IM-SAFE.EU

Harmonised Transport Infrastructure Monitoring in Europe for Optimal Maintenance and Safety

IM-SAFE (ref. 958171)

www.IM-safe-project.eu

https://www.linkedin.com/company/im-safe-project/

https://cordis.europa.eu/project/id/958171

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AFTERNOON SESSION

Moderated by A.J. Bigaj-van Vliet (TNO, the Netherlands)

Data-informed structural performance assessment

Contributors:

P. Darò [1], G. Mancini [1], A. Strauss [2], D.L. Allaix [3], A.J. Bigaj-van Vliet [3]

Risk assessment and risk-based framework

Contributors:

H. van Meerveld [3], B. Cerar [3], A.J. Bigaj-van Vliet [3], A. Strauss [2], L. Ptacek [2]

[1] SACERTIS Ingegneria S.r.l., Turin, Italy
[2] University of Natural Resources and Life Sciences, Vienna, Austria
[3] TNO, Delft, the Netherlands

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Data-informed structural performance assessment

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Speaker:
P. Darò (SACERTIS Ingegneria S.r.l., Turin, Italy)

Dr.ir. Paola Darò

- IM-SAFE WP Leader (Data informed safety evaluation and maintenance management)
- SACERTIS Ingegneria S.r.l
- Technical Director Engineering Department
- SHM, structural diagnostics, data analytics field expert
- Former Research Fellow DISEG - Politecnico di Torino
- MIT Technology Review Italy - Award as Young Innovator TR35 2019

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DATA-INFORMED STRUCTURAL PERFORMANCE ASSESSMENT

a. **14:00-14:30 |** Overview on the risk-based, reliability based and semi-probabilistic assessment methods for existing structures

Q&A

b. **14:30-15:00 |** Current and future use of monitoring data in the structural assessment process and model updating methods

Q&A

c. **15:00-15:30 |** Risk-based prioritization process for assessment, maintenance monitoring and remedial interventions on existing structures

Q&A

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Definition of Structural Performance

IM-SAFE definition	The **behaviour of a structure**, a **structural component**, or a condition as a consequence of **actions**, usually classified by means of a **quantitative parameters** (e.g. reliability index, ratio between (local/overall) resistance capacity and action effect).

fib Model Code 2010:2013	*COST TU1402*	*ISO 2394:2015*	*ISO 13822:2010*	*ISO 13824:2009*	*ISO 13824:2020*
The behaviour of a structure or a structural element as a consequence of actions to which it is subjected or which it generates.[1]	Behaviour of the structure or one of its members usually quantified by means of a quantitative parameters (e.g. reliability index, ratio between resistance capacity and action effect)	Qualitative or quantitative representation of the behaviour of a structure (e.g. load bearing capacity, stiffness, etc.) related to its safety and serviceability, durability, and robustness.	Qualitative or quantitative representation of the behaviour of a structure (e.g. load bearing capacity, stiffness) in terms of its safety and serviceability.	-	-

[1]Note : In fib Model Code 2010:2013 the term structural performance is referred to as *performance*

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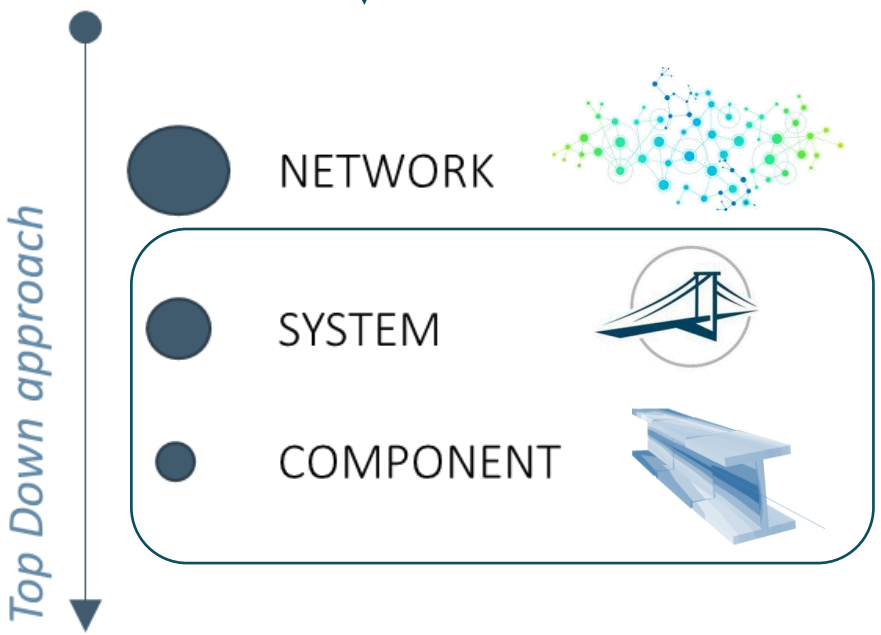

focus of the STRUCTURAL PERFORMANCE ANALYSIS

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RAMSSHE€P risk-driven maintenance concept

(Wagner, 2014)

PERFORMANCE REQUIREMENTS:

TECHNICAL ASPECTS
- **R**eliability
- **A**vailability
- **M**aintainability
- **Safety** → focus of IM-SAFE

SUSTAINABILITY ASPECTS
- **S**ecurity
- **H**ealth
- **E**nvironment
- **E**conomics
- **P**olitics

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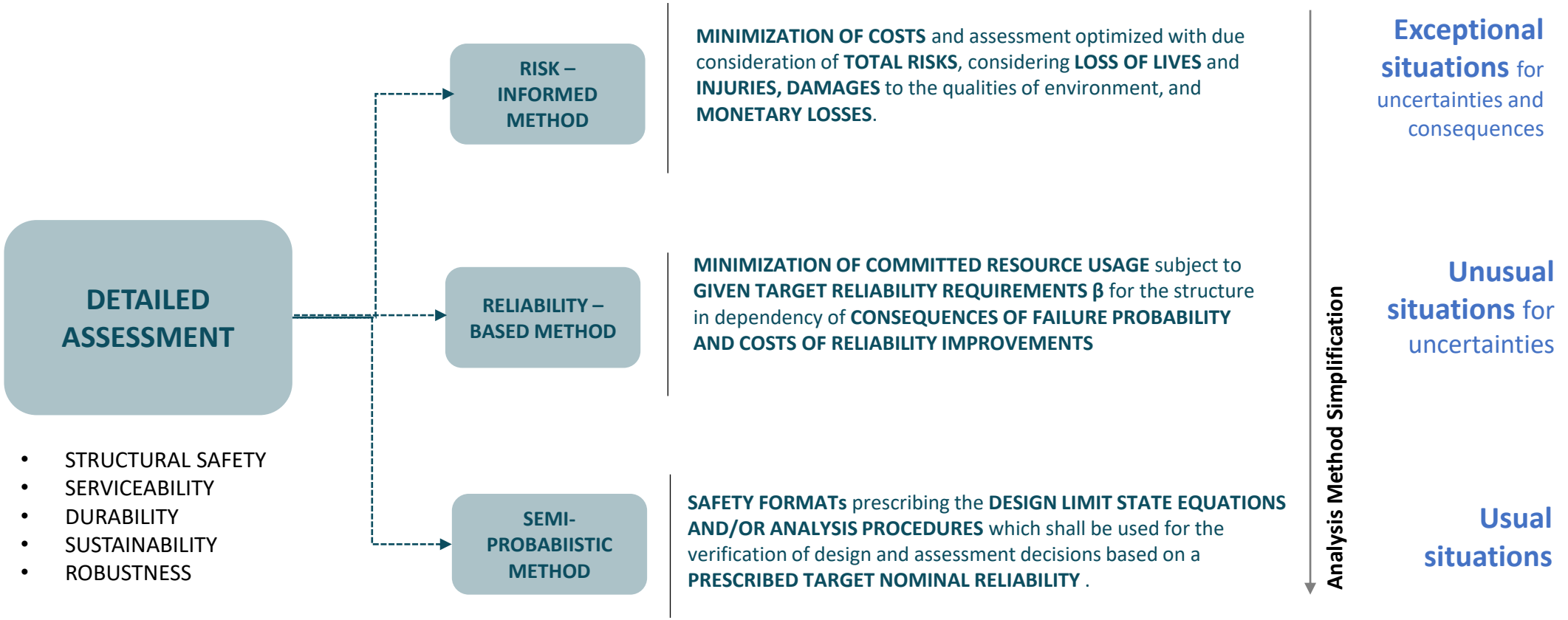
Structural Performance Assessment



- STRUCTURAL SAFETY
- SERVICEABILITY
- DURABILITY
- SUSTAINABILITY
- ROBUSTNESS

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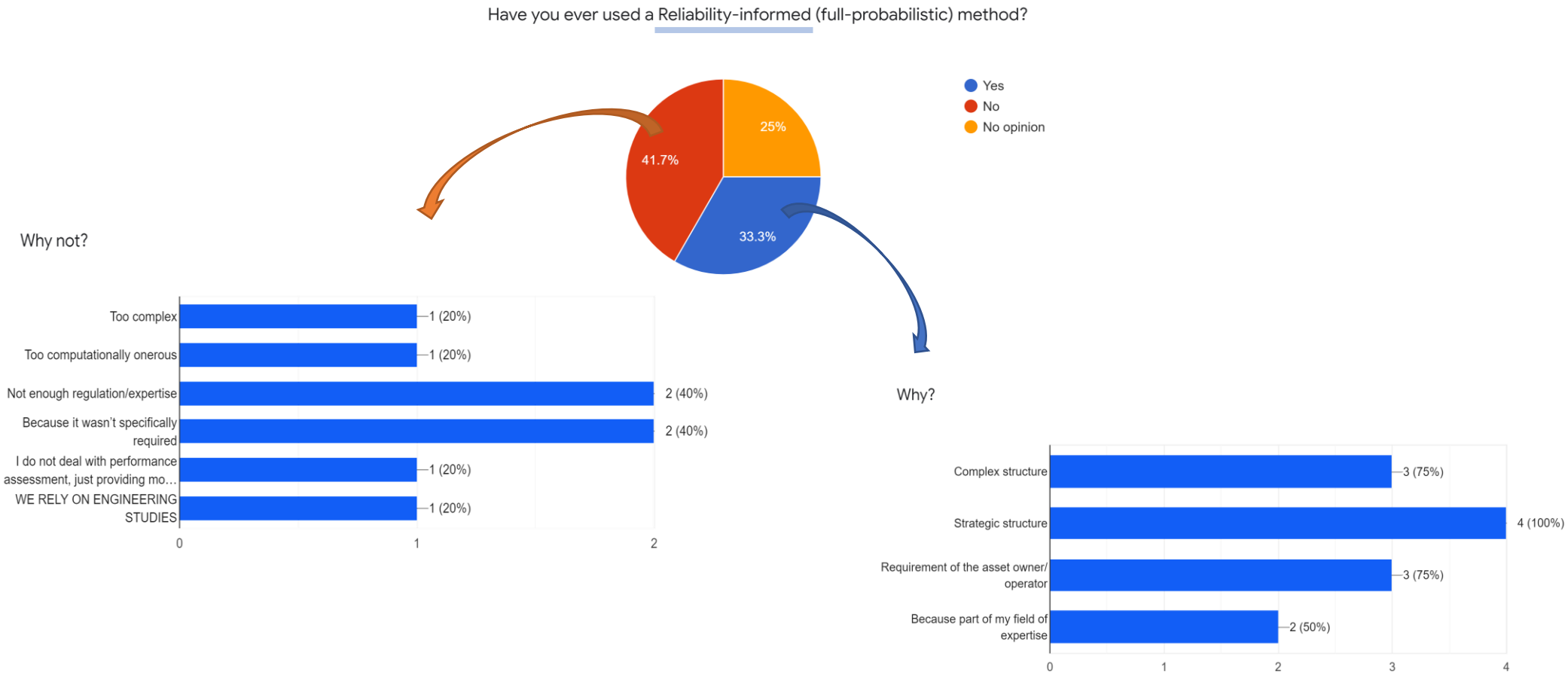
a.

CoP experience

ASSESSMENT METHODS



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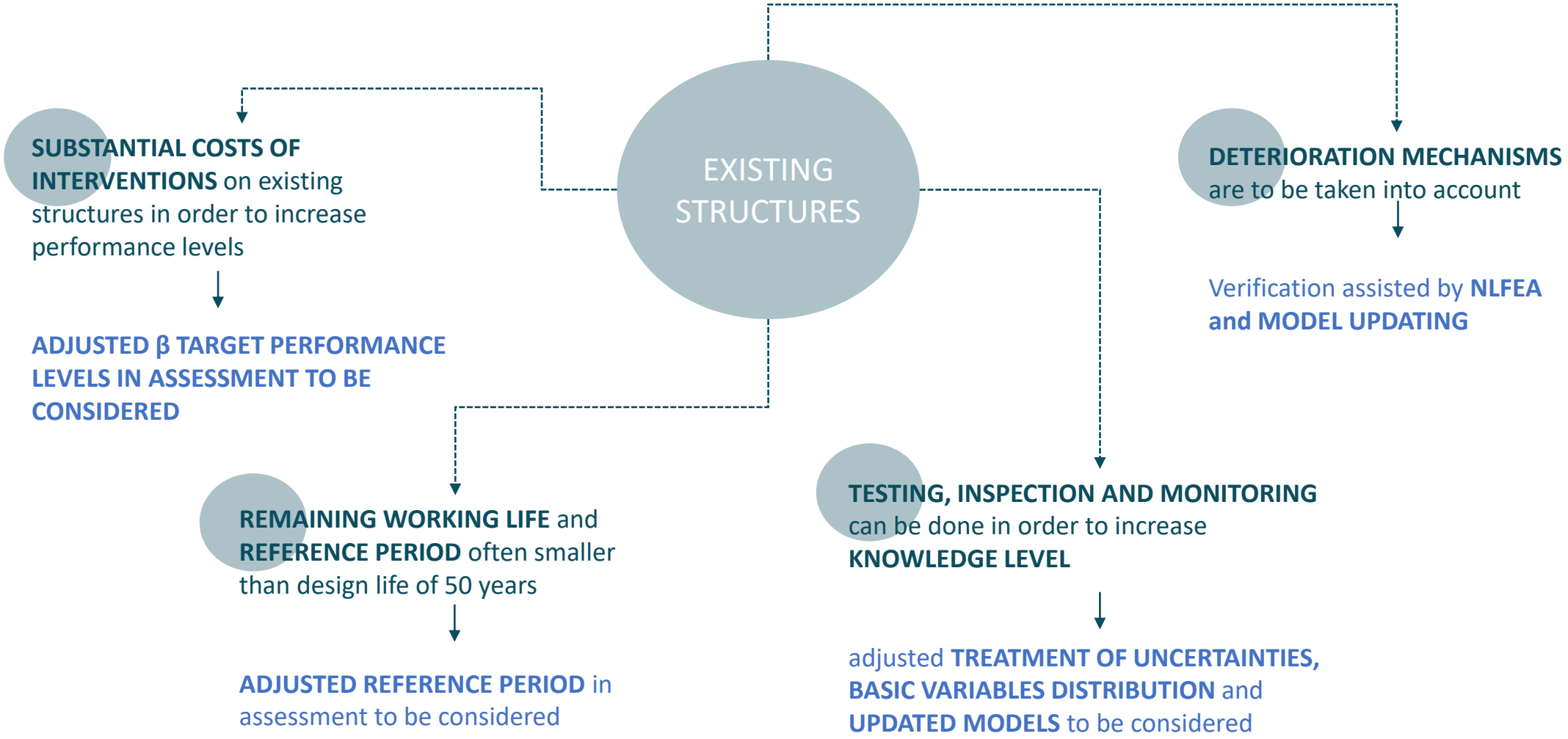
a.

Differentiation between NEW | EXISTING STRUCTURES



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Differentiation between NEW | EXISTING STRUCTURES

reliability index β:

$$\beta = -\Phi^{-1}(P_f) \qquad (3.3\text{-}1)$$

where

$\Phi(\cdot)$ is the standard normal probability distribution function;

P_f is the failure probability corresponding to a specified reference period.

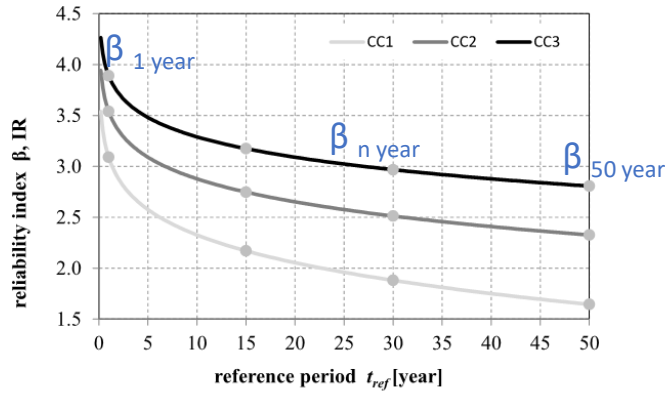

Fig. 3.3-1: Reliability index resulting from individual risk criterion for buildings.

[Fib Bulletin 80]

The **REFERENCE PERIOD** is the timeframe used as a basis for assessing the statistical parameters of time dependent variables and of the target reliability.

EXISTING CONCRETE STRUCTURES:

Recommended target reliability levels for structural design (ULS)			
Annual target β-values for structures to be designed, based on economic optimisation			
Relative cost of safety measure	Consequence Class		
	CC1	CC2	CC3
Large (A)	3.1	3.3	3.7
Normal (B)	3.7	**4.2**	4.4
Small (C)	4.2	4.4	4.7
Informative target reliability indices β for structures to be designed, related to a 50-year reference period			
Relative cost of safety measure	CC1	CC2	CC3
Normal (B)	3.3	**3.8**	4.3
Recommended annual target reliability levels for assessment of existing structures (ULS)			
Relative cost of safety measure	CC1	CC2	CC3
Large (A)	3.1	3.3	3.7
Recommended target reliability levels for upgrade of existing structures (ULS)			
While slightly lower values can be normally justified for β_{up}-levels in comparison to design target levels, it is common and reasonable to require the compliance with the design levels when upgrading the structure.			

[A.J. Bigaj-van Vliet (TNO), JCSS Workshop on Assessment of Existing Structures, 28th - 29th Jan 2021]

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a.

Differentiation between NEW | EXISTING STRUCTURES

New **MODEL CODE 2020** recommends principles of probabilistic structural limit state design with a possibility for differentiating the **RELIABILITY LEVEL PROMOTING THE ANNUAL APPROACH**:

NEW

βnew - level indicating desired reliability for design of new structures

FITTNESS FOR PURPOSE

β_0 - level below which the existing structure is considered unreliable and should be upgraded

REPAIR / UPGRADE

β_{up} - level indicating an optimum upgrade strategy while upgrading of existing structures

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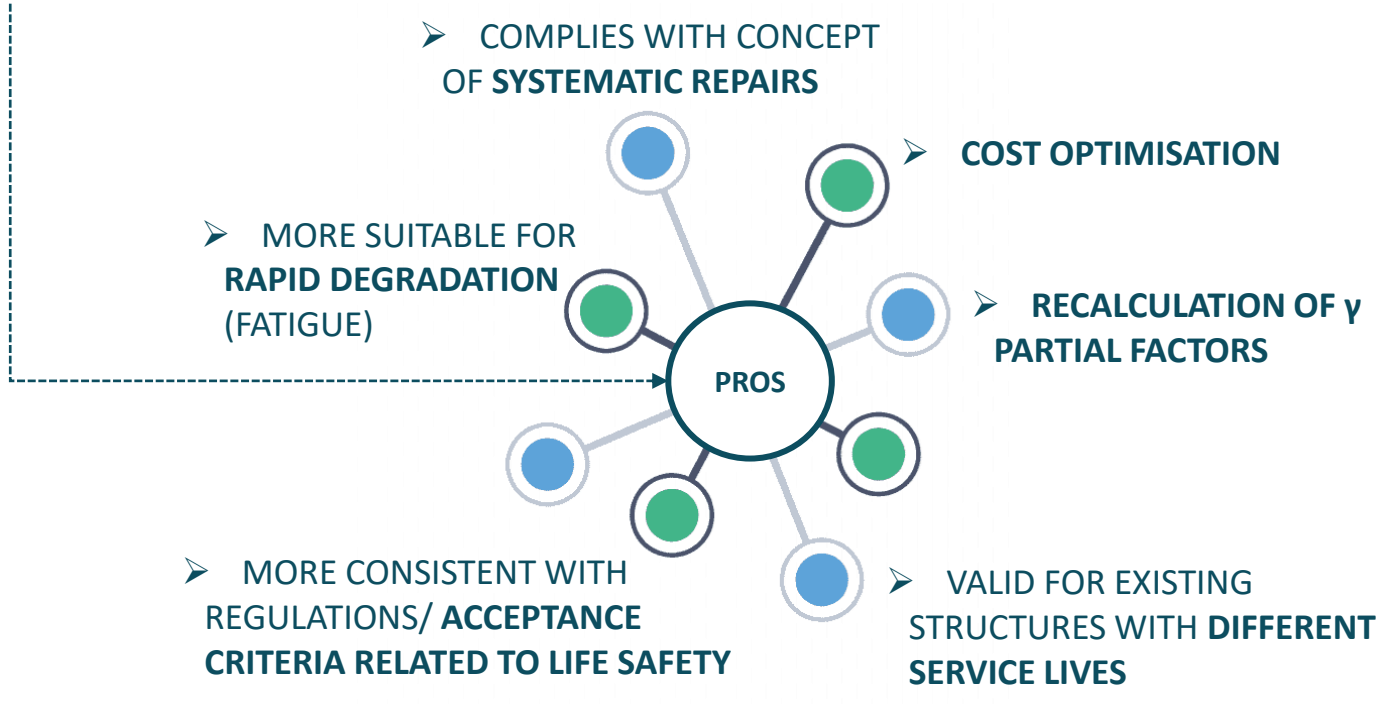

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Q&A

ZOOM POLL QUESTION:

- Is the **RELIABILITY DIFFERENTIATION BETWEEN NEW AND EXISTING BRIDGES** already known/regulated in your country?

NEW	**βnew** - level indicating desired reliability for design of new structures
FITTNESS FOR PURPOSE	β_0 - level below which the existing structure is considered unreliable and should be upgraded
REPAIR / UPGRADE	β_{up} - level indicating an optimum upgrade strategy while upgrading of existing structures

OPEN DISCUSSION:

- Do you see the **BENEFITS** of having the differentiation?

Framework for standardization

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b.

EXISTING STRUCTURES | Need for assessment

[CEN/TS 17440]

NEED FOR ASSESSMENT IN TIME EXTERNAL CAUSE	STRUCTURAL ISSUES	N – S – C LEVEL*	ASSESSMENT TYPE	AVAILABLE / REQUIRED INFOs
	CONSTRUCTION ERRORS	S | C	DETAILED	• ORIGINAL DESIGN DOCUMENTS • AS-BUILT & CONSTRUCTION DETAILS (BIM)
SCHEDULED ASSESSMENT for ASSET MANAGEMENT PROGRAMME		N | S | C	PRELIMINARY | DETAILED	• PERIODIC/DETAILED INSPECTION, SURVEYS OUTCOMES
	DETERIORATION PROCESSES	N | S | C	PRELIMINARY | DETAILED	• DEFECTS, DETERIORATION CHARACTERIZATION
CHANGE OF DESIGN LOADS		N | S | C	PRELIMINARY | DETAILED	INSPECTION AND TESTING RESULTS ON: • MATERIAL PROPERTIES • HAZARDS DISCRETE/CONTINUOUS (IN SPACE AND TIME) DATA FROM: • NDT/DT • MONITORING SYSTEMS
CHANGE OF HAZARDS (e.g. landslide, accidental actions)*		S | C	DETAILED	
RETROFITTING		S | C	DETAILED	
NEED FOR EXTENSION OF WORKING LIFE		S | C	DETAILED	

Working life

Incremental level of knowledge

**[IM-SAFE integration to CEN/TS 17440]*

*[*N=Network S=System C=Component]*

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INFORMATION FROM INSPECTION, MONITORING, TESTING

The proposed framework for the DATA INFORMED PERFORMANCE ASSESSMENT allows to incorporate:

ALTERNATIVE TARGET RELIABILITY LEVELS

REMAINING WORKING LIFE

ADDITIONAL INFORMATION FROM INSPECTION, MONITORING AND TESTING →

DIRECT INFORMATION = quantity of interest

- **BASIC VARIABLES**: updating of probability distributions, mean values or assessment values of basic variables

INDIRECT INFORMATION = indicator of the quantity

- **PROBABILITY OF FAILURE**: updating of the probability of the structural failure by using information from load testing or about the past performance
- **MODEL UPDATING**: deterministic or probabilistic methods to update numerical structural models

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MEASUREMENT & MODEL UNCERTAINTIES

Decisions concerning structures shall account for all uncertainties of relevance for their performances such as:

UNCERTAINTIES	INFLUENCE OF INSPECTION, MONITORING & TESTING
ALEATORY UNCERTAINTIES inherent natural variability	-
STATISTICAL UNCERTAINTIES lack of data	Reduced with **INCREASED NUMBER OF SAMPLES** - Updated **STANDARD DEVIATION** of basic variables with the **DATA COLLECTION**
Other EPISTEMIC UNCERTAINTIES lack of knowledge on the structural system (as-built), model uncertainties	Reduced with **SENSITIVITY ANALYSIS** to identify **KEY PARAMETERS** and **VULNERABLE ZONES** to be monitored

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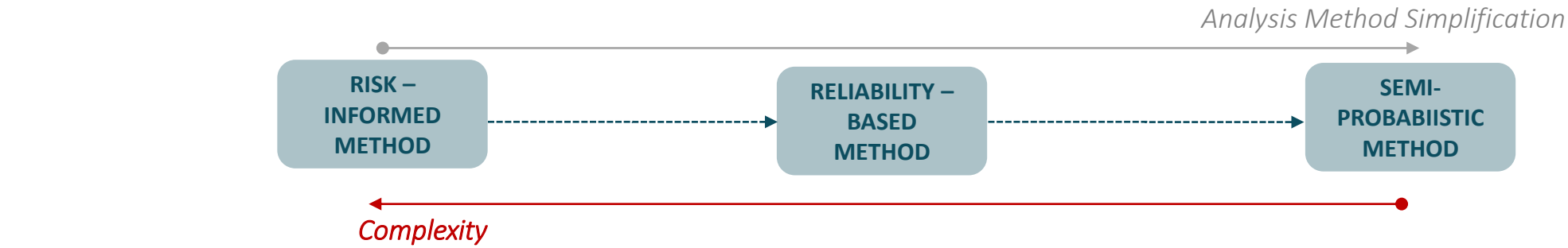
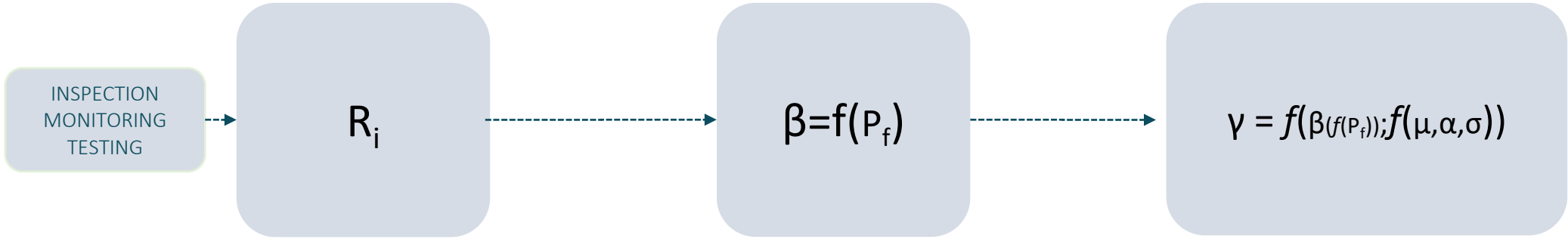
b.

DATA INFORMED PERFORMANCE ASSESSMENT





$$\beta = -\Phi^{-1}(P_f)$$

$$\gamma_m = \frac{X_k}{X^*} = \frac{\mu_X\,(1-1{,}645\,\delta_X)}{\mu_X\,(1-\alpha_R\,\beta\,\delta_X)}$$

UPDATE OF RISK EVALUATION, CONSEQUENCES AND COSTS OF MITIGATION ACTIONS on LEVEL OF KNOWLEDGE

UPDATING ACTUAL RELIABILITY β based on LEVEL OF KNOWLEDGE and DAMAGE MODELING

- **PARTIAL FACTORS** based on **DATA** and **ADJUSTED PROBABILISTIC MODELS** (mean, std) for basic variables and **adjusted MODEL UNCERTAINTIES**
- **GLOBAL RESISTANCE FORMAT** based on **MODEL UPDATING MODELS**

More complex applicability in practice

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DATA INFORMED PERFORMANCE ASSESSMENT

SEMI-PROBABIISTIC METHOD

LIMIT STATE GENERAL FRAMEWORK (EN 1990/2002)

For every limit state (LS):

LS Function

$$g(F_d, X_d, a_d, \vartheta_d) > 0$$

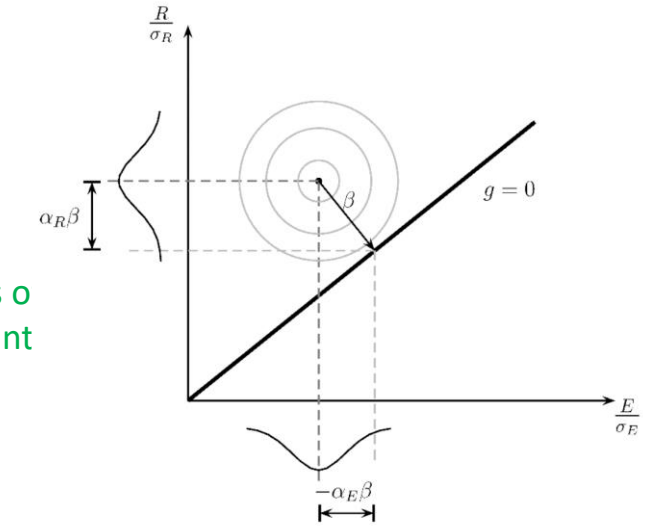
Actions
design values

Material properties
design values

Design values of
geometrical quantities

Design values o
model uncertaint

FORM-based design point



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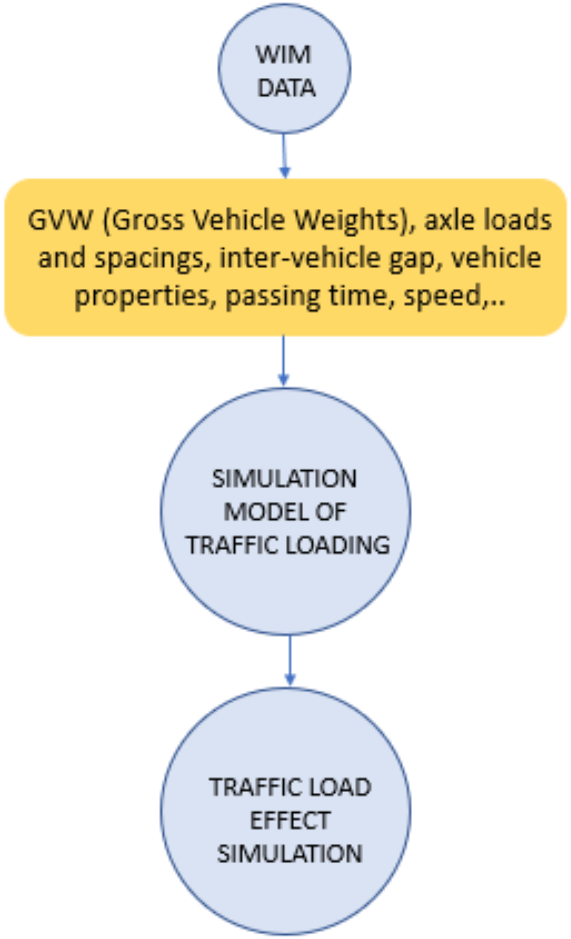
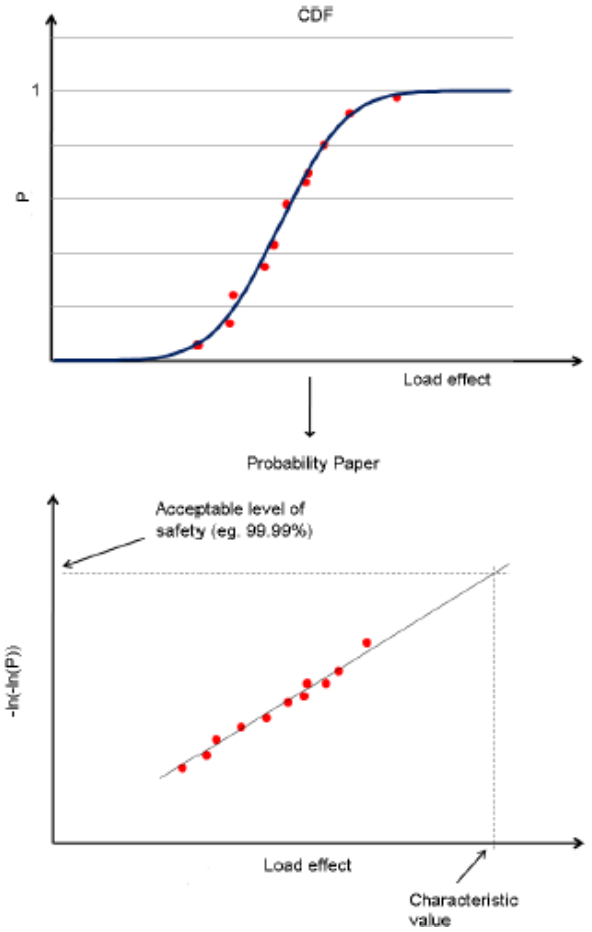
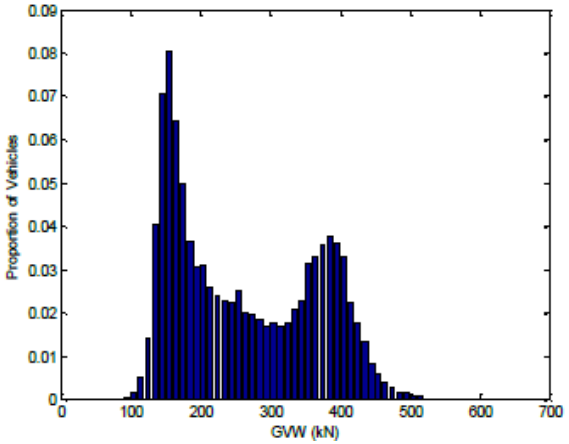
INFORMATION UPDATING

ACTIONS : TRAFFIC LOADS







USE DATA TO EVALUATE THE TRAFFIC LOAD:

↓

DETERMINATION OF SUITABLE ADJUSTMENT FACTORS (I.E. α FACTORS) FOR EUROCODE LM1

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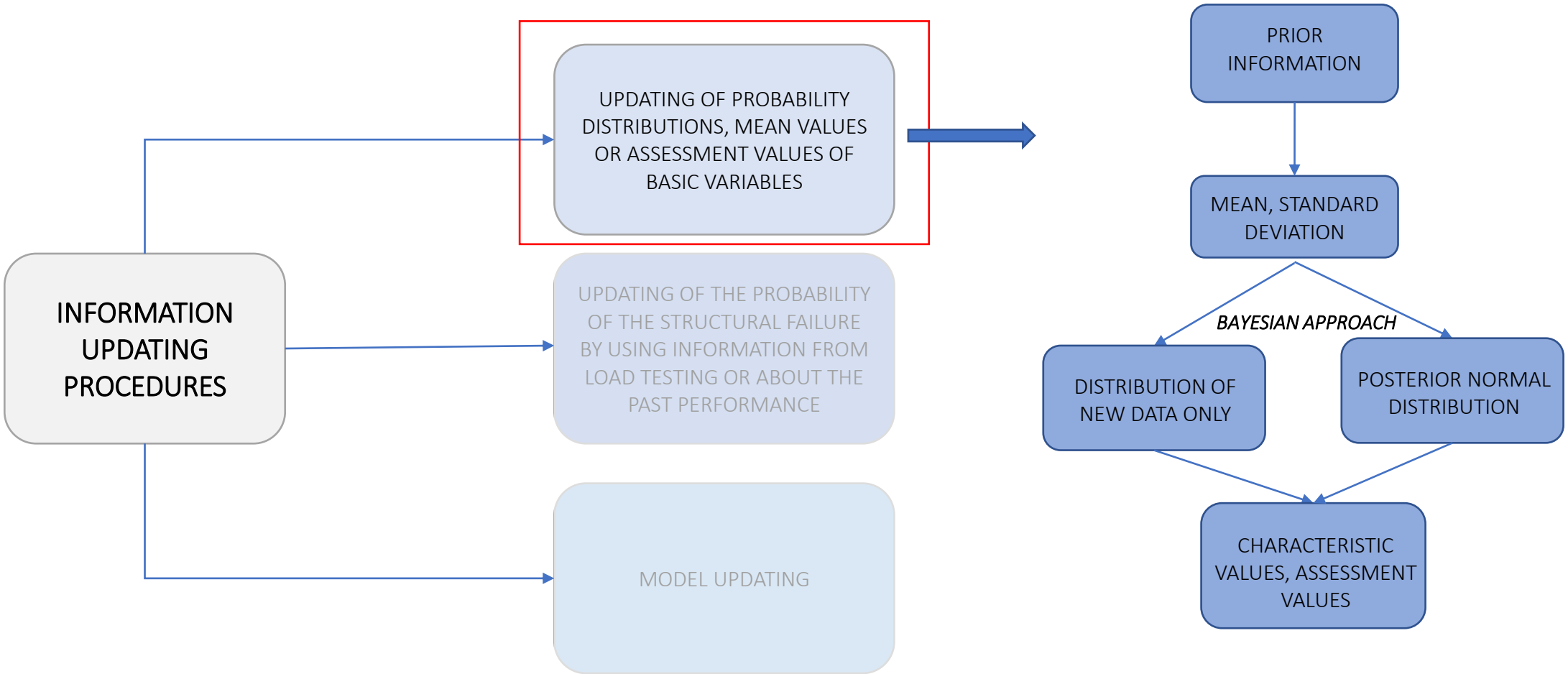
b.

INFORMATION UPDATING

RESISTANCE :



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INFORMATION UPDATING

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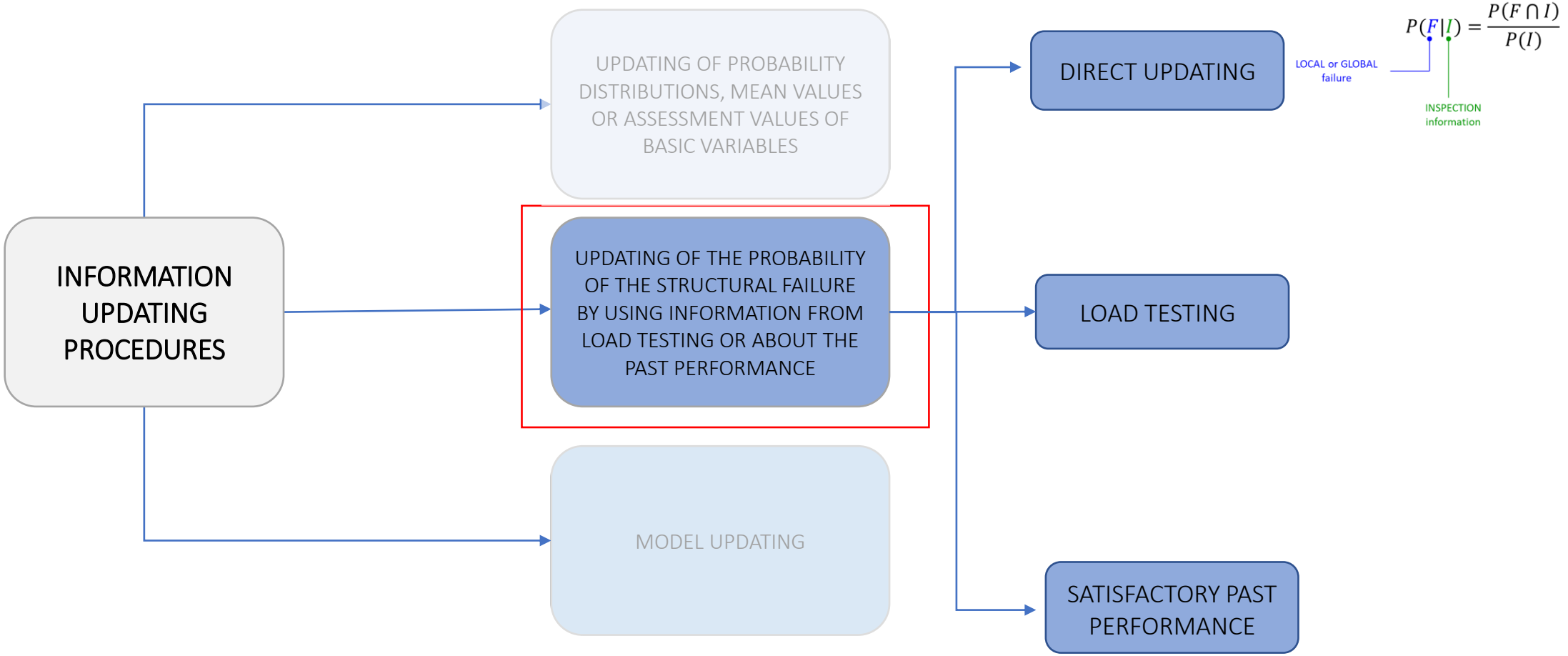

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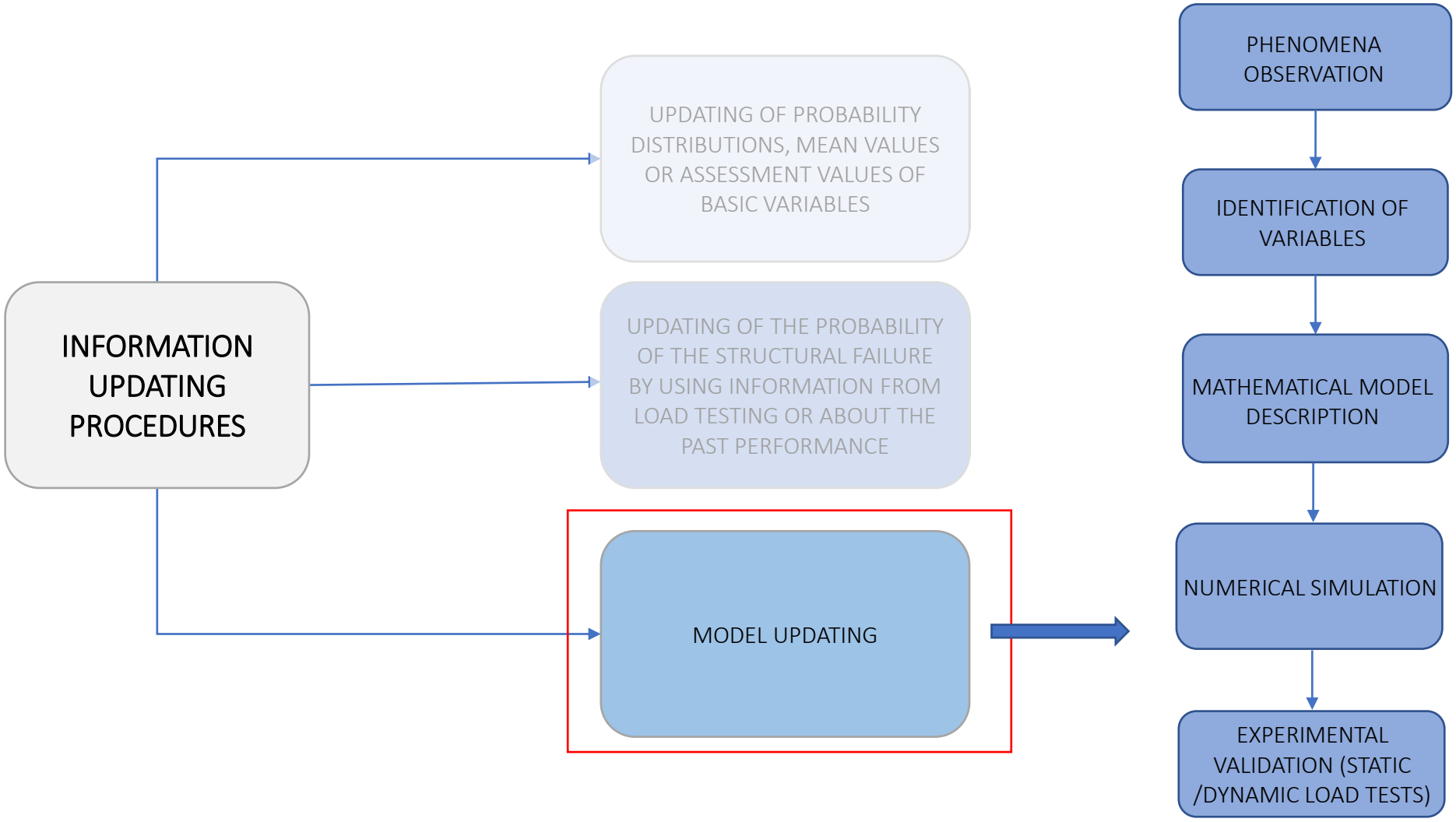

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INFORMATION UPDATING

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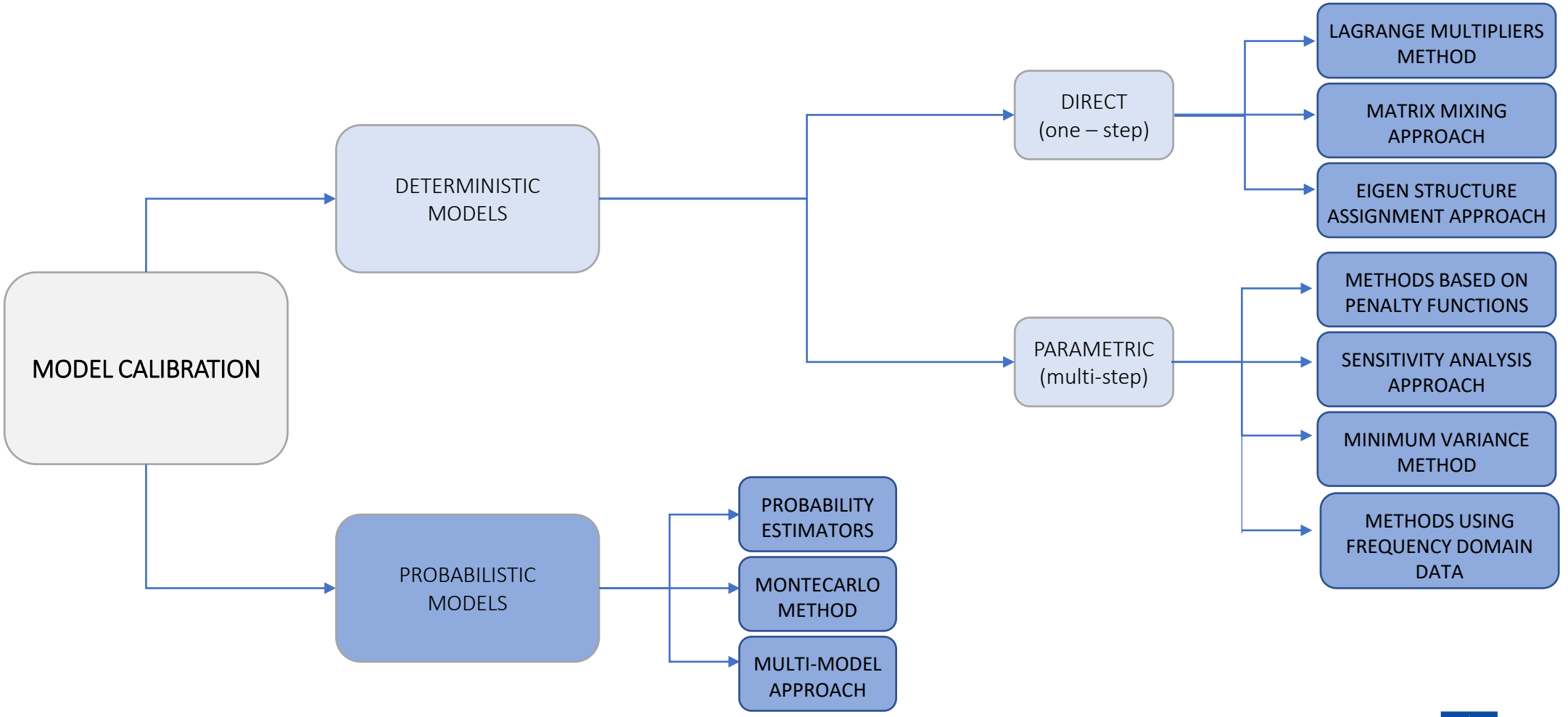

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b.

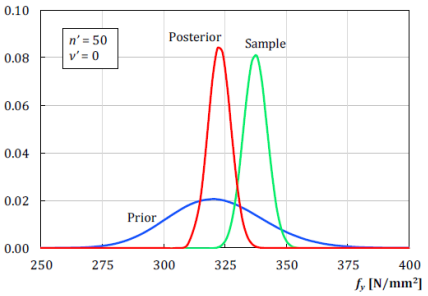
DATA INFORMED PERFORMANCE ASSESSMENT

Example:

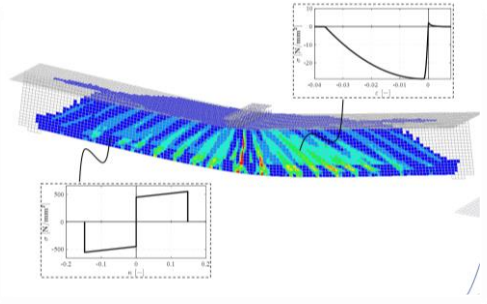
SEMI-PROBABIISTIC METHOD

LEVEL	ANALYSIS METHOD	INFORMATION UPDATING
COMPONENT	PARTIAL FACTOR METHOD	• Update **RESISTANCE+ACTIONS DISTRIBUTIONS (σ , μ)** • **BAYESIAN APPROACH** • Update **PARTIAL FACTORS** for materials and permanent/variable actions
SYSTEM	GLOBAL FACTOR METHOD	• Use **UPDATED NLFEA MODELS** based on **DIAGNOSTICS LOAD TESTS** • Include **DAMAGE PERFORMANCE MODELS** (evolution+prediction) • Model **MULTIPLE DAMAGE SCENARIOS** • Update **RESISTANCE+ACTIONS DISTRIBUTIONS (σ , μ) + use mean values** • Update **GLOBAL FACTORS**

Increase Analysis Level of Approximation



$$\gamma_m = \frac{X_k}{X_d} = \frac{\mu_x \cdot (1 - 1{,}645 \cdot V_x)}{\mu_x \cdot (1 - \alpha_R \beta \cdot V_x)}$$



$$R_d = \frac{R_{NLFEM}(f_m)}{\gamma_R \cdot \gamma_{Rd}}$$

Log-normality assumption:

$$\gamma_R = \exp(\alpha_R \cdot \beta \cdot V_R)$$

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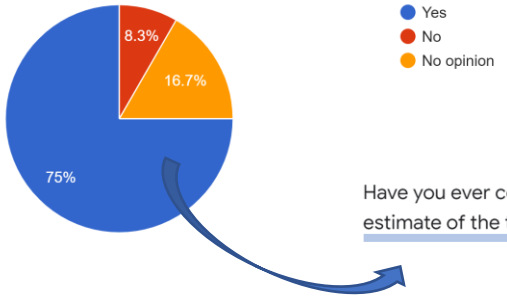
b.

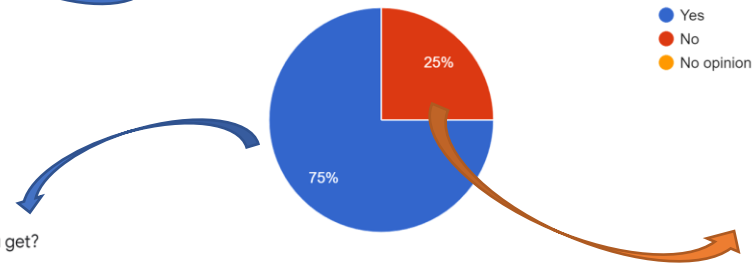
CoP experience

HAZARDS & ACTIONS

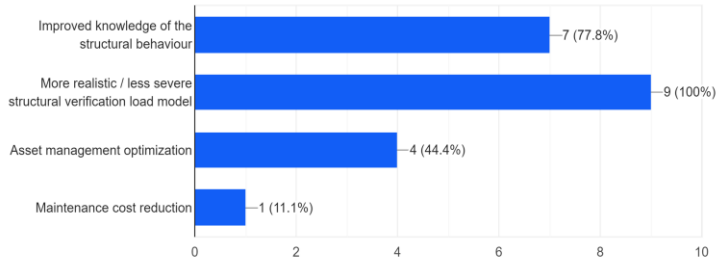
If available, would you consider using standardised procedures **to use data** to identify or quantify the actions and the hazards?



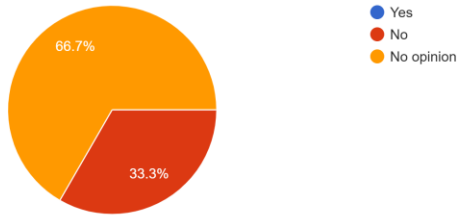
Have you ever commissioned collection of data about traffic loads to obtain a more realistic estimate of the traffic load effects for assessment of existing structures[1]?



What benefit did you get?



Would you consider it if the procedure is included in the Standards?



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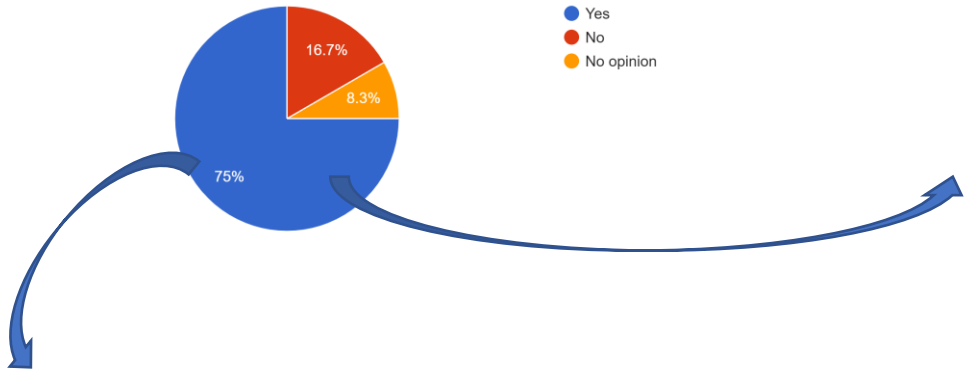
b.

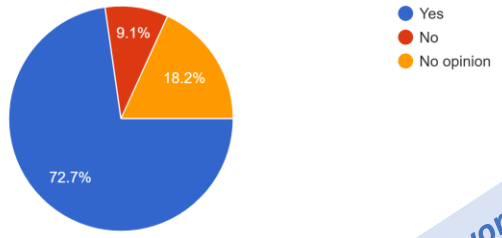
CoP experience

DATA-INFORMED PERFORMANCE ASSESSMENT

When dealing with performance assessment of existing structures, do you use data to assess structural safety?

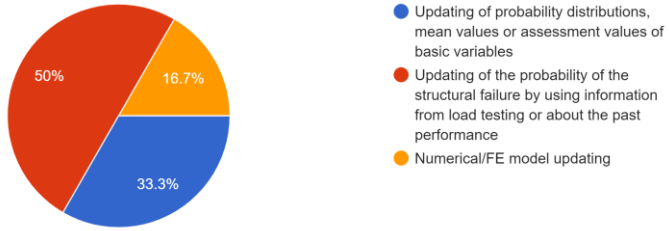


If available, would you consider using a standardised procedures to include data in assessing structural safety of existing structures?



Framework for standardization

Which approach do you use?



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a.

Q&A

- Is **STANDARDIZATION A PRECONDITION** for the use of **DATA-INFORMED SAFETY ASSESSMENT**?

  - is the **DEGRADATION EFFECT or INCREASE/CHANGE OF ACTIONS MAJOR TRIGGERS for data-informed safety assessment** in your practice?

Framework for standardization

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DATA-INFORMED STRUCTURAL PERFORMANCE ASSESSMENT

a. **14:00-14:30 |** Overview on the risk-based, reliability based and semi-probabilistic assessment methods for existing structures

Q&A

b. **14:30-15:00 |** Current and future use of monitoring data in the structural assessment process and model updating methods

Q&A

c. **15:00-15:30 |** Risk-based prioritization process for assessment, maintenance monitoring and remedial interventions on existing structures

Q&A

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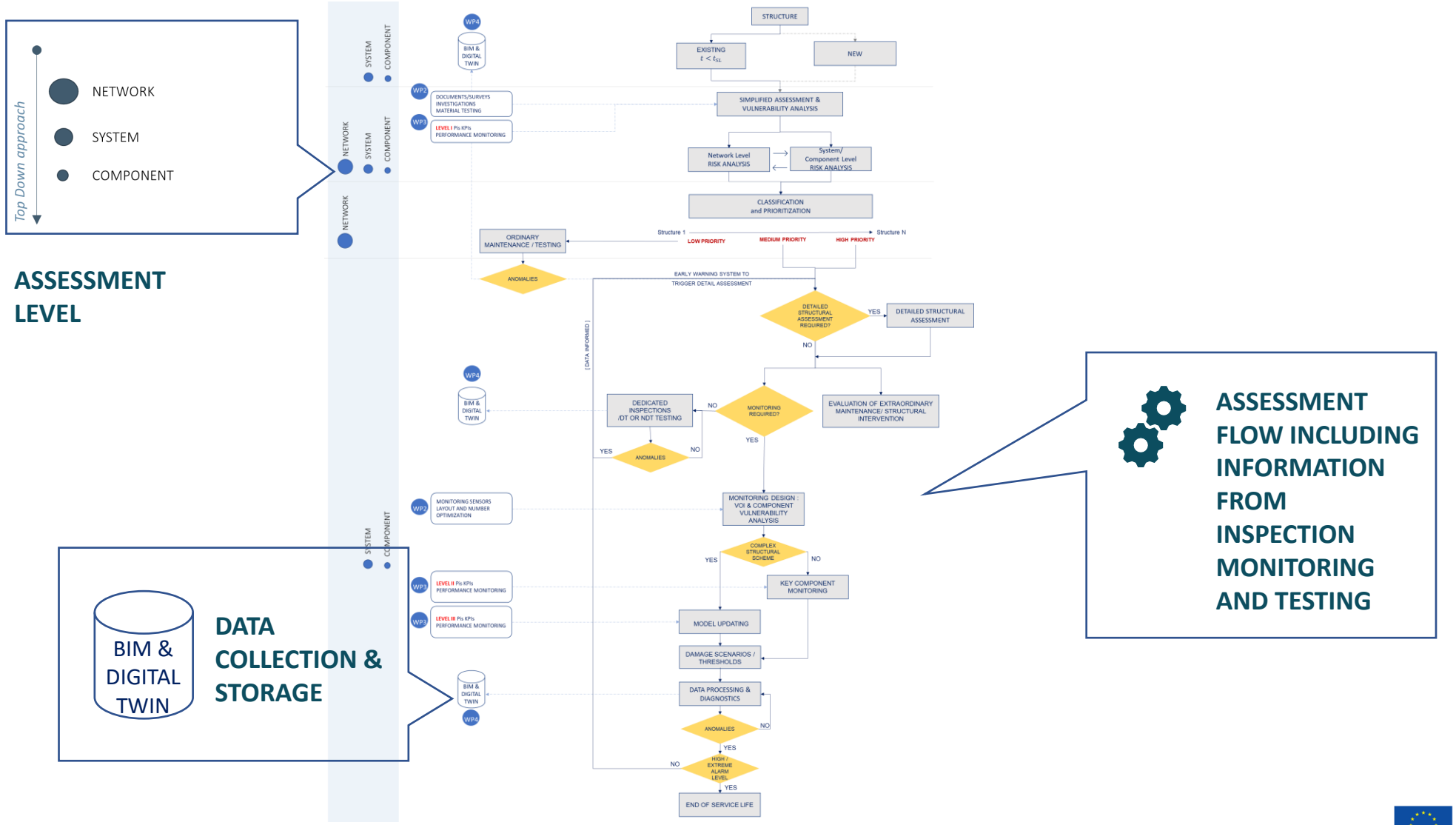
DATA INFORMED PERFORMANCE ASSESSMENT FLOW



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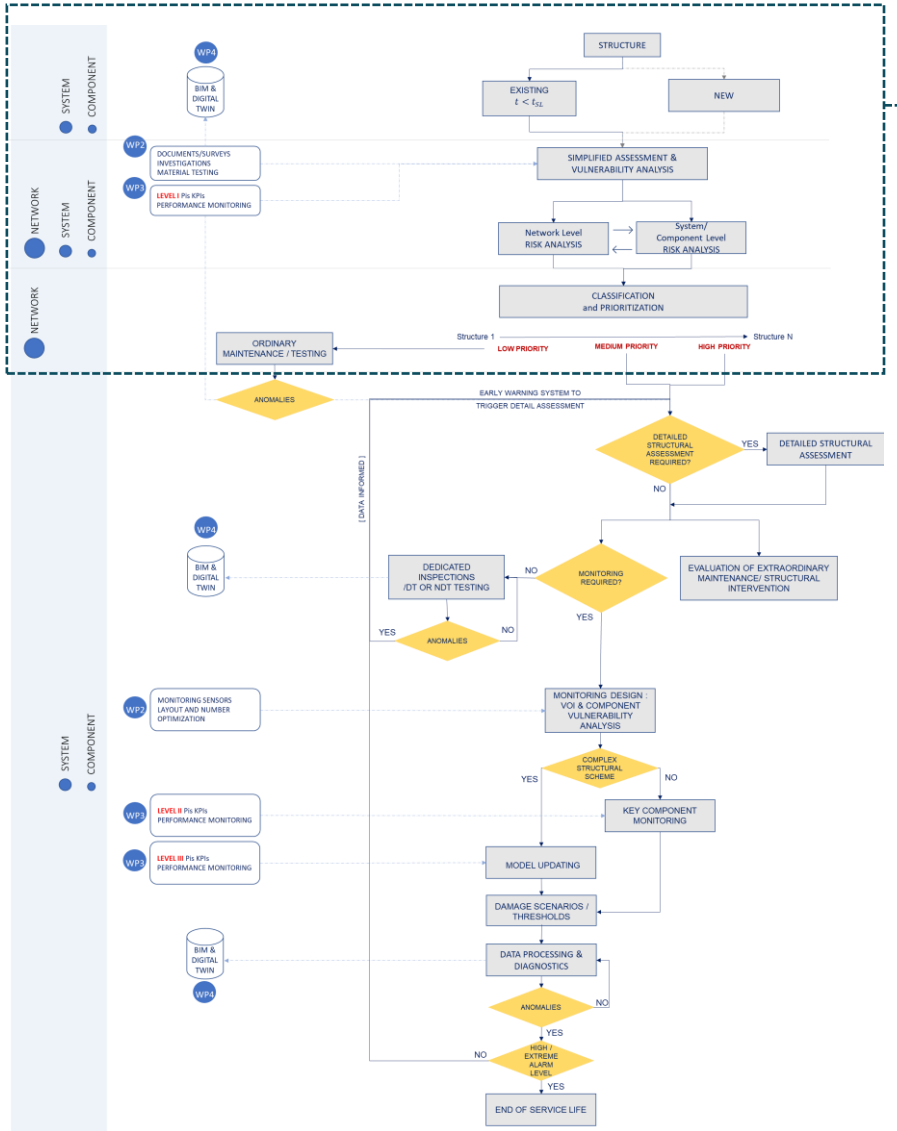
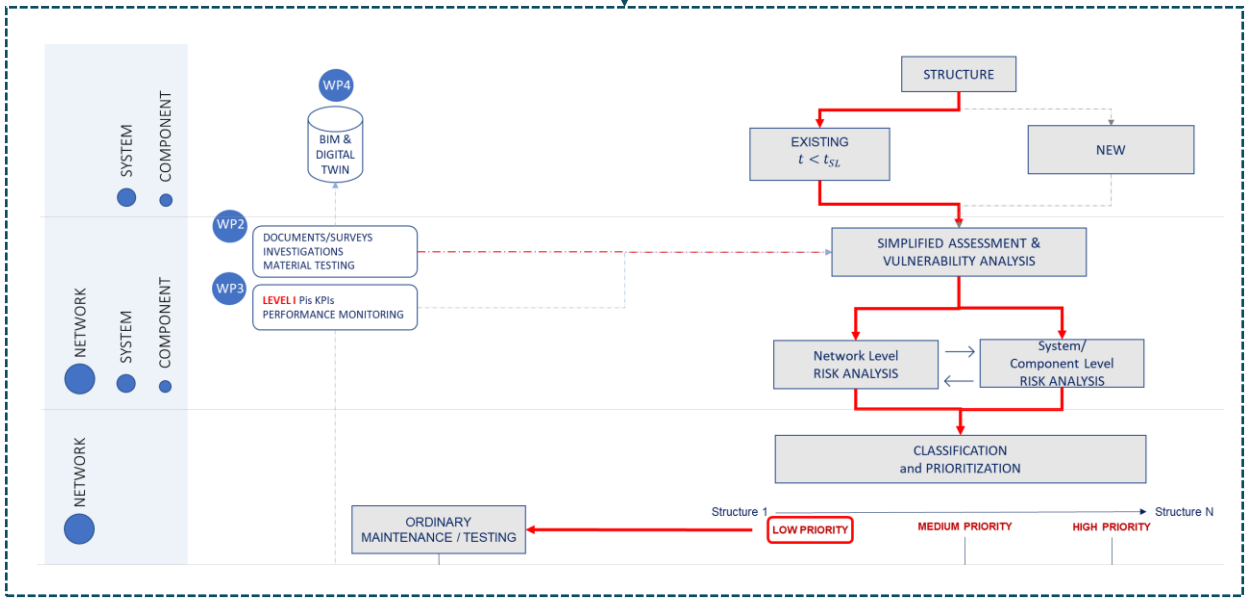
C.

DATA INFORMED PERFORMANCE ASSESSMENT FLOW





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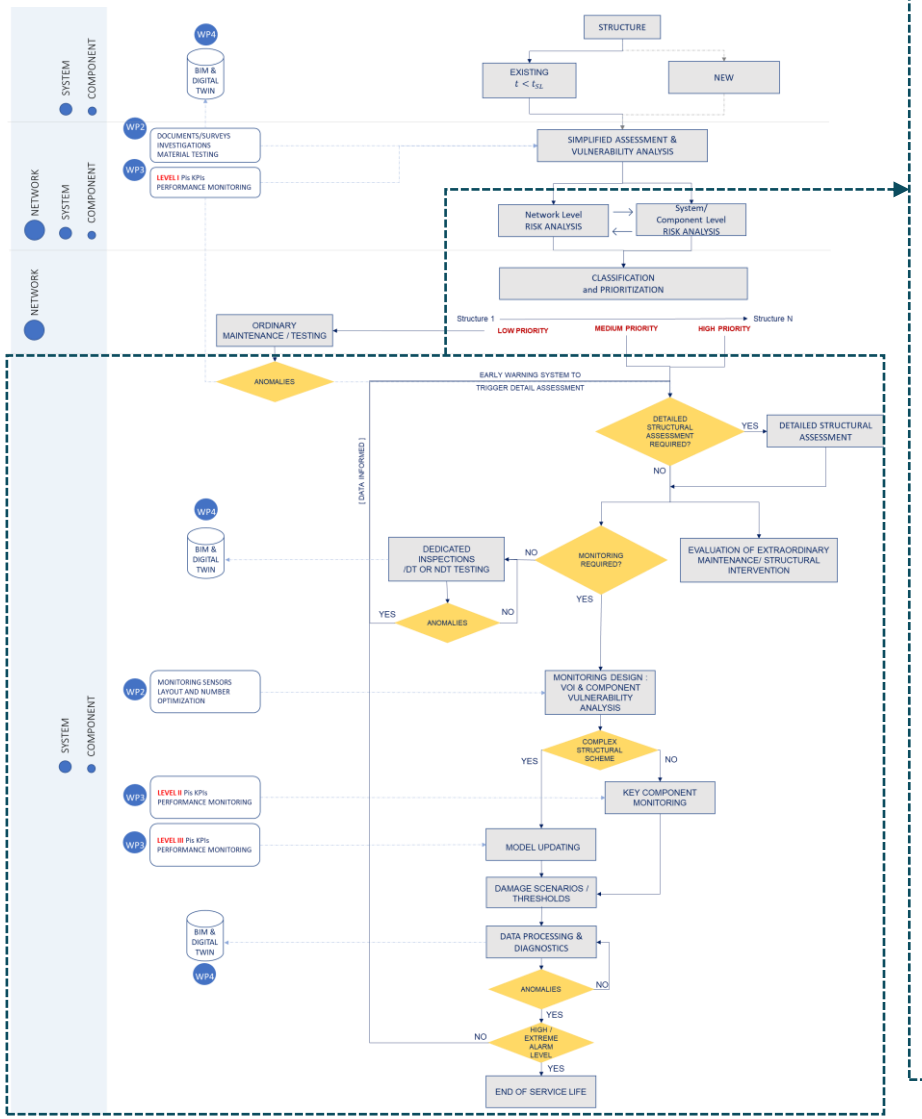

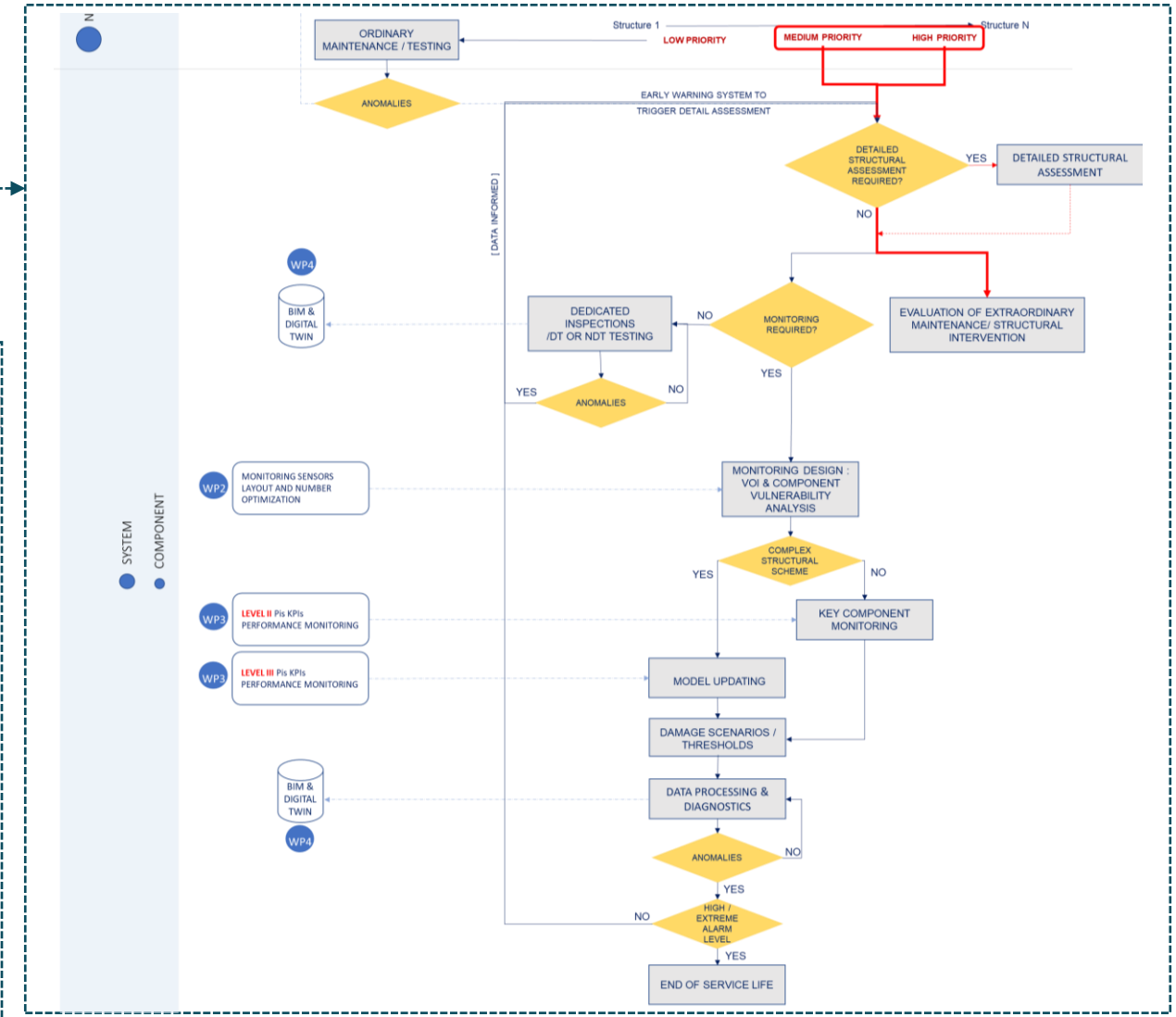

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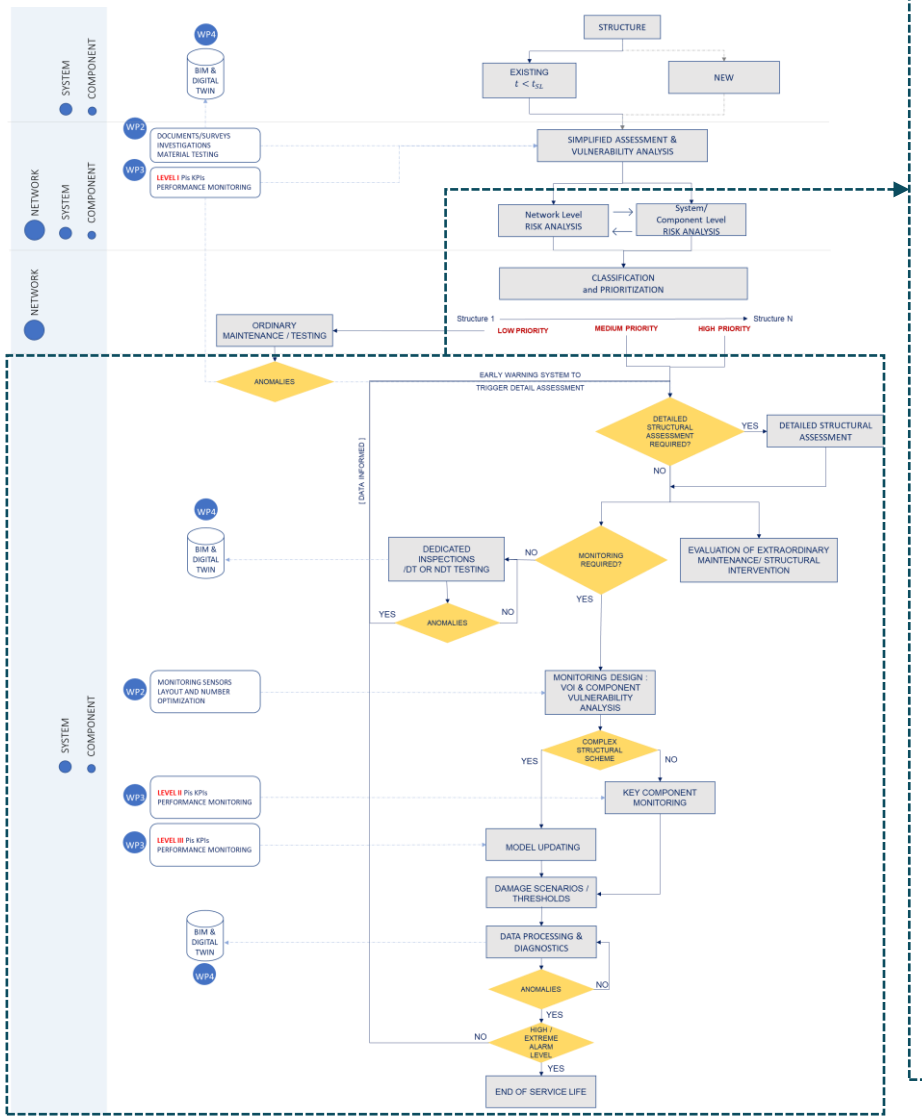

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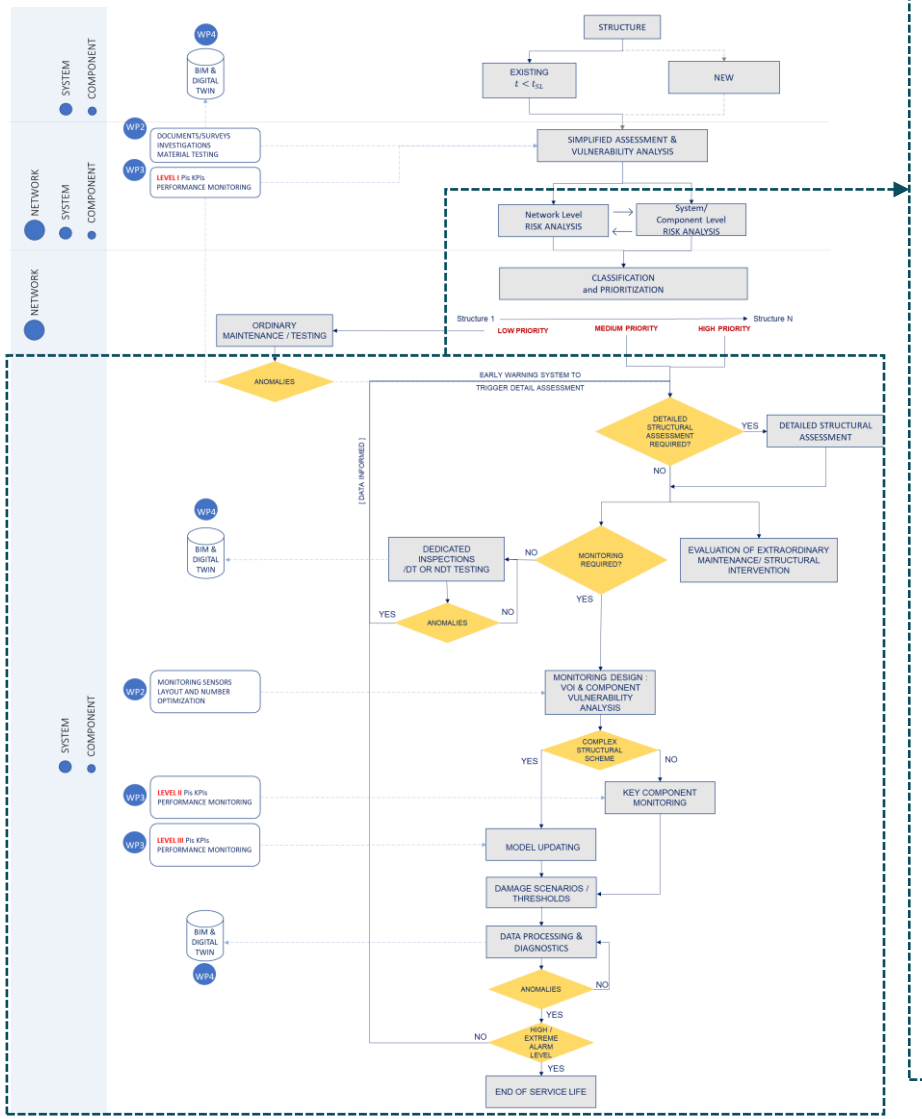

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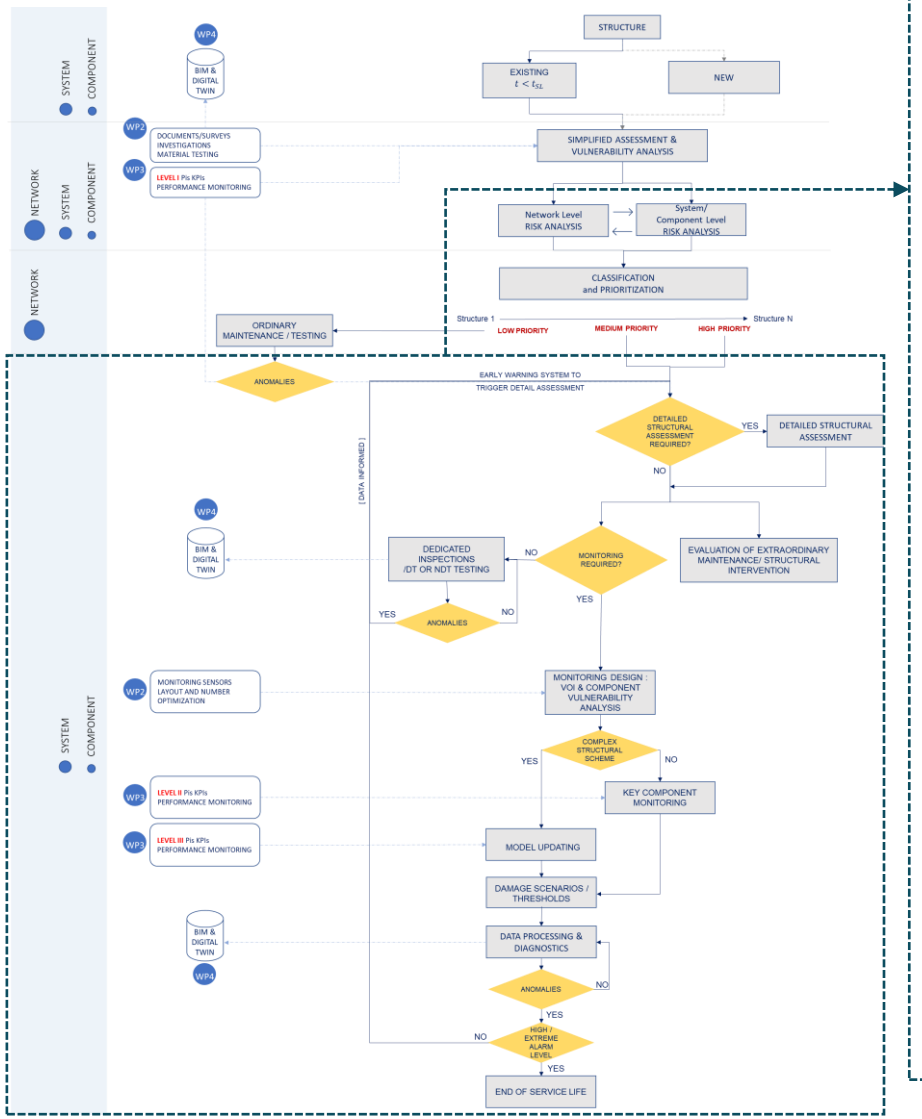

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Q&A

IM SAFE aims to RATIONALIZE THE **DATA-INFORMED SAFETY ASSESSMENT FLOW**

- Can **STANDARDIZED PROCEDURES** provide a **VALID GUIDANCE** to REGULATE **WHEN/WHY/HOW** TO **REQUEST DATA** for **SAFETY ASSESSMENT** ?

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Thank you all for attending, questions, input, etc.

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