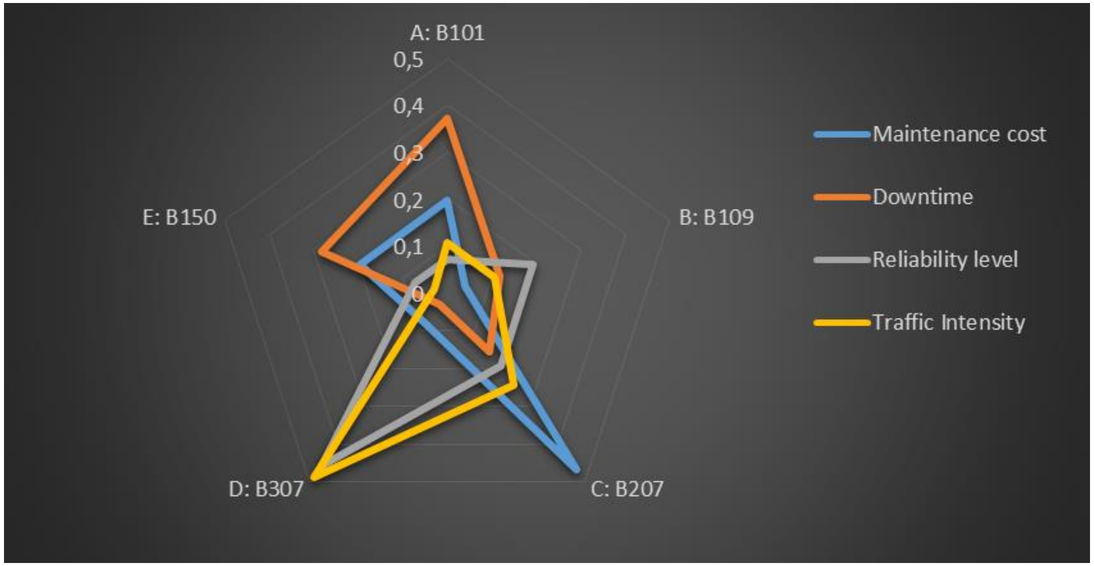


5 Multi-objective optimization models

5.1 Analytic Hierarchy Process

5.2 Multi-attribute Utility Functions

5.3 Discussion and conclusions



6 Conclusion

Future developments should concentrate on the unification of:

- Standardization of the assessment procedures,
- Collection of PIs and quantification of KPIs,
- Development of maintenance optimization tools which can be applied in practice.

- Appendix 1 Environmental impact per kg of material ($EE_{i,j}$)
- Appendix 2: Instructional Manual for the application of MAUT web-based tool

MAUT tool for bridge ranking for maintenance planning

- Management of bridges while achieving following performance goals:
    - Maximize the condition (reliability)
    - Minimize the owner cost (economy)
    - Minimize the user delay cost (availability)
    - Minimize the environment cost (environment)

- Objective: Rank/prioritize the bridges that are in need of maintenance while satisfying performance goals
- Tool is provided online on the COST TU 1406 website

Conclusions

- Large disparity in Europe regarding the way performance indicators are quantified and how performance goals / requirements are specified.
- Main challenges are:
  - how to quantify performance goals other than technical, and
  - how to link strategic level to the performance requirements on the project level.
- An important notion is that in many countries, the main focus of bridge management is still the condition assessment of the particular objects or elements.

Summary

- Technical performance goals (structural safety)
  - on the object level
  - linked to standards, value defined
  - can be internationally agreed
- Economic, environmental, societal and other performance goals
  - Depend on each country / agency goals
  - Mostly defined as constraints
  - Used as comparative method (no absolute values)
  - On the object level LCC to select optimal maintenance option
  - On the network level to select optimal maintenance strategy (performance goals: to increase availability, to decrease the environmental impact)

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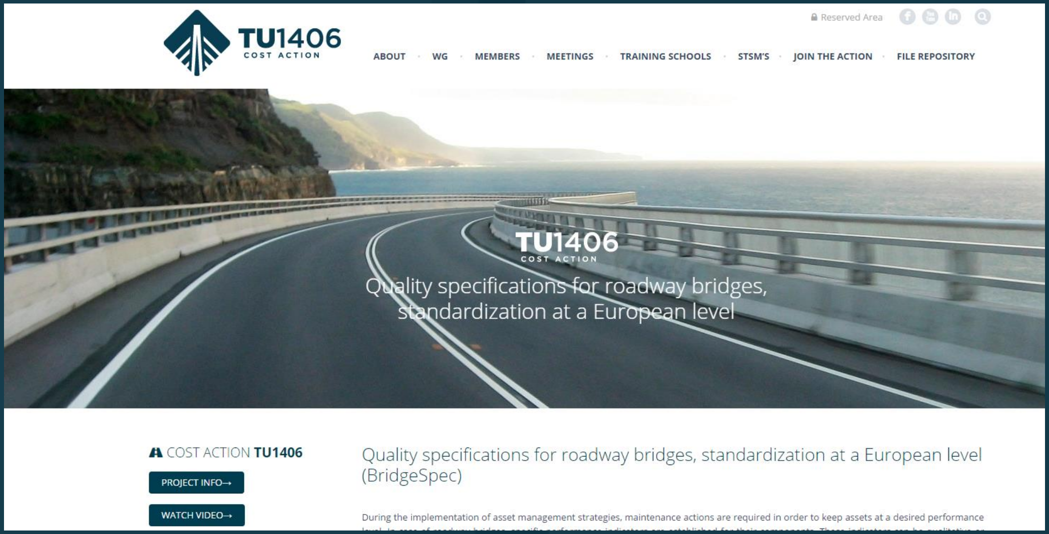

Thank you for your attention!

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QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Multi-criteria decision making models

Irina Stipanovic, University of Twente, The Netherlands

Content

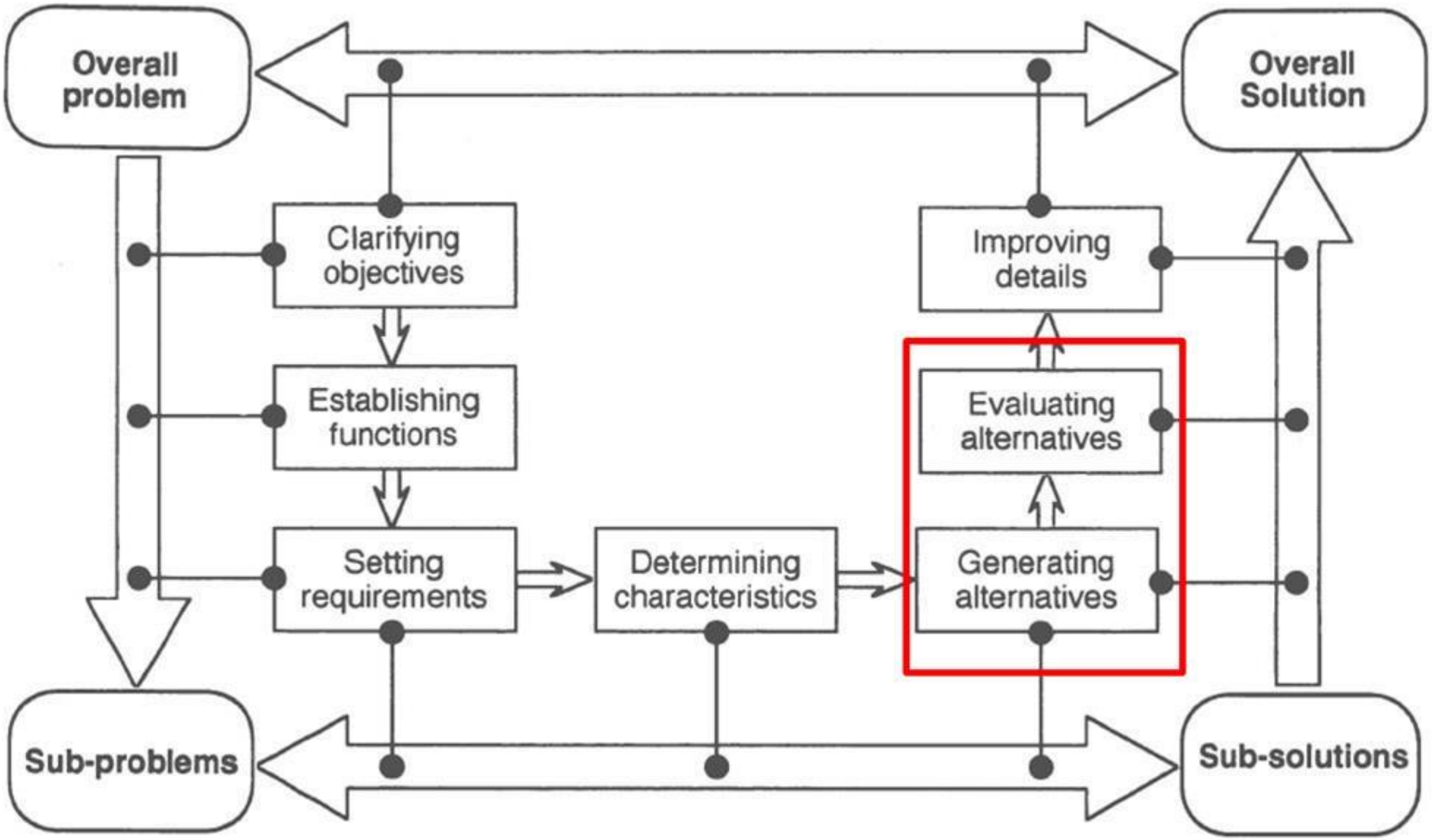
1. What is MCDA
2. MCDA method
3. Analytical Hierarchy Process (AHP)
4. Application of AHP
5. Workshop

WHAT IS MCDA

- Multi-criteria decision analysis
- Selection of best solution from set of alternatives based on multiple criteria
- Number of MCDA methods exist for this purpose
  - SAW (Simple Additive Weighting)
  - AHP (Analytical Hierarchy Process)
  - ANP (Analytical Network Process
  - MAUT (Multi-Attribute Utility Theory)
  - ELECTRE (Elimination et Choice Translating Reality)
  - TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution)

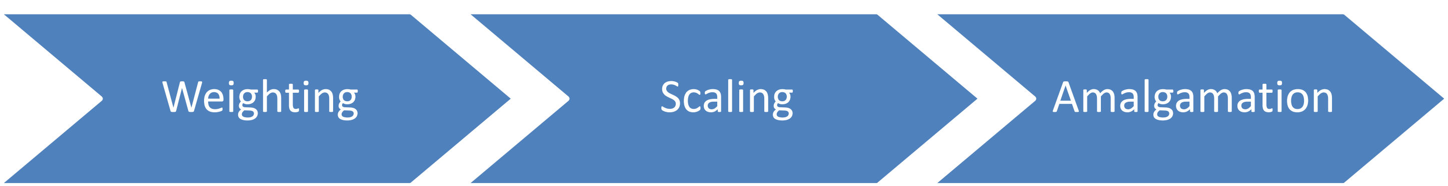
2. MCDA METHOD

Decision making!



Multi-criteria decision making
For maintenance planning

- Systematic approach to evaluate multiple conflicting objectives in decision making
  - Limited budget vs. aging bridge
  - Demands of availability vs. need of maintenance
  - Risk of failure vs. criticality
- Enable the decision maker to provide preferences when exposed with conflicting objectives



3. ANALYTICAL HIERARCHY PROCESS

- Proposed by Thomas L. Saaty in 1970
- One of the widely used MCDA method
- Has wide variety of application such as government, business, industry, healthcare, etc
- Incorporate quantitative as well as qualitative criteria for decision making
- Algorithm

1. Determine the relative weights of decision criteria
2. Determine the relative ranking of alternatives

3. ANALYTICAL HIERARCHY PROCESS

- Components of Decision making
  - Objective
    - Example: Select a car
    - Example: Select the best design solution
  - Criteria
    - Style, safety, price, capacity, etc
    - environment cost, society cost, etc.
  - Alternatives
    - Ford excort, Accord seden, Pilot SUV
    - Alternative 1, Alternative 2, etc

3. ANALYTICAL HIERARCHY PROCESS

- Ranking of weights and Alternatives
  - Pairwise comparison is made to decide the relative importance of each criteria
  - The scale of comparion is also introduced by Saaty

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

3. ANALYTICAL HIERARCHY PROCESS

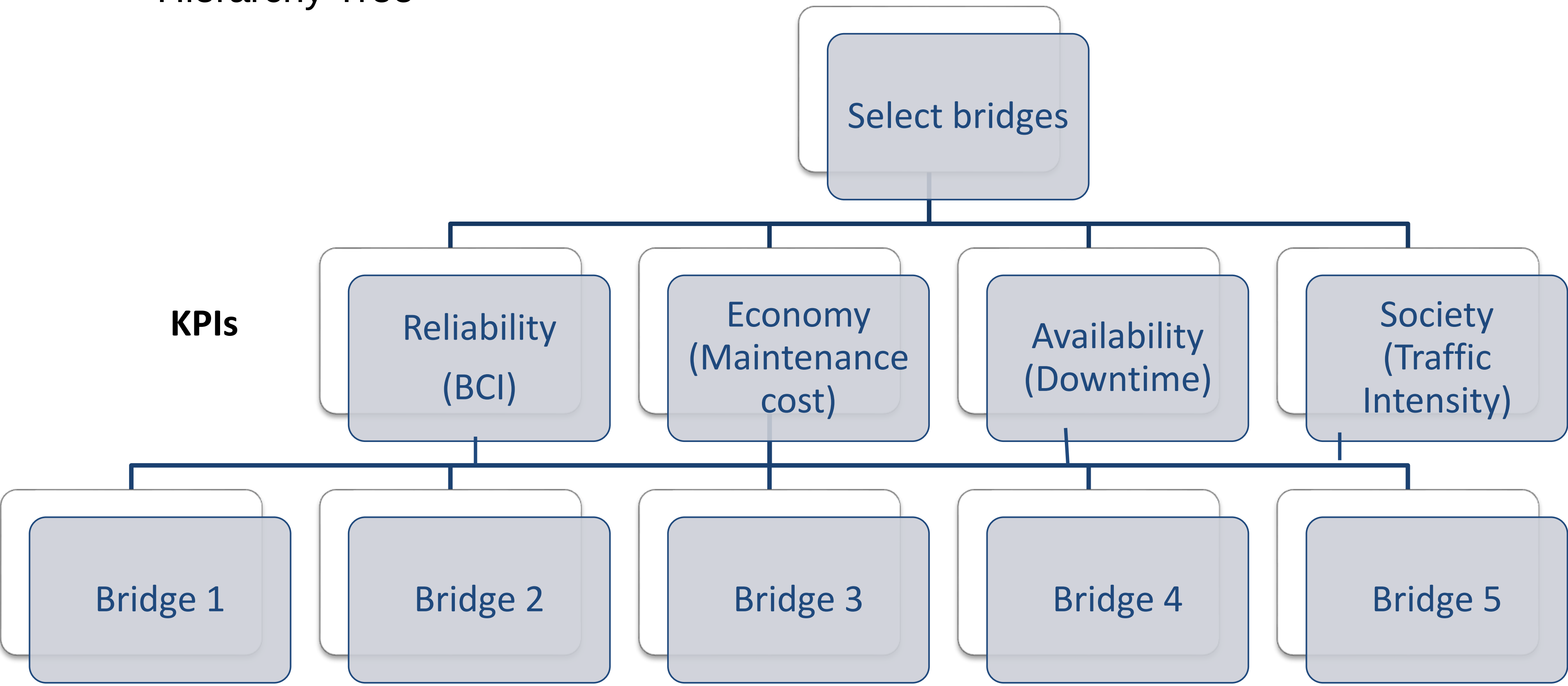
- Illustrative Example

Due to budget constraints, a decision has to be made regarding the selection of bridge for maintenance. The objective is to select those bridges where the cost and downtime can be kept the minimum.

- Select bridges - Objective
- Cost, downtime, etc – Criteria
- All the bridges under consideration – Alternatives

3. ANALYTICAL HIERARCHY PROCESS

- Hierarchy Tree



Analytical Hierarchy Process

Illustrative example

Define objective and identify criteria

Objectives

- Minimize the maintenance cost
- Minimize the downtime

Key Performance indicator → Criteria → Scale → Alternatives

	Reliability	Economy	Availability	Society
Bridges	Reliability level	Maintenance cost	Downtime	Importance on the network
Name	Score card	Euros	Hours	Traffic Intensity (# cars / day)
A: B101	3	500k	30	9000
B: B109	4	1000k	70	10000
C: B207	4	200k	60	13000
D: B307	5	800k	180	15000
E: B150	3	500k	40	5000

3. ANALYTICAL HIERARCHY PROCESS

- Comparison matrix

Bridge	Condition index	Maintenance cost	Downtime	Traffic Intensity
Name	Score card*	Euros (k)	Hours	# of cars/day
Bridge A	3	500	30	9000
Bridge B	4	1000	70	10000
Bridge C	4	200	60	13000
Bridge D	5	800	180	15000
Bridge E	3	500	40	5000

*1 is very good state of bridge and 6 is out of service

SCORE CARD

Bridge Condition Index	Description
1	Very Good (no faults)
2	Good (minor faults well within tolerance)
3	Fair (tolerable faults, no restriction in use necessary)
4	Poor (significant structural defects)
5	Very poor (seriously deficient, mitigation measures necessary)
6	Out of service (on high risk of failure, mitigation needed urgently)

3. ANALYTICAL HIERARCHY PROCESS

	Maintenance cost (MC)	Downtime (DT)	Reliability (RL)	Traffic intensity (TI)
Maintenance cost	1	1	3	5
Downtime	1	1	3	3
Reliability	1/3	1/3	1	7
Traffic intensity	1/5	1/3	1/7	1

3. ANALYTICAL HIERARCHY PROCESS

- Ranking of Criteria

Criteria		**Importance & Intensity**	
A	B	Imp	Intensity
Maintenance cost	Downtime	A	**1**: Equal importance
Maintenance cost	Reliability	A	**3:** Moderate
Maintenance cost	Traffic Intensity	A	**5:** Strong
Downtime	Reliability	A	**3:** Moderate
Downtime	Traffic Intensity	A	**3:** Moderate
Reliability	Traffic Intensity	A	**7:** Very Strong

3. APPLICATION EXAMPLE – AHP

- Ranking of Criteria

- To find the ranking of priorities, namely the Eigen Vector X:

  1) Normalize the column entries by dividing each entry by the sum of the column.

  2) Take the overall row averages.

  – A is the comparison matrix of size n×n, for n criteria, also called the priority matrix.

  – x is the Eigenvector of size n×1, also called the priority vector.

$$A = \begin{pmatrix} 1 & 1 & 3 & 5 \\ 1 & 1 & 3 & 3 \\ 0.33 & 0.33 & 1 & 7 \\ 0.2 & 0.33 & 0.14 & 1 \end{pmatrix} \xrightarrow{\text{Normalized}} \begin{pmatrix} 0.39 & 0.38 & 0.42 & 0.31 \\ 0.39 & 0.38 & 0.42 & 0.19 \\ 0.13 & 0.13 & 0.14 & 0.44 \\ 0.08 & 0.13 & 0.02 & 0.06 \end{pmatrix} \xrightarrow{\text{Geometric mean of row}} X = \begin{pmatrix} 0.37 \\ 0.33 \\ 0.18 \\ 0.06 \end{pmatrix}$$

Sum = **2.53** **2.66** **7.14** **16**   **1** **1** **1** **1**

Priority Vector

3. Application Example – AHP

Comparison of decision criteria (Experts' judgment)

Matrix normalization

- Create the comparison matrix from the preference structure
- Reduce the matrix from 0 to 1 by

$$\overline{b}_{ij} = \frac{b_{ij}}{\sum_{k=1}^{n} b_{kj}}, (i, j = 1, 2, \cdots, n),$$

- Calculate the final Eigen vector from the preferences of each alternative by

$$\overline{\mathbf{w}}_i = \sum_{j=1}^{n} \overline{b}_{ij}, (i = 1, 2, \cdots, n).$$

$$\mathbf{w}_i = \frac{\overline{\mathbf{w}}_i}{\sum_{j=1}^{n} \overline{\mathbf{w}}_j}, (i = 1, 2, \cdots, n).$$

3. ANALYTICAL HIERARCHY PROCESS

- Comparison matrix

Bridge	Condition index	Maintenance cost	Downtime	Traffic Intensity
Name	Score card*	Euros (k)	Hours	# of cars/day
Bridge A	3	500	30	9000
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Bridge C	4	200	60	13000
Bridge D	5	800	180	15000
Bridge E	3	500	40	5000

*1 is very good state of bridge and 6 is out of service

3. Application Example – AHP

Comparison of decision criteria (Experts' judgment)

Comparison Matrix

Comparison among criteria	*Maintenance cost*	*Downtime*	*Reliability*	*Traffic Intensity*
Maintenance cost	1.00	1.00	3.00	5
Downtime	1.00	1.00	3.00	3
Reliability level	0.33	0.33	1.00	7
Traffic Intensity	0.20	0.33	0.14	1

Matrix Normalization

$$\overline{b}_{ij} = \frac{b_{ij}}{\sum_{k=1}^{n} b_{kj}}, (i, j = 1, 2, \cdots, n),$$

Normalized matrix	*Maintenance cost*	*Downtime*	*Reliability*	*Traffic Intensity*
Maintenance cost	0.39	0.38	0.42	0.31
Downtime	0.39	0.38	0.42	0.19
Reliability level	0.13	0.13	0.14	0.44
Traffic Intensity	0.08	0.13	0.02	0.06

3. Application Example – AHP

Comparison of decision criteria (Experts' judgment)

$$\overline{\mathbf{w}}_i = \sum_{j=1}^{n} \overline{b}_{ij}, (i = 1, 2, \cdots, n).$$

$$\mathbf{w}_i = \frac{\overline{\mathbf{w}}_i}{\sum_{j=1}^{n} \overline{\mathbf{w}}_j}, (i = 1, 2, \cdots, n).$$

Calculate eigenvector

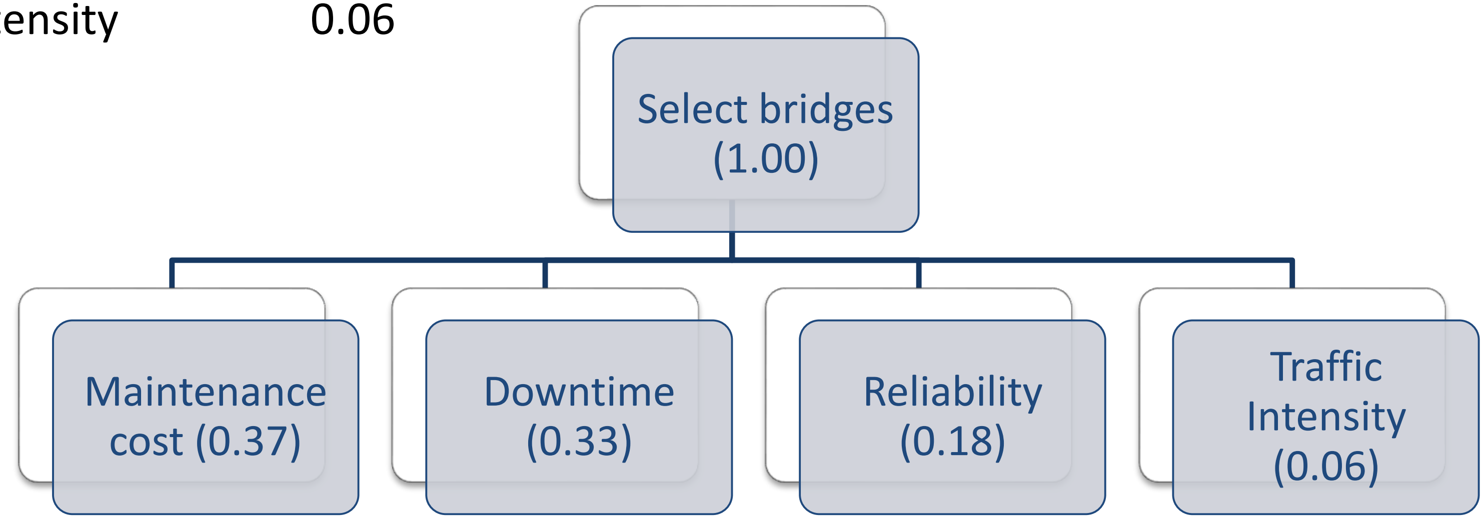
Normalized matrix	*Maintenance cost*	*Downtime*	*Reliability level*	*Traffic Intensity*
Maintenance cost	0.39	0.38	0.42	0.31
Downtime	0.39	0.38	0.42	0.19
Reliability level	0.13	0.13	0.14	0.44
Traffic Intensity	0.08	0.13	0.02	0.06

Scores
0.37
0.33
0.18
0.06

3. APPLICATION EXAMPLE – AHP

- Ranking of Criteria

- Maintenance cost 0.37
- Downtime 0.33
- Reliability 0.18
- Traffic Intensity 0.06



3. APPLICATION EXAMPLE – AHP

- Ranking of Alternative

- For qualitative criteria, the fundamental scale of pairwise comparison is used
- For quantitative criteria, the normalized procedure can be used for simplicity

In our example, we have only quantitative values, which are normalized as follows

	Maintenance cost	Normalized
B1	500	**0.17**
B2	1000	**0.33**
B3	200	**0.07**
B4	800	**0.27**
B5	500	**0.17**
SUM	3000	1

3. APPLICATION EXAMPLE – AHP

- Ranking of Alternative

Comparison Matrix

	MC	DT	RL	TI
B1	500	30	3	9000
B2	1000	70	4	10000
B3	200	60	4	13000
B4	800	180	5	15000
B5	500	40	3	5000
SUM	3000	380	19	52000

Normalized Priority Matrix

MC	DT	RL	TI
0.17	0.08	0.16	0.17
0.33	0.18	0.21	0.19
0.07	0.16	0.21	0.25
0.27	0.47	0.26	0.29
0.17	0.11	0.16	0.10
1.00	1.00	1.00	1.00

ANALYTICAL HIERARCHY PROCESS

MATRIX NORMALIZATION

	Maintenance cost	Downtime	Reliability level	Traffic Intensity
A: B101	0,16	0,17	0,08	0,17
B: B109	0,21	0,33	0,18	0,19
C: B207	0,21	0,07	0,16	0,25
D: B307	0,26	0,27	0,47	0,29
E: B150	0,16	0,17	0,11	0,10

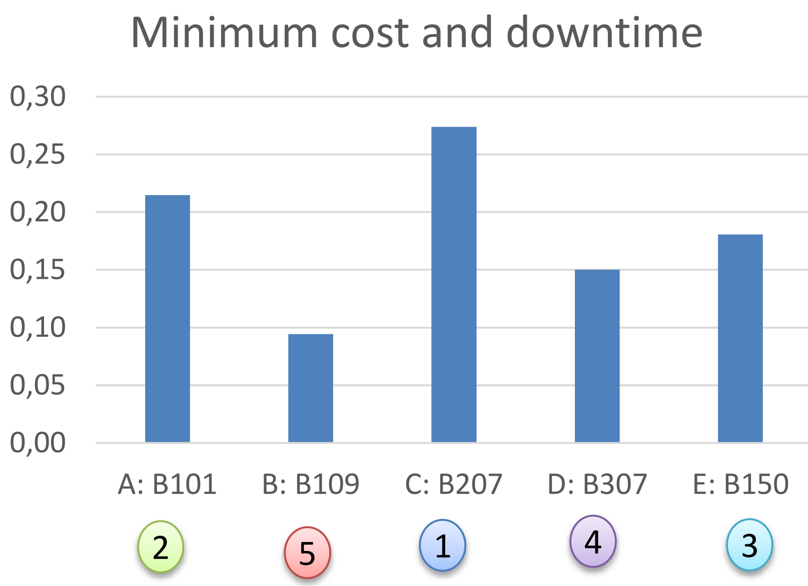
Scores
0.37
0.33
0.18
0.06

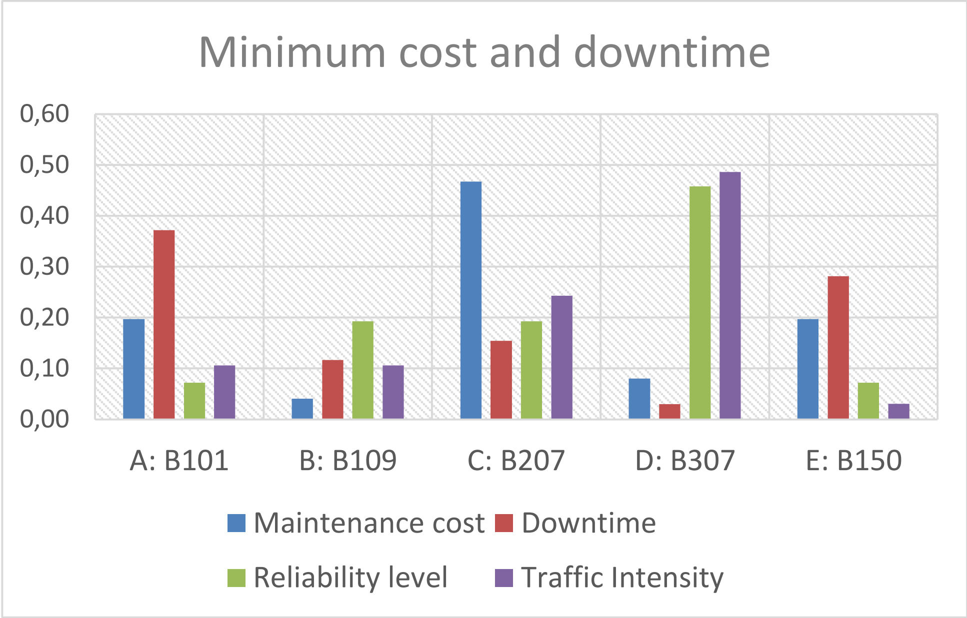
Overall score
0.21
0.09
0.27
0.15
0.18

Matrix Multiplication

BRIDGES RANKING RESULTS

Results





Conclusion

- The framework of multi-criteria decision making (MCDM) provides a guidance on how to implement multiple performance goals
- The methods of MCDM incorporate decision makers preferences on multiple (conflicting) performance indicators
- The pairwise comparison of AHP grows exponentially when presented with large number of performance indicators
- For the maintenance optimization over the network, a link between the performance indicators at object level and the goal on network level needs to be established.
- The quantification of performance goals, other than technical goals, is a challenge.

3. USE OF AHP

- How can you use AHP for to select best design solution?
- How do you define best solution? By defining criteria..!
- How will you define the criteria?
- Who will define which criteria is most important as compared to others?

4. WORKSHOP

i.stipanovic@utwente.nl

COST ACTION TU1406: QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Training School on Bridge Quality Control , December 18 – 22, 2017
Zell am See, Austria

Quality Control Framework – Implementation and further research

Prof. Dr. Rade Hajdin - University of Belgrade, Serbia

Грађевински факултет
Универзитет у Београду
ESF provides the COST Office through a European Commission contract
COST is supported by the EU Framework Programme
COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

What is Quality?

- Wiki: Philosophy and common sense tend to see qualities as related either to subjective feelings or to objective facts. The qualities of something depends on the criteria being applied to and, from a neutral point of view, do not determine its value (the philosophical value as well as economic value). Subjectively, something might be good because it is useful, because it is beautiful, or simply because it exists. Determining or finding qualities therefore involves understanding what is useful, what is beautiful and what exists. Commonly, quality can mean degree of excellence, as in, "a quality product" or "work of average quality".
- Wiki: In business, engineering and manufacturing, quality has a pragmatic interpretation as the non-inferiority or superiority of something; it's also defined as fitness for purpose. Consumers may focus on the specification quality of a product/service, or how it compares to competitors in the marketplace. Producers might measure the conformance quality, or degree to which the product/service was produced correctly.

What is Quality regarding bridges?

- In ISO 9000: Degree to which a set of inherent characteristics of a product or service fulfills requirements.
- Bridge is definitely a product that has to fulfill certain requirements
- The requirements are defined in “codes of practice”. Typical requirements are defined to safety and serviceability.
- The bridge is fit for purpose if safety and serviceability requirements are met.
- Safety and serviceability are inherent characteristics (following the above definition) of a bridge
- In realm of bridge management the term “performance goals” are often use instead of “requirements”.
- The evaluation if safety and serviceability goals are met can be performed in any time instance.
- These goals are normally met at the time of acceptance.

Quality of existing bridges

- Wiki: Support personnel may measure quality in the degree that a product is **reliable**, **maintainable**, or **sustainable**. A quality item (an item that has quality) has the ability to perform satisfactorily in service and is suitable for its intended purpose.
- Fulfillment of the **safety and serviceability goals over time**.
- Assuming that the safety and serviceability goals are met at acceptance (-> handover to the owner or operator) what wouldn't they be met in some time in future.

Ravages of time

- Slow, observable and therefore interceptable processes (corrosion, frost, alkali aggregate(?), climate, traffic)
- Slow unobservable and therefore non-interceptable processes (corrosion of posttensioning steel, alkali aggregate)
- Sudden events (flooding, earthquake, fire)
- These processes can endanger the fulfillment of these requirements.

Quality control

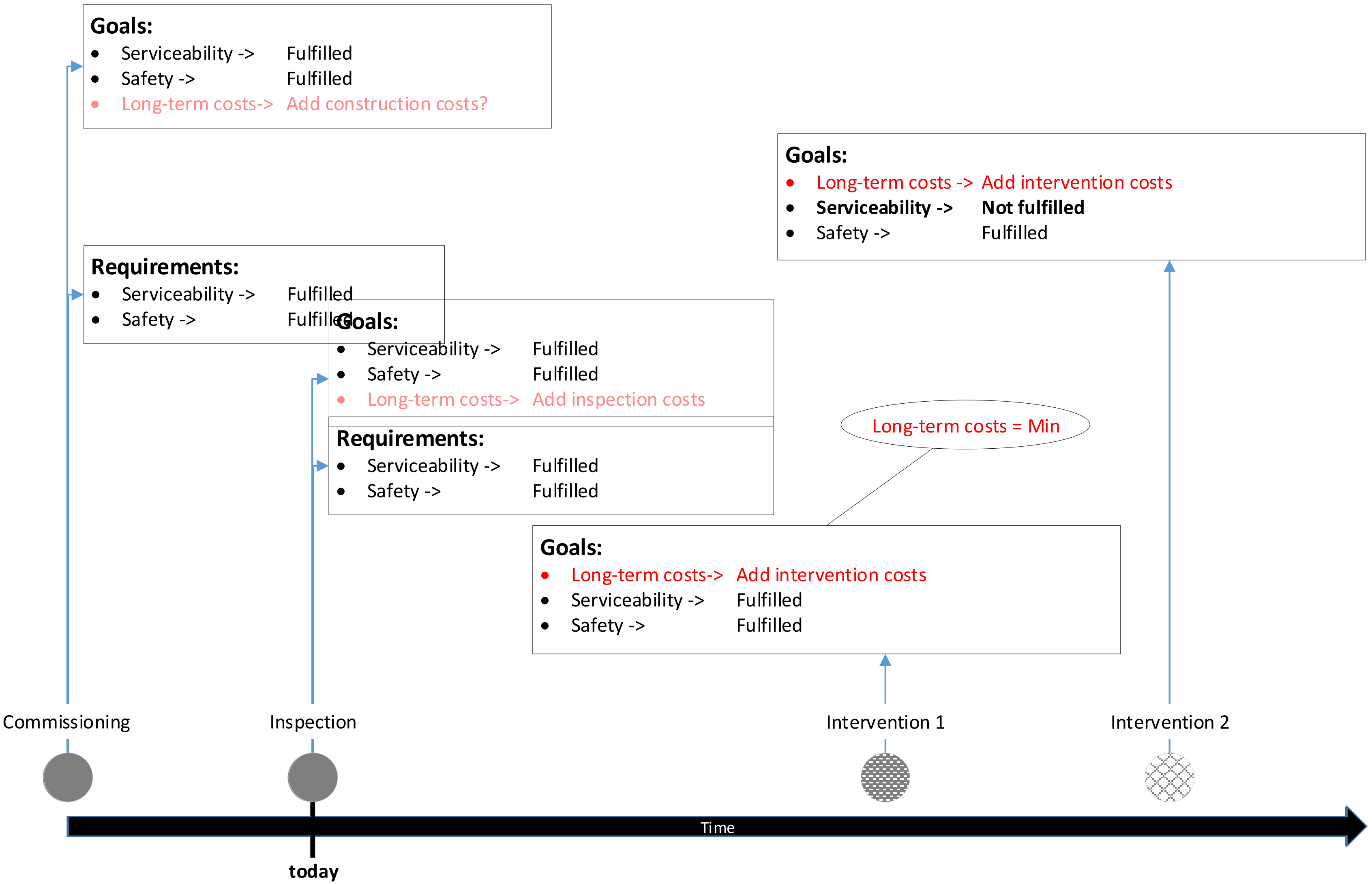
- There are quite a few definitions reflecting the ambiguous meaning of the word “control” as
  - Verify, check or inspect or
  - Command, direct or rule.
- In business the quality control is defined as:

  “The process of inspecting products to ensure that they meet the required standards” or

  “The activity of checking goods as they are produced to make sure the final products are good”
- The first definition applies to the topic of this COST Action.
  - Check if product meet the standards, requirement or goals.
  - Car check, health check, etc.
- However, this COST Action goes beyond mere checking and verifying and provide guidance to “command and direct” actions to ensure long-term quality.

Quality control for bridges

- **Static (snap shot) interpretation**: Inspect and investigate a bridge and determine whether the serviceability and safety goals are met.
  - Basis for the decision making on actions
- **Dynamic interpretation**: Static interpretation + plan and execute actions to **ensure long term fulfillment of safety and serviceability goals. -> Bridge Management**
- There are different ways to ensure that goals are met on the long-term:
  - Preventive action
  - Corrective actions
  - Operational actions
- Which one to take? What is the criterion for decision making?
  - Economics (Cost); Which costs? One time costs or long term costs?
- There is therefore another goal of Quality Control -> **Economics!!!**


Goals:
Serviceability -> Fulfilled
Safety -> Fulfilled
Long-term costs-> Add construction costs?
Requirements:
Serviceability -> Fulfilled
Safety -> Fulfilled
Goals:
Serviceability -> Fulfilled
Safety -> Fulfilled
Long-term costs-> Add inspection costs
Requirements:
Serviceability -> Fulfilled
Safety -> Fulfilled
Goals:
Long-term costs -> Add intervention costs
Serviceability -> Not fulfilled
Safety -> Fulfilled
Long-term costs = Min
Goals:
Long-term costs-> Add intervention costs
Serviceability -> Fulfilled
Safety -> Fulfilled
Commissioning
Inspection
Intervention 1
Intervention 2
Time
today

Performance goals

- The goal of road users is simple: to get from A to B safely in expected time.
- The road connection has to be reliable.
- Operational reliability -> not directly considered
- Structural **reliability!**
  - EN 1990:

    "Ability of a structure or a structural member to fulfil the specified requirements, including the design working life, for which it has been designed. Reliability is usually expressed in probabilistic terms
    NOTE: Reliability covers **safety, serviceability** and durability of a structure."

    Durability: The structure shall be **designed** such that deterioration over its design working life does not impair the **performance** of the structure below that intended, having due regard to its environment and the anticipated level of maintenance.
  - EN 1992:

    A design using the partial factors given in this Eurocode (see 2.4) and the partial factors given in the EN 1990 annexes is considered to lead to a structure associated with reliability Class RC2 -> $\beta_{safety} = 3.8$, $\beta_{serviceability}=1.5$ for 50years

Further performance goals

- **Reliability** include the probability of structural failure (safety) or operational failure (serviceability).
- **Availability** is the proportion of time a system is in a functioning condition.
  - WG2 (somewhat cryptical): Meet object specific requirements with regard to the fulfilment of object function.
  - For our purposes: Additional travel time due to imposed traffic regime on bridge.
  - ***Not reliability-related disruption of bridge users***
- **Economic efficiency** -> minimizing long term cost
- **Safety** (not structural safety) minimize (eliminate) the **harm people** during the service life of a bridge. Loss of life and limb due to structural failure is normally not included!
- **Environmental friendliness** -> minimize the **harm to environment** during the service life of a bridge.

RAMSSH€EP

- **Reliability**
- **Availability**
- **Maintainability** is the ease with which a product can be maintained in order to correct defects or their cause, repair or replace faulty components without having to replace still working parts and prevent unexpected working condition -> *design aspect and is covered with economic efficiency*
- **Safety**
- **Security** is degree of protection against vandalism -> *similar to maintainability is design aspect included in economic efficiency*
- **Health** is absence of non-failure causes of illnesses (e.g. asbestos) -> *regulated*
- **€conomics**
- **Environment** -> regulated
- **Politics** include elimination of causes for public outcry, image protection etc. -> downstream performance goal; Fulfilled if RAS€E goals are met.

Conclusion

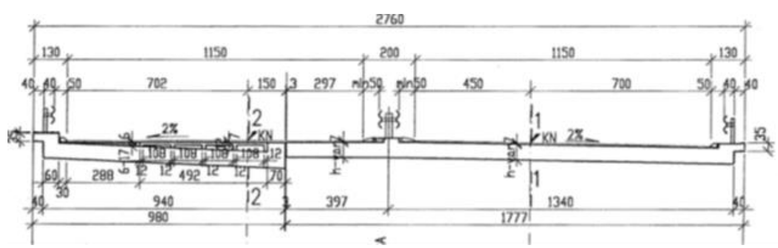
- Within the QC Framework
  - Reliability
  - Availability
  - Safety
  - €conomics

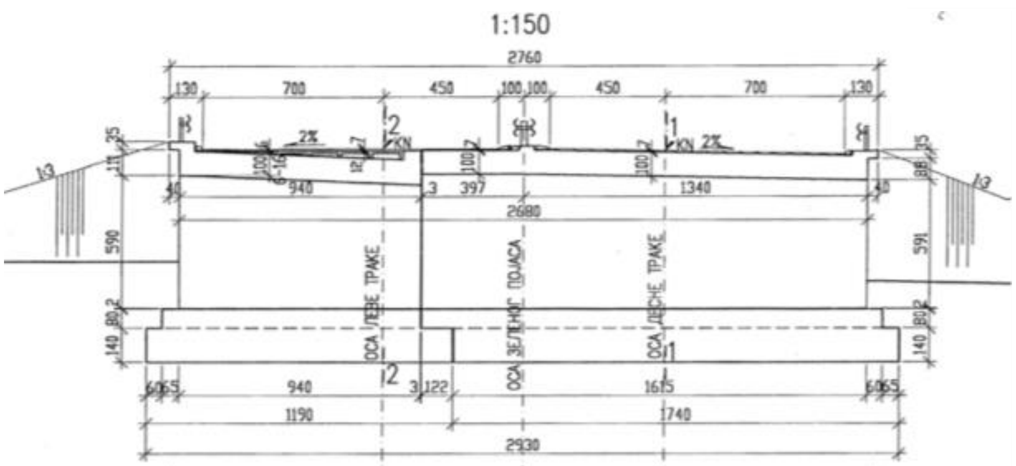
  will be evaluated for different maintenance scenarios
- Environment is mostly regulated, but in some cases can be also included.
- **Snapshot or static quality** control includes
  - Reliability (structural safety and serviceability) and
  - Safety (not structural safety) regarding loss of life and limb
- **Dynamic quality control** (bridge management) include
  - Feasible maintenance scenarios that define costs and availability over certain time frame
  - Reliability and Safety forecasts

Quality Control - Process

- Preforms snapshot quality control
  1. Preparatory work
  2. Inspection on site
  3. Lab test
  4. Assessment of reliability
  5. Assessment of safety (life and limb)
- Perform dynamic quality control (as far as possible)
  6. Assessment of a remaining service life
  7. Maintenance scenario
  8. Decision making

1. Preparatory work – inventory information





RC Frame

ADT 10’000

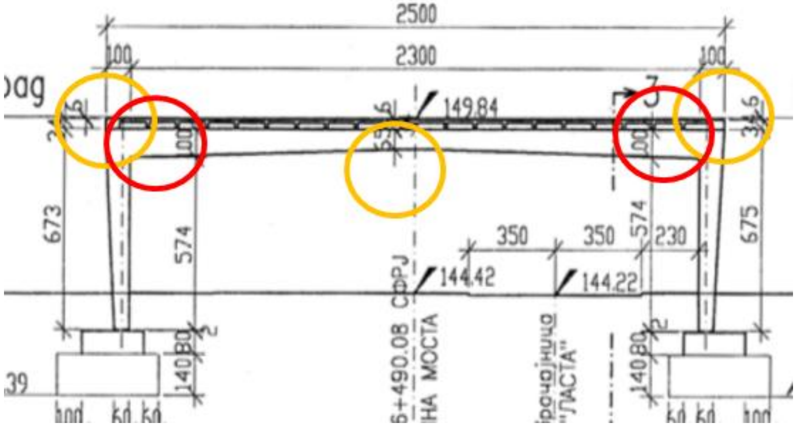
Construction year 1963

Widened in 1977

No natural hazards

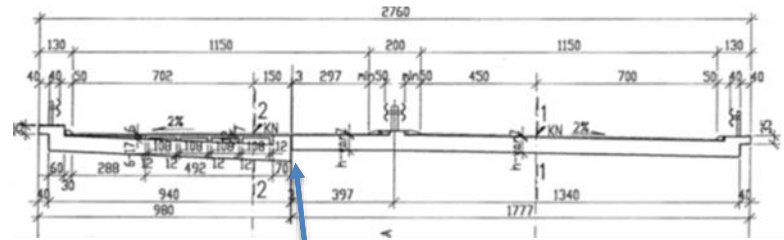
1. Preparatory work – other information

- No particular weaknesses of original design
- The obvious weakness is longitudinal joint connecting the old and the new parts of bridge
- No particular material weaknesses are known – steel bars didn't have any ductility problems
- The traffic load in code of practice did increase since 1963, but the bridge was recalculated in 1977.
- Prior reliability index (safety) is 3.8



HMS-high suging moment zone	orange circle	ductile
HMH - high hoging moment zone		
HSS - high shear zone	red circle	britle

2. Inspection on site – damages



2. Inspection on site – other hazards

- There is a road beneath the bridge
- It is rural road with low traffic volume
- There is however a danger of falling concrete on vehicles or persons
- Railings can’t performed as designed

4. Assessment of resistance reduction

- There are some indication of diminished resistance:
  - Spalling at the width of (in average) 1.5 meters over the whole span.
  - Uncertain bonding
  - Significant corrosion ~10% section loss (old structure)
  - Corrosion to ~5% section loss in vulnerable zone (new structure)
  - Based on the symptoms there is probably corrosion over the piers, which is a vulnerable zone belonging to same failure mechanism
  - Redistribution in perpendicular sense has positive effects.
  - Uncertain cause and development of the diagonal crack.
- Based on experience and elementary statics the resistance reduction has been assessed to 10% (probably conservative)
- There is no urgent necessity to perform in depth investigation.
- Clearly, the assessment is rather rough and based on inspector's experience but so is condition rating.

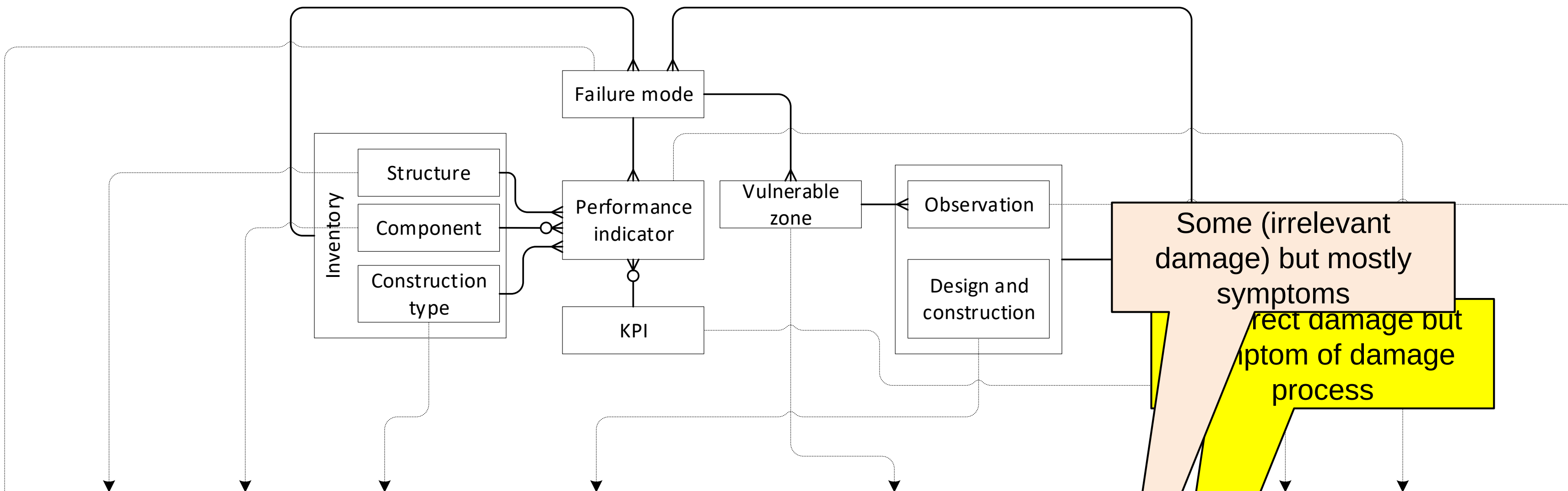
4. Qualitative assessment of reliability

4. Some comments

- The value of virgin reliability due to current loading is critical!
- It is advisable for old bridges to estimate the real loading by means of axle load measurements. The real traffic loading can be sometimes higher but sometimes significantly lower (less aggressive).
- In this particular case the traffic loading increased from 1977.
- The assessment od reliability is similar to the condition assessment with two crucial differences:
  - It takes into account virgin reliability,
  - focuses on failure modes and
  - related vulnerable zones.
- Most inspection practices focus implicitly on the latter two, but not explicitly.
- Hint: Thinking in failure mechanisms helps since it allows one to estimate the reduction of dissipation work due to damages.
- The example bridge will probably not fail catastrophically but rather experience a warping deformation.

5. Assessment of safety (life and limb)

- The loss and life and limb due to structural failure is **not included**.
- Falling concrete cover can endanger persons in and outside the vehicles.
- It is very unlikely that large chunks are going to fall down.
- The chunks that are found on the street were maximum 10x10x2 cm.
- The traffic volume is very low both pedestrian and vehicles.
- The capacity for spalling has also diminishes as water cannot reach reinforced bars that are still covered with concrete.
- The falling height is relatively small.
- The damaged railings jeopardize traffic safety
- Taking the observations into account and the above reasoning the danger for life and limb is relatively small i.e. 2.
- The performance indicator of 1 is no danger (injury return period > 100 years) and performance indicator of 5 characterizes immediate danger (injury return period < 10 years)



Frame bridge	Deck (old)	Reinforced concrete	1963	Bending failure mode	HMS	Corroded reinforcement	Reliability (Structure safety)	3	3
	Deck (new)	Reinforced concrete	1977			Corroded reinforcement			
	Deck (old)	Reinforced concrete	1963			Spalling			
	Deck (new)	Reinforced concrete	1977			Spalling			
	Deck (new)	Reinforced concrete	1977		HMH	Corroded reinforcement			
	Deck (old)	Reinforced concrete	1963			Corroded reinforcement			
	Deck (new)	Reinforced concrete	1977			Spalling			
	Deck (old)	Reinforced concrete	1963			Spalling			
	Deck (new)	Reinforced concrete	1977			Efflorecences			
	Deck (old)	Reinforced concrete	1963			Efflorecences			
	Deck (old)	Reinforced concrete	1963	Shear failure mode	HSS	Crack		2	
	Deck (old)	Reinforced concrete	1963	Falling chunks		Spalling	Safety (Life and limb)	2	2
	Deck (new)	Reinforced concrete	1977			Spalling		2	
	Railings	Steel	1977	Falling of the bridge		Broken		2	

2. Catalog of observations

- WG1 collected observations from almost all European countries.
- The observations were clustered in different categories.
- WG 3 reduced the list by focusing on “real” observation and not interpretation.

changes in dynamic behavior
approach slab settlement
porous concrete
insufficient concrete cover
aggregate segregation
cladding damages
cladding deformations
deformation
cracks
crushing
rupture
delamination
scaling
spalling
coupling joint deficiency
wire break

presstresing cable failure
reinforcement bar failure
stirrup rupture
efflorescence/crypto-florescence
holes
wet spots
gel exudation
hydroxide calcium exudation
chloride content
shear connection failure
anchorage failure
debonding
protection duct damage (of prestreesed cable)
grouting deficiency
damaged adhesive
tensioning force deficiency

4. Uncertainties and lack of information

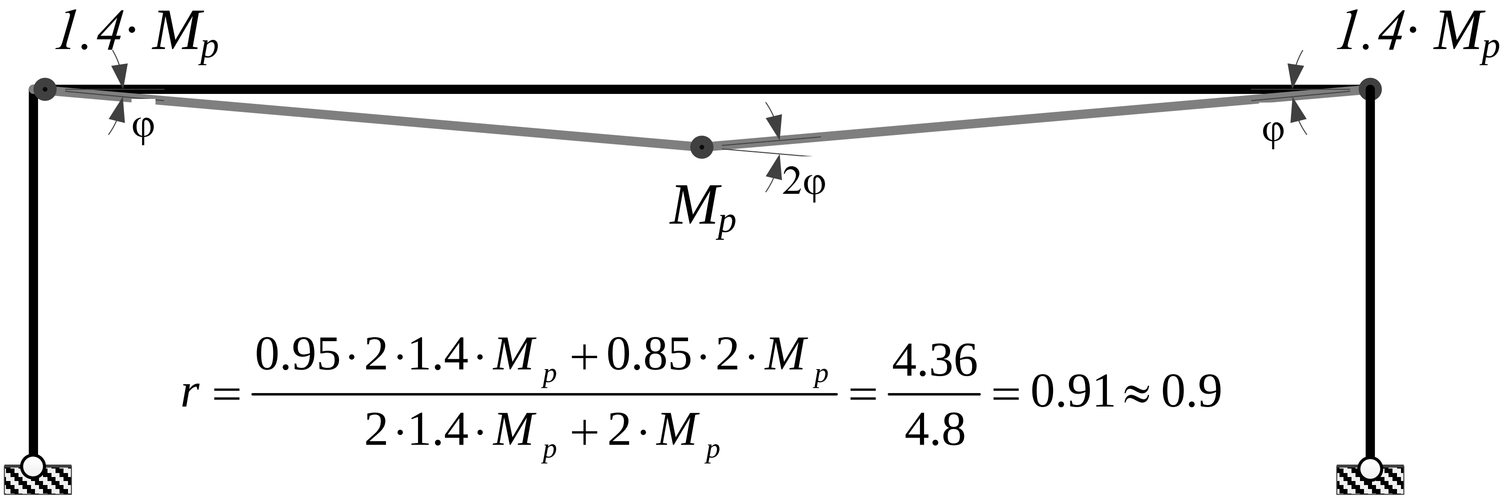
- The same observation (actually the observed “thing”) can have different causes.
- A crack > 0.2 mm indicated that the reinforcement yielded
- This can be due to a one-time overloading or error in design.
- The inspector can decide which of this possibility is more likely and attach his/her degree of belief.
- If the crack is closed due to bleaching it is unlikely that the element is under designed.
- If however the crack width changed between the inspection it can well be that the resistance is not sufficient.
- Similar reasoning can be applied to other observations e.g. fatigue cracks

4. Reliability against which failures?

- Failure – Ultimate Limit State
  - Rigid body movement
  - Internal mechanism (plastic, brittle)
  - Fatigue (brittle)
- Failure – Serviceability Limit State
  - Functionality
  - Comfort
  - Visual appearance
- Probability that stresses in a cross-section exceed certain value
- Probability of development of a mechanism
- Probability of undesired appearance -> RAMSSH€E**P(olitics)**
- Each country has to establish guidelines according to their value system.

4. Assessment of reliability related to ULS

- Kinematic theorem of the theory of plasticity can be quite useful.
- Upper bound -> not on the safe side.
- Failure mechanism can be assumed -> relatively simple for vertical loads
- Resistance is essentially internal dissipation rate that decrease with each damage.



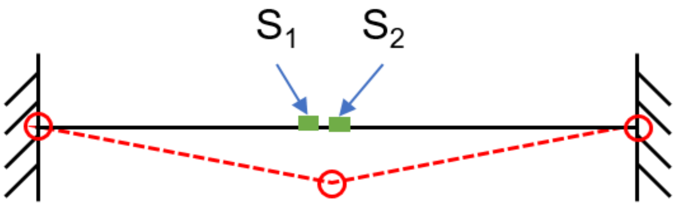
$$r = \frac{0.95 \cdot 2 \cdot 1.4 \cdot M_p + 0.85 \cdot 2 \cdot M_p}{2 \cdot 1.4 \cdot M_p + 2 \cdot M_p} = \frac{4.36}{4.8} = 0.91 \approx 0.9$$

Failure mechanisms

Reliabilty assessment

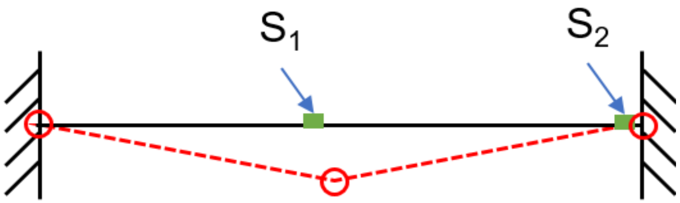
- Damages at the same location, either of them trigger a mechanism

  → The worst one counts; the other is not active



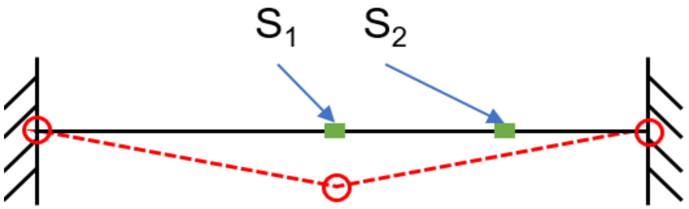
- Damages at the different locations, both contribute to the same mechanism

  → Cumulative resistance reduction

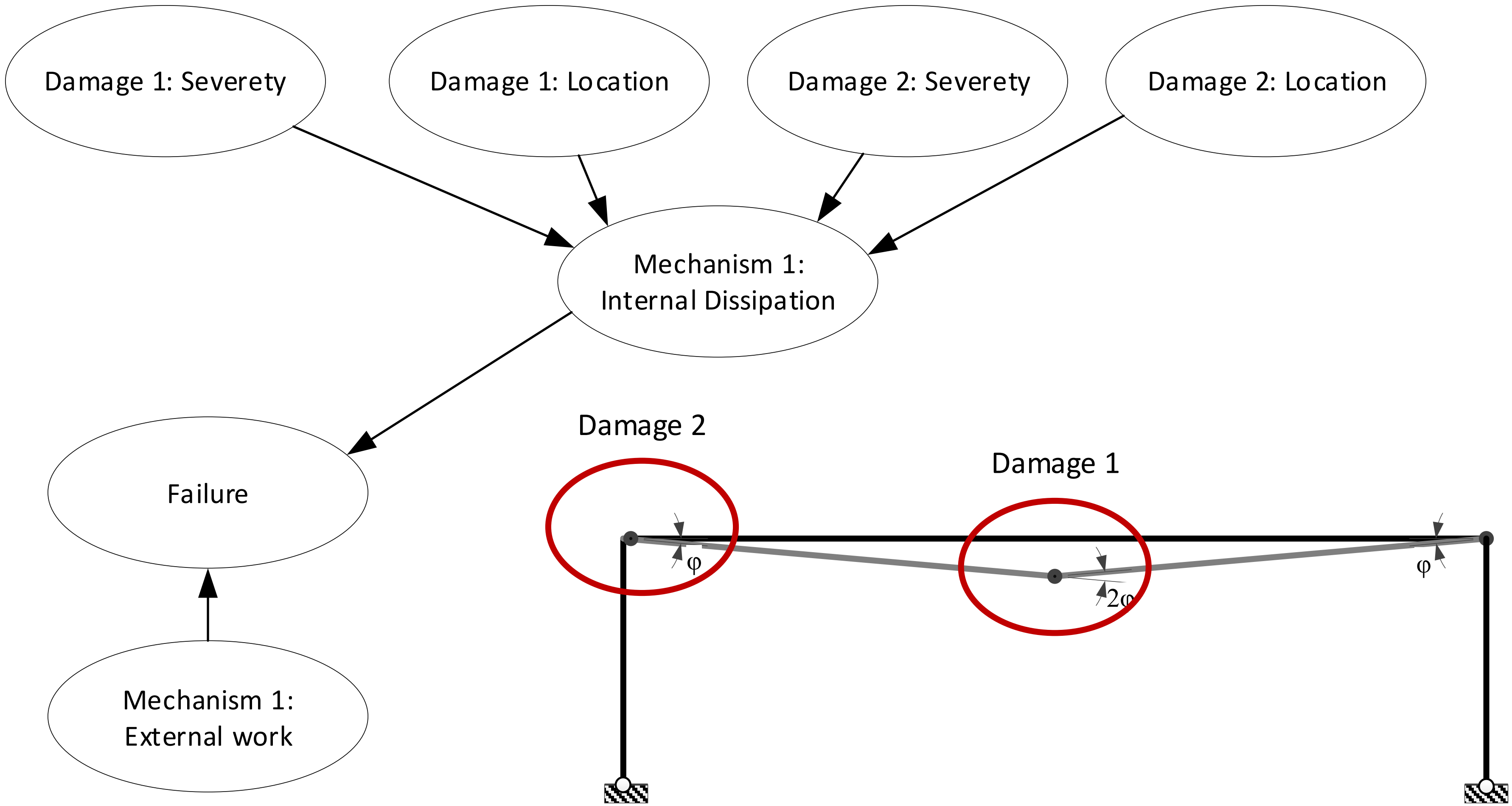


- Damages at the different locations, triggering different mechanims

  → Corelated serial system



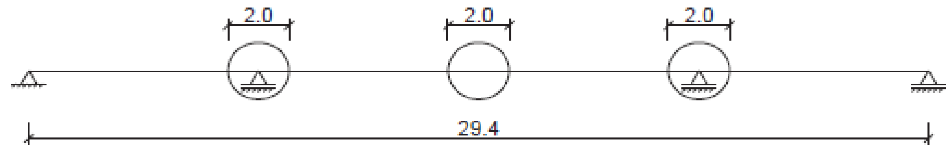
Reliability assessment - example



4. STSM – Example

Possible plastic mechanism:

Hot areas:



Node definitions:

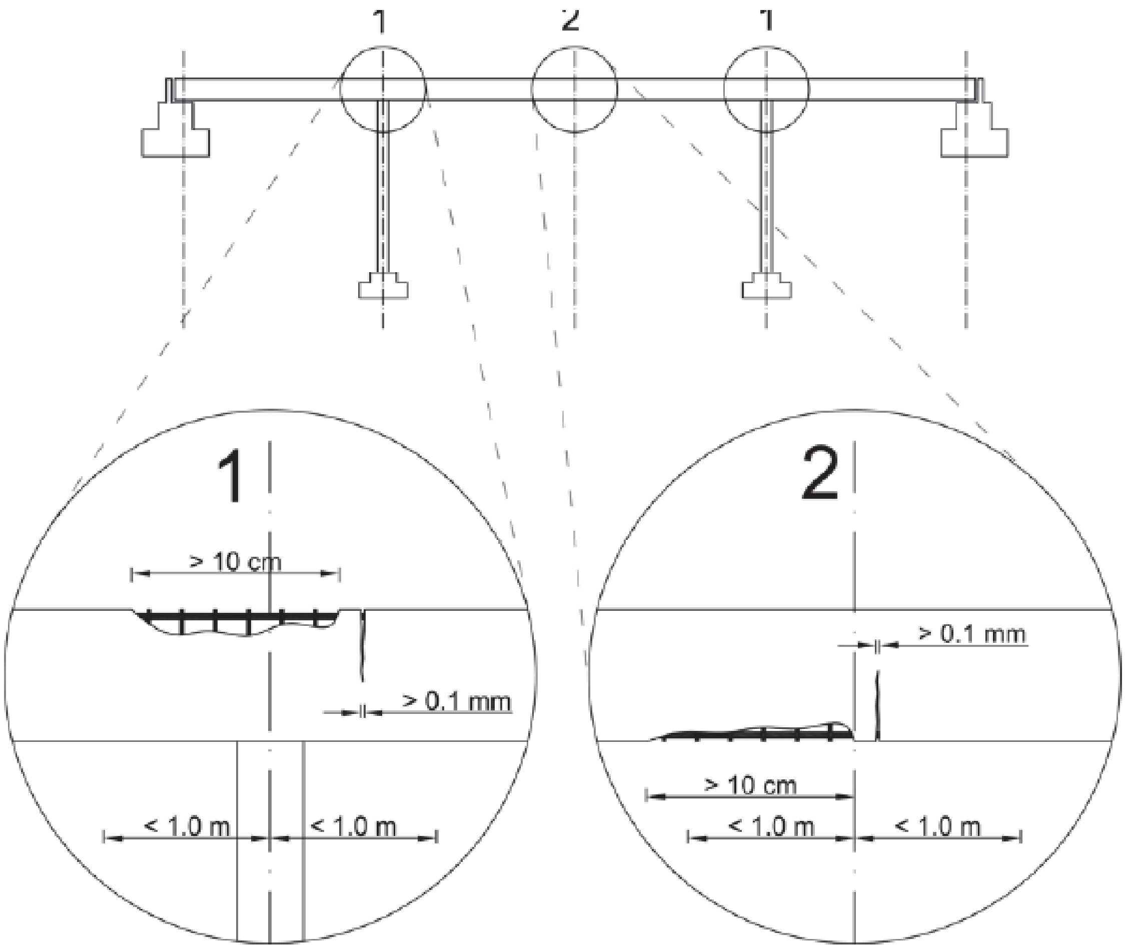
Node: Crack severity	
Stiffness reduction	Likelihood
5%	0.6
10%	0.2
15%	0.1
20%	0.1

Node: Crack location	
Location	Likelihood
Outside hot area	= (29.4 - 2 - 2*2)/29.4 = 0.7959
Plastic hinge 1	= (2 + 2) / 29.4 = 0.1361
Plastic hinge 2	= 2 / 29.4 = 0.0680

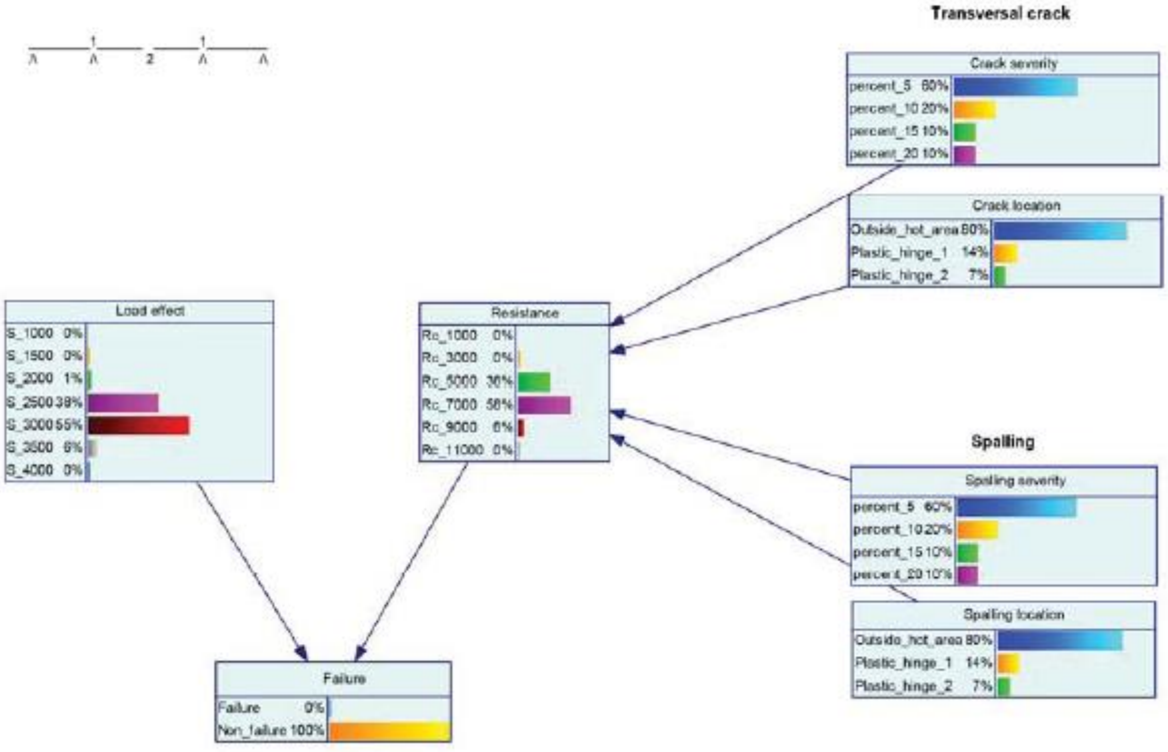
Node: Spalling severity	
Section loss	Likelihood
5%	0.6
10%	0.2
15%	0.1
20%	0.1

Node: Spalling location	
Location	Likelihood
Outside hot area	0.7959
Plastic hinge 1	0.1361
Plastic hinge 2	0.0680

4. STSM – Inspection results



4. STAM - Bayesian networks



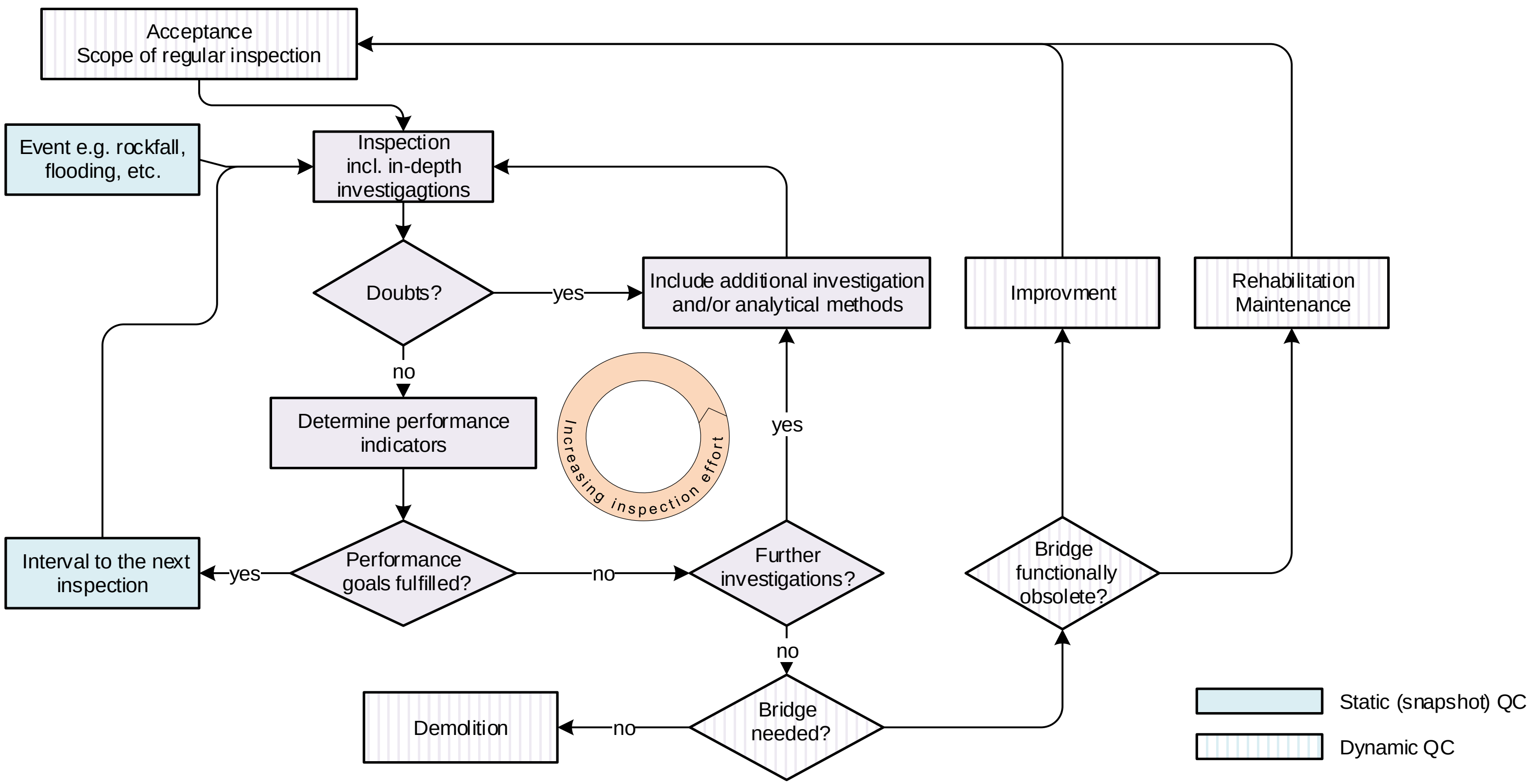
6. Return period and remaining service life

- The reliability index β for structural safety expresses the probability of failure due to combination of excessive load and uncertainty related to resistance of a bridge for a **given design life**.
- The design life is actually **failure return period**!
- It does not include **damages** that may or may not occur during the service life nor the **change in traffic loads**.
- The damages can reduce the resistance of a bridge resulting the in lower reliability index for safety and therefore also shorten failure return period.
- This should not be confused with the remaining service life due to deterioration.
- The failure return period of a heavily deteriorated bridge can be 10 years, which can be regarded as a threshold value to close a bridge. It is not connected with the time period in which this deteriorated state has been reached.

Assessment of the remaining service life

- The identification of active damage process and its drivers is essential for dynamic quality control.
- The further development of observed damages or behavior of the bridge is governed by damage processes.
- The development of these processes over time can be modelled based on physical processes and/or statistical data.
- In Bridge Management Systems different deterministic and probabilistic models are implemented, mostly for condition state.
- Common model for condition development is Markov Chains.
- The focus of this school is not on the time models for KPI but rather on principles that govern decision making.
- The remaining service life defined the point in time, at which the reliability of safety reach some threshold.

Stages of investigation

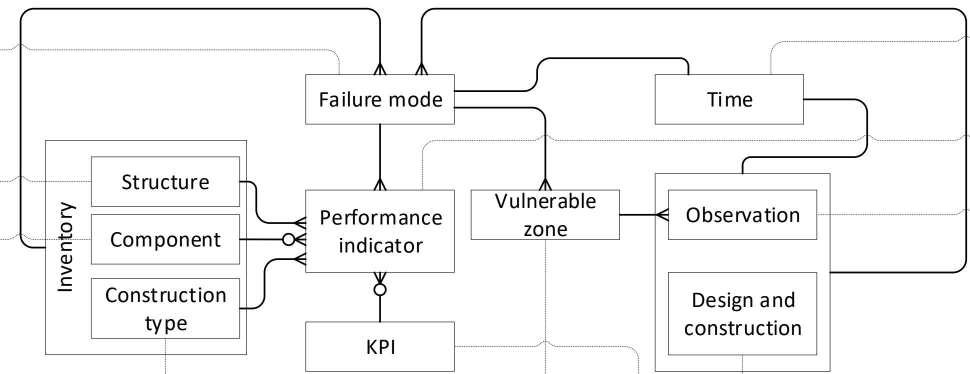


7. Maintenance scenarios

- Availability and Economics are governed by maintenance scenarios.
- The snapshot assessment of availability is of little interest as the bridge is either available or not. The key issue lied with the duration of restricted availability or closure.
- The costs that are required to assess economics are even less reasonable to asses as snapshot indicator. It is the cash flow over time that need to be assess.
- To compare different scenarios it is necessary to define a reference scenarios. This can be any scenario, but most common is to choose a “do nothing” scenario, in which the action are taken only at threshold values of a KPI.
- Mostly the reliability (in the current practice the condition state) is the triggering criterion for the interventions.

7. Maintenance scenarios - Forecasts

- Forecasts of reliability and safety
  - There are many model to forecast condition state of components and whole structures.
  - There are some models to forecast development of existing damages in the future (Germany, Switzerland).
  - These can be used as basis for the model that forecast the reliability level in the future.
  - The alternative is to let the inspector decide on remaining service life (=reaching reliability level 5)
- The speed of deterioration (=diminishing reliability and safety) depends highly on observations of both damages and symptoms
- Symptoms are not damages but observable and measurable artefacts that accompany damage processes.

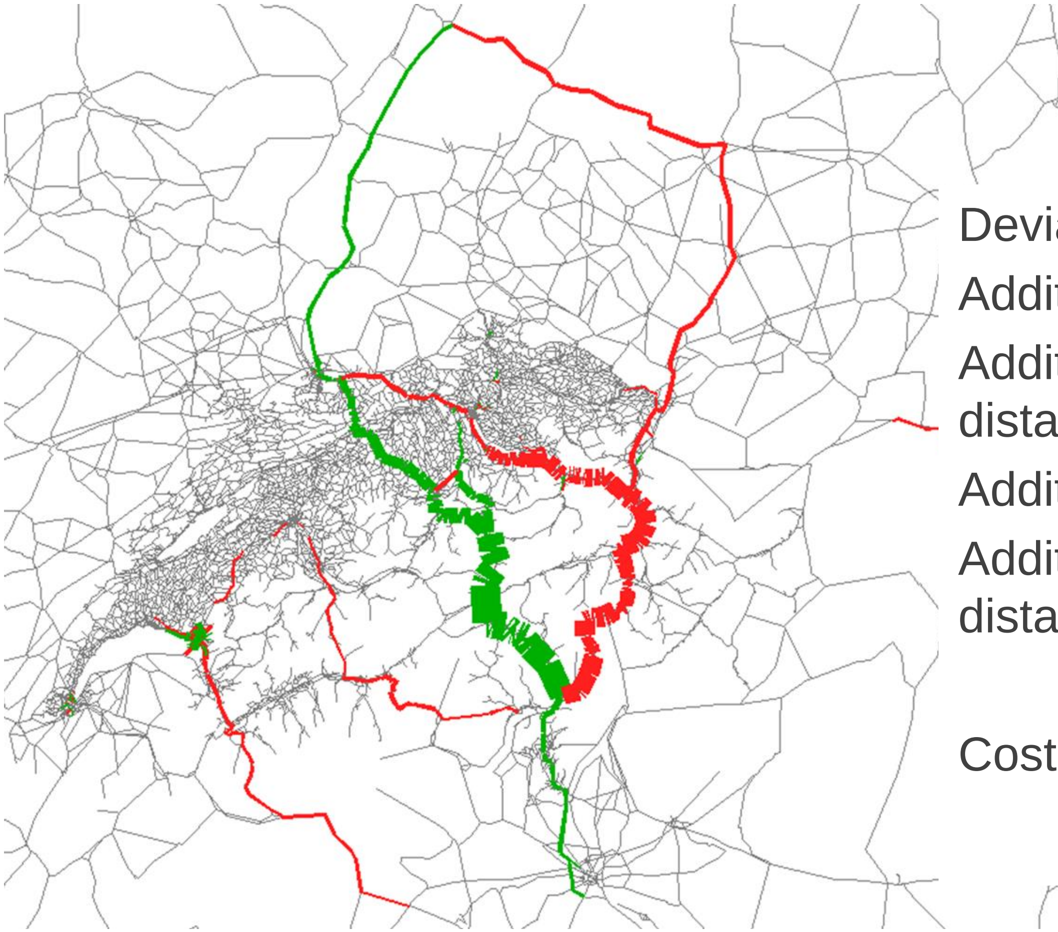


Frame bridge	Deck (old)	Reinforced concrete	1963	Bending failure mode	HMS	Corroded reinforcement	Reliability (Structure safety)	3	**3**	**15 years**
	Deck (new)	Reinforced concrete	1977			Corroded reinforcement				
	Deck (old)	Reinforced concrete	1963			Spalling				
	Deck (new)	Reinforced concrete	1977			Spalling				
	Deck (new)	Reinforced concrete	1977		HMH	Corroded reinforcement				
	Deck (old)	Reinforced concrete	1963			Corroded reinforcement				
	Deck (new)	Reinforced concrete	1977			Spalling				
	Deck (old)	Reinforced concrete	1963			Spalling				
	Deck (new)	Reinforced concrete	1977			Efflorescences				
	Deck (old)	Reinforced concrete	1963			Efflorescences				
	Deck (old)	Reinforced concrete	1963	Shear failure mode	HSS	Crack		2		
	Deck (old)	Reinforced concrete	1963	Falling chunks		Spalling	Safety (Life and limb)		**2**	**40 years**
	Deck (new)	Reinforced concrete	1977			Spalling		2		
	Railings	Steel	1977	Falling of the bridge		Broken		2		

7. Maintenance scenarios - Availability

- Maintenance interventions require certain traffic regime, which may include closure for certain type of vehicles or lane closure or narrower lanes.
- Deteriorated bridge may be also closed for certain type of vehicles, which may be also regarded as traffic regime.
- For a given bridge there are not many possible traffic regimes, so they can denoted by letters or integer. The traffic regime 1 is the one with no restrictions.
- The other traffic regimes can be ranked by the additional travel time they cause for the road users.
- More appropriate would be to monetize these addition travel times based on the type of the vehicles and rank them.
- The complete closure is the worst case.

7. Additional travel time

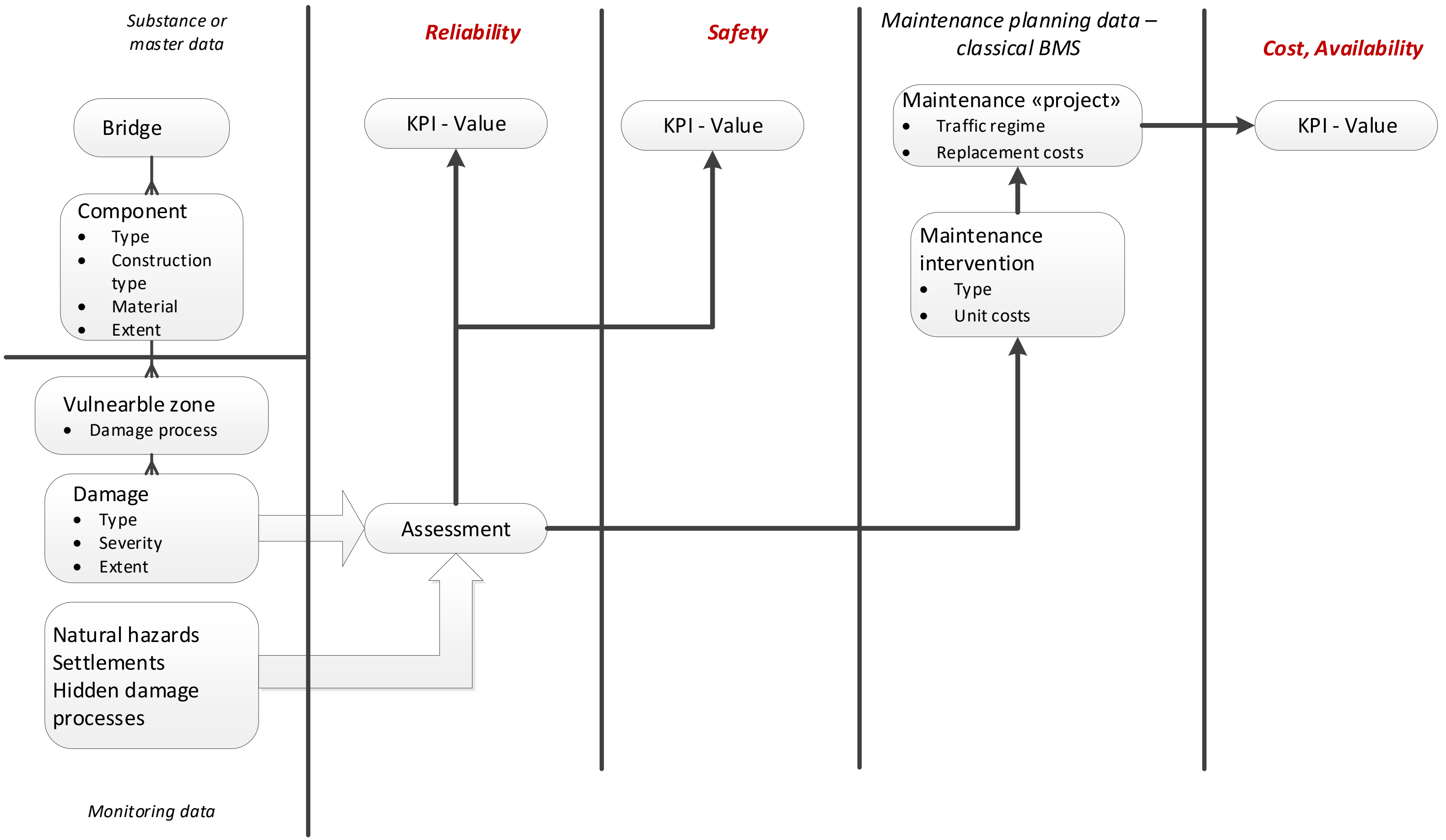


Deviated vehicles:	18’053/d
Additional travel time:	15’673 h/d
Additional travel distance:	1.3 Mio. Km
Additional travel time:	55 min./veh.
Additional travel distance:	57 km/veh.
Costs:	652’000 CHF

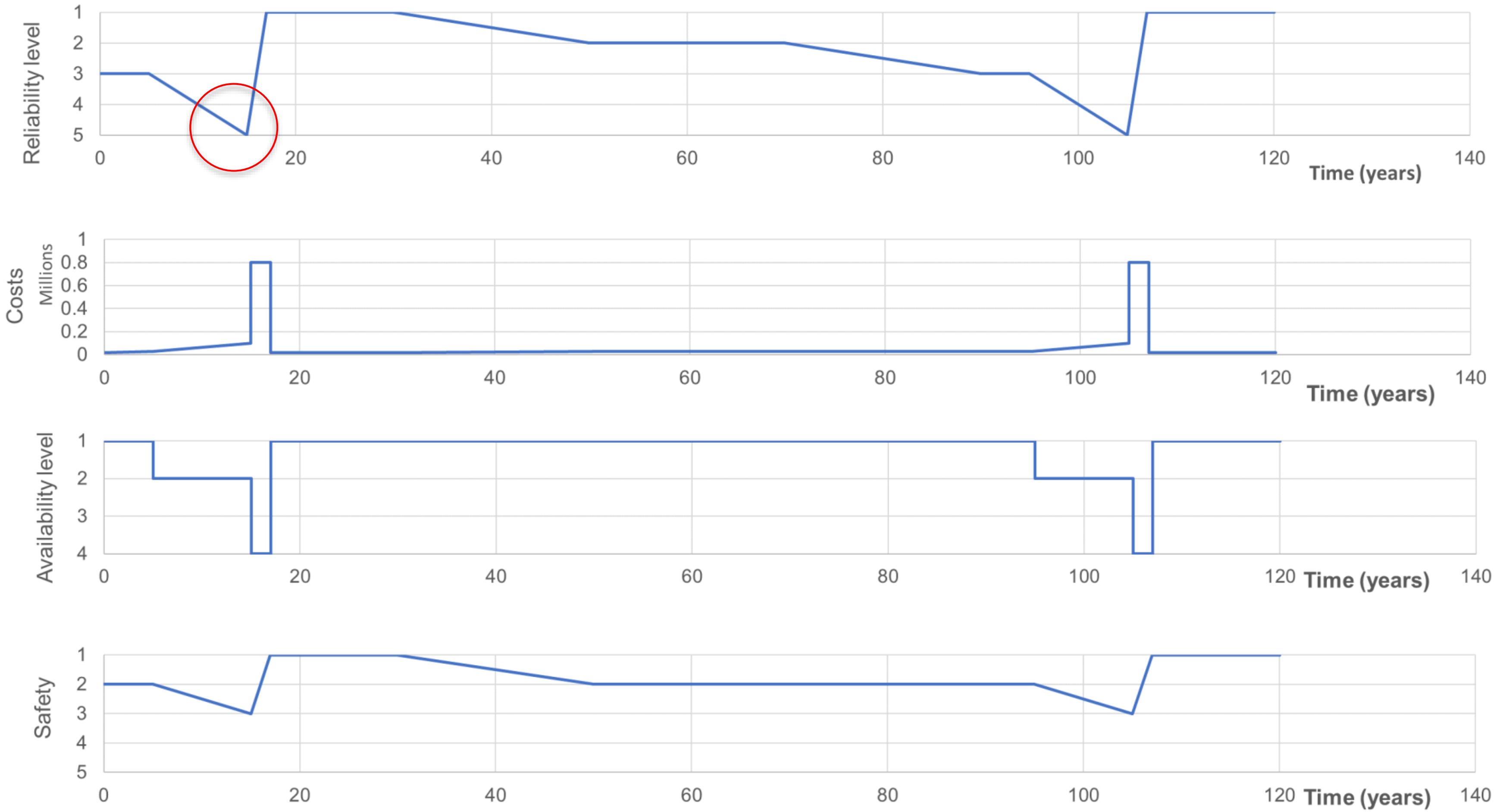
7. Maintenance scenarios - Cost

- “Classical” BMS
- Inspection results:
  - Severity of damage
  - Extent of damage
  - Location (Component)
- Unit costs
- Mobilization costs
- Damage forecast
- Generation of “Maintenance Intevention”
  - Type (Repair, Rehabilitation, Replacement)
  - Estimated costs

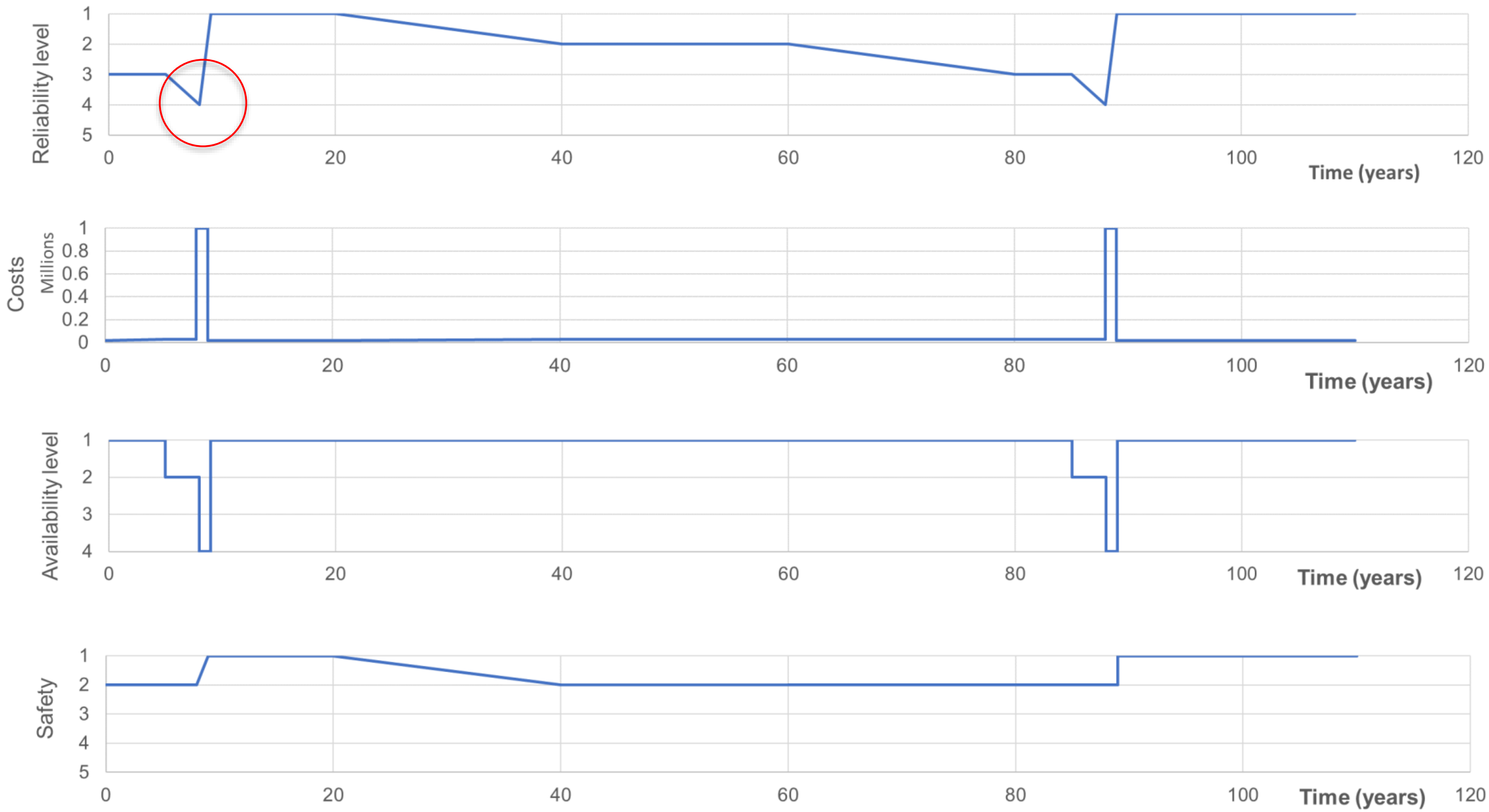
7. Maintenance scenarios - Summary



7. Reference scenario



7. Preventative scenario



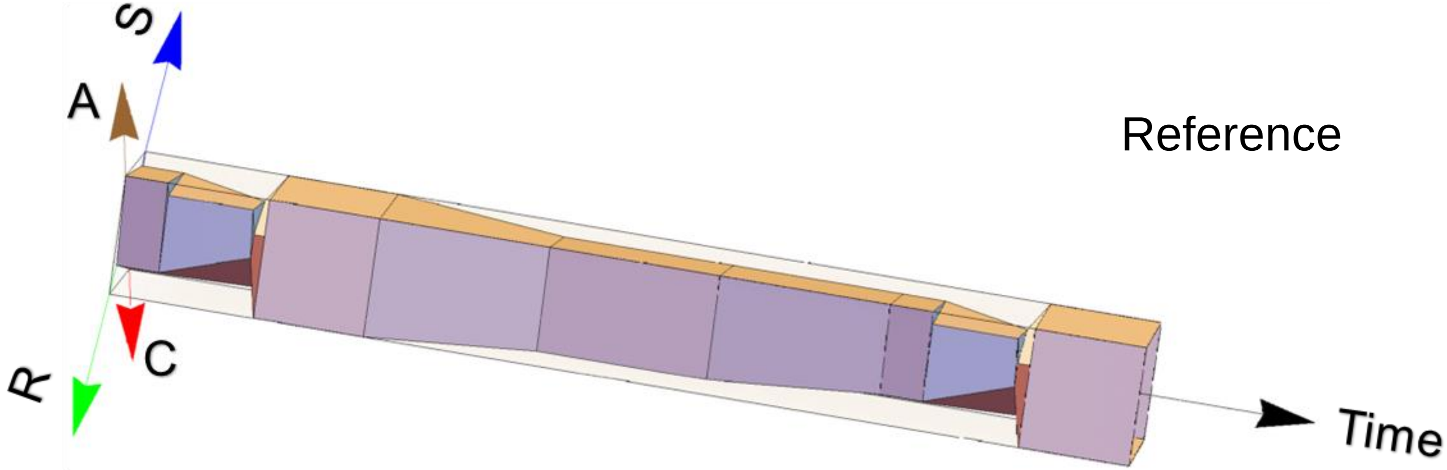
8. Comparing scenarios

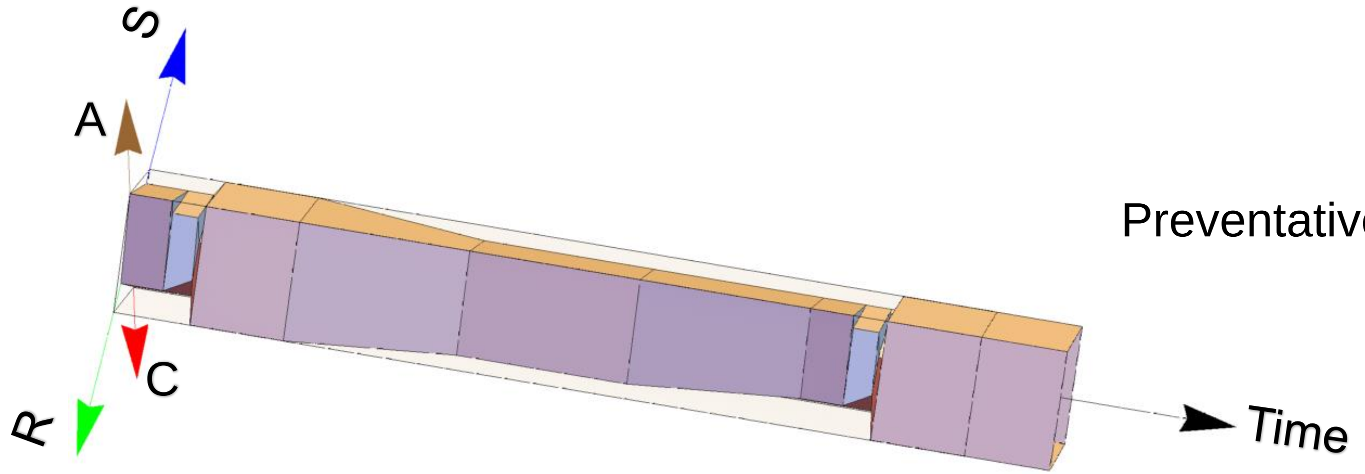
- Monetization
  - Cost are already monetized
  - Availability can be easily monetized
  - Reliability can be only monetized together with the consequences of “failure” -> Risk
  - Safety can be only monetized together with the consequences for “life and limb” -> Risk
- The monetization is widely adopted method in research community.
- In this COST Action this approach was not chosen.
- The scenarios can be only compared if the consequences of the “failure” and for the “life and limb” are equal.

8. Spider Diagram

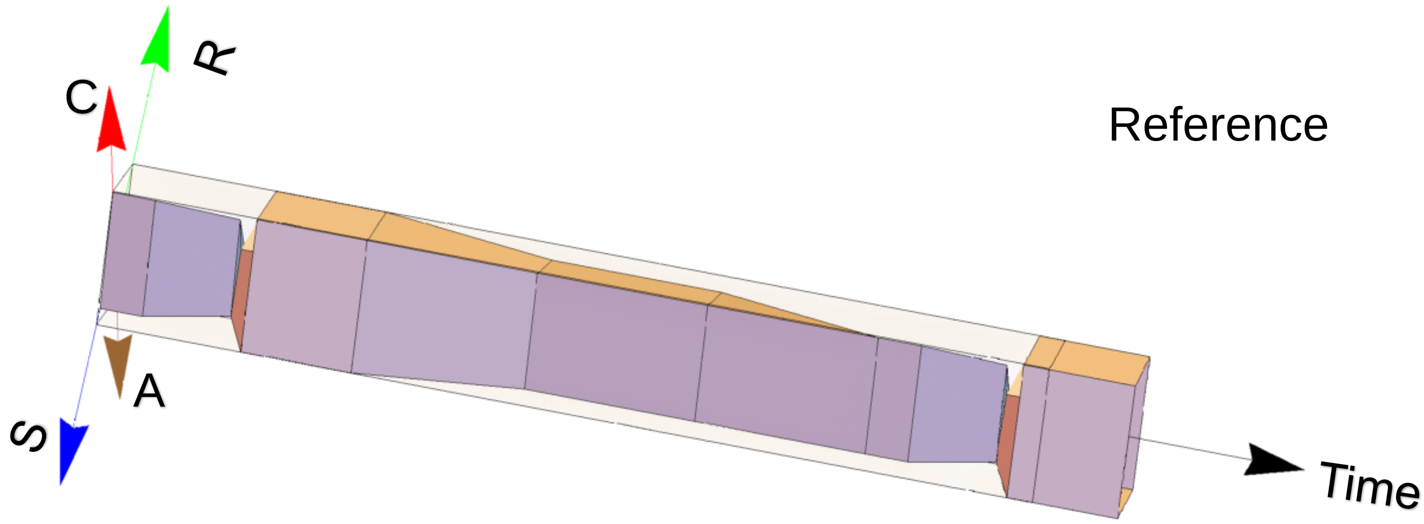
- All relevant KPI are to be expressed on the scale from 1 to 5.
- Rating 1 is the best and 5 is the worst.
- Reliability and Safety is already expressed in this manner.
- Availability will be transformed from the 1 to 4 scale into 1 to 5 scale.
- Zero costs are expressed with 0 and the highest costs/year are expressed as 5
- The highest costs/year in both scenarios are 1Mio/year -> rating 5
- In this manner a 3D spider diagram for both scenarios can be generated.

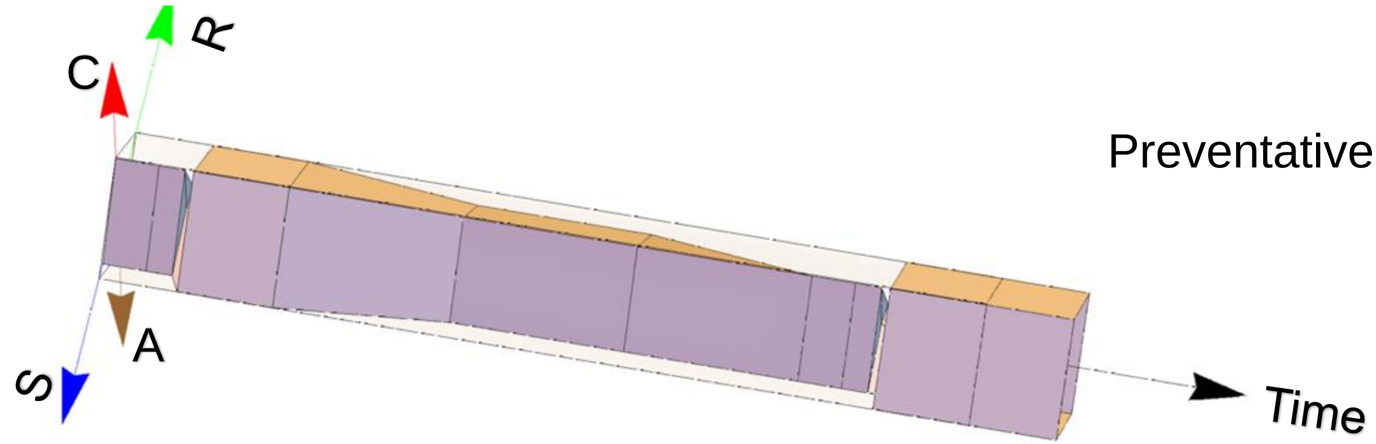
8. Decision making – 3D Spider/front view





8. Decision making – 3D Spider/rear view





8. Time preference

- How to evaluate future events and compare them with present events?
- What is more important? A reliable bridge now or in the future?
- For costs or cash flows there is an established procedure: Discounting
- The future expenditures are discounted to present: NPV (Net Present Value)
- With the discount rate or 2% the expenditure of € 1.02 in a year is equal to € 1.00 today.
- How about availability, reliability or safety?
- There are different methods but essentially it comes also to “discounting”?
- The reliability, availability and safety is more important today then in 1, 2 or 10 years.
- This seems fair: The interventions on the short term are more expensive but the benefits are also more valuable!

8. Ordinal utility theory

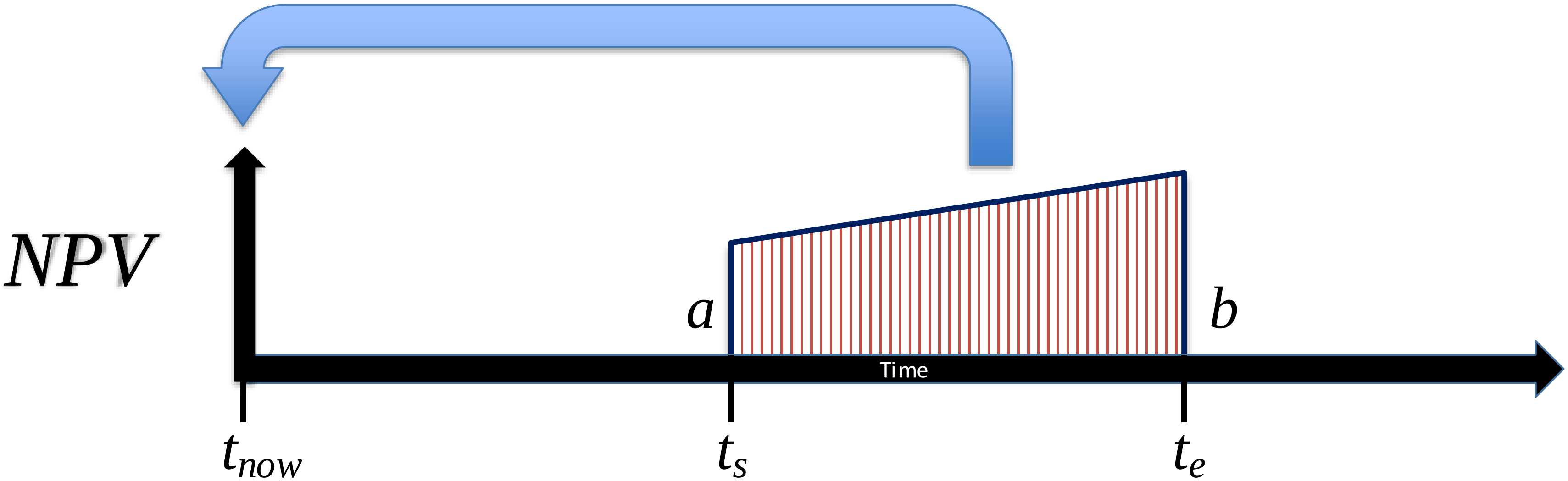
- The ordinal utility theory claims that it is only meaningful to ask which option is better than the other, but it is meaningless to ask how much better it is or how good it is.
- If the ranking of options doesn't change in time then it can be reasonable asked for the same options whether is execution today is more or less preferable than execution it at some time point in future.
- Consumer impatience
- Comparison of utility streams
- The problem of averaging ordinal scores –> condition states

8. Monetization

- Reliability, availability and safety can be monetized
- Reliability -> Risk due to failure
- Availability -> User costs and externalities
- Safety -> Statistical value of life, cost of injuries
- Discount rate needs to follow the productivity increase in construction industry
- Effort needed to today to perform a certain activity compared to the effort to perform the same activity in the future.
- Quite low ca. 1 to 2%

8. Discounting

$$NPV = \frac{\{[r\cdot(t_e - t_s) - 1]\cdot b + a\}\cdot e^{-rt_e} + \{[r\cdot(t_s - t_e) - 1]\cdot a + b\}\cdot e^{-rt_s}}{r^2\cdot(t_e - t_s)}$$

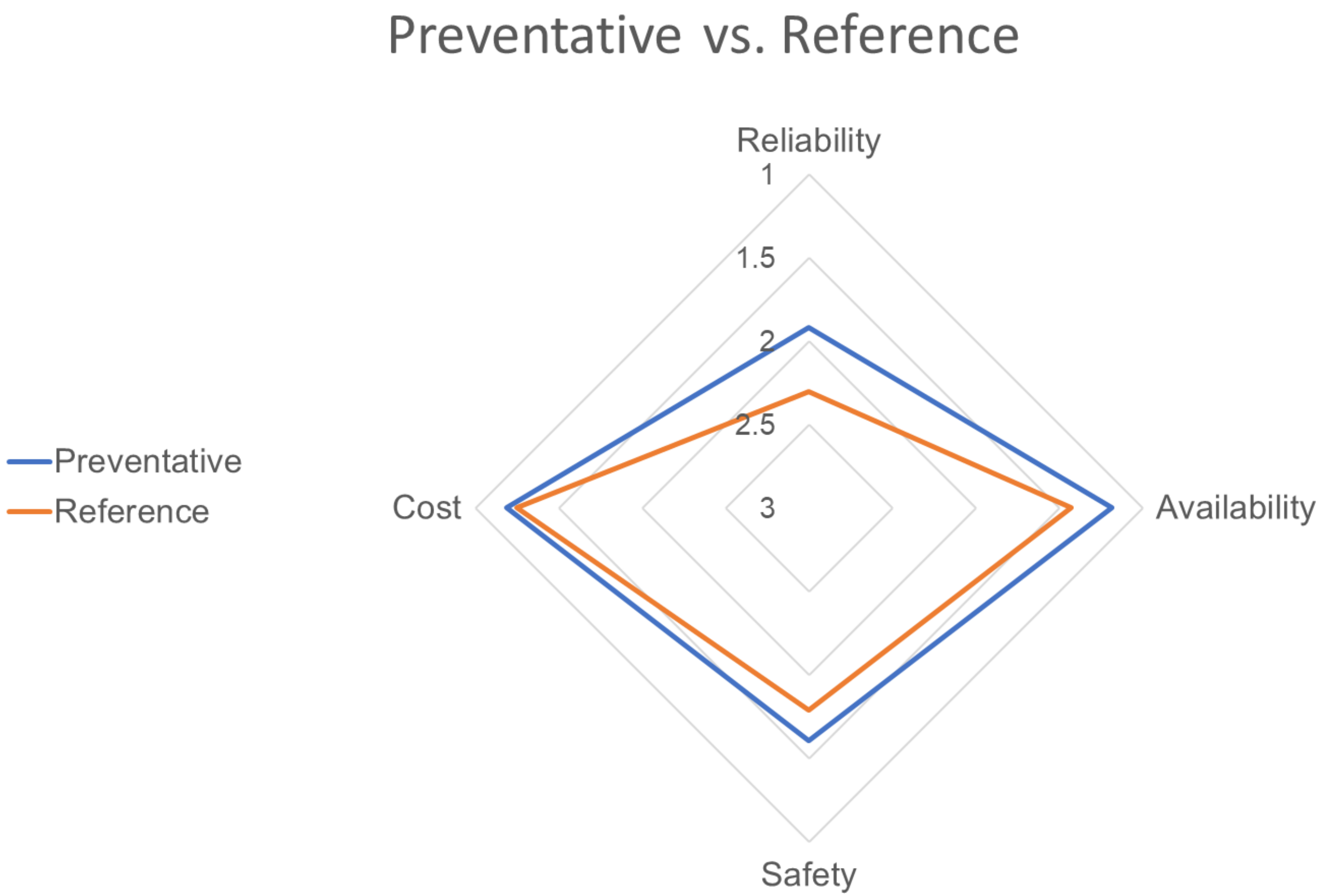


r = continuous discount rate

8. Normalization

- Net present value of all KPIs is already directly comparable due to the same scale.
- In order to reduce the KPIs to the same scale as for any time instance the NPV is divided with NPV which is calculated if all KPI were 1 over the whole investigation period.
- These value can be regarded as “average” long term KPIs.

8. Decision making – Net present KPIs



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Monitoring OFFSHORE STRUCTURES

Assessment, Inspection and Management

Helmut **WENZEL**

Zell am See, December 2017

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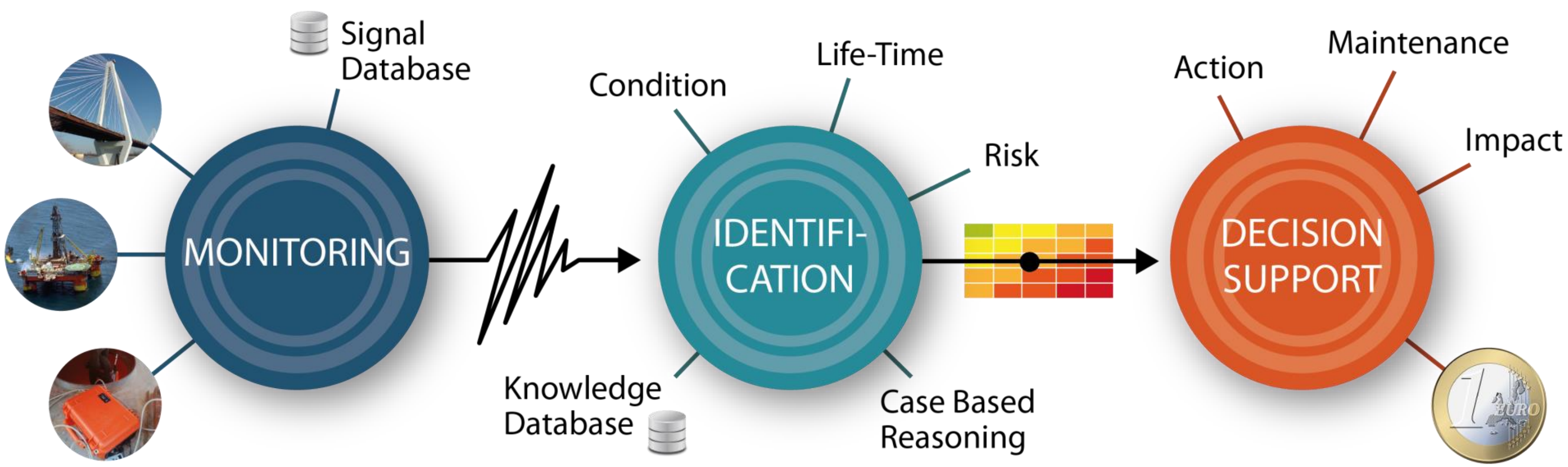
3. Decision Support
4. Summary



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North Sea Application

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North Sea Application

North Sea Application

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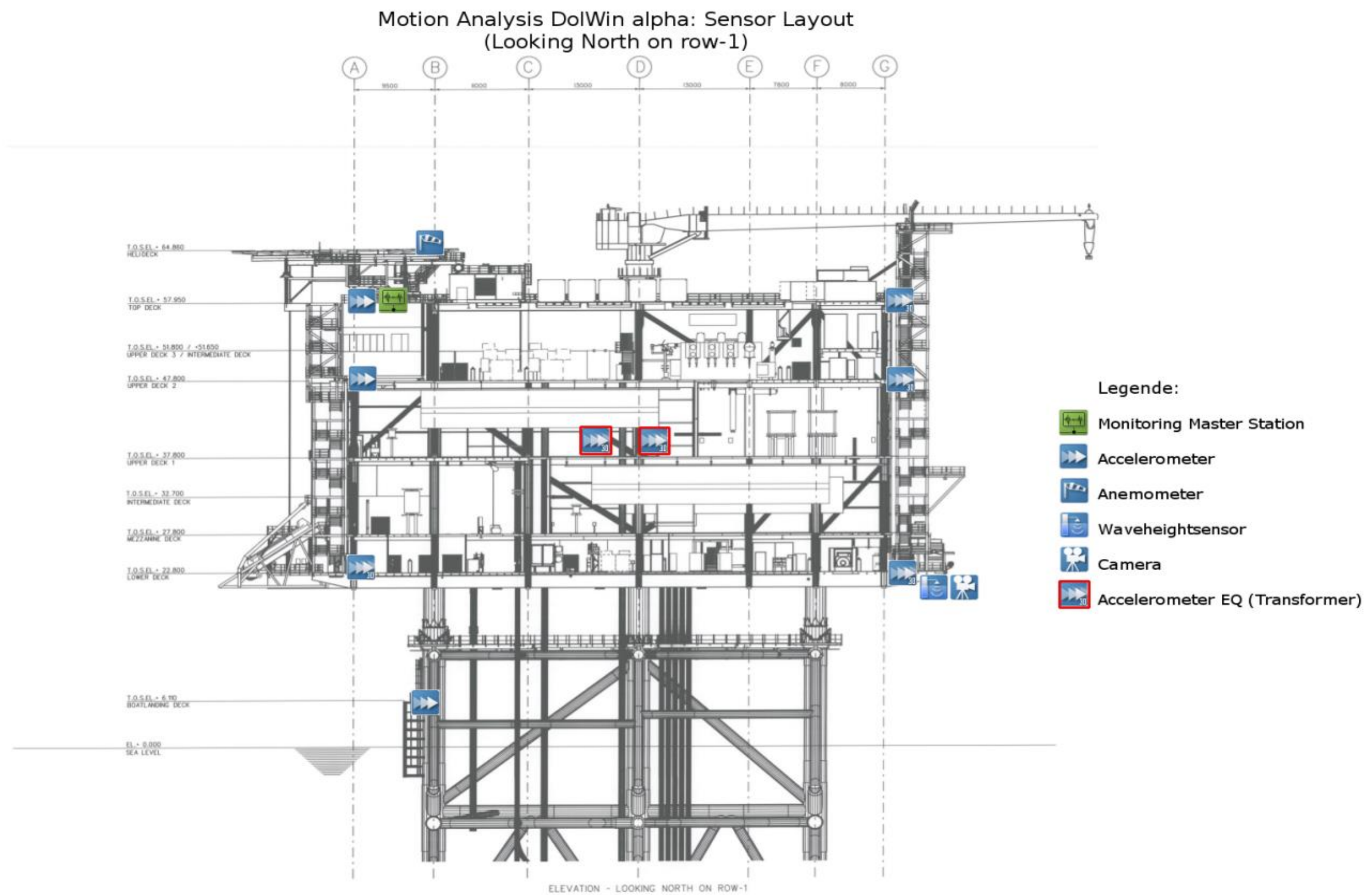
North Sea Application

Layout Monitoringsystem



North Sea Application

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North Sea Application

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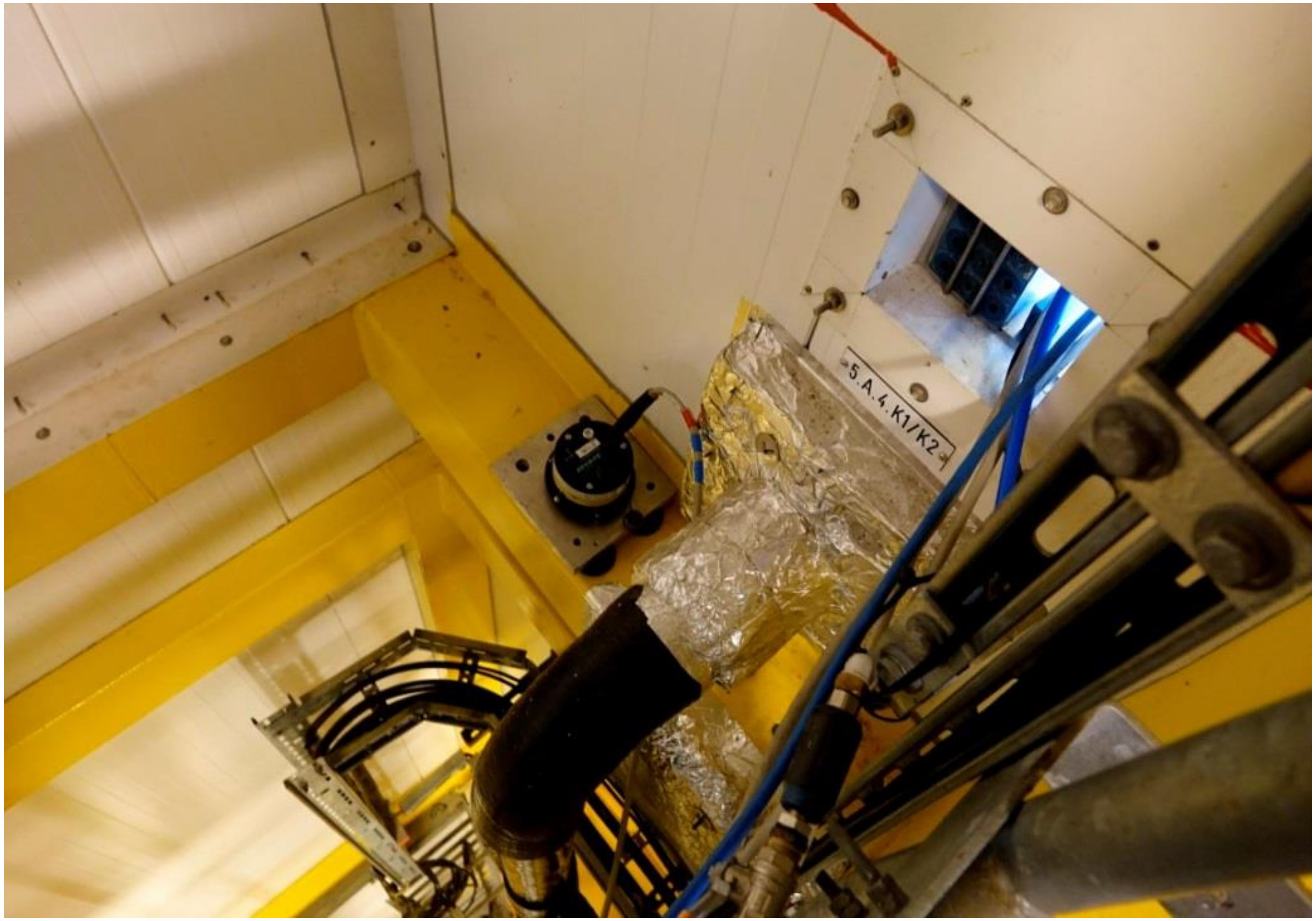

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North Sea Application

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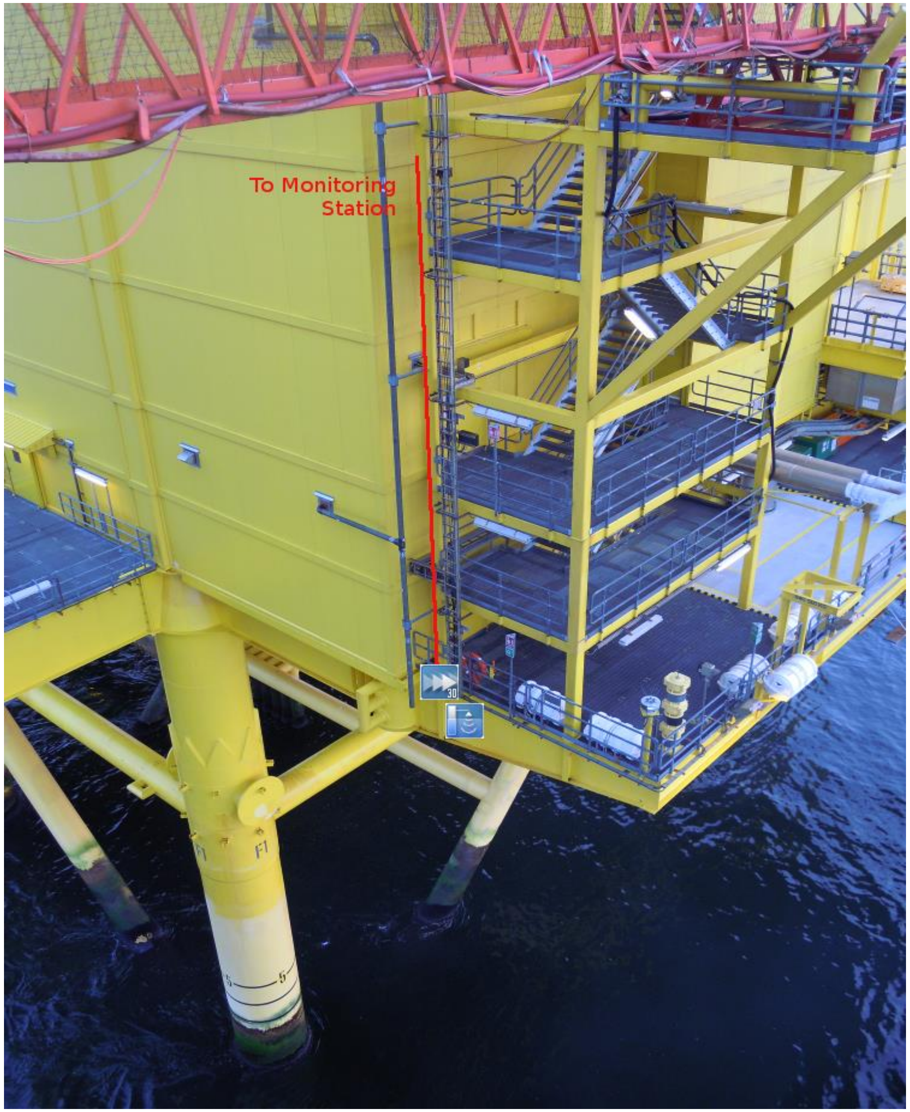

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North Sea Application

North Sea Application

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Monitoring

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Targeted Inspection Programme
Permanent Monitoring

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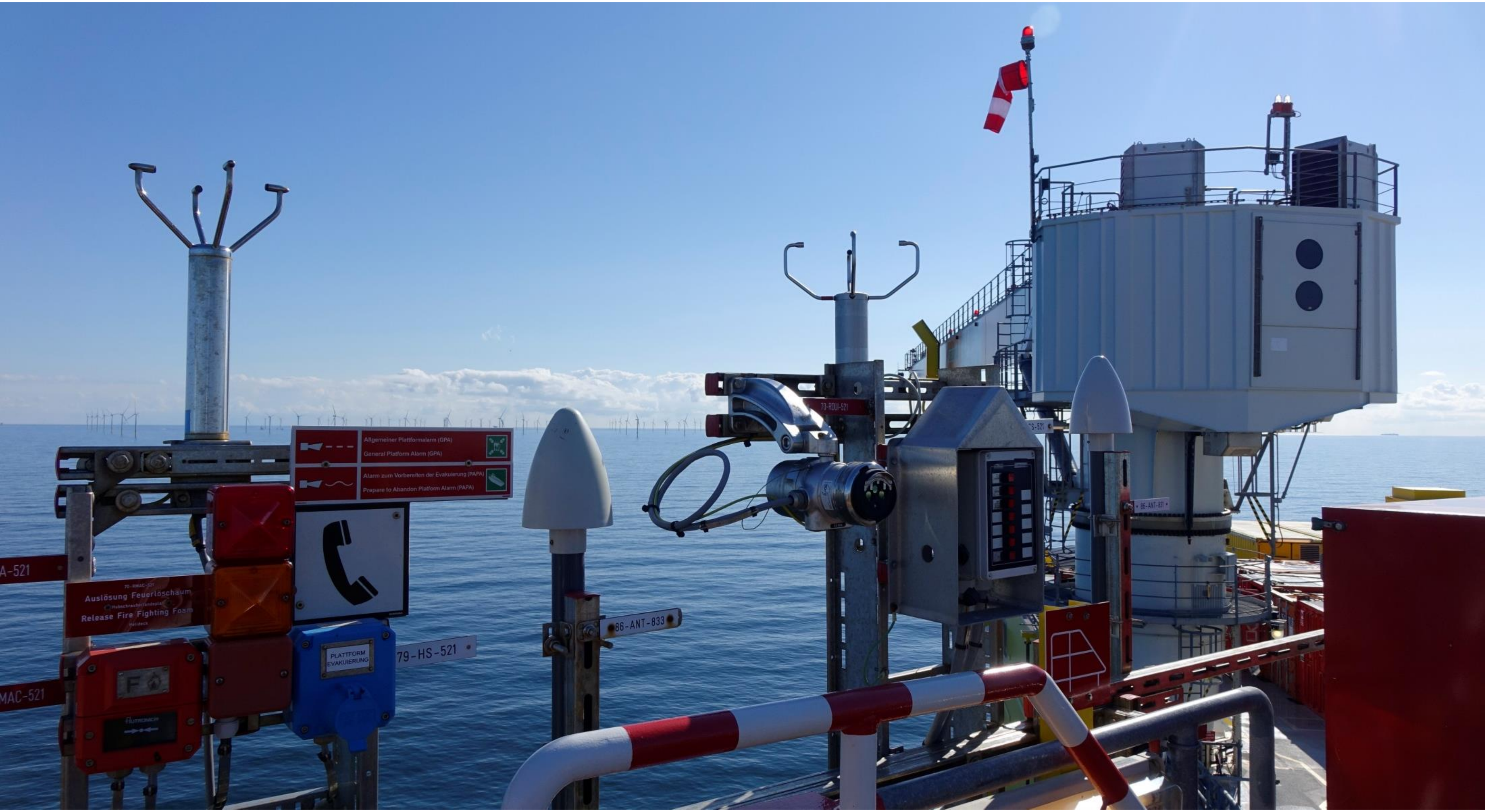

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Permanent Monitoring

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Monitoring for
System Identification Purpose

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North Sea Application

Model vs Measurements

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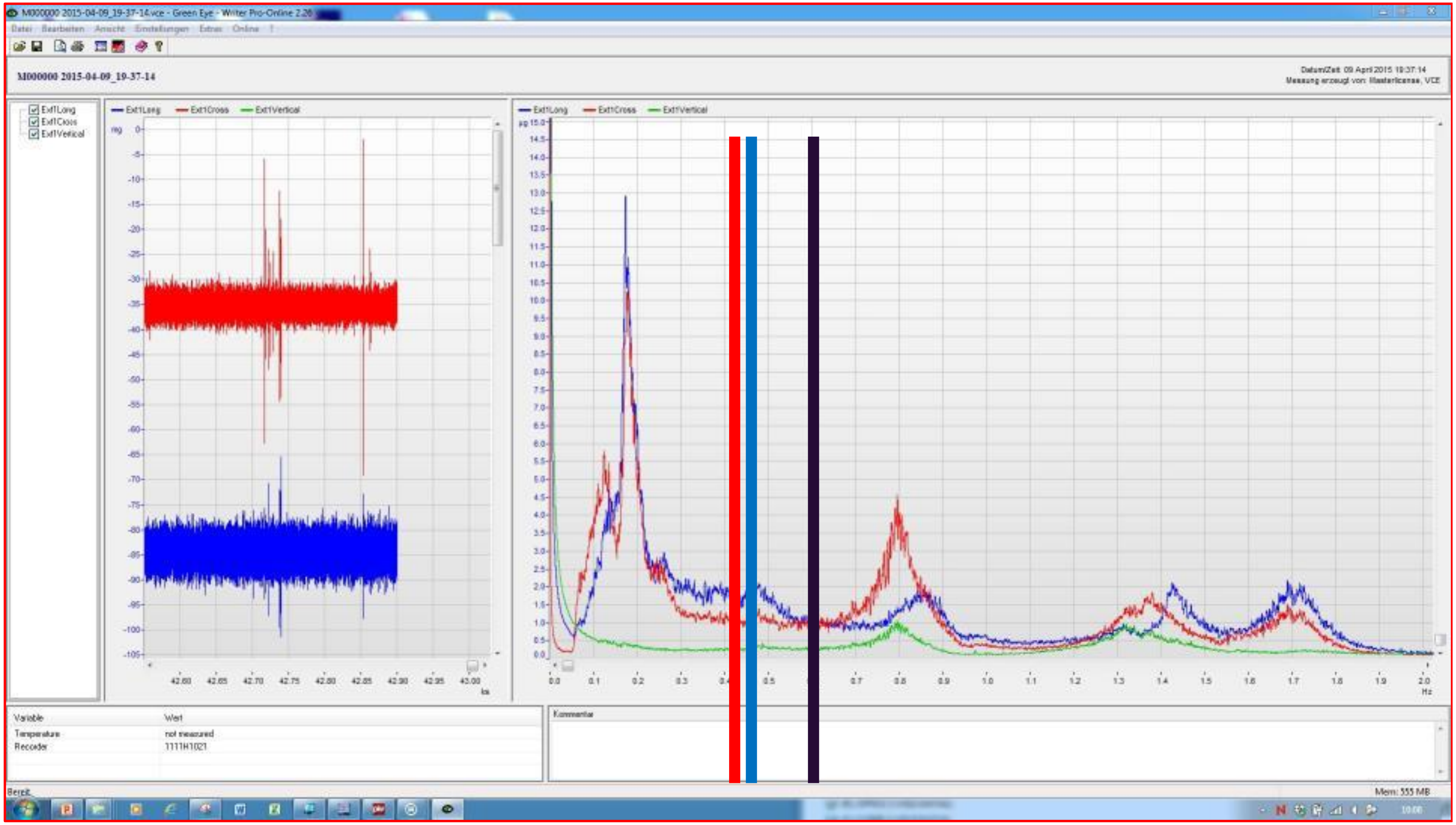

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Monitoring Frequencies

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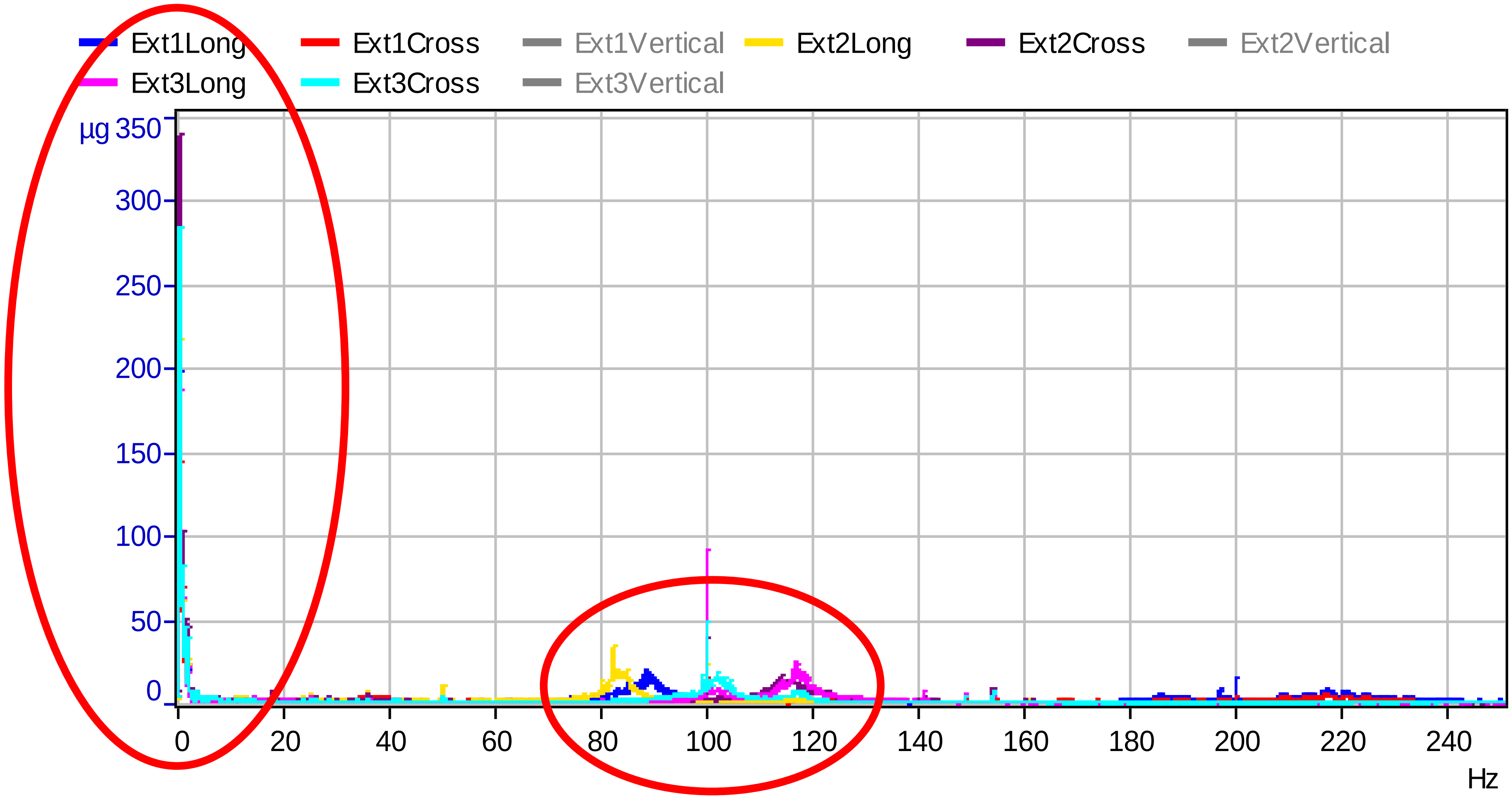

Monitoring Action

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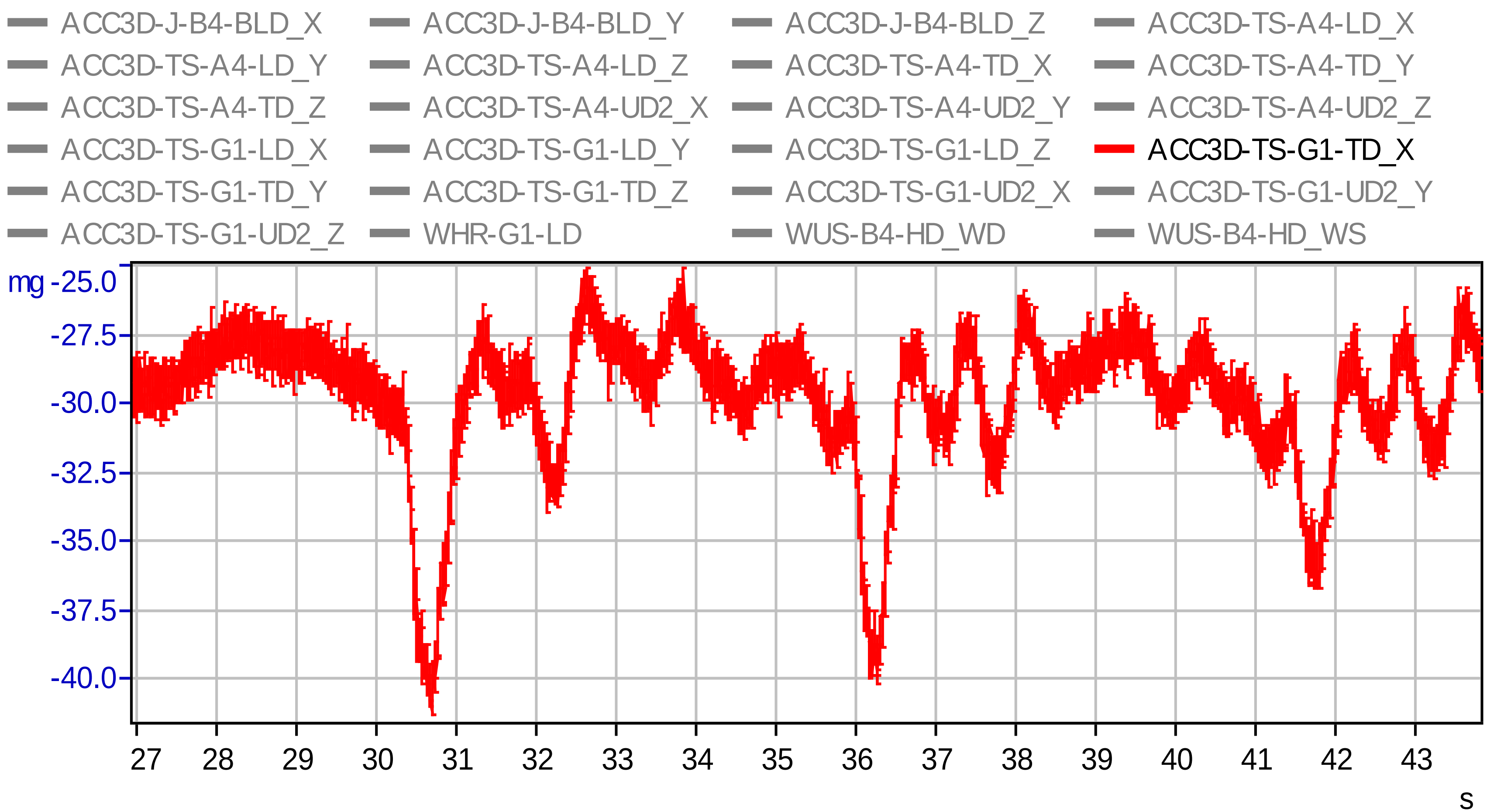

Monitoring Displacement

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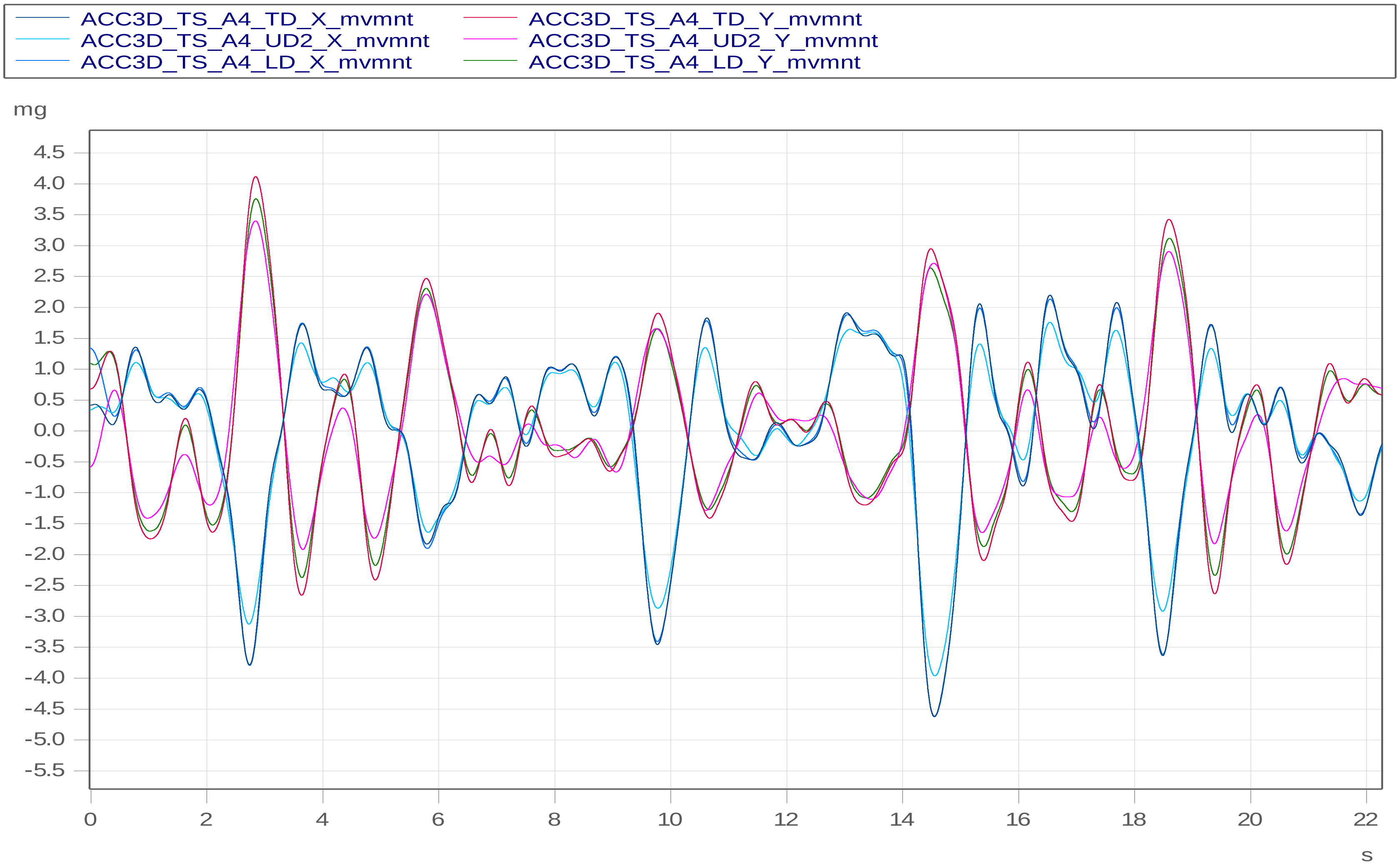

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Monitoring Performance

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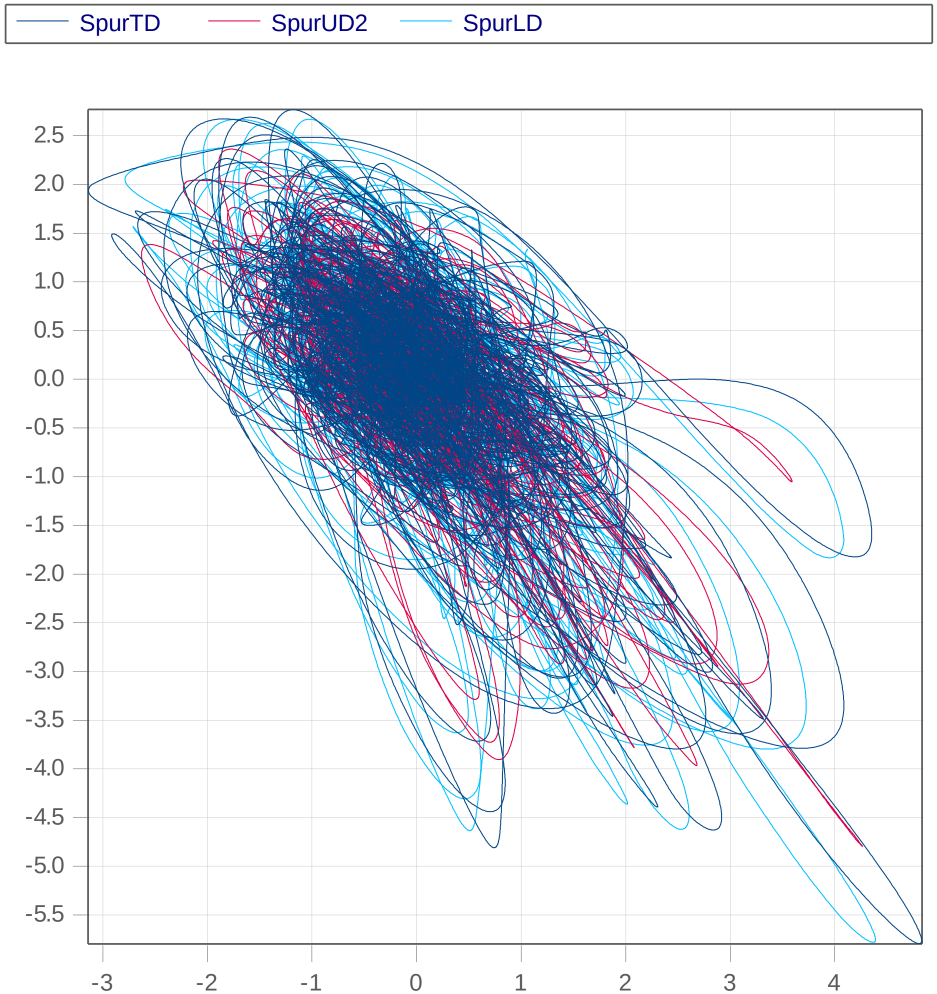

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North Sea Application

Scan ABB 2015: Multibeam

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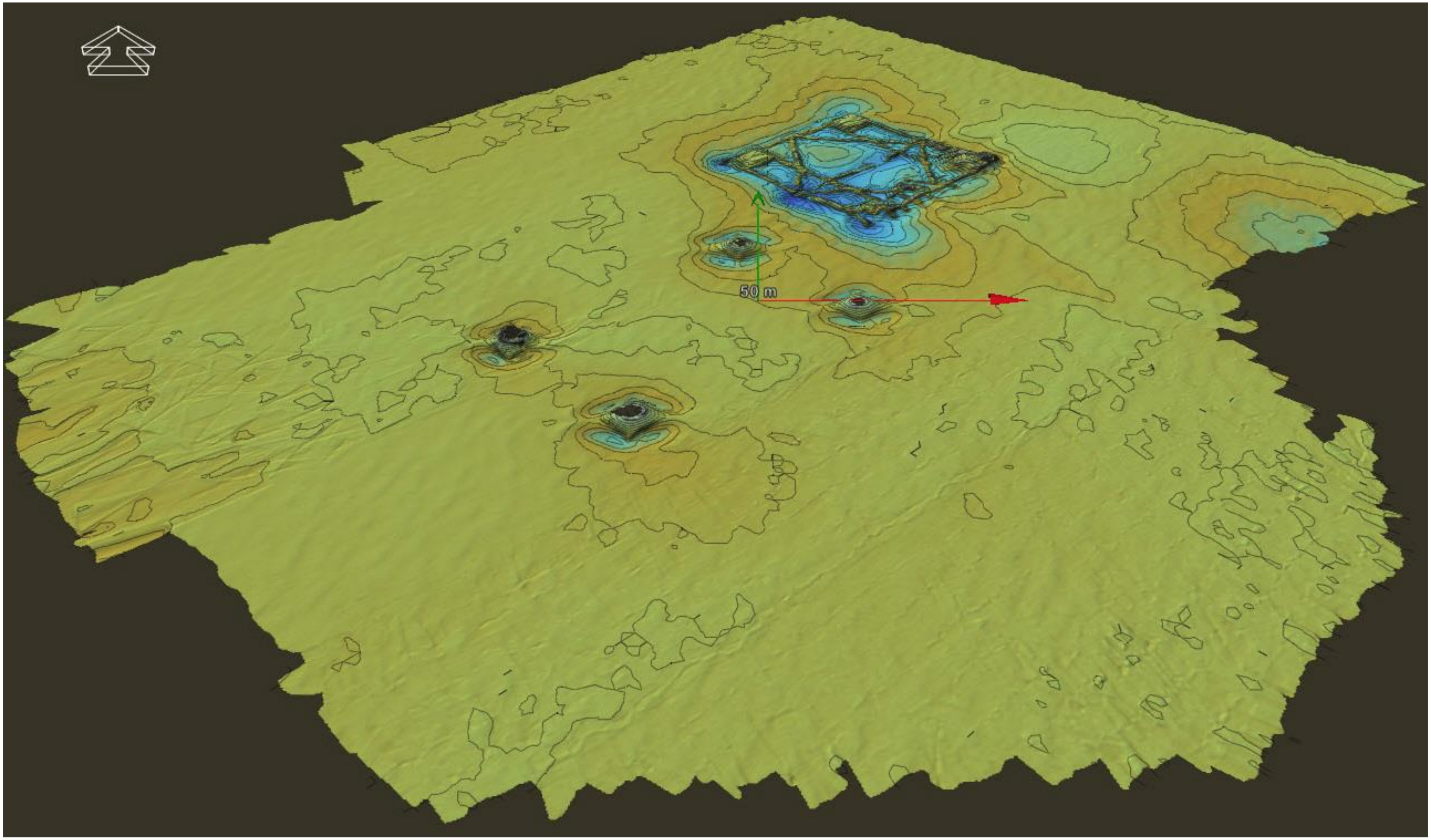

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North Sea Application
Scan ABB 2015: Detail

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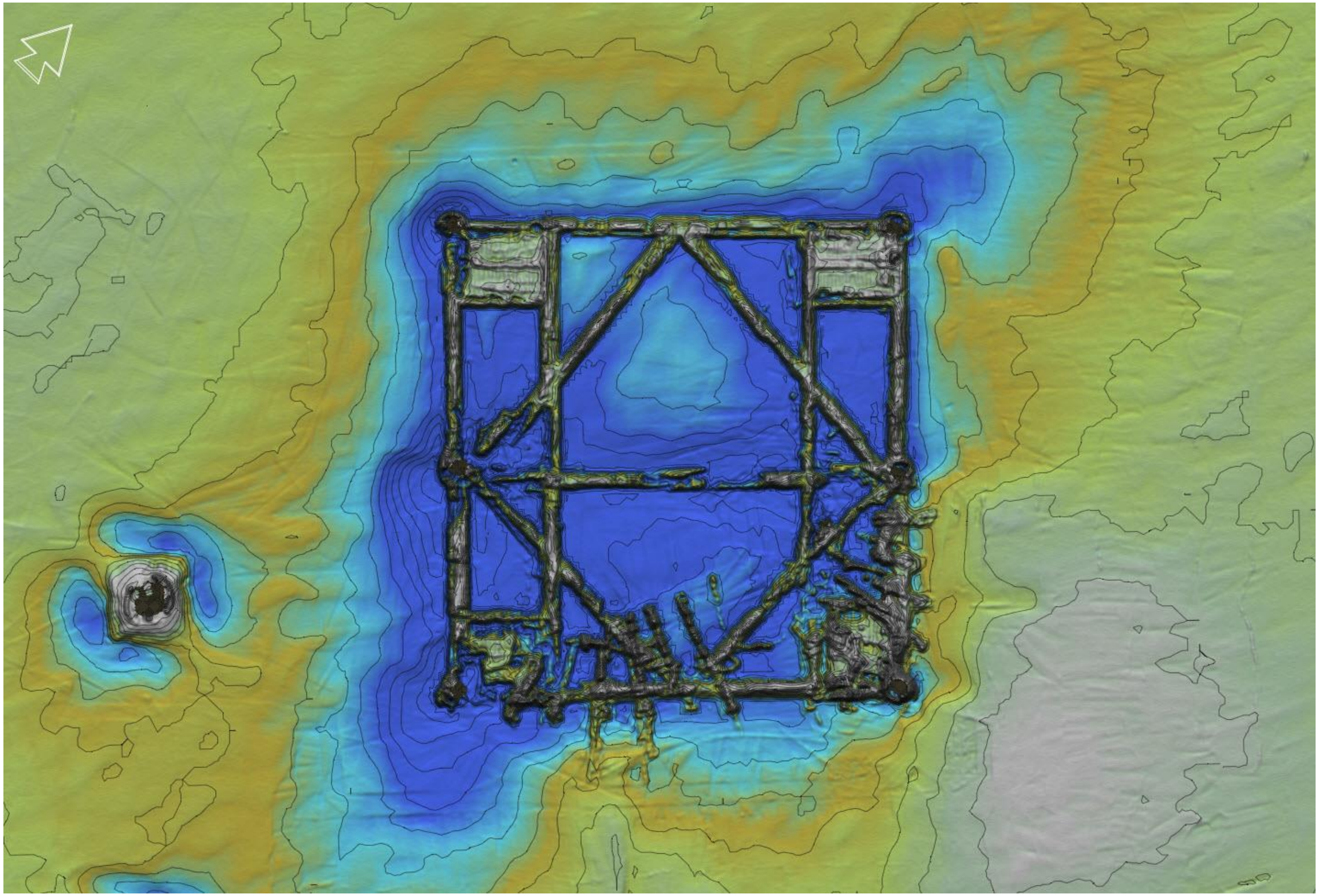

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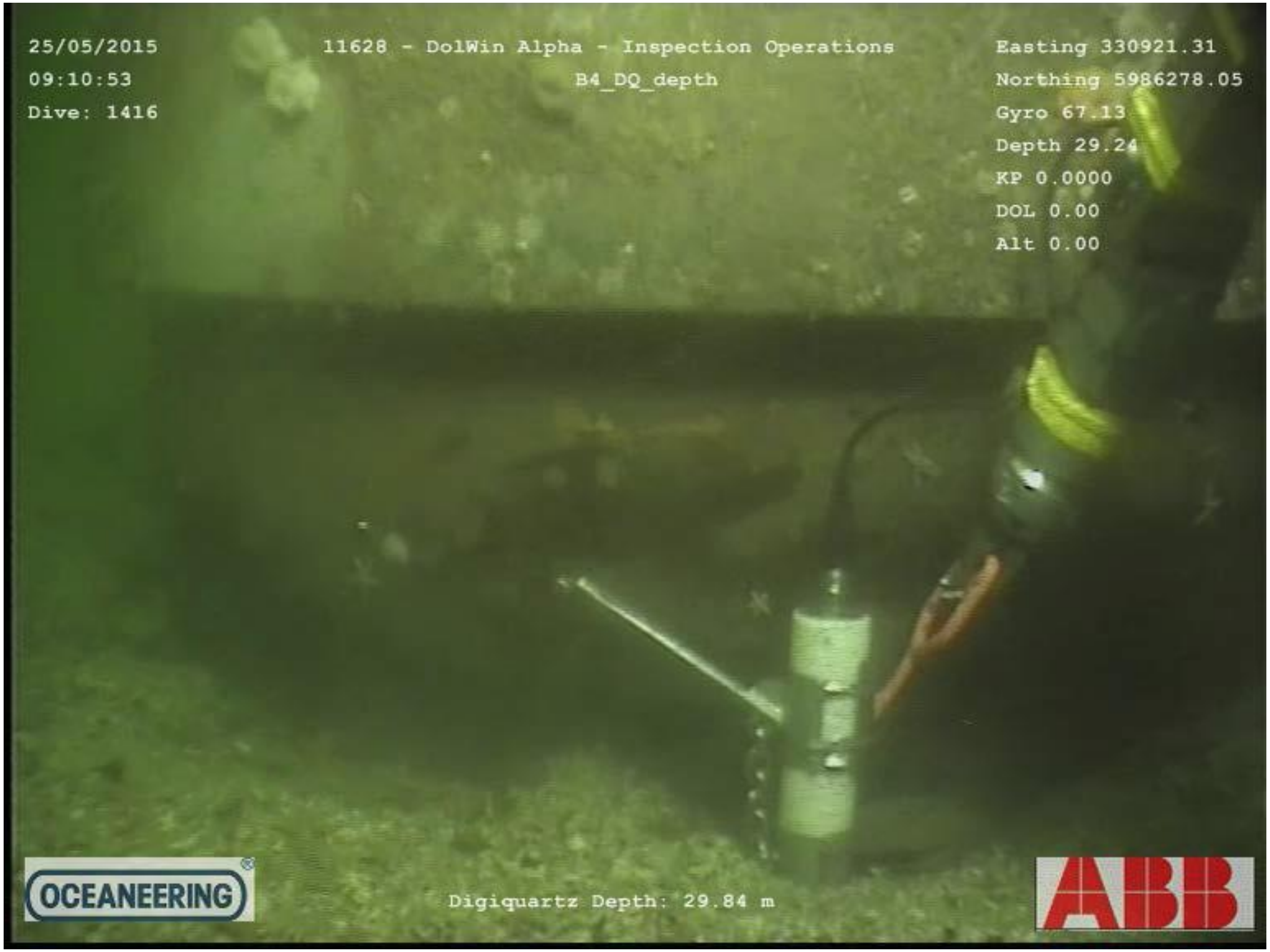
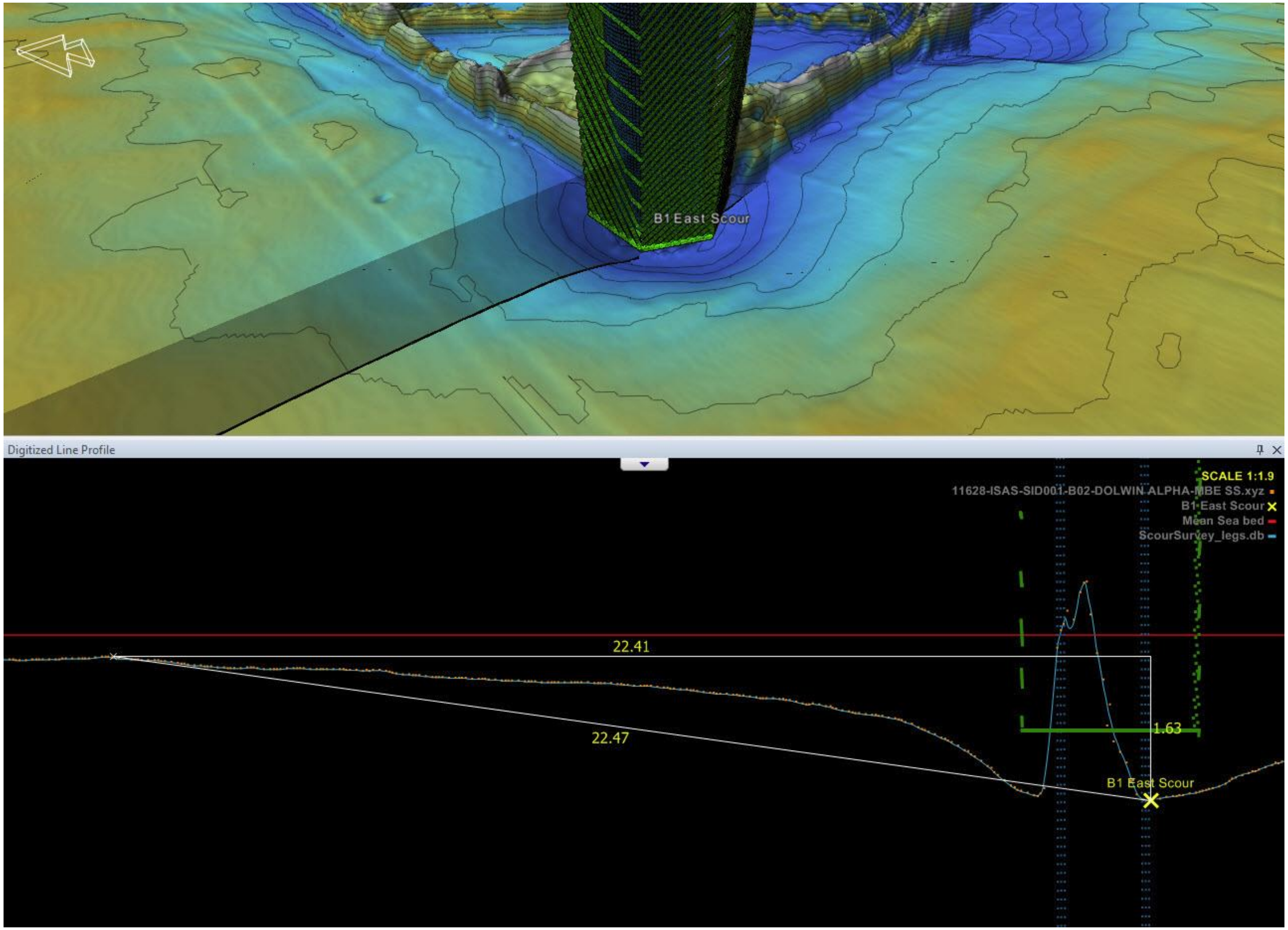
North Sea Application

Scan ABB 2015: Jacket und Pile, Scour



LEG B4 Digiquartz on seabed - Photo Ref. No: 166479-DWA-001

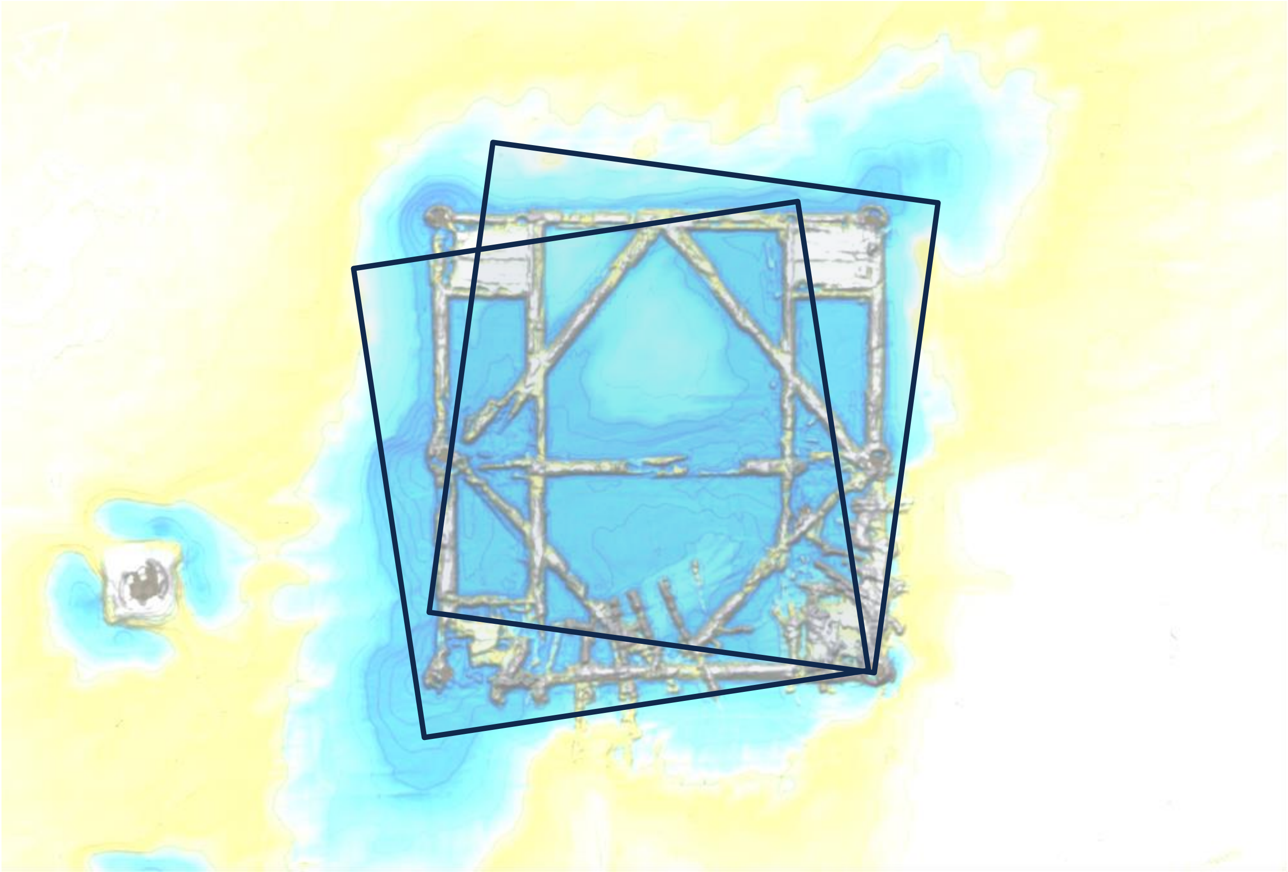
North Sea Application
Scan ABB 2015: Profil



LEG B1 Multibeam vertical section profile ROW 1

North Sea Application

Scan ABB 2015: Detail



North Sea Application

Correlation: Weather vs Response

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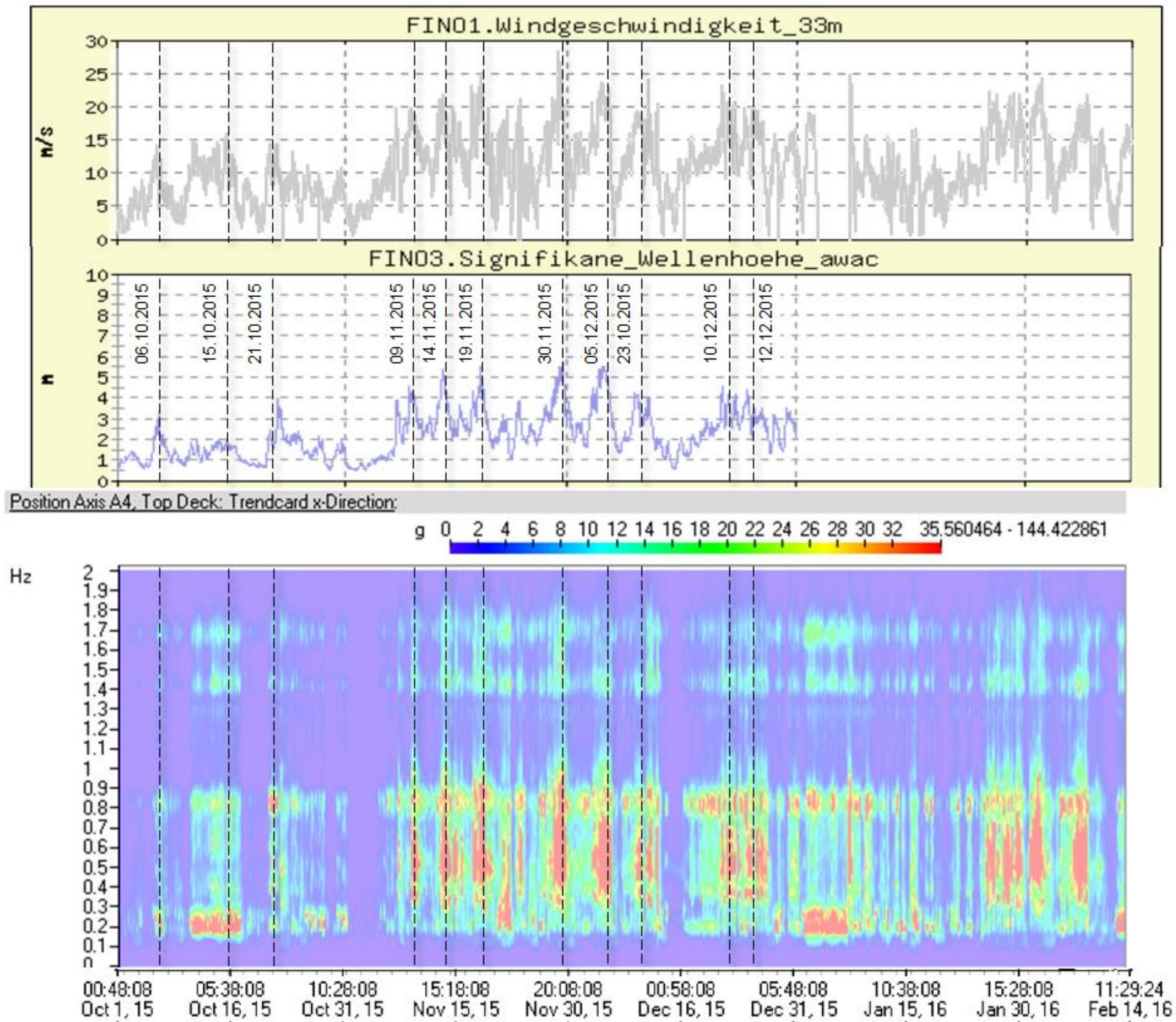
Wind [m/s]

Wellen [m]

Systemantwort [Hz]



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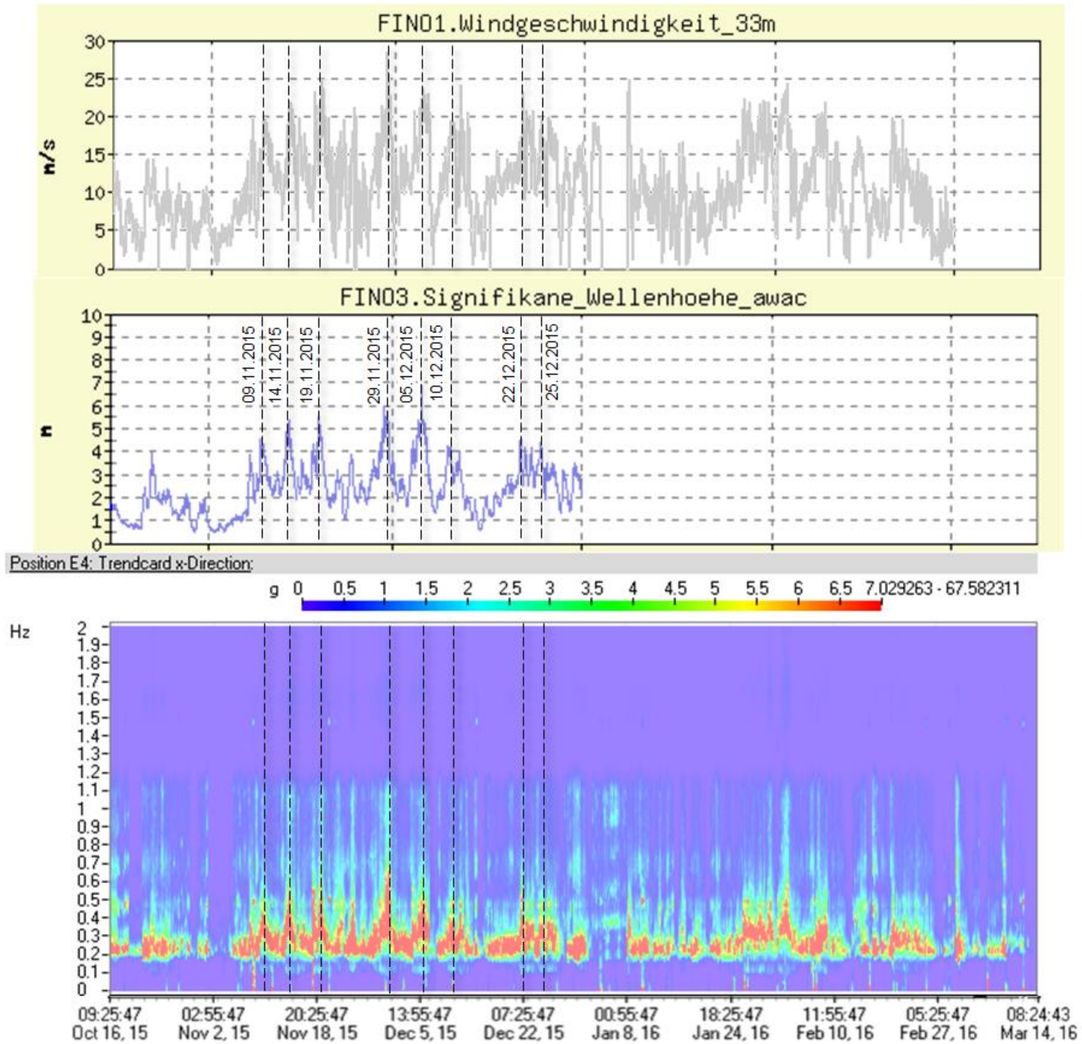
North Sea Application

Correlation: Weather vs Response

Wind [m/s]

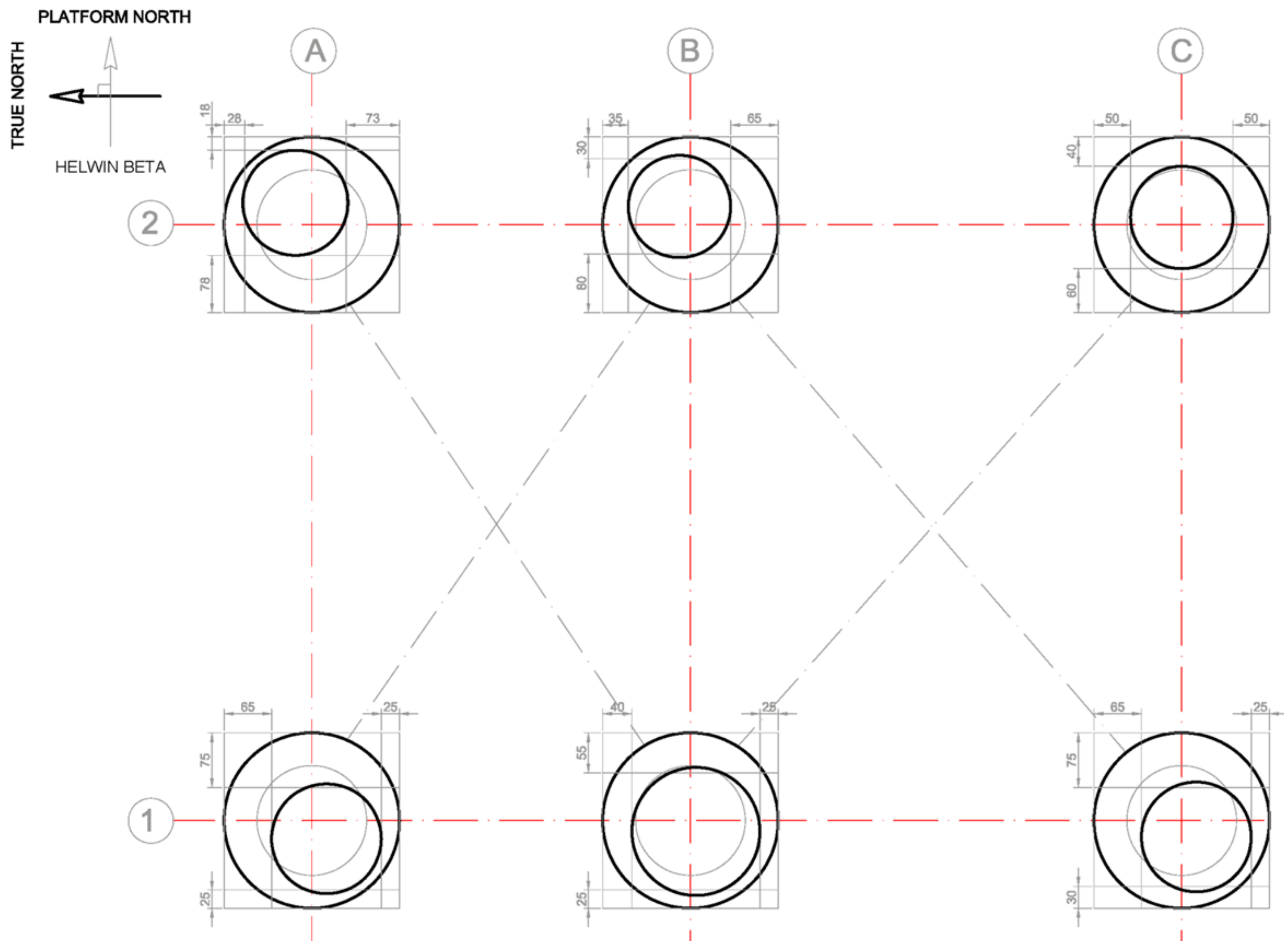
Wellen [m]

Systemantwort [Hz]



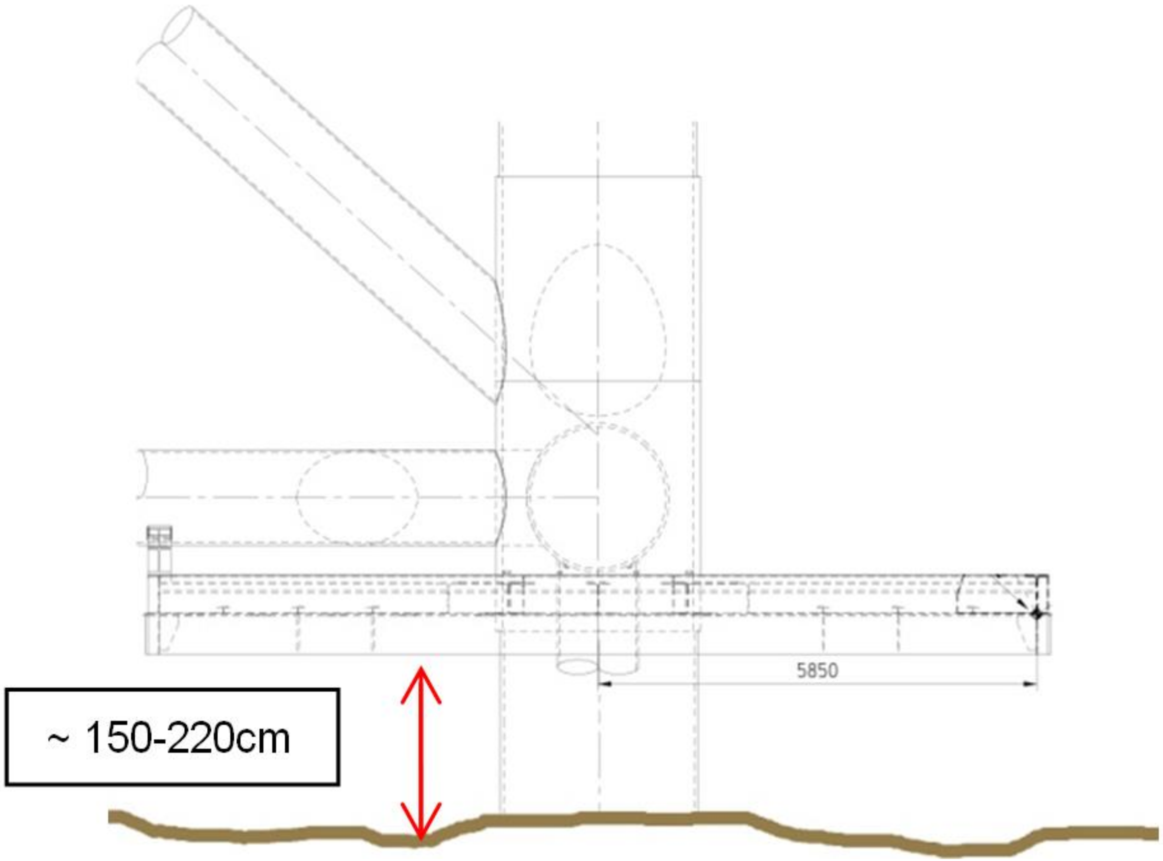
North Sea Application

Actual Position: Jacket – Piles



North Sea Application

Sea Bed Survey Information



North Sea Application
Sea Bed Survey Information

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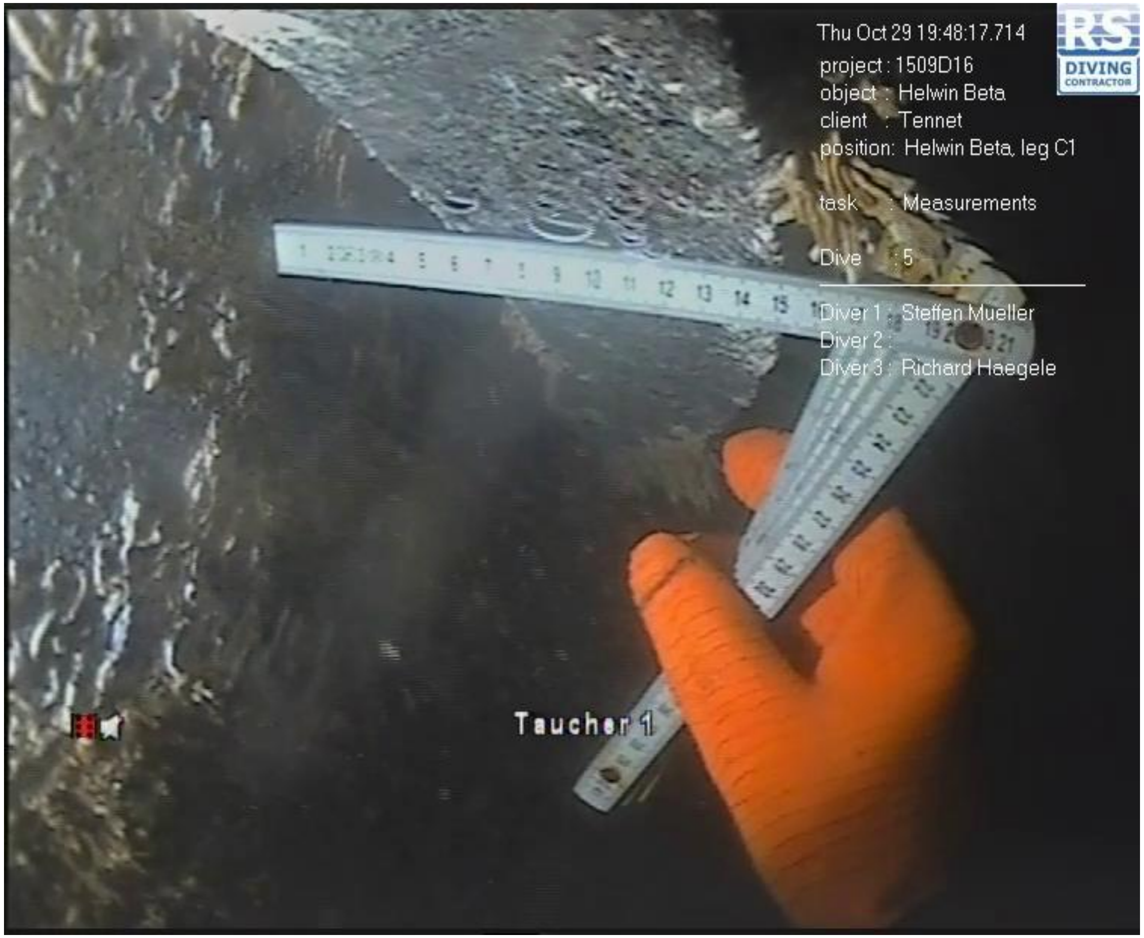

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Identification Objectives

1. Ultimate Load
2. Fatigue Life Determination
3. Targeted Inspection Programme
4. Quantification of Life Extension

Life Time Performance

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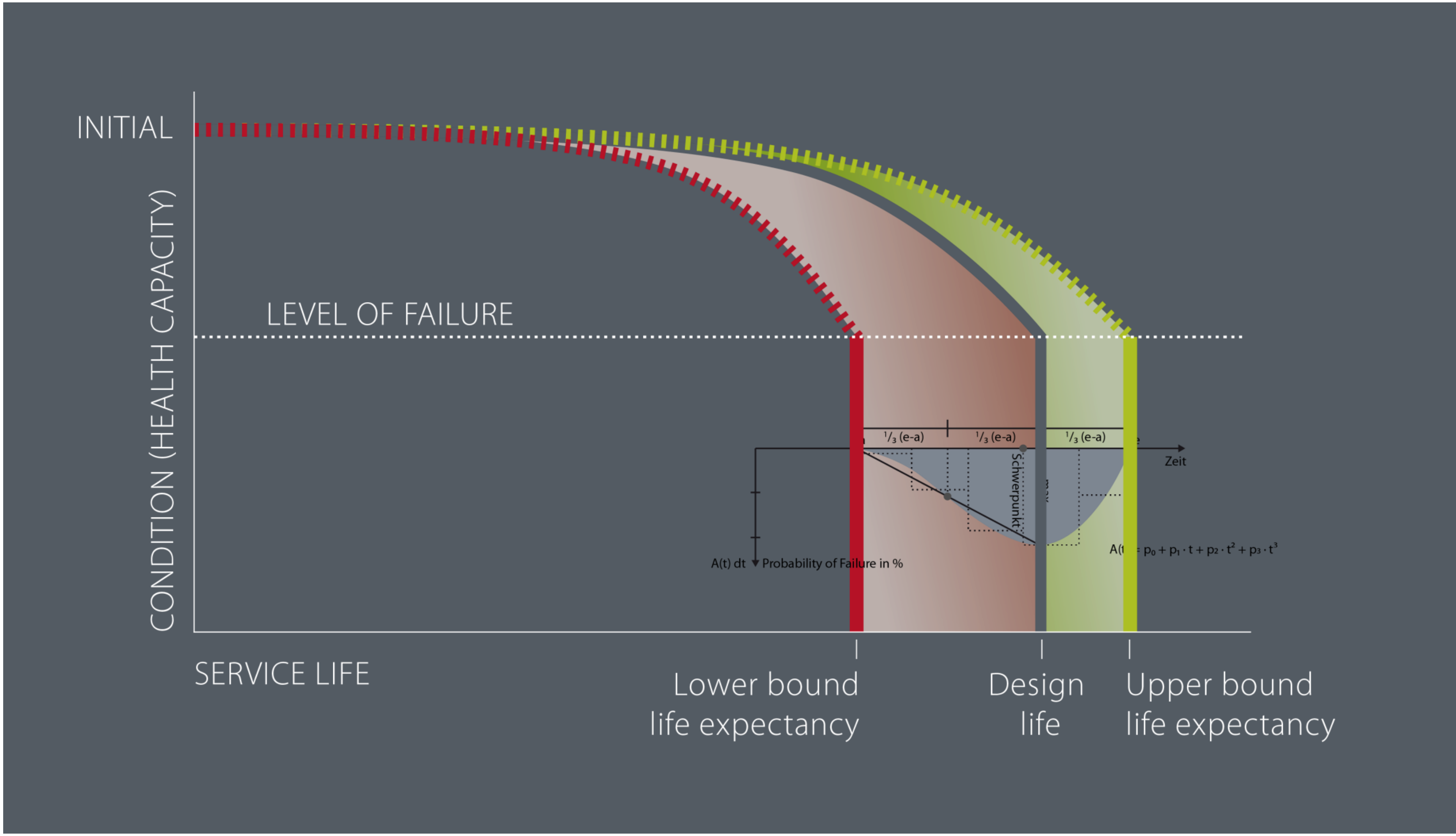

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Ultimate Load

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Ultimate Load

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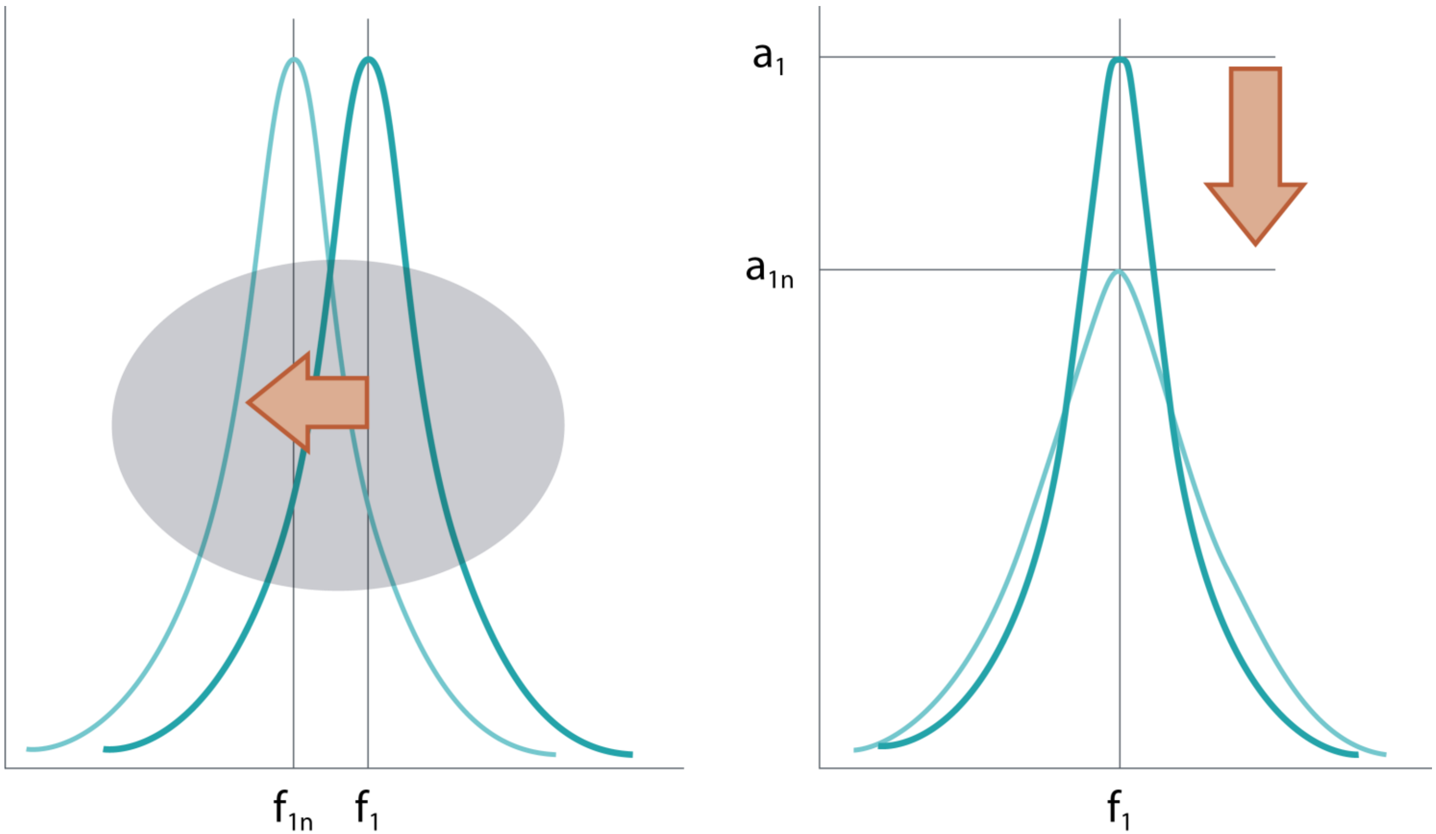

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Ultimate Load

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UL Design: 59 400 kN

UL Monitoring: 76 000 kN

CAPACITY: 128 %

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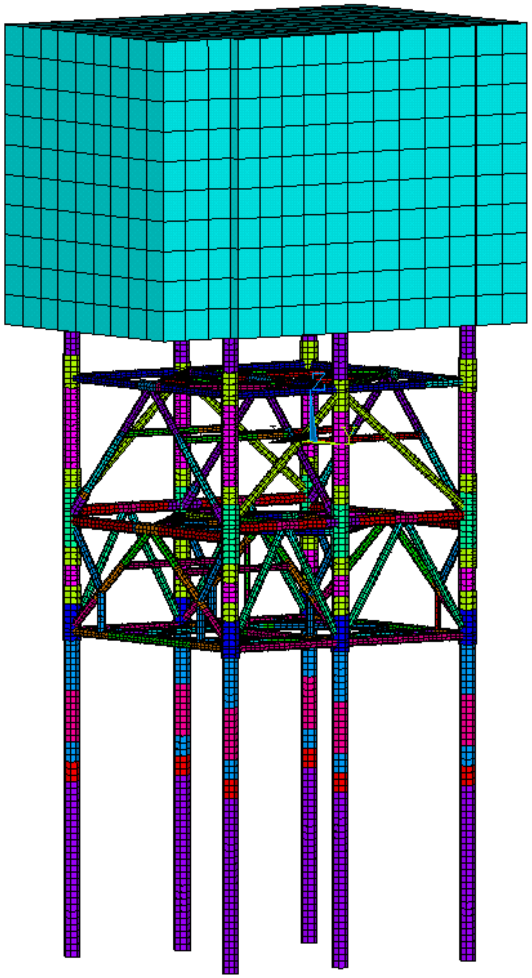
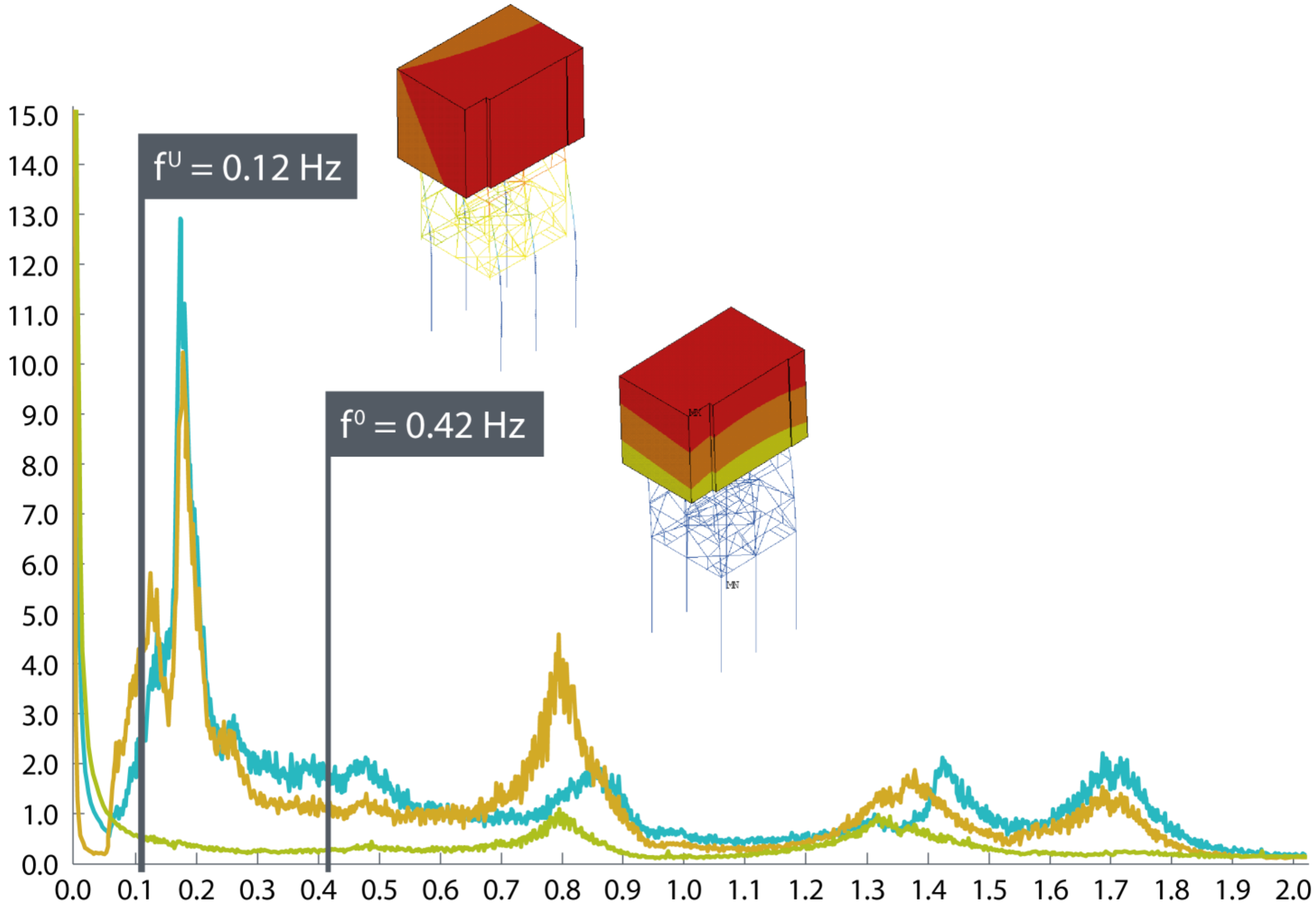
Ultimate Load

Modelling



Ultimate Load
Update

SHManager®



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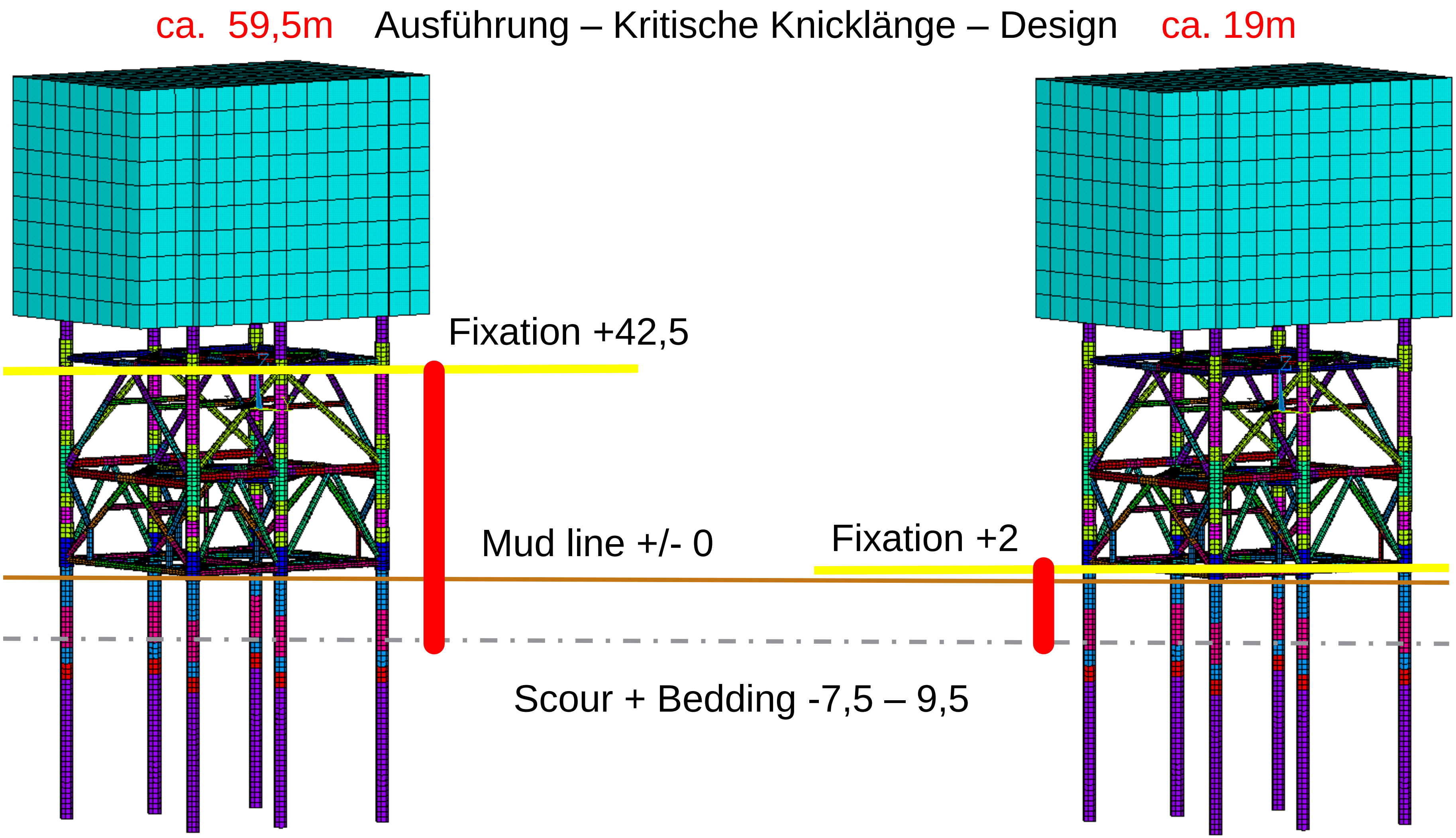
DolWin alpha

Design vs Ausführung: Knicken eines Pfahls



EUROCODE 1992
Knicken von Bauteilen

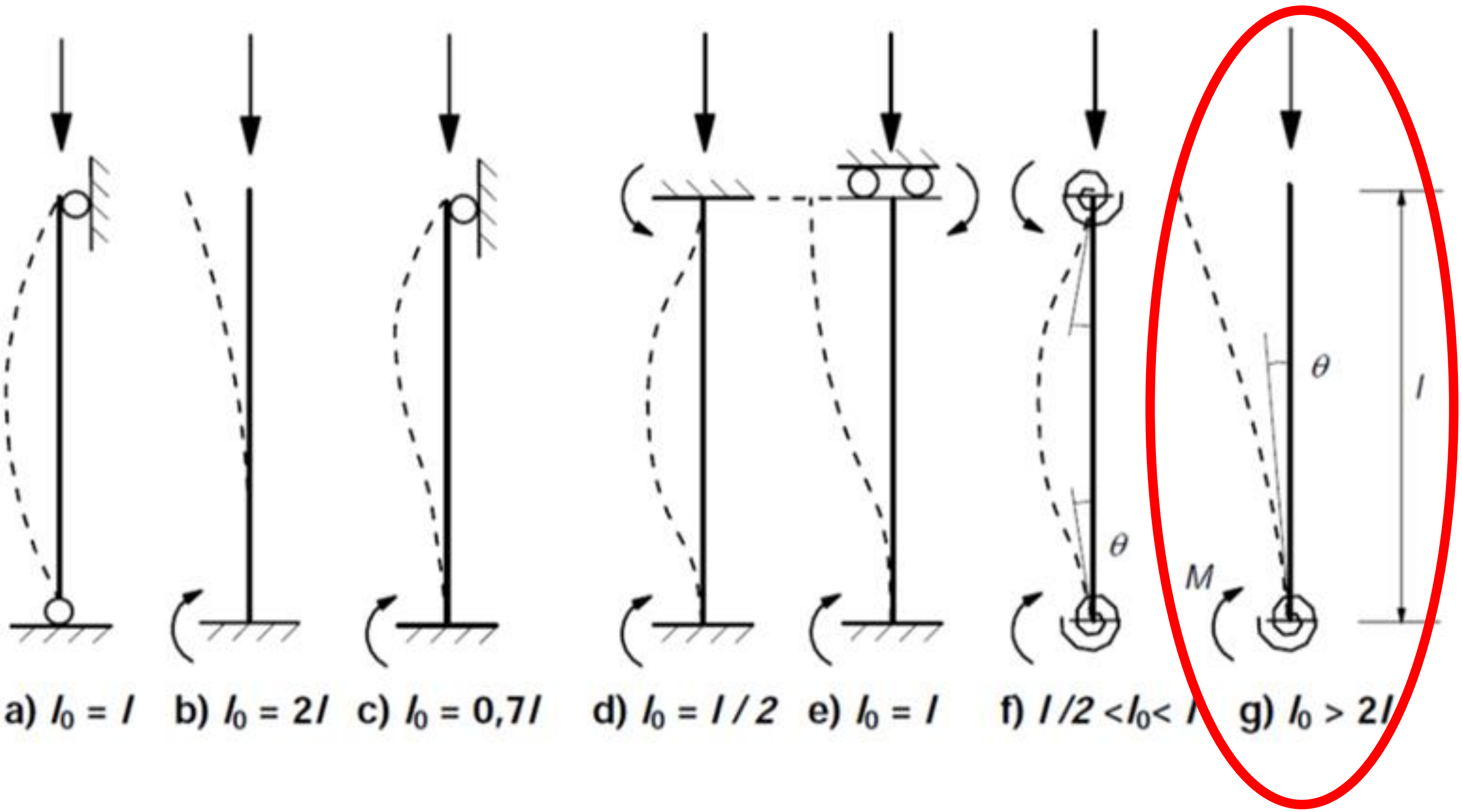
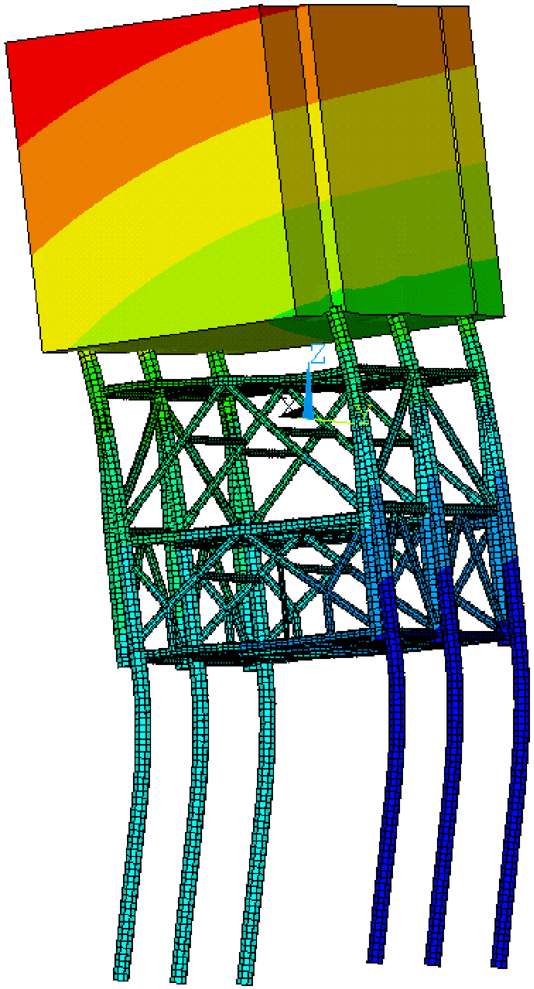


Figure: EN 1992-1-1:2004, pag. 66: Examples of different buckling modes and corresponding effective lengths for isolated members.

Ultimate Load

Failure Mode



Ultimate Load

Maximum Strain

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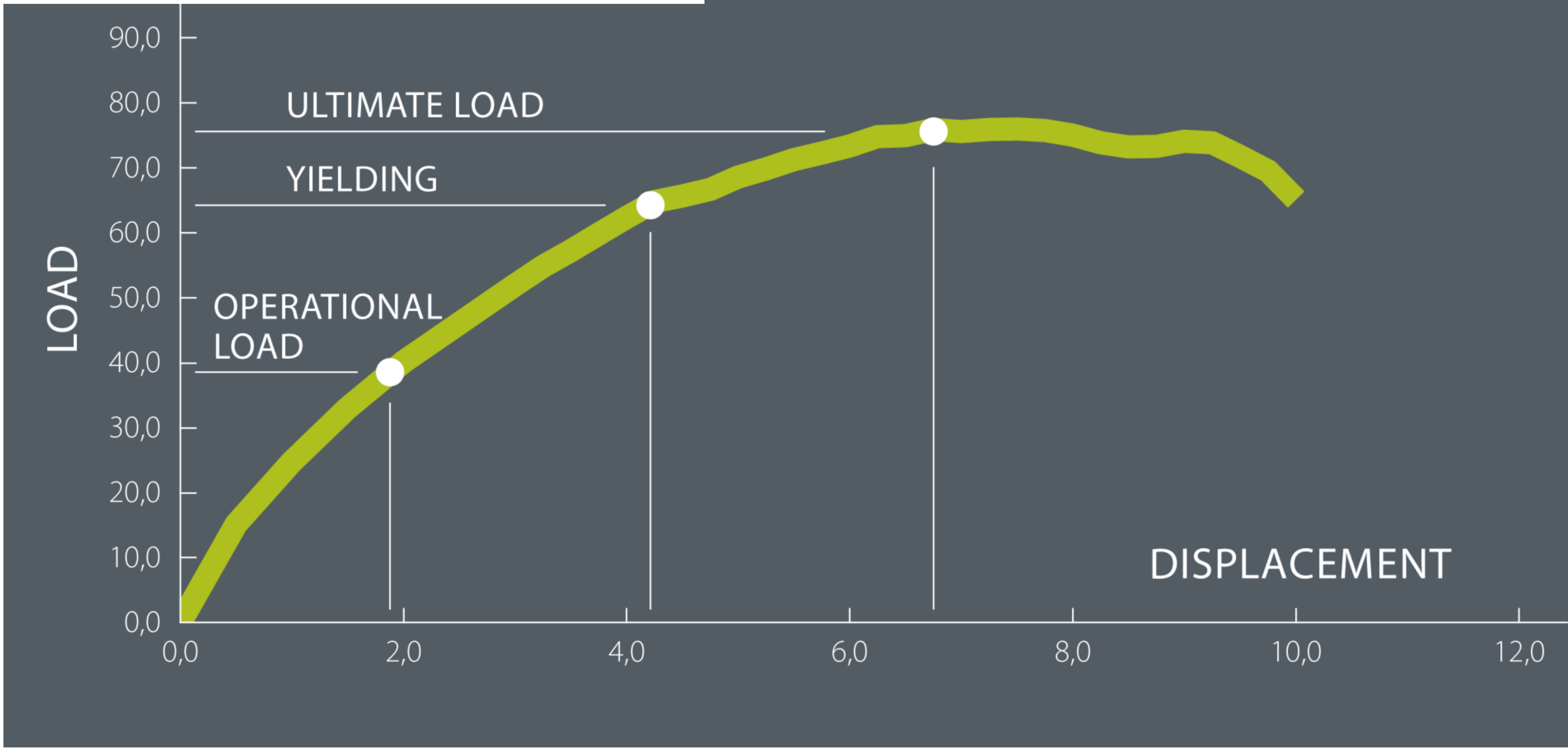
► Ultimate Load 76000 kN ◄



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Fatigue Life Determination

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Fatigue Life Determination

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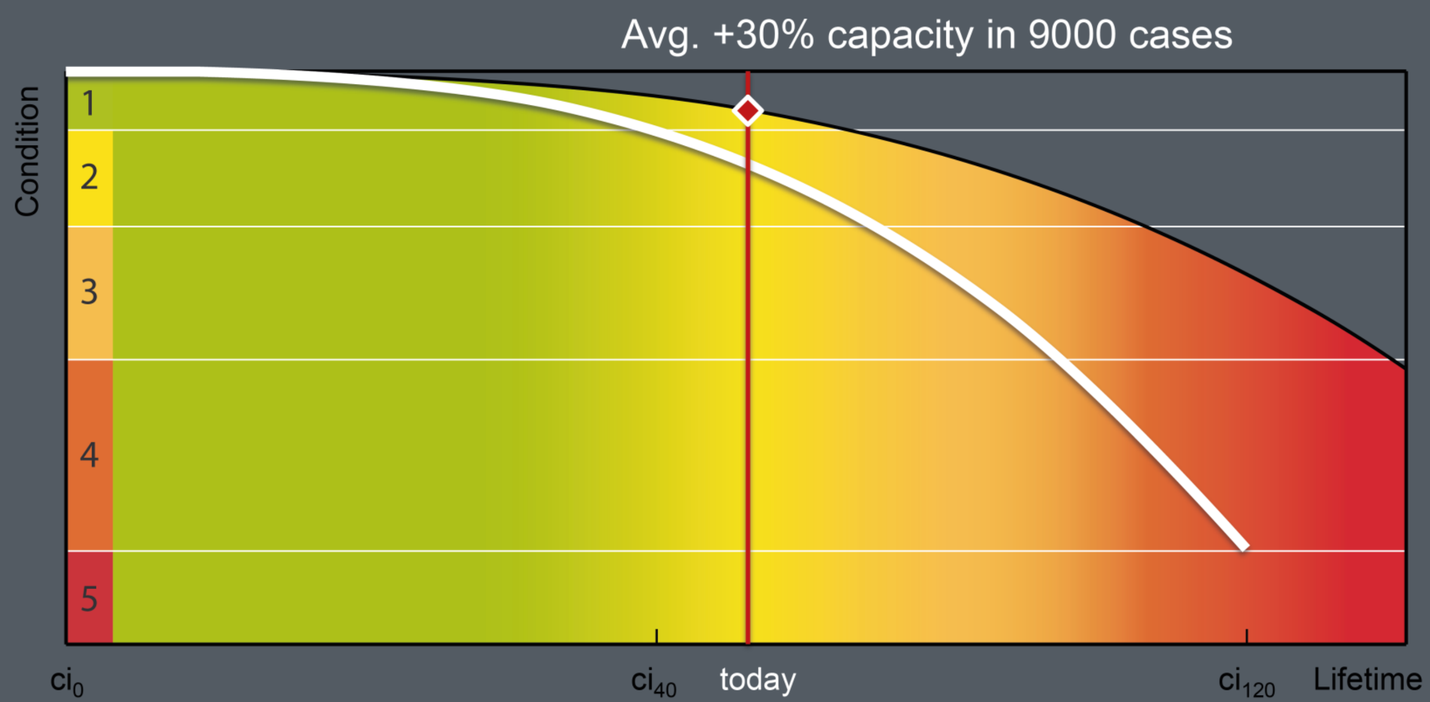

ci_n … condition index ci_0 … construction $_n$ … years

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Fatigue Deterioration of Welded Steel Structures

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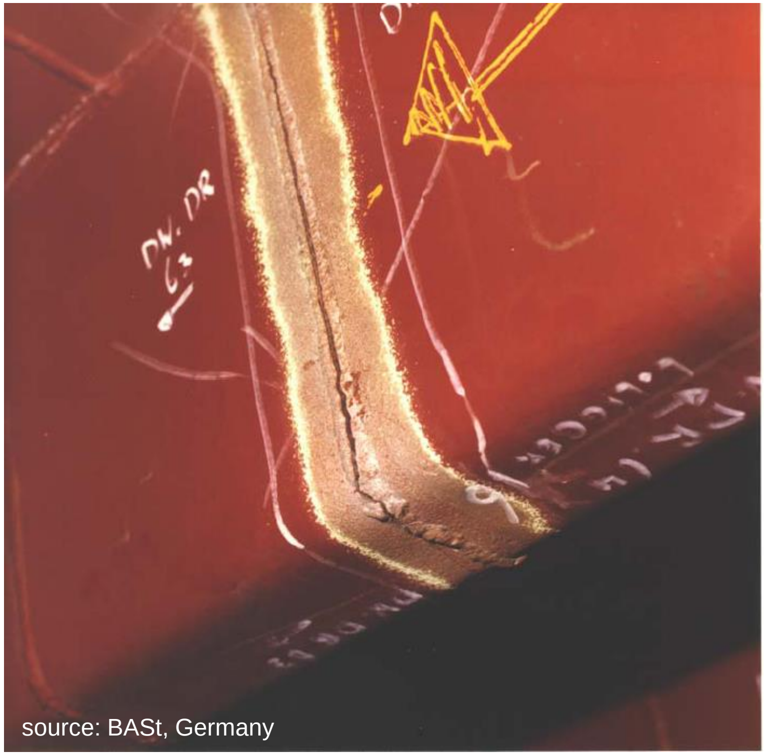

These crack show up in the dynamic response of the structure!

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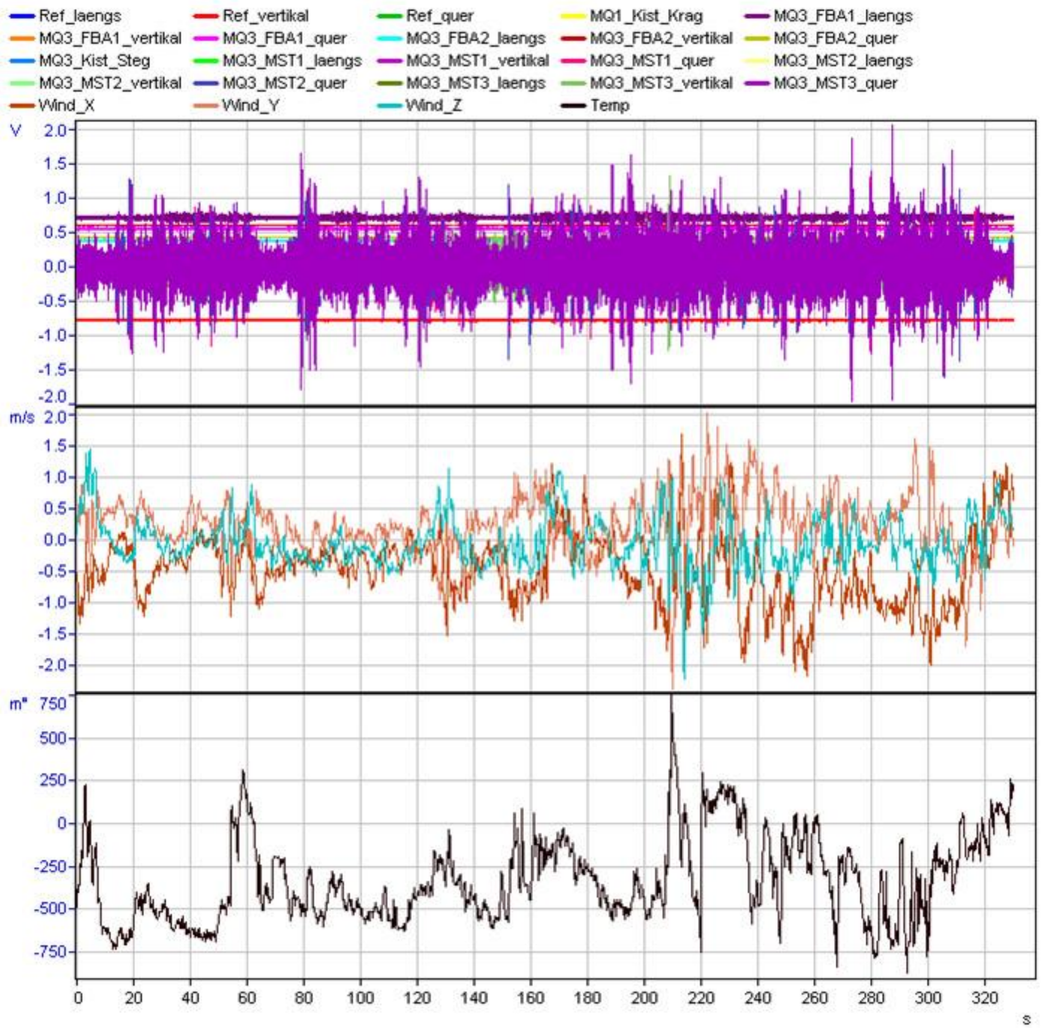
Fatigue Life Determination

Permanent Monitoring-System



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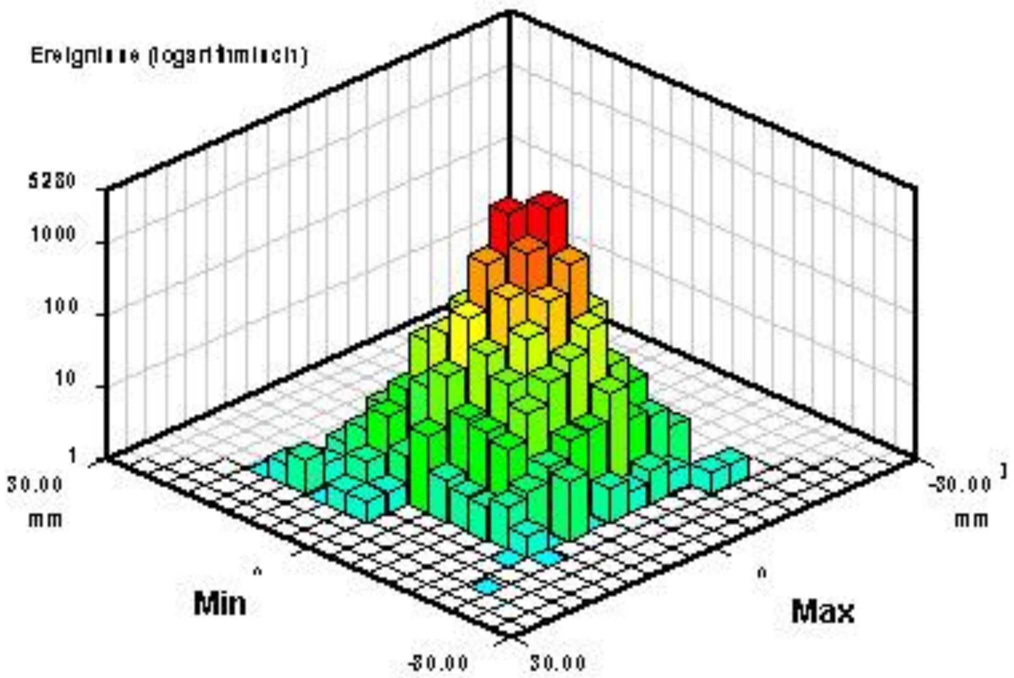
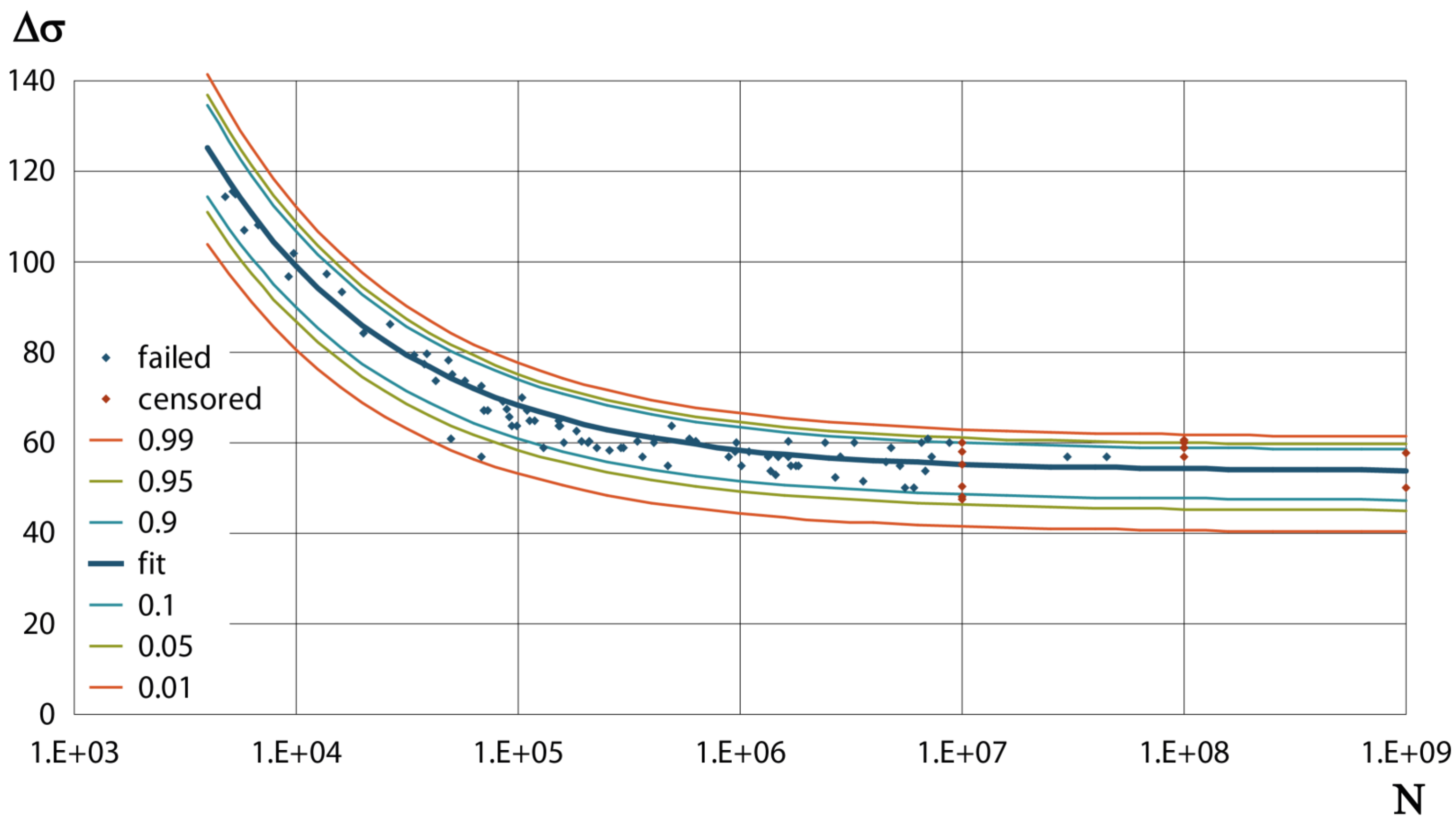
Fatigue Life Determination

Rainflow-Matrix (Counting)



Fatigue Life Determination
Fatigue Contribution (Wöhler-Curves)



Fatigue Life Determination
Damage-Matrix (Assessment)

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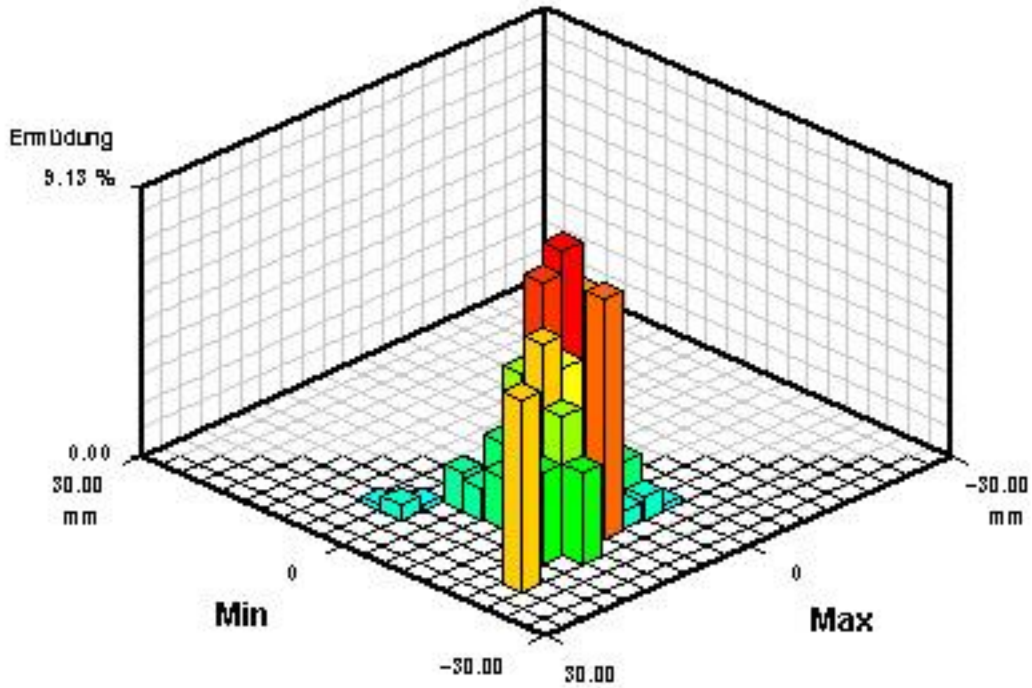

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Date: 2014-01
CEN/TC 319
Secretariat: NEN UNI

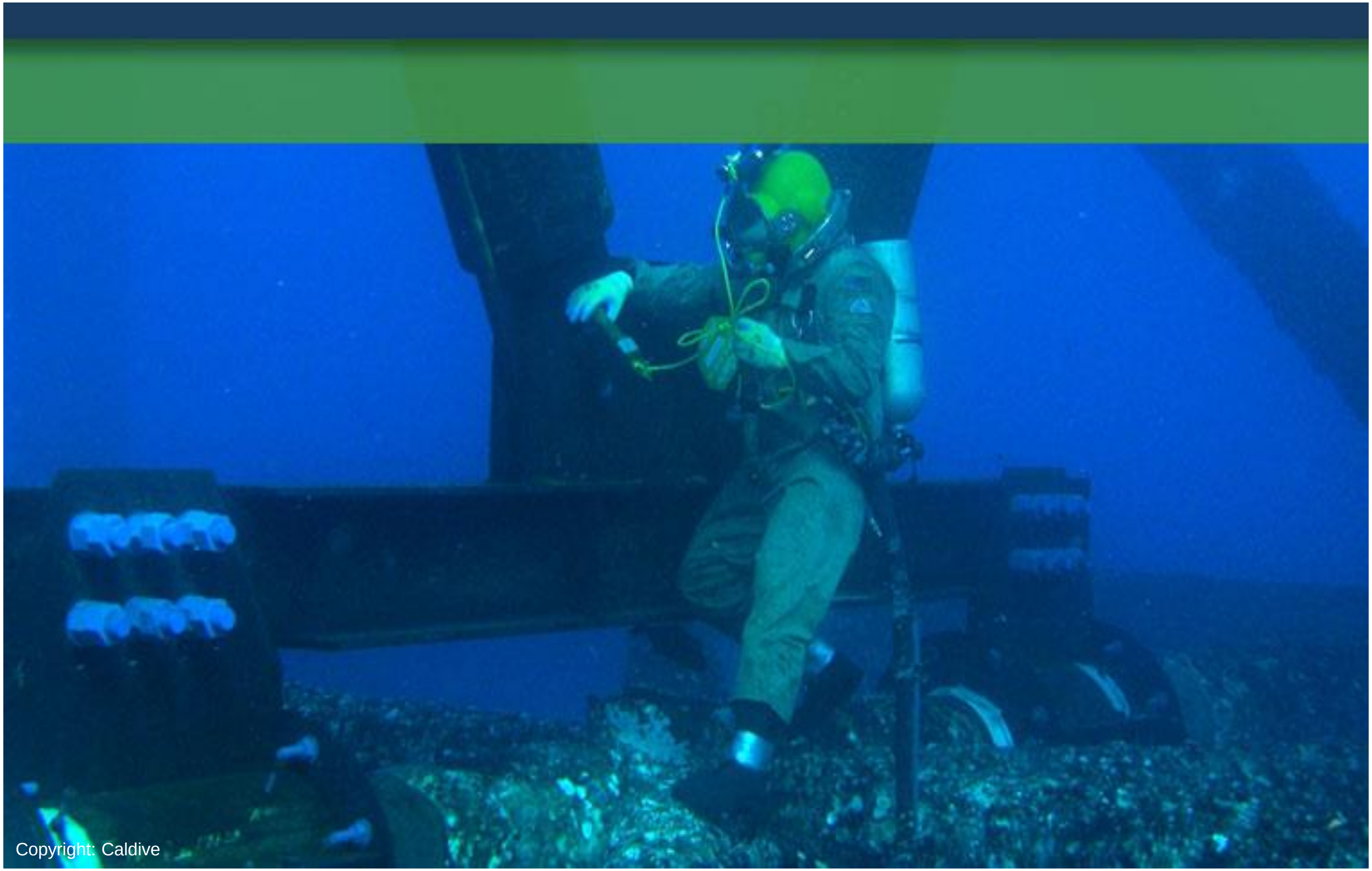
Risk-Based Inspection Framework

Document type: European Standard
Document subtype:
Document stage: CEN Enquiry
Document language: E

Offshore Wind Industry

Different Asset Management Concepts

SHManager®



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Offshore Wind Industry
Different Asset Management Concepts

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Offshore Wind Industry
Different Asset Management Concepts

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Offshore Wind Industry

Different Asset Management Concepts

Targeted Inspection Programme

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ntenance and replacement according to standard maintenance-intervals

erstructure	concrete	
ace	90 (-45/+30) years	2017
ntenance	30 years	2002, 2032
structure	concrete	
ace	90 years	
ntenance	30 years	2002, 2032
ring	rubber	
ace	50 (+/-20) years	2002, 2022, 2042
ntenance	- years	
e beam	concrete	
ace	33 (+/-16) years	1989, 2005, 2021, 2022, 2038
ntenance	25 years	1997, 2030
. joint	steel profile, synthetic resing concrete, rubber	
ace	30 years	2002, 2032
ntenance	10 years	1982, 1992, 2012, 2022, 2042
le rail	steel	
ace	25 years	1997, 2022, 2047
ntenance	- years	
ng	steel	
ace	50 years	2022
ntenance	20 years	1992, 2012, 2042
nage	cast-iron inlet with steel collector pipe	
ace	50 years	2022
ntenance	11 years	1983, 1994, 2005, 2016, 2033, 2044

Targeted Inspection Programme

Inspection Schedule & Programm

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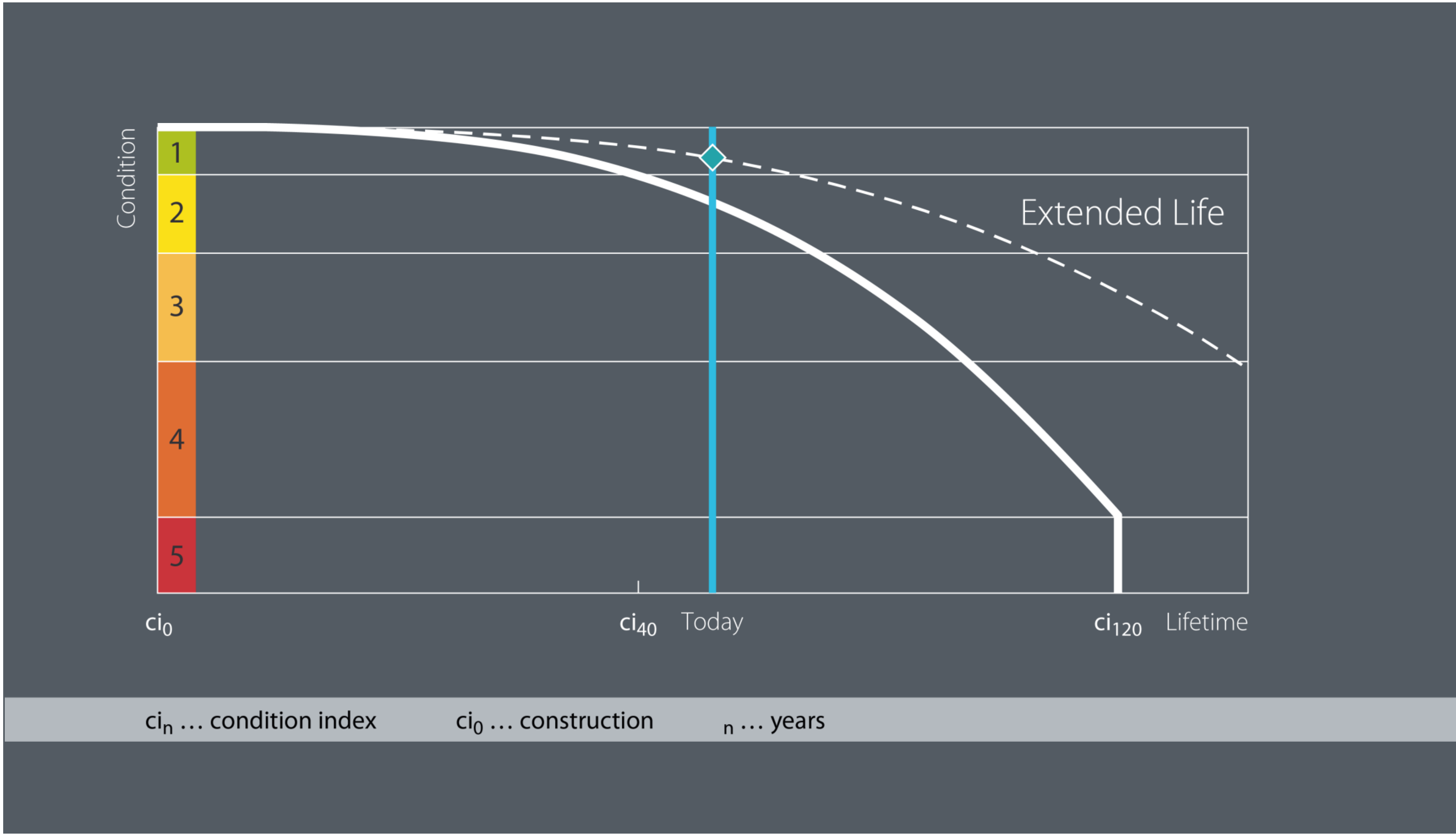

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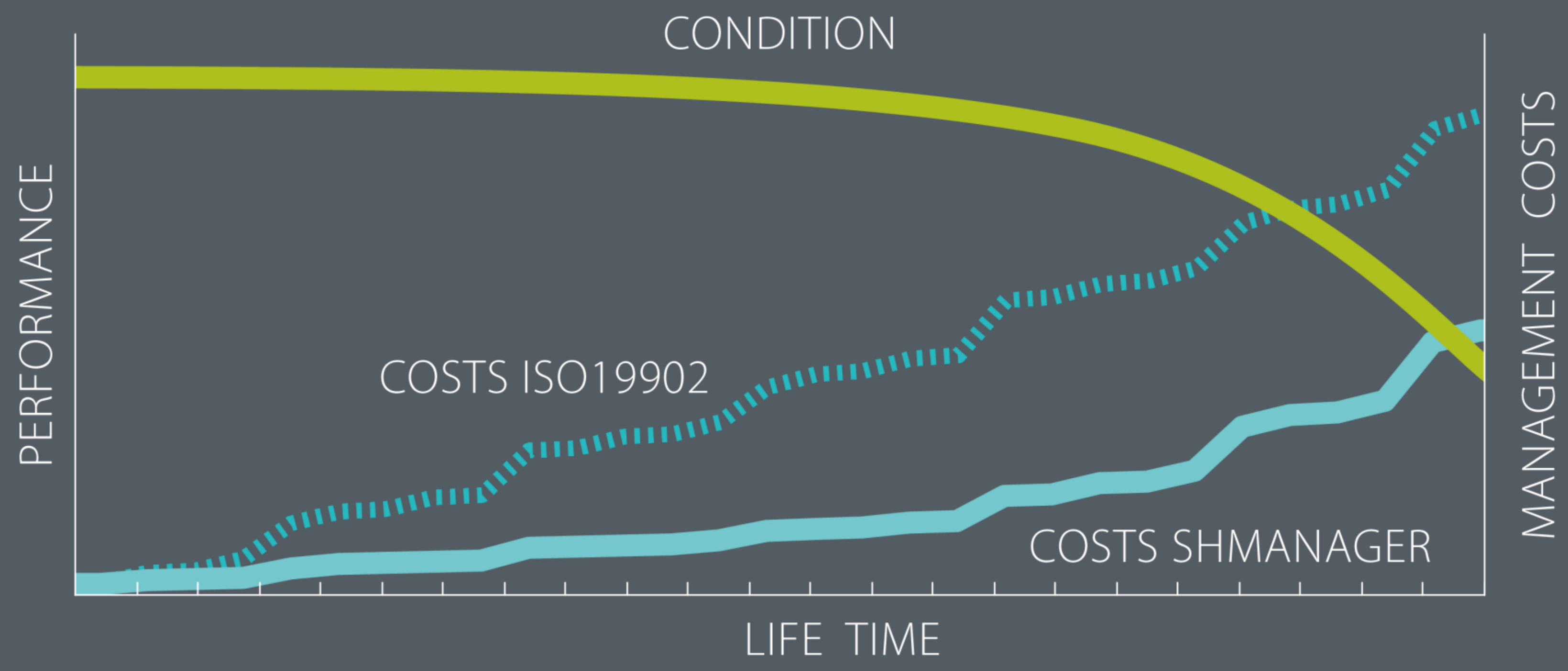
Targeted Inspection Programme

Condition vs. Management Costs

► Reduced Management Costs ◄



Quantification of Life Extension

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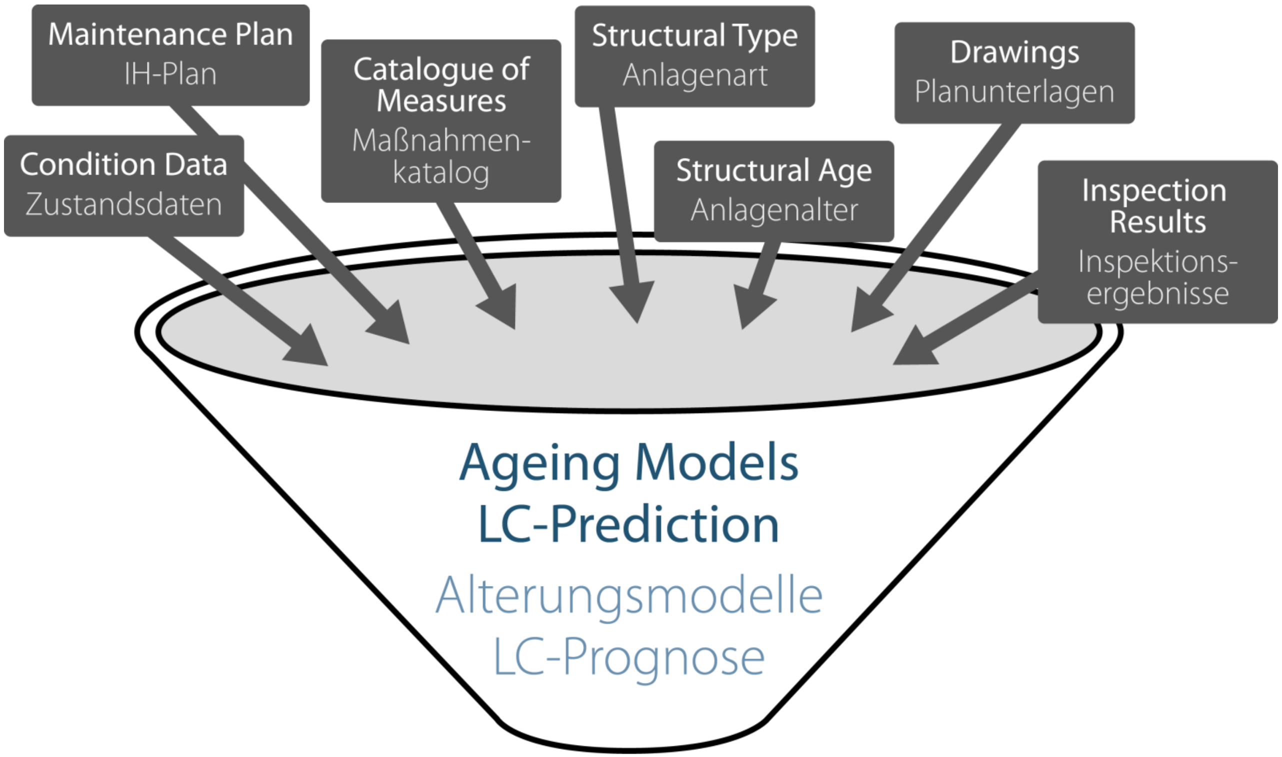
Quantification of Life Extension

SHManager®



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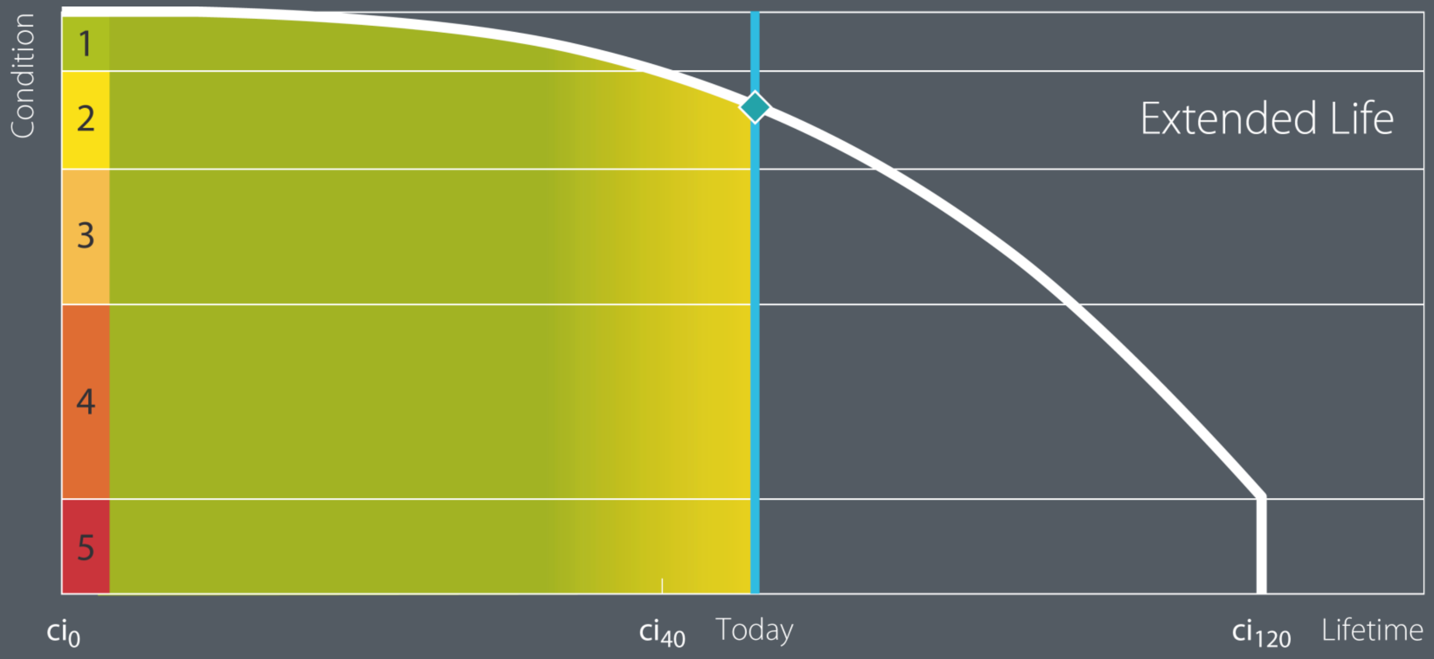
Quantification of Life Extension

Extension of Life Potential

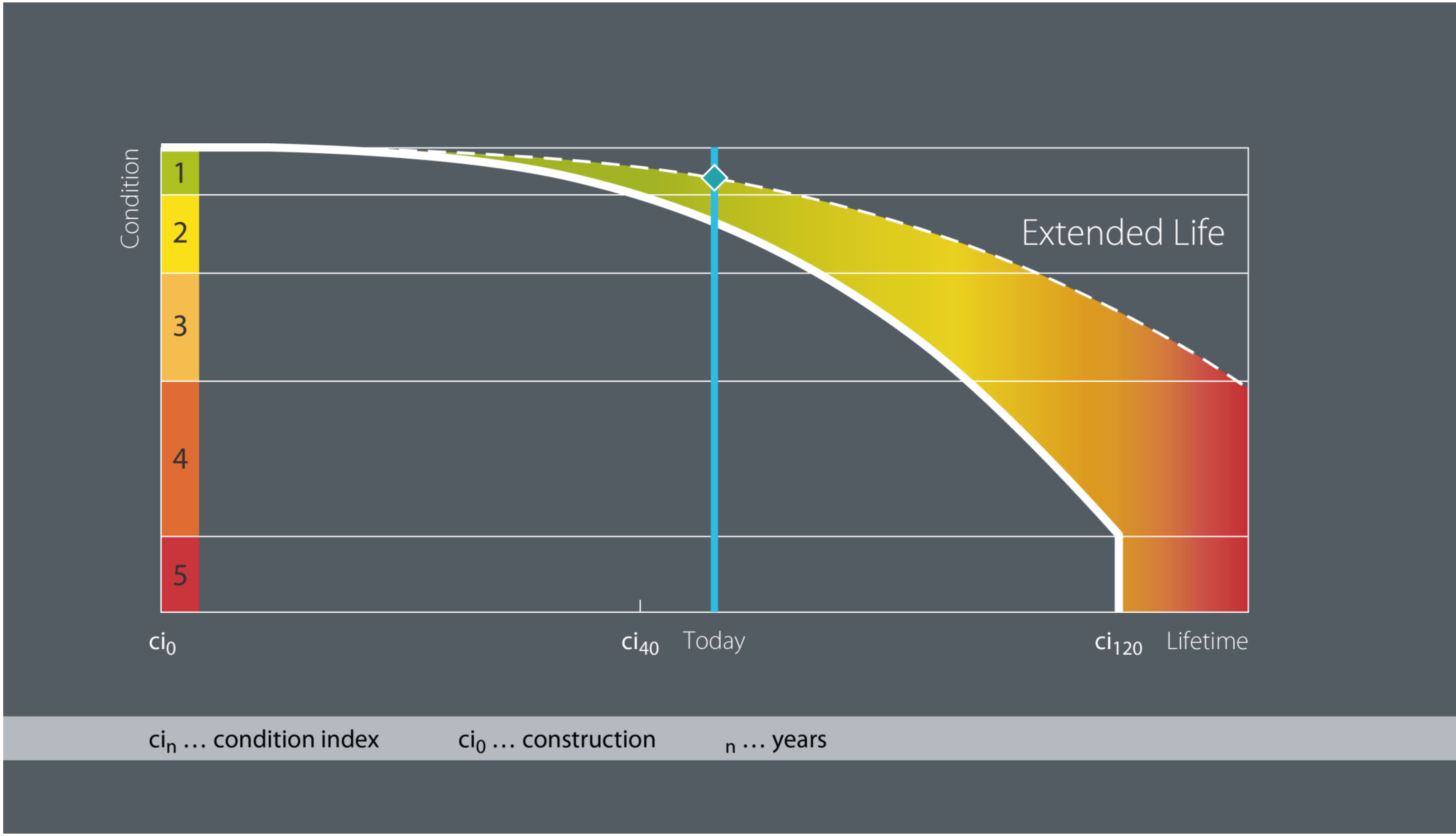


ci_n … condition index ci_0 … construction $_n$ … years

Quantification of Life Extension

Extension of Life Potential

SHManager®



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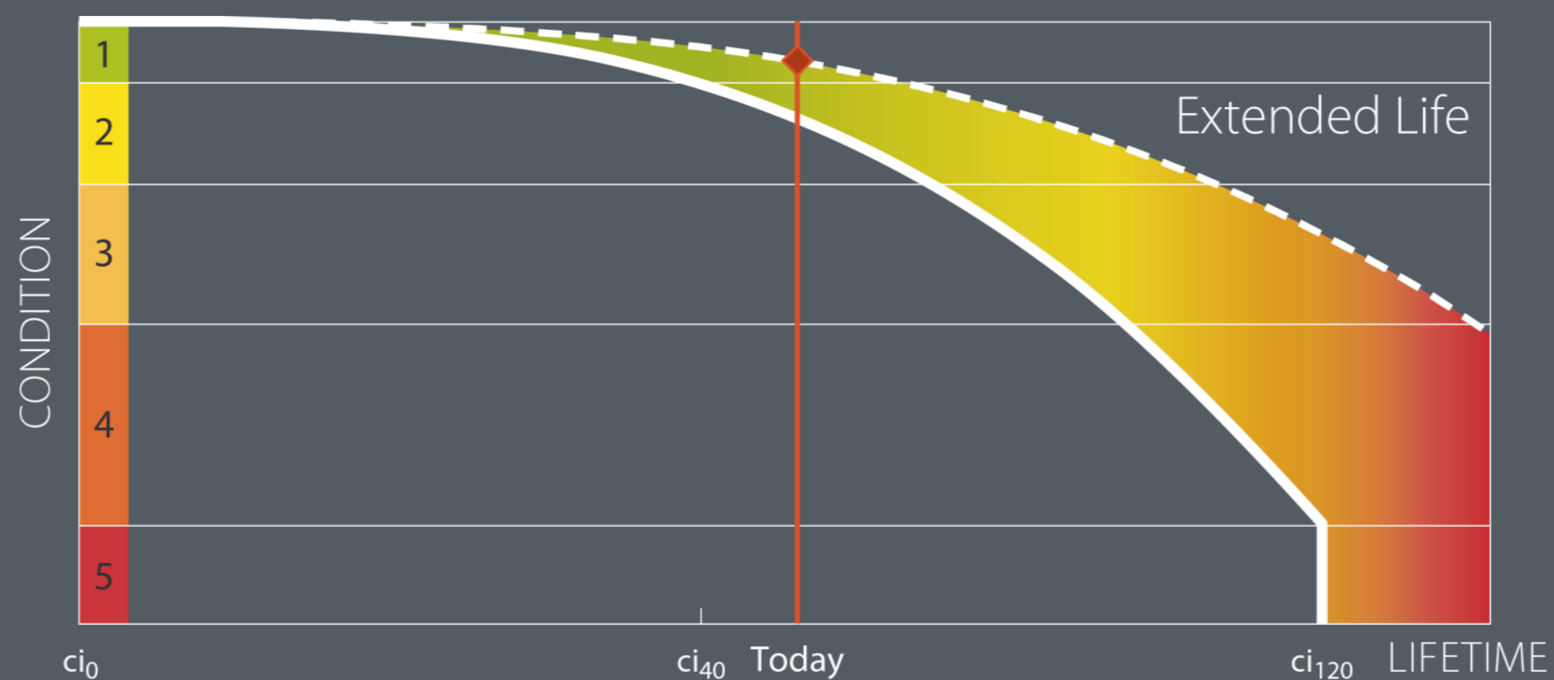
Quantification of Life Extension

Extension of Life Potential

SHManager®

► Potential Life Extension: 16 Years ◄



ci_n … condition index ci_0 … construction $_n$ … years

Decision Support

Ultimate Load

SHManager®

UL Design: 59 400 kN

UL Monitoring: 76 000 kN

CAPACITY: 128 %

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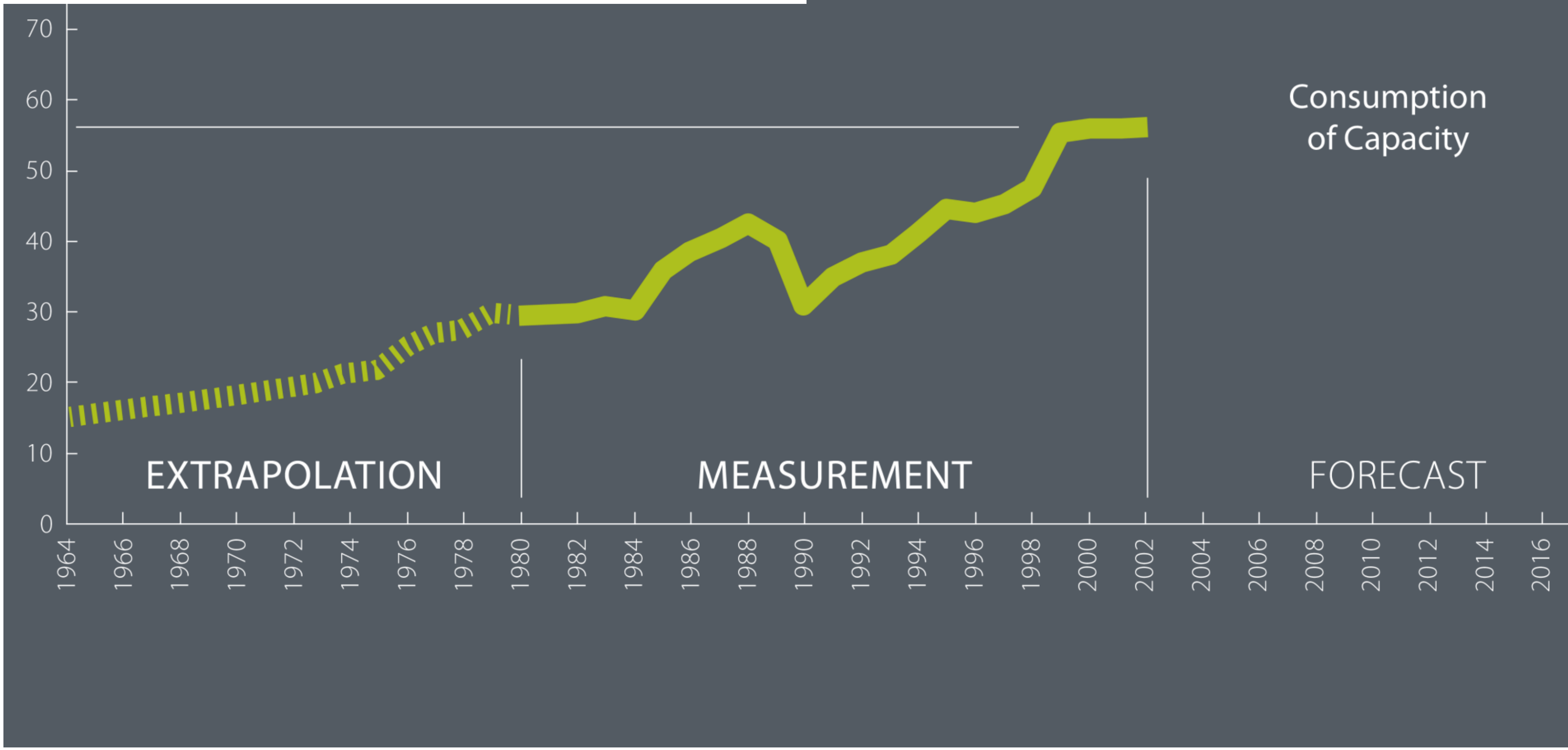
Fatigue Life Determination

Consumed Life

▶ Fatigue Life Consumed 60 % ◀



Targeted Inspection Programme

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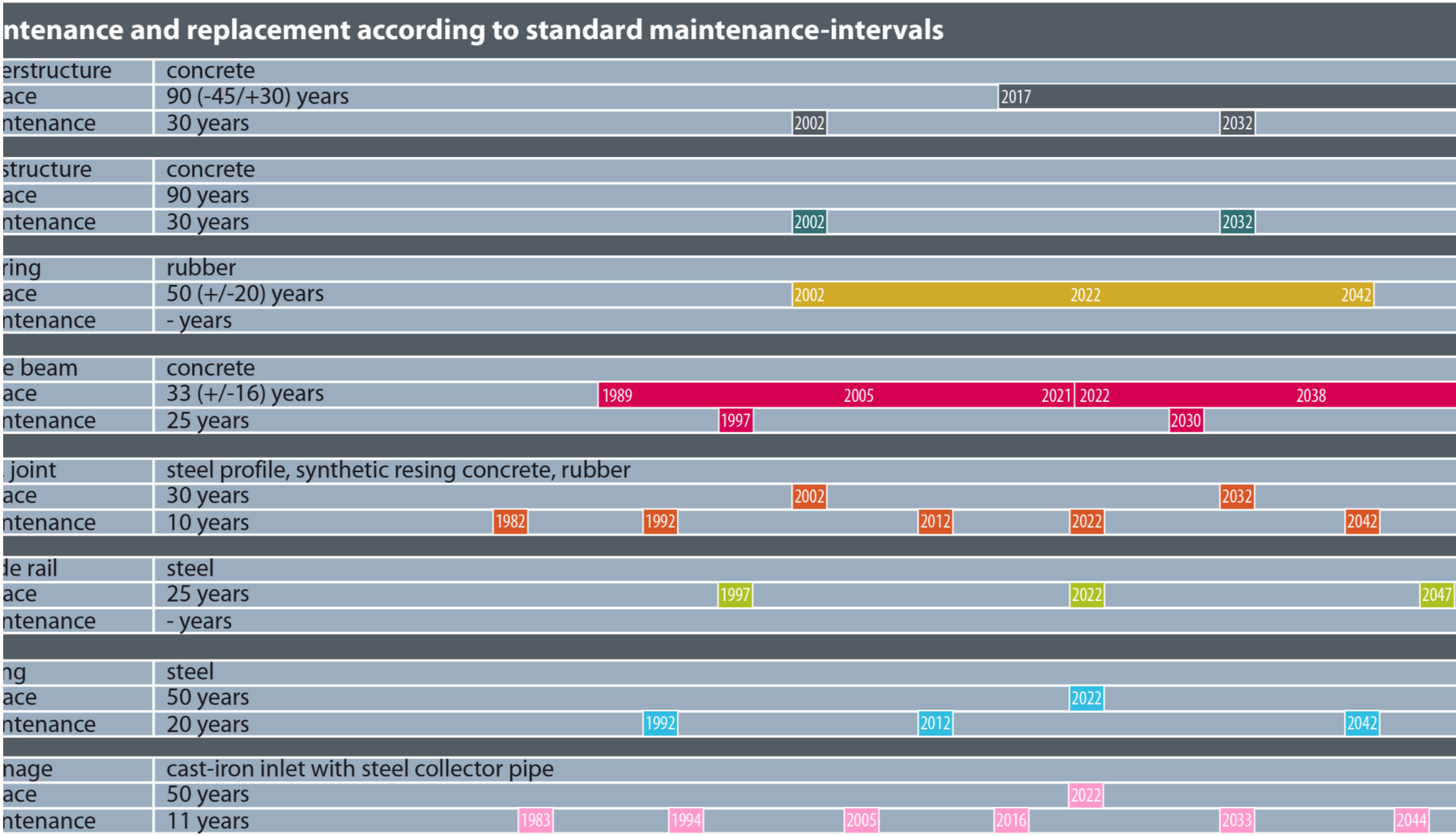

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Quantification of Life Extension

SHManager®

Remaining Life

16 Years

Total Life: 30 + 16 = 46 years

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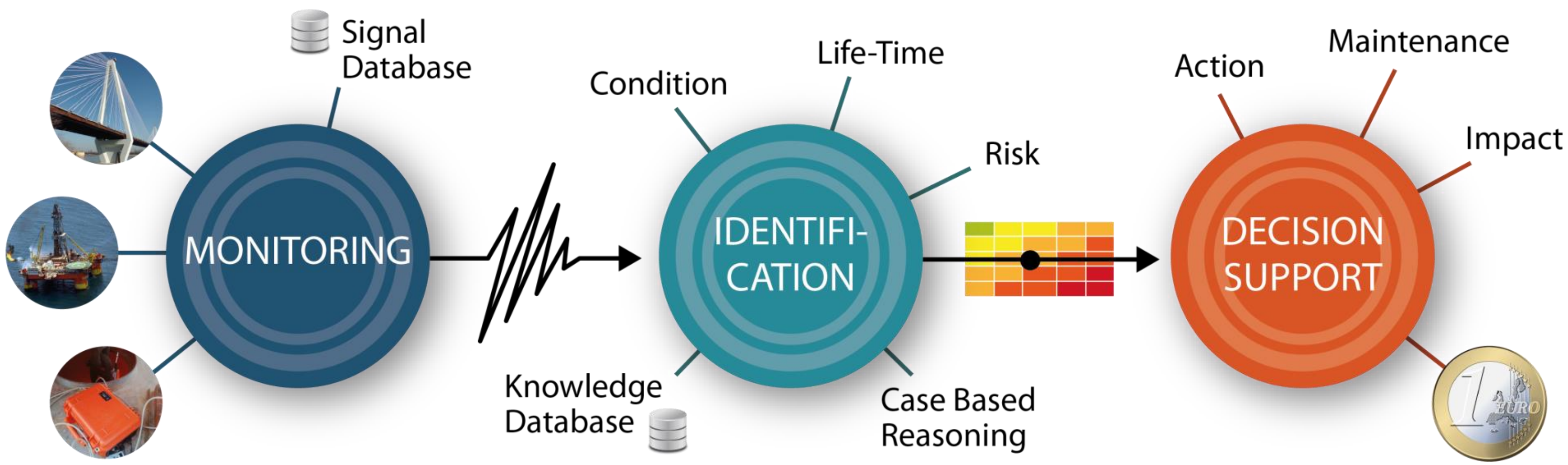
SHM Process



Signal
Database
MONITORING
Condition
Life-Time
Risk
IDENTIFI-
CATION
Knowledge
Database
Case Based
Reasoning
Action
Maintenance
Impact
DECISION
SUPPORT

Offshore Wind Industry
Different Asset Management Concepts

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Summary

SHManager®

- Vibration monitoring is a most helpful tool
- Accurate Condition rating and performance assessment is feasible using Monitoring Information
- Asset Management is supported (knowledge)
- Costs are reduced without sacrificing safety (knowledge)
- Inspection programs are individually designed
- Extension of life time is quantified and justified

Thank You !

helmut.wenzel@boku.ac.at

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