JCSS ♦ Assessment of Existing Structures ♦ 2021

Assessment of bridges based on updated information: *current practice and potential for further developments, Croatian perspective*

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1. Introduction: research and actions of the Chair for Bridges

- **Action TU 1406: Quality specifications for road bridges, standardisation at a European level; www.tu1406.eu**

- **Action TU1402: Quantifying the value of structural health monitoring; www.cost-tu1402.eu**

- **Key Performance Indicators of existing bridges, supported by University of Zagreb**

- **Influence of concrete damage on reinforcement corrosion - computer simulation and in service performance of bridges: CODEbridges https://www.grad.unizg.hr/codebridges**

- **Durability of reinforced concrete structures - Croatian and Canadian practices: CROCANDY**

2. Condition assessment

Five road authorities responsible for approximately 3500 bridges

Road authority	Croatian Motorways	Rijeka- Zagreb Motorway	Croatian Roads	City of Zagreb	County roads of Krapina-Zagorje County
Total length of road network [km]	2 x 920.5 (full motorway profile)	2 x 175.0 (full motorway profile)	7129.62	2589.00	661.23
Road classification	Motorways	Motorways	National roads	Unclassified roads	County and local roads
Number of bridges	1 213 (L > 5 m)	75 large bridges; > 100 overpasses, underpasses and other passages/ crosses	≈ 1 800 (L > 2 m)	≈ 228 (L > 2 m)	70 (L > 5 m)
Duration of the program for investment in the maintenance	1 year	1-2 years	4 years	1 year	1 year
Updated bridge inventory	Yes	Yes	Yes	Yes	Yes
Bridge management system	Yes, since 2008	No	Yes, since 1996, updated in 2001	No	No
Basis for decision on repairs, reconstruction or demolition of bridges	Periodical visual inspection; Hazards followed by non-periodical visual inspection	Periodical visual inspection; Hazards followed by non-periodical visual inspection	Periodical visual inspection; Hazards followed by non-periodical visual inspection	Periodical visual inspection; Hazards followed by non-periodical visual inspection	Periodical visual inspection; Hazards followed by non-periodical visual inspection
Developed standardized procedure for visual inspection of bridges	Yes	Yes	Yes	No	No
Type and frequency of periodical visual inspection of bridges					
Routine – regular road patrol	min 3x/day	min 3x/day	min 1x/day	n/a	min 3x/day
Seasonal visual inspection	2x/year	2x/year	-	-	2x/year
Annual visual inspection	-	-	1x/2 years	1x/2 years	-
Main visual inspection	1x/6 years	1x/6 years	1x/6 years	1x/6 years	1x/6 years

- **BMS** established only by CM and CR
- For other road bridges → **visual inspections** → less objective results
- **Periodical visual inspection**

→ basis for development of bridge maintenance program

→ making decisions on non-regular maintenance

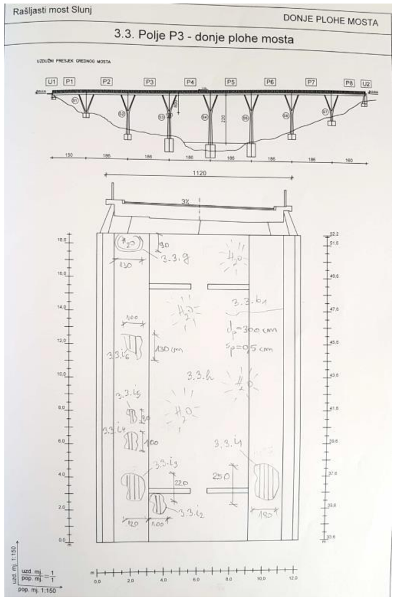
- **Special visual inspection** complemented by testing

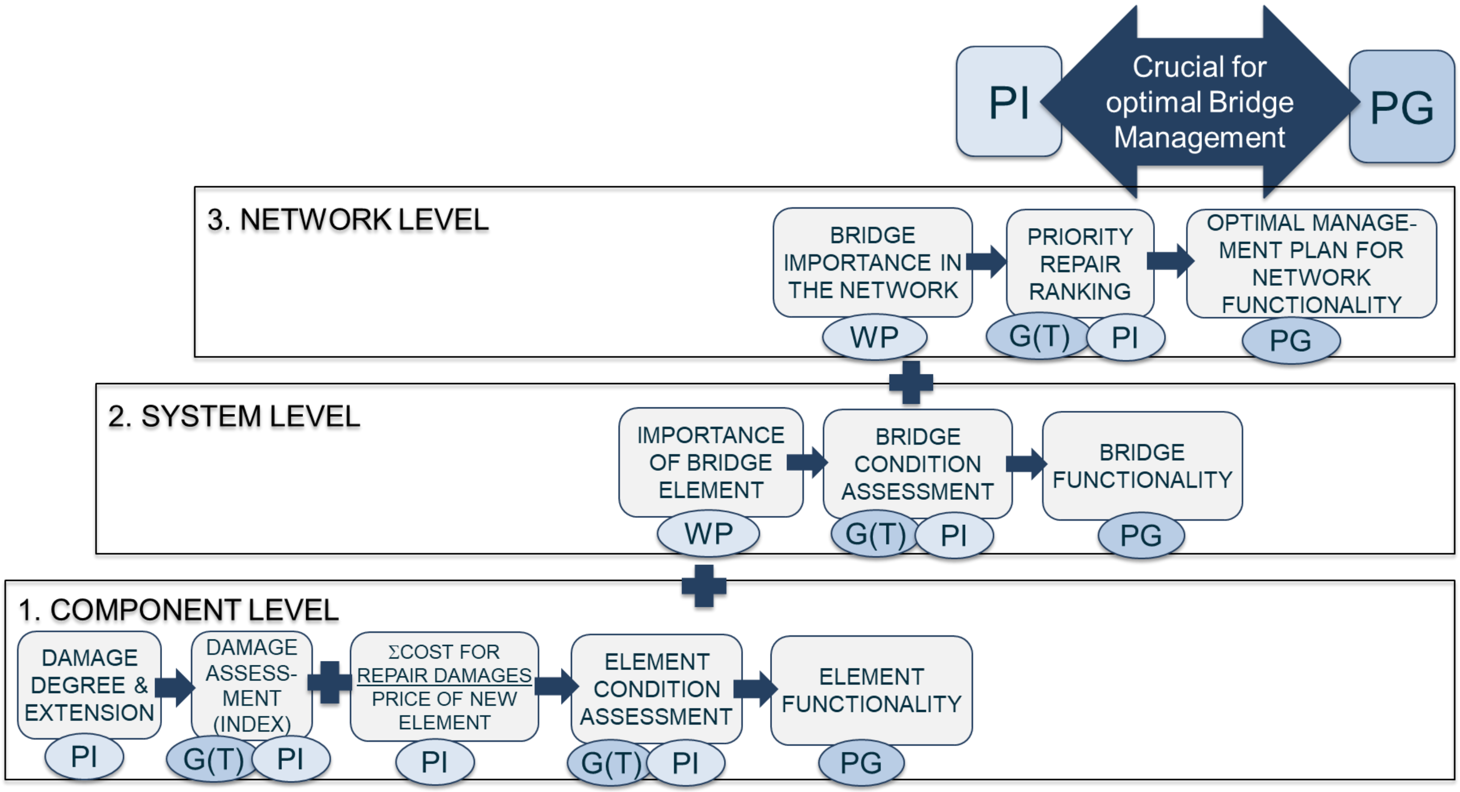
→ carried out after decision on required increased maintenance,

→ in order to define scope and complexity of rehabilitation work.

2. Condition assessment

from the component damage, through the bridge condition, up to the priority ranking at the network level





2. Condition assessment

PI ↔ PG: COMPONENT LEVEL

- Inspection carried out by components forming three main sub-systems

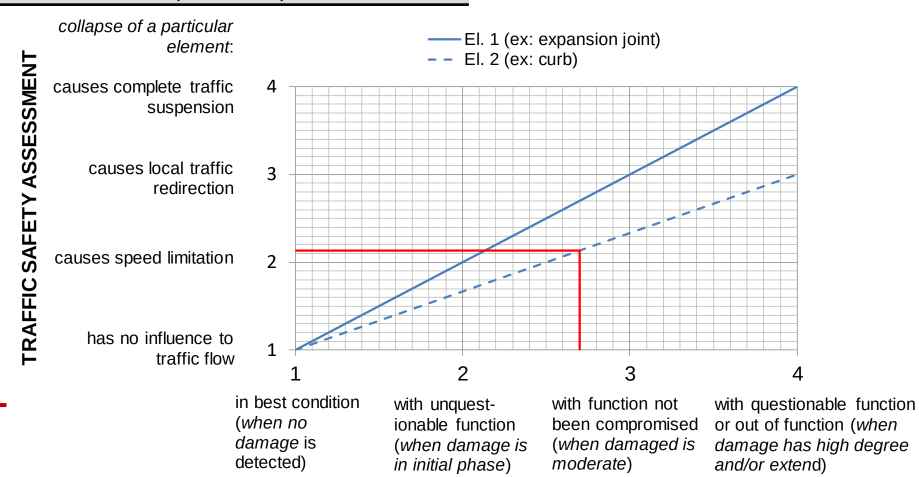
Substructure	Superstructure	Roadway + equipment
Foundations (concrete)	Superstructure (reinforced concrete)	Pavement
Deep foundations, piles (concrete)	Superstructure (prestressed concrete)	Curb & Cornices
Deep foundations, piles (steel)	Superstructure (steel)	Railings & anchorage, barriers
Deep foundations,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

2. Condition assessment

PI ↔ PG: SYSTEM LEVEL

- Importance of the component to evaluate impact to the entire structure

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



$T=1+((EL-1)*(T_{MAX}-1)/3)$

2. Condition assessment

PI ↔ PG: SYSTEM LEVEL

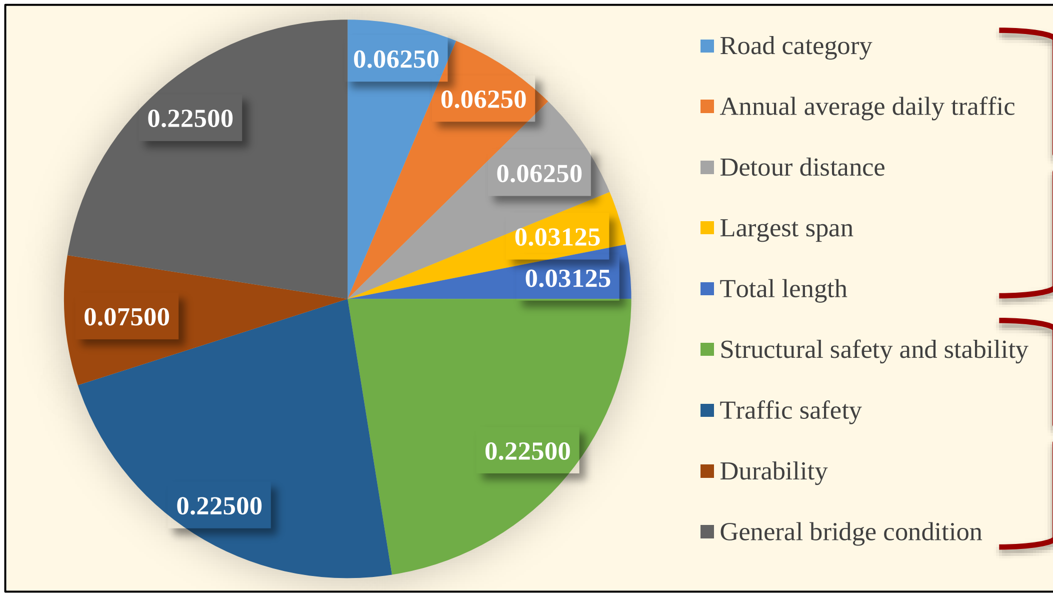
- + introducing bridge availability in the case of measures necessary in relation to bridge condition assessment

ROAD TRAFFIC	***KPI*$_{AV,SY,road}$**
Traffic flow on the bridge is flowing smoothly, without the need for slowing down	1
Traffic flow is slowed down and jammed due to bridge pavement condition; both lanes are functioning	2
Traffic from both directions is in the same lane, along with speed restrictions	3
Traffic restrictions for heavy vehicles, trucks etc.	4
A bridge is closed for traffic	5
RAIL (TRAIN, TRAMS) TRAFFIC	***KPI*$_{AV,SY,rail}$**
Railroad traffic is flowing smoothly	1
Traffic is slowed down due to rails conditions	2
Traffic is flowing only on one rail track - separately from both directions	3
Traffic restriction for trams/trains	4
A bridge is closed for all the rail tracks	5

2. Condition assessment

PI ↔ PG: NETWORK LEVEL

- Example of weight of performance criteria for priority repair ranking



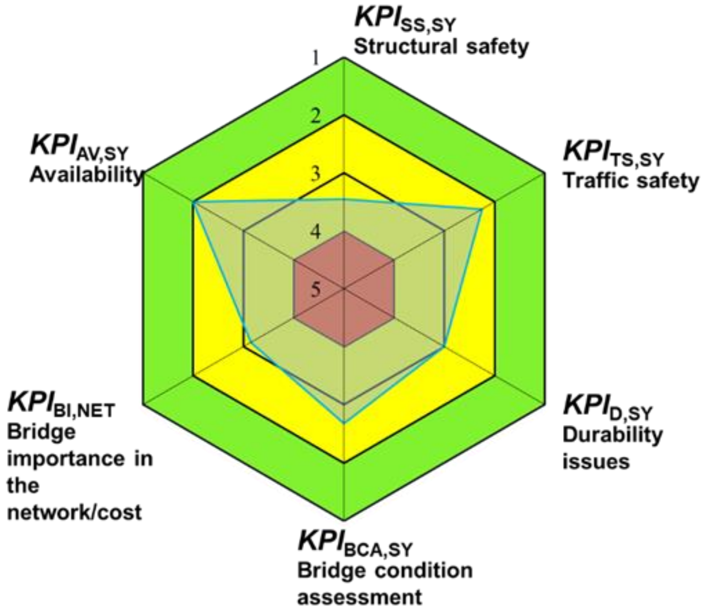
Indicating bridge importance in the network: 25% weight

Indicating bridge condition assessment: 75% weight

ROAD CATEGORY[1]	G_{RC}	ANNUAL AVERAGE DAILY TRAFFIC[2] (N vehicles)	G_{AADT}	DETOUR DISTANCE[3] (km)	G_{DD}	LARGEST SPAN[4] (m)	G_{LS}	TOTAL LENGTH[5] (m)	G_{TL}
unclassified road	1	< 500	1	adjacent traffic lane	1	<5	1	<20	1
local road	2	500 -15000	2	< 5km	2	5-20	2	20-80	2
inter-state road	3	15000-50000	3	5km-20km	3	20-50	3	80-200	3
state road	4	50000-500000	4	20km-60km	4	50-100	4	200-500	4
highway	5	>500000	5	> 60 km	5	>100	5	>500	5

2. Condition assessment

- Example graphical representation of the six most important bridge KPIs + table representation of most influencing individual part for the overall bridge KPIs



Indiv. Parts	$KPI_{SS,IP}$	$KPI_{TS,IP}$	$KPI_{D,IP}$	$KPI_{BCA,IP}$
Sidewalk	2.00	**2.25**	**3.00**	2.33
Pavement	0.69	2.08	2.08	1.72
Girder structure	2.00	2.00	1.00	2.00
Arch structure	3.00	0.75	1.50	2.33
Abutment	0.00	0.00	0.00	0.00
Pillar	**3.45**	0.86	1.73	**2.68**
Drainage	0.67	1.50	2.00	1.50
System	$KPI_{SS,SY}$	$KPI_{TS,SY}$	$KPI_{D,SY}$	$KPI_{BCA,SY}$
Bridge	**3.45**	**2.25**	**3.00**	**2.68**

2. Condition assessment

DAMAGE ASSESSMENT

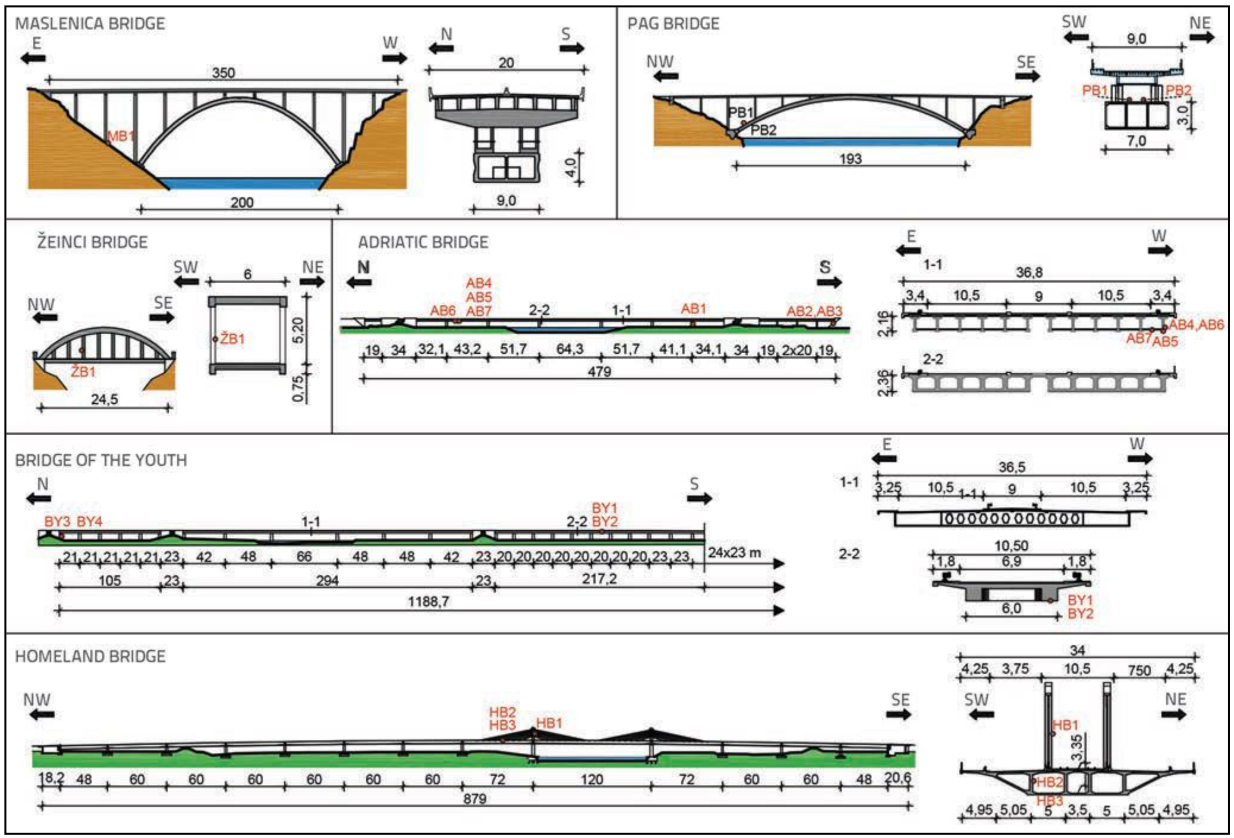
- Four main approaches in damage detection are:
  - visual inspection,
  - non-destructive testing,
  - probing and
  - SHM

key activity in current bridge management

corrosion can be detected only at the advanced stage, when structural repairs are required → chance for optimal maintenance of bridges is lost

3. Pro-active approach to bridge inspection

- **CODEbridges** https://www.grad.unizg.hr/codebridges



3. Pro-active approach to bridge inspection

- **new approach: visual inspection + simple and efficient NDT**

1. **Reinforcement grid, concrete cover and rebar diameter** → cover meter
2. **Crack width** → ruler (crack width rod) and optical microscope
3. **Crack depth and E$_{dyn}$** → ultrasonic pulse velocity device
4. **Crack pattern and concrete cover delamination** → visual inspection + sounding (tapping) with a hammer
5. **Concrete strength** → Schmidt hammer
6. **Corrosion assessment** → half-cell potential and concrete resistivity

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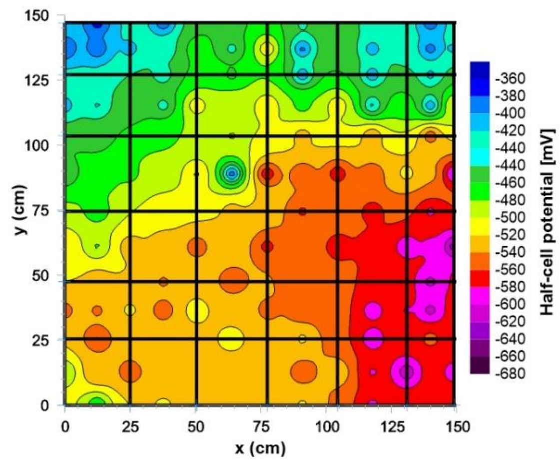
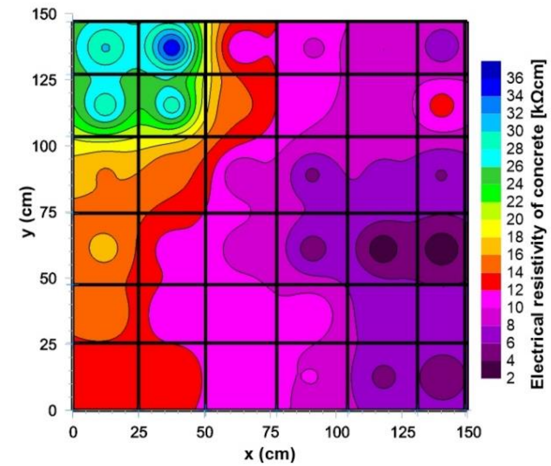
3. Pro-active approach to bridge inspection

Results of non descructive testing at the pier foundation of the Maslenica bridge S2





Measuring location | *very negative* ***half-cell potential*** | *extremely low* ***electrical resistivity***

Visual inspection: few cracks and partial color change on the concrete surface

< -200 mV medium risk
< -350 mV high risk

<50 kΩ cm medium risk
<10 kΩcm high risk

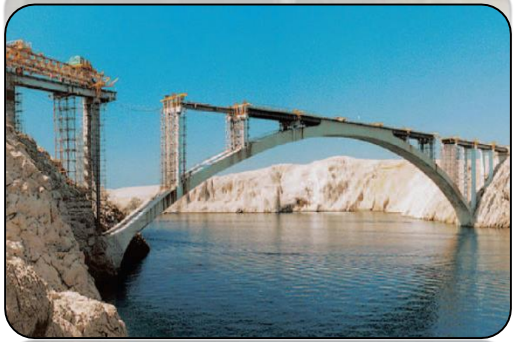
high chloride content in concrete and active corrosion with high corrosion rate

4. Employing safety/reliability assessment

Condition assessment	Safety assessment
▪ Safety evaluation based on ▪ individual components damage assessment and ▪ weight of their influences at the structural safety of the overall bridge	▪ Repeating static analysis in order to ▪ determine the bridge safety more realistic and ▪ reveal bridge reserves in remaining service life ▪ to determine whether and in which way it requires repair or retrofitting

4.1 Adequate assessement of bridges?

- **Current codes for design:**
  - do not offer optimum approach
  - based on conservative assumptions
  - could result in extremely large costs for bridge maintenance
- **Sophisticated methods:**
  - probabilistic approach
  - additional knowledge and assets
  - more complicated for practical application



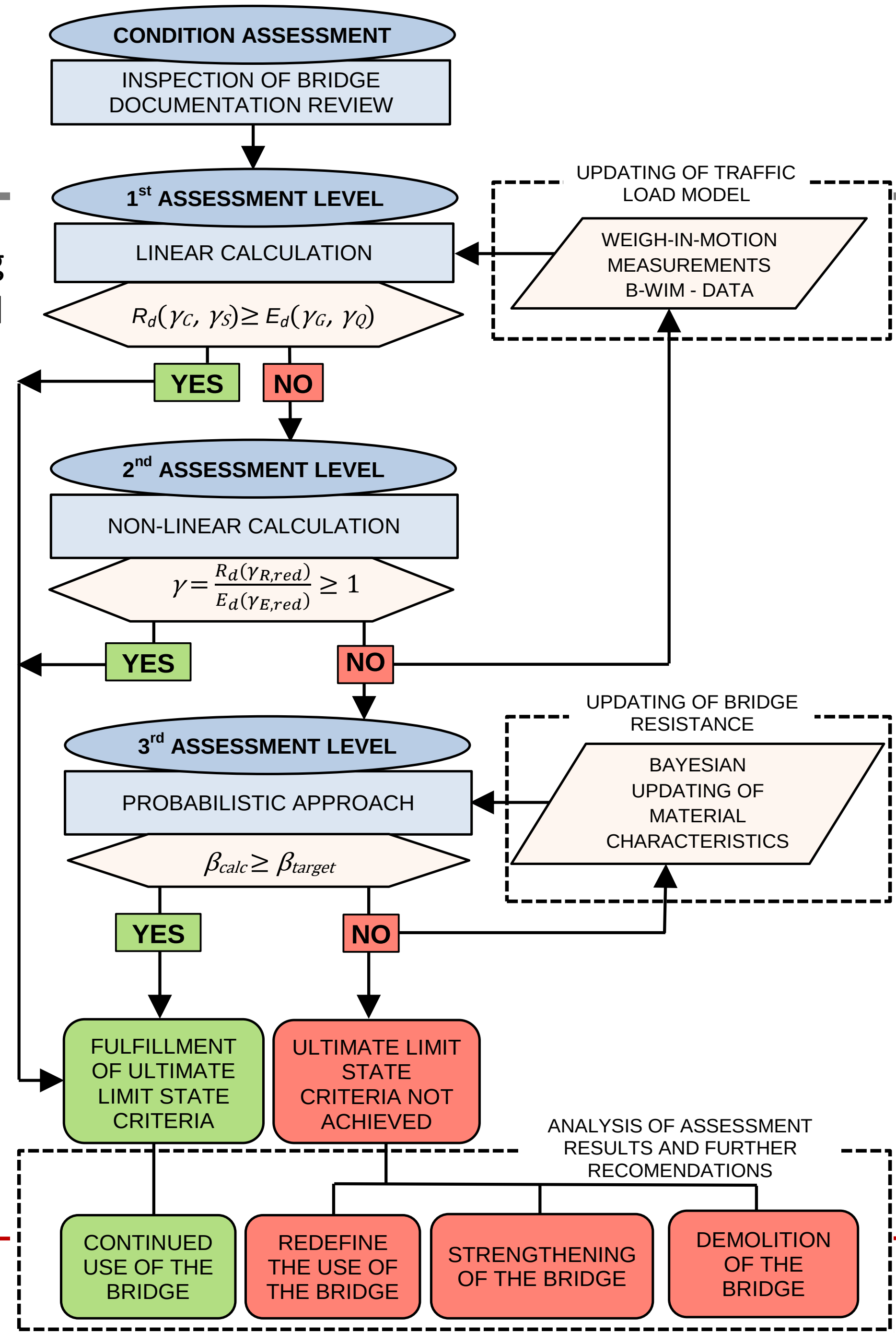
SOLUTION?

MULTI-LEVEL ASSESSMENT METHODS

accuracy & complexity increase on subsequent levels

4.2 Assessment of road bridges for traffic load

- N>> small and medium span bridges, built during 70s and 80s, are designed according to **outdated regulations**.

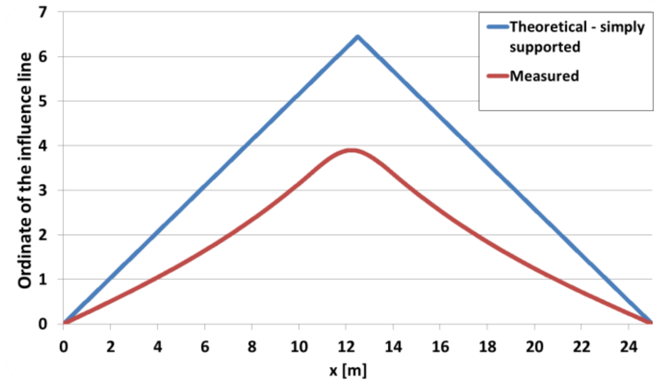


4.3 Implementation of VoI for Quantifying the value of B-WIM

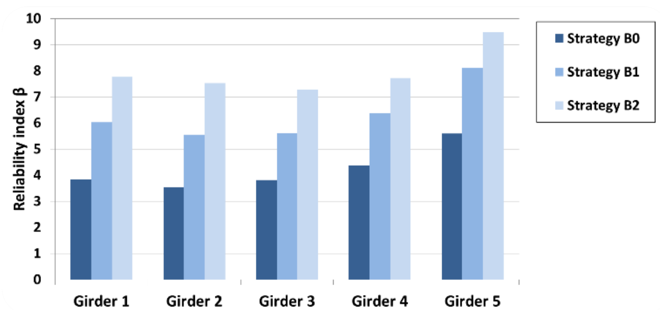
- **Possibilites/goals:**
- reveal hidden bridge reserves
- predict bridge reliability development over a specified lifetime
- permit unrestricted use of a bridge over a much longer remaining service life

- **B-WIM**
- Short: IL, GDF
- Long: DAF, site-specific load models

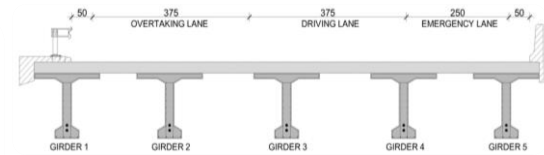
- **VoI:**
- modelling of all the associated probabilities (μ,σ; R, E),
- costs and benefits required for the decision tree (C_{REP}, C_{FAIL}, C_{SHM}, $C_{N/A}$, C_{BV}),
- classification of bridge based on its importance in the infrastructure networks ($f_B = f(G_{RC}, G_{AADT}, G_{DD}, G_{LS}, G_{TL})$)



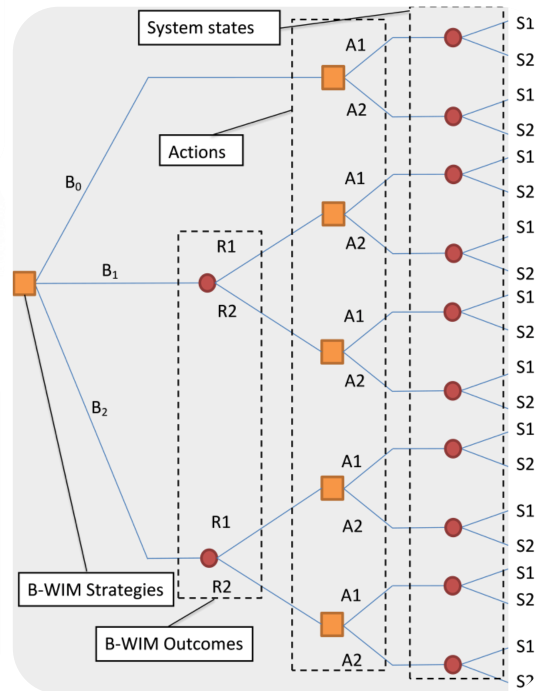
Difference between measured and theoretical influence line



Reliability assessment with and without additional SHM data



Cross Section of Case Study Bridge



Decision tree example for VoI analysis

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5. Conclusion

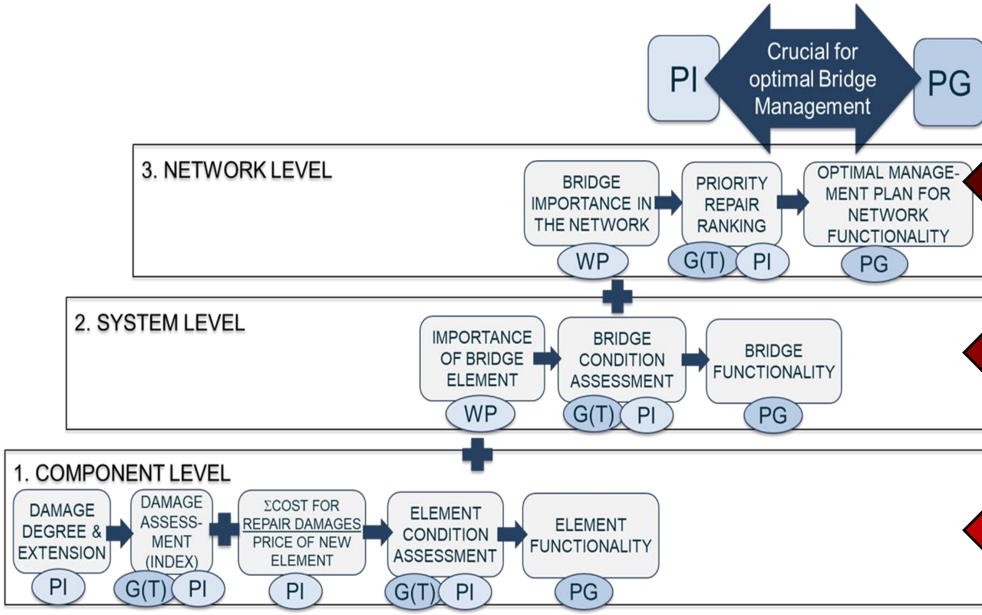
1. Establish a pro-active regular maintenance based on visual inspection supported with adequate testing techniques

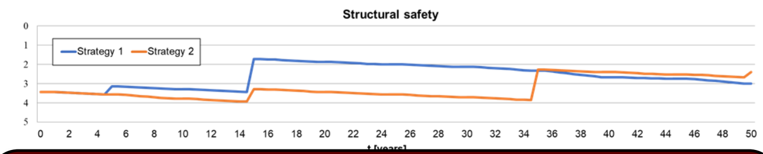
2. Perform multi level assessment methods of existing bridges by structural bridge engineers

3. Activate monitoring methods proven as valuable and collect long term data as inputs for more precise assessment

4. New type of engineers with knowledge from different disciplines (structures, materials, durability, management, …?)

5. Conclusion – guidelines for improvement

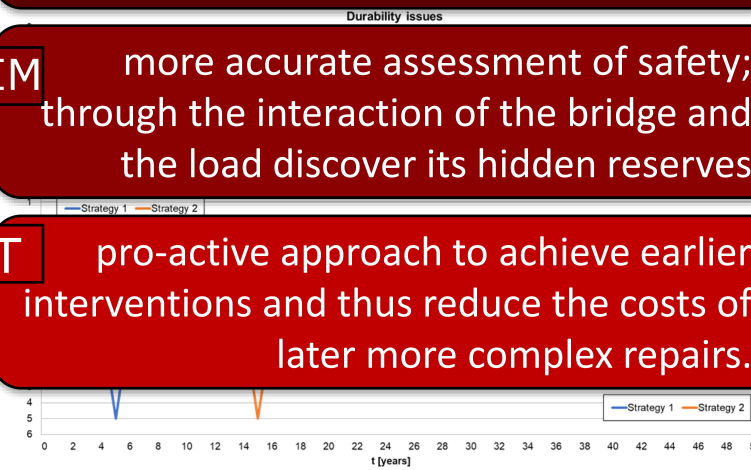




VoI – assess the relationship between costs and benefits - contribution to decision-making in ranking priorities at the network level

B-WIM – more accurate assessment of safety; through the interaction of the bridge and the load discover its hidden reserves

NDT – pro-active approach to achieve earlier interventions and thus reduce the costs of later more complex repairs.



Unique procedure: actual procedures in CRO practice + theoretically established systematization of KPI at the EU level

KPI = *f* (t between inspections)
+ digitalisation of the entire process

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current practice and potential for further developments,

Croatian perspective

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Thank you for your attention!

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