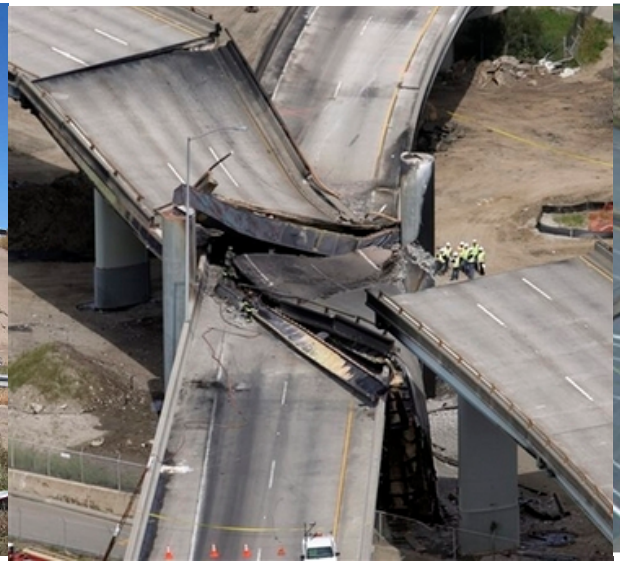
Risk analysis of bridges using a new reliability-based robustness assessment methodology

Hugo Guimarães


Agenda

- Motivation and Research Goal
- Metamodeling-based methods for reliability analysis
- Framework for robustness assessment
- Case studies
- Additional Contributions
- Conclusions and Future Developments

Bridge Management Systems

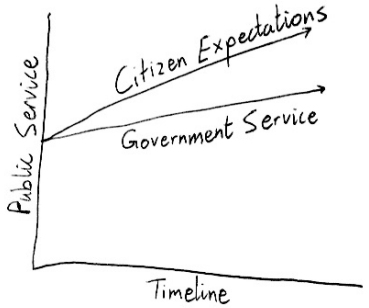
…Challenges for Owners

Decay Process

Public Demands

Efficient Management

Limited Resources

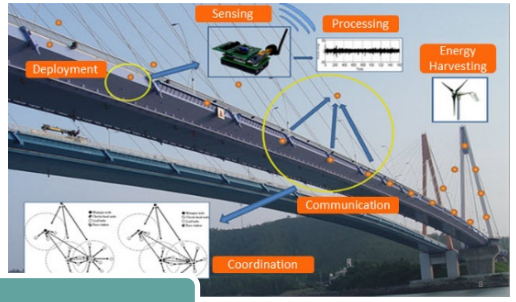


Public Expectations

Bridge Management Systems

…Component Level

Visual Inspection



NDT Testing

Monitoring system

Performance indicator

Condition rating

Recent Events

… More than **40 bridge failures** were reported since 2014!!!

… Majority of them was made by concrete

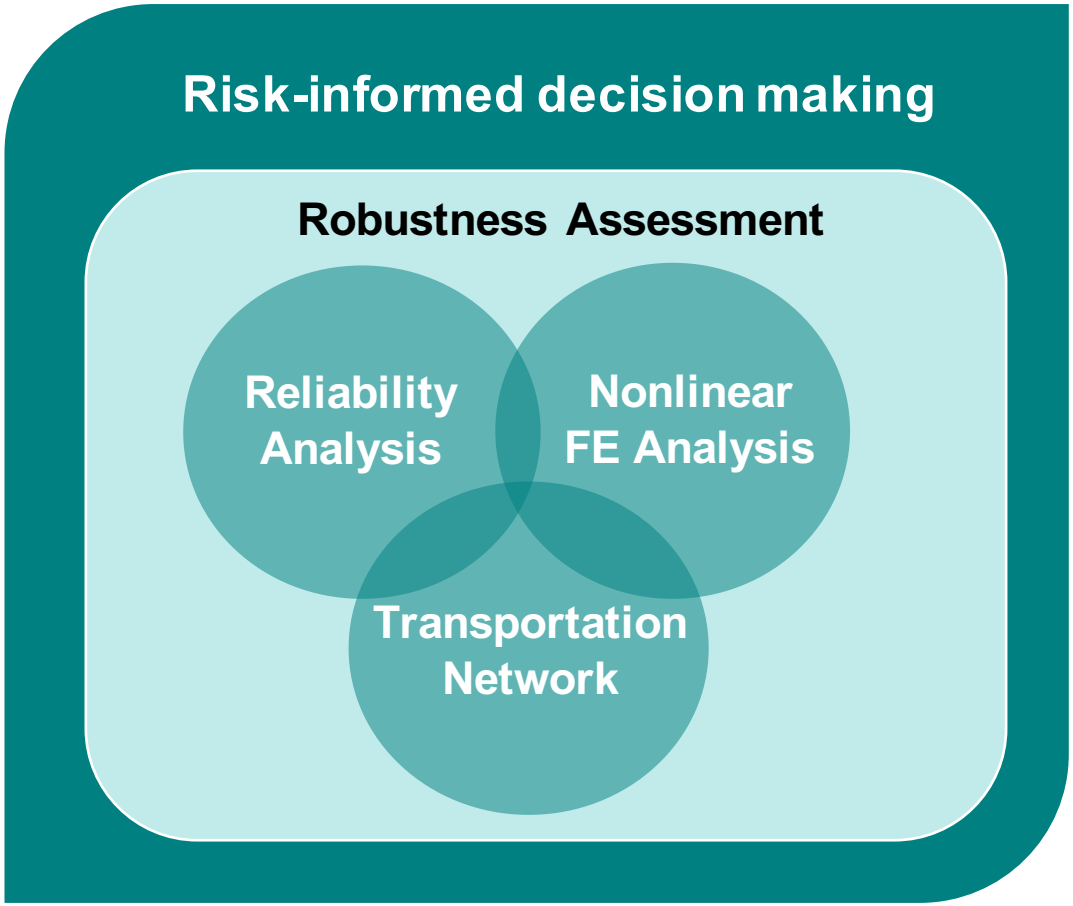
… Main reasons were:

- Faulty design or construction error
- Loss of Key elements by:
  - Collision
  - Landslide
  - Scour
- Poor Maintenance

Recent bridge failures

Recent bridge traffic disruptions

Research Goal

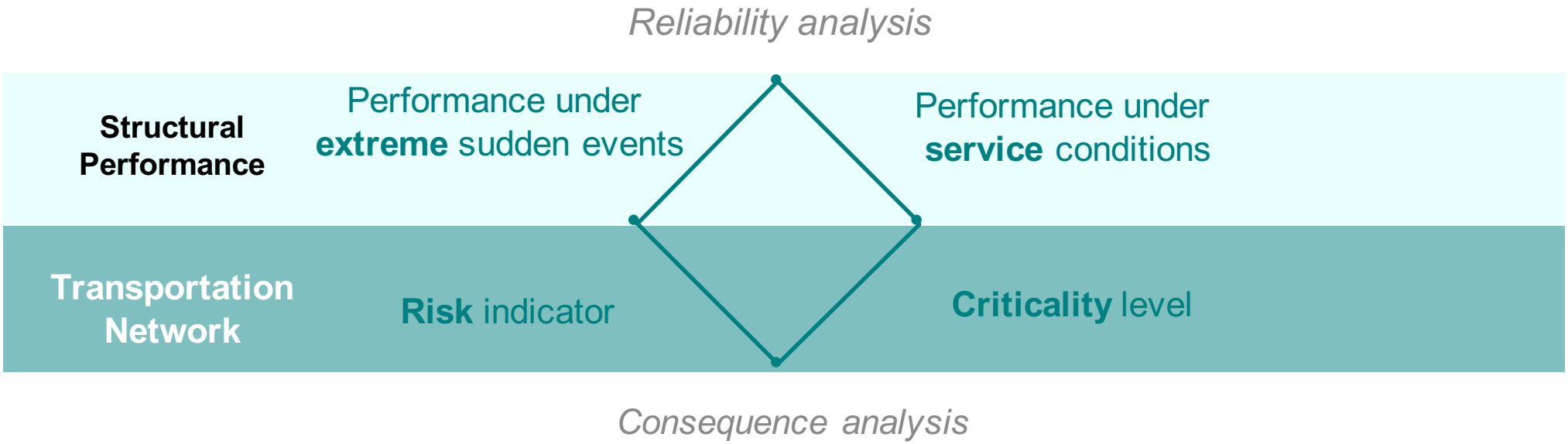


The goal is to contribute new generation of risk-based bridge management systems

Robustness assessment methodology

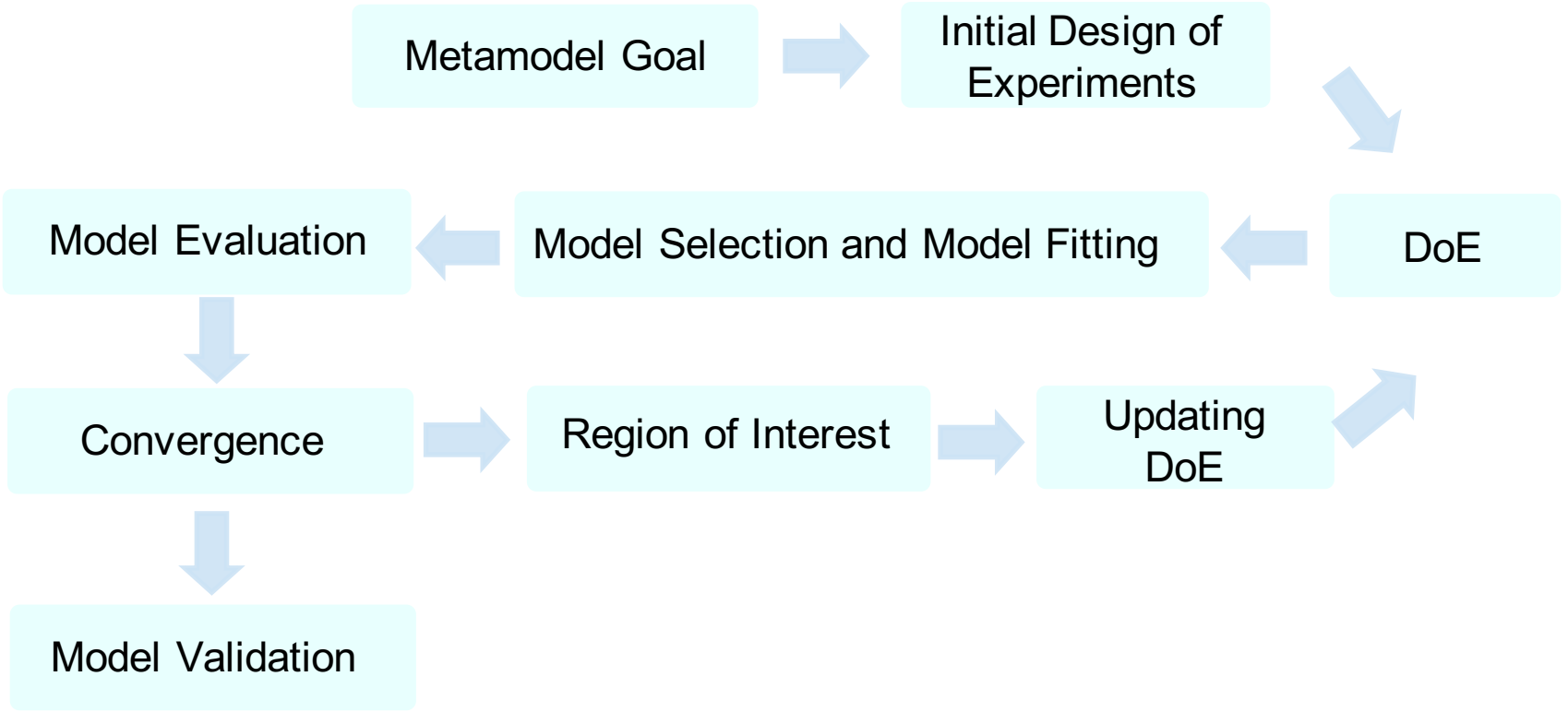
… System-level performance

… Wide spectrum of Key Performance Indicators



Metamodeling for Reliability Analysis

$$P_f = P\{G(\mathbf{x}) \leqslant 0\} = \int_{G(\mathbf{x})\leq 0} f_{\mathbf{x}}(\mathbf{x})\mathrm{d}\mathbf{x}$$



… More than 40 papers were reviewed!

"Metamodeling-based methods for reliability analysis: a comparative review and insights for future developments" will be submitted to Reliability engineering and System Safety

Metamodels

Response Surface Methods

$$\hat{G}(\mathbf{x}) = \beta_0 + \sum_{i=1}^{d} \beta_i \mathbf{x}_i + \sum_{i=1}^{d} \beta_{ii} \mathbf{x}_i^2 + \sum_{i=1}^{d-1} \sum_{j=1}^{d} \beta_{ij} \mathbf{x}_i \mathbf{x}_j + \epsilon$$

Kriging or Gaussian Process

$$G(\mathbf{X}) = \mathbf{f}(\mathbf{X})^{\mathrm{T}} \beta + Z(\mathbf{X})$$

Artificial Neural Networks (ANN)

$$\tilde{z} = g_N \left(\sum_{j=1}^{k_m} w_j^b x_j + \varpi \right)$$

Support Vector Machines (SVM)

$$G(\boldsymbol{x}) = \mathrm{sgn}\left[\sum_{i=1}^{n} \alpha_i^* y_i \mathrm{Kf}(\boldsymbol{x}_i \cdot \boldsymbol{x}) + b^* \right]$$

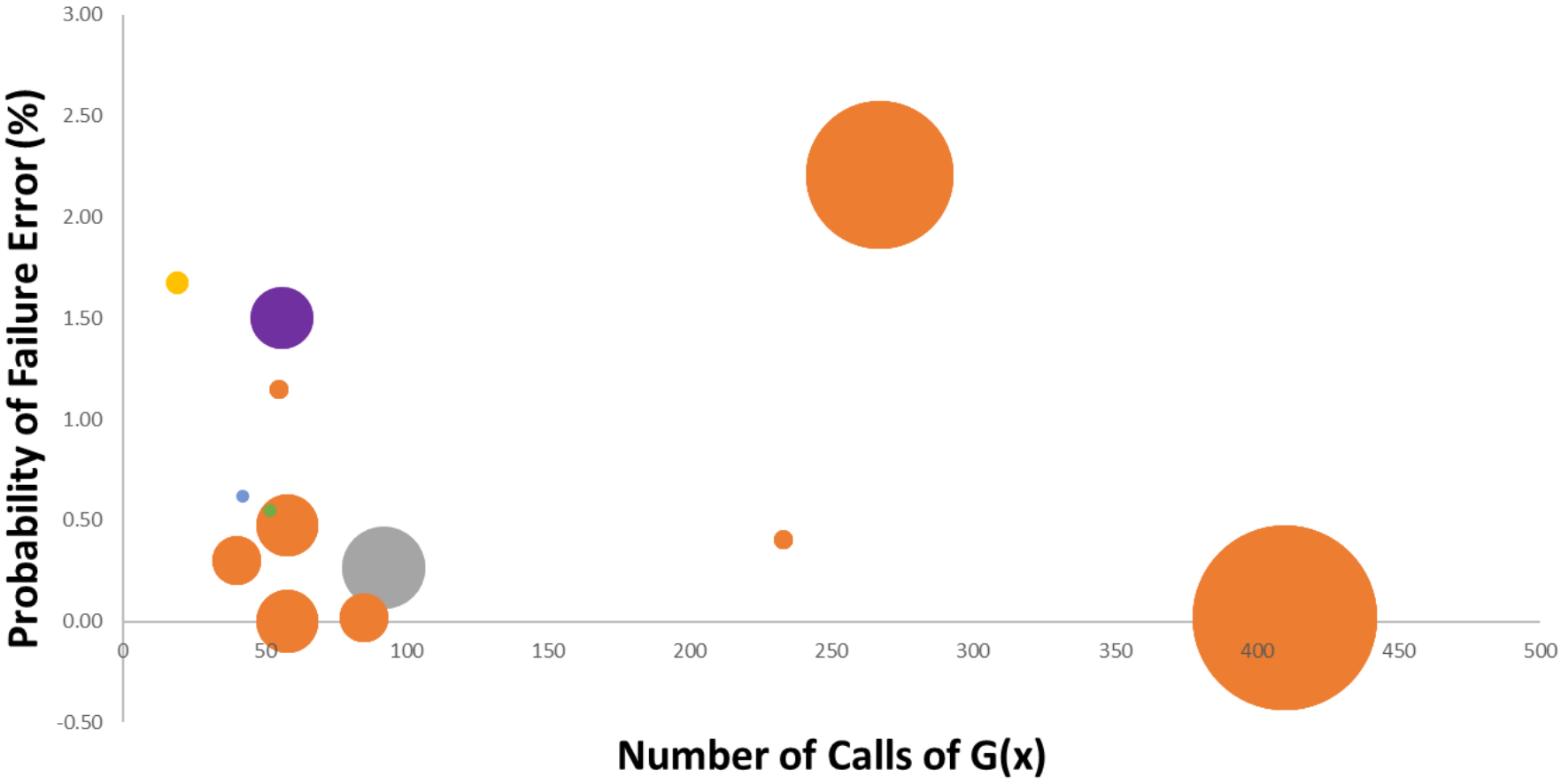
Polynomial Chaos Expansion (PCE)

$$Z = \mathcal{W}(\xi) \approx \sum_{l=0}^{P-1} c_l \psi_l(\xi)$$

… Benchmarking methods is not a straightforward task!

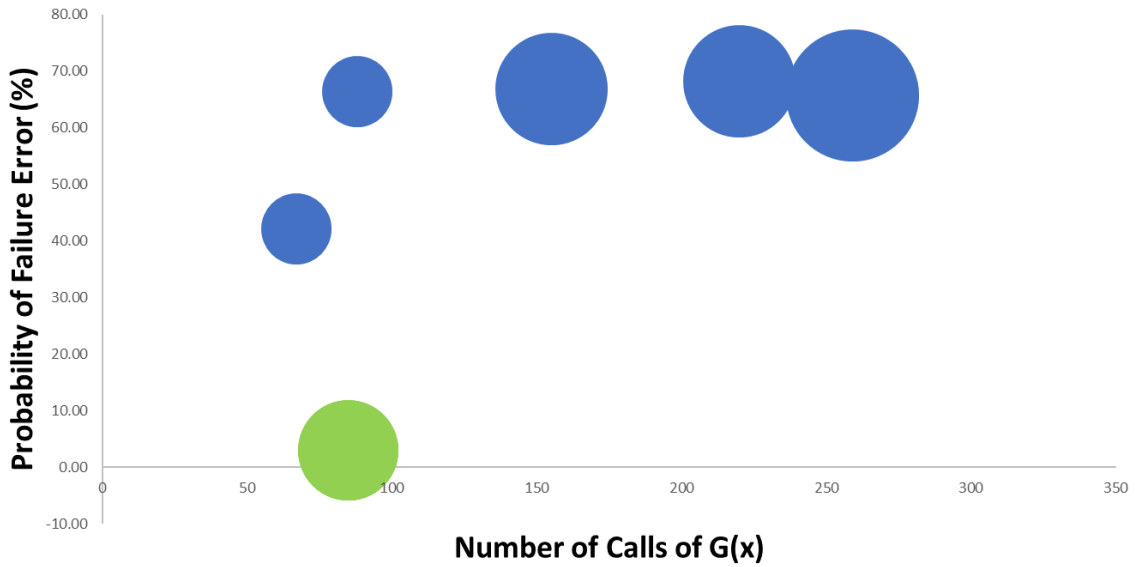
Still a reduced list of test examples was selected.

Dynamic Problem with 6 RV

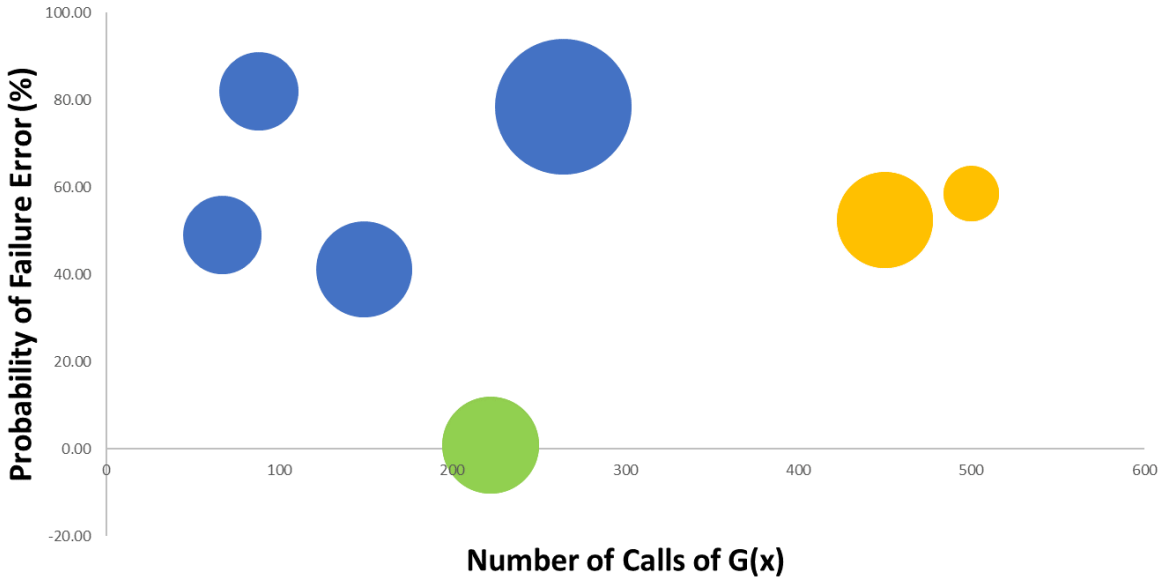


Kriging ANN SVM PCE Spline iRS

3-bay 5-story Building Frame (21 RV)



Correlation is not efficiently addressed by existing RSM



PCE RSM iRS

Developed Method - iRS

… Main features

- Optimized DoE
- Double weighted regression technique
- Stepwise Selection
- Region of Interest
- Cross-Validation
- CI based on bootstrapping

$$w_g = \alpha_g \cdot \frac{g^g_{\text{best}}}{|g(\mathbf{x}_i)|} \text{ and } g^g_{\text{best}} = \min |g(\mathbf{x}_i)|$$

$$w_d = \alpha_d \cdot \frac{g^d_{\text{best}} - ||\mathbf{x}_i - \mathbf{x}_d||}{g^d_{\text{best}}} \text{ and } g^d_{\text{best}} = \max ||\mathbf{x}_i - \mathbf{x}_d||$$

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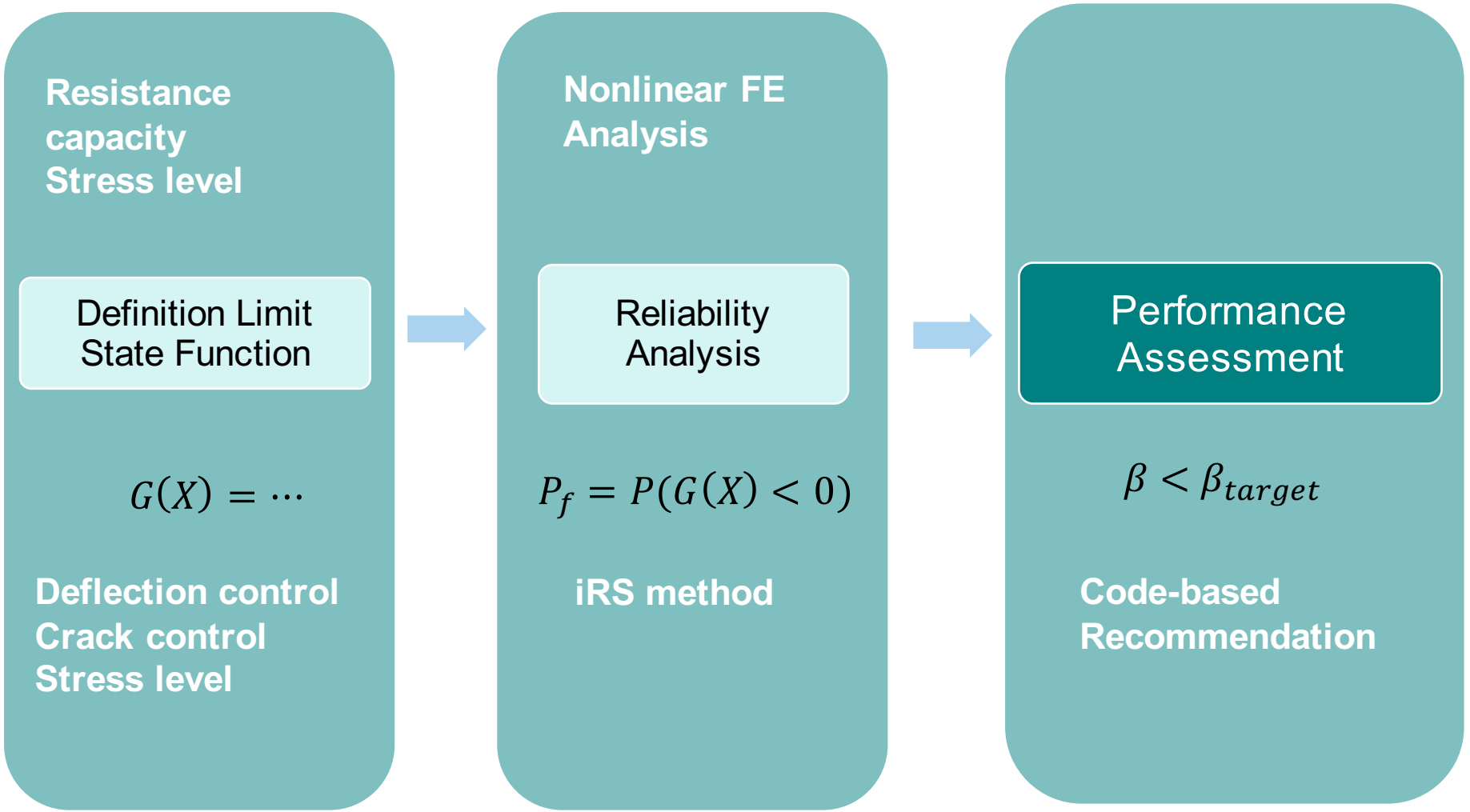
journal homepage: www.elsevier.com/locate/strusafe

An innovative adaptive sparse response surface method for structural reliability analysis

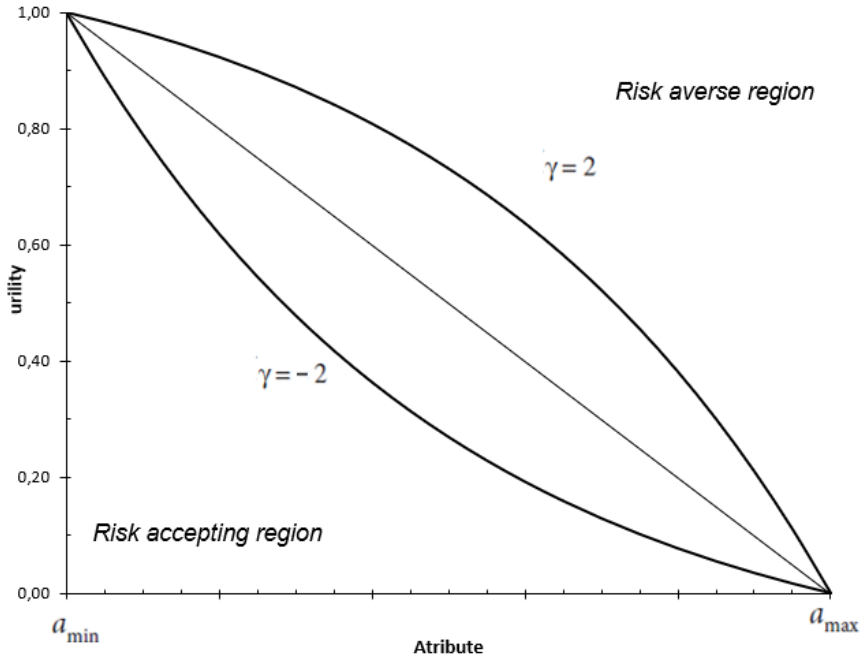
Hugo Guimarães [a,*], José C. Matos [a], António A. Henriques [b]

Structural Performance Assessment



Transportation Network

Normalized risk indicator which considers consequences of disruption



Maximum admissible direct losses:
% annual budget for maintenance

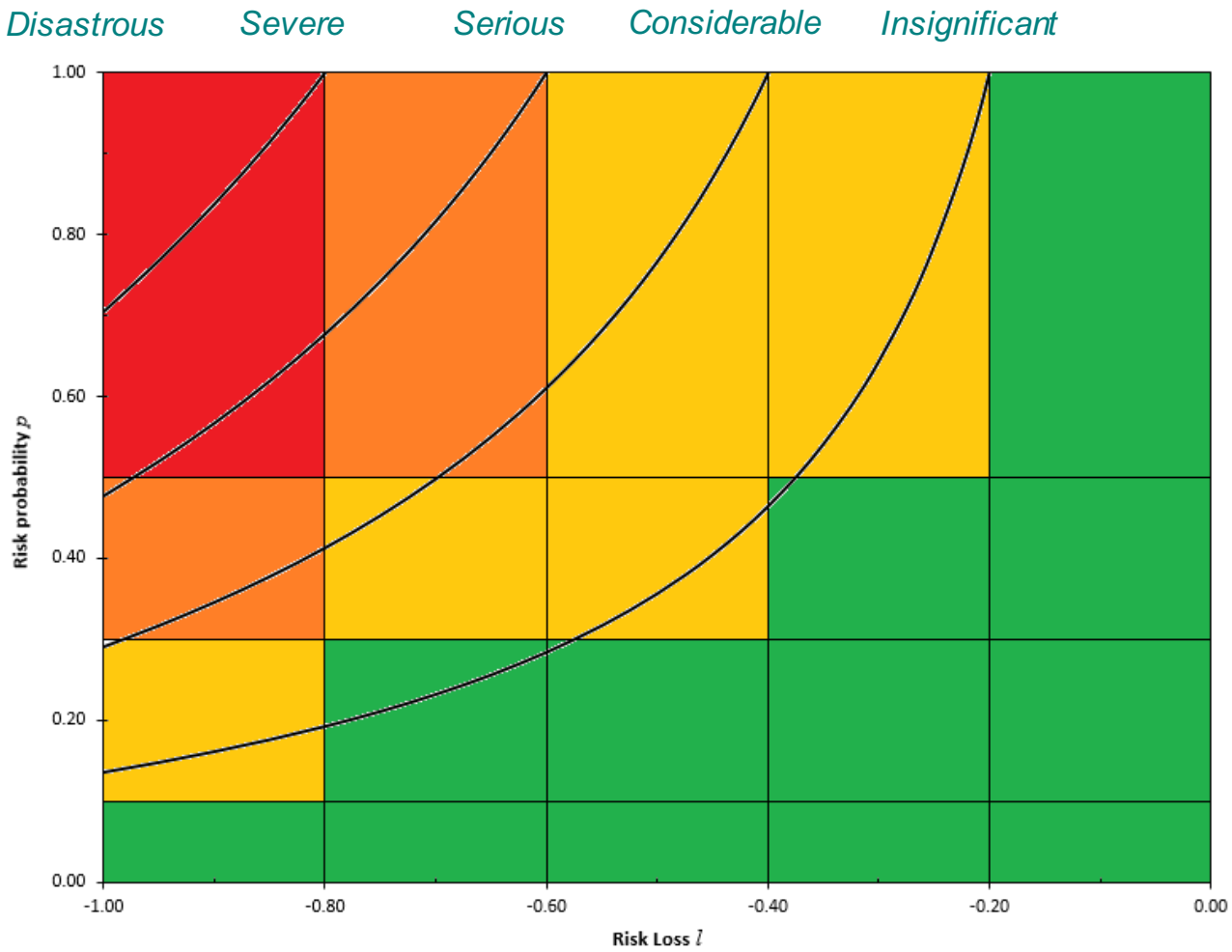
Maximum admissible indirect losses:
% GDP of affected region

$$u = \frac{1}{1 - \exp[-\gamma]}\left(1 - \exp\left[-\gamma \frac{a_{max} - a}{a_{max} - a_{min}}\right]\right)$$

Sabatino (2015a, 2015b)

Transportation Network

Utility indifference curves for risk-averse attitude



Very Likely (50-100%)

Likely (30-50%)

Occasional (10-30%)

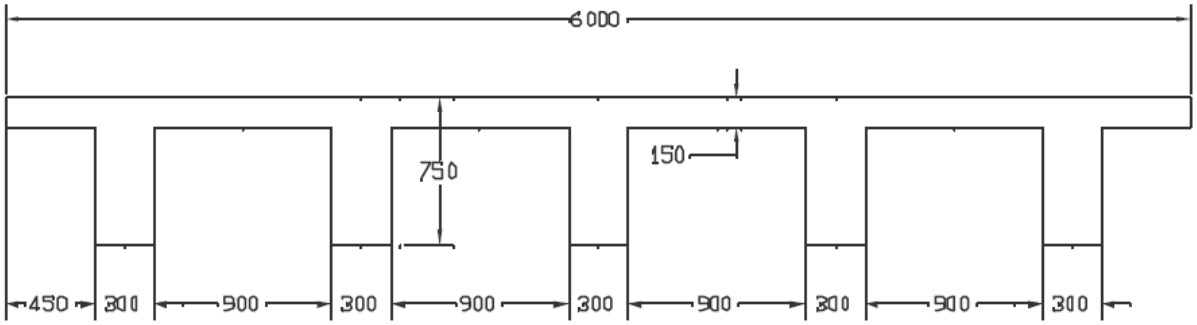
Unlikely (0-10%)

Negligible - 1
Acceptable - 0,8
Controllable - 0,6
Critical - 0,2
Unacceptable - 0

Ruan et al. (2015a)

Case studies

… Short-span RC bridge studied by Wong et al. (2005)



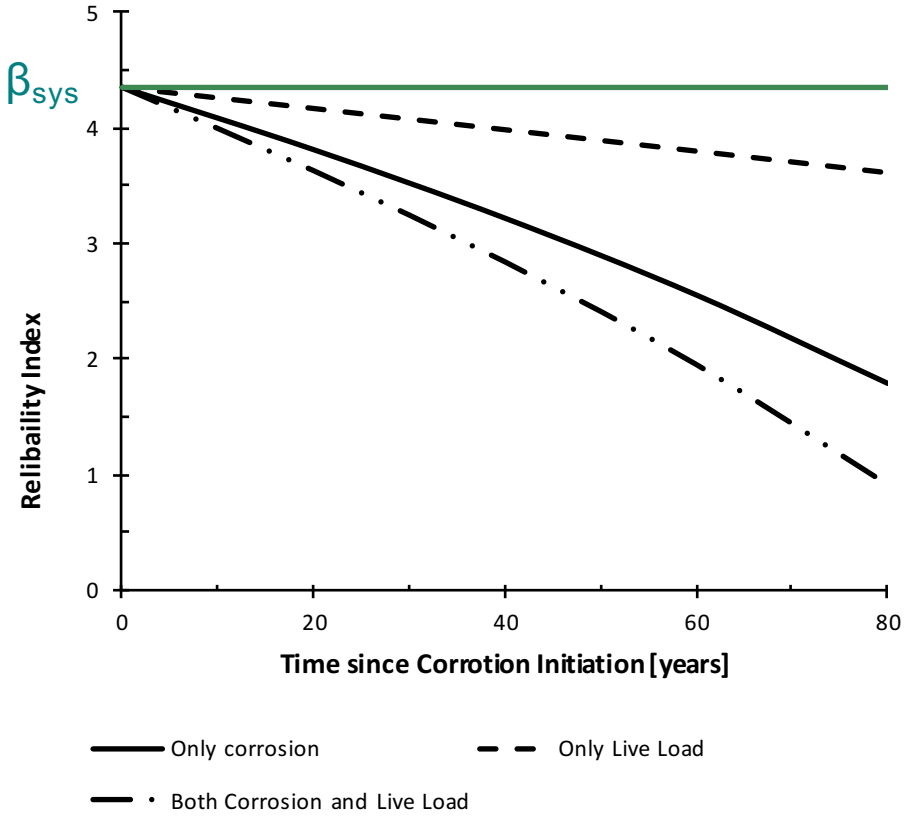
1. Several numerical difficulties were encountered using classical RSM (Wong et al. 2005)

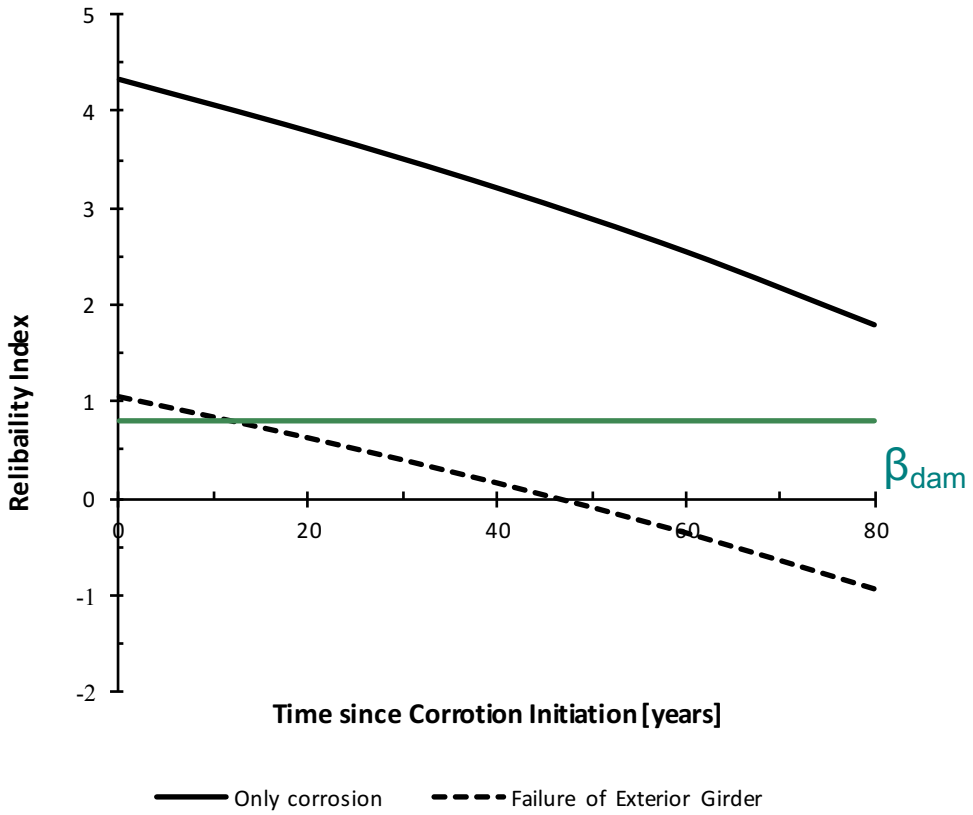
2. Typical configuration of highway overpasses

3. Life-cycle performance assessment

Simply supported girder bridge

$$G(X) = LF(X) - LL$$



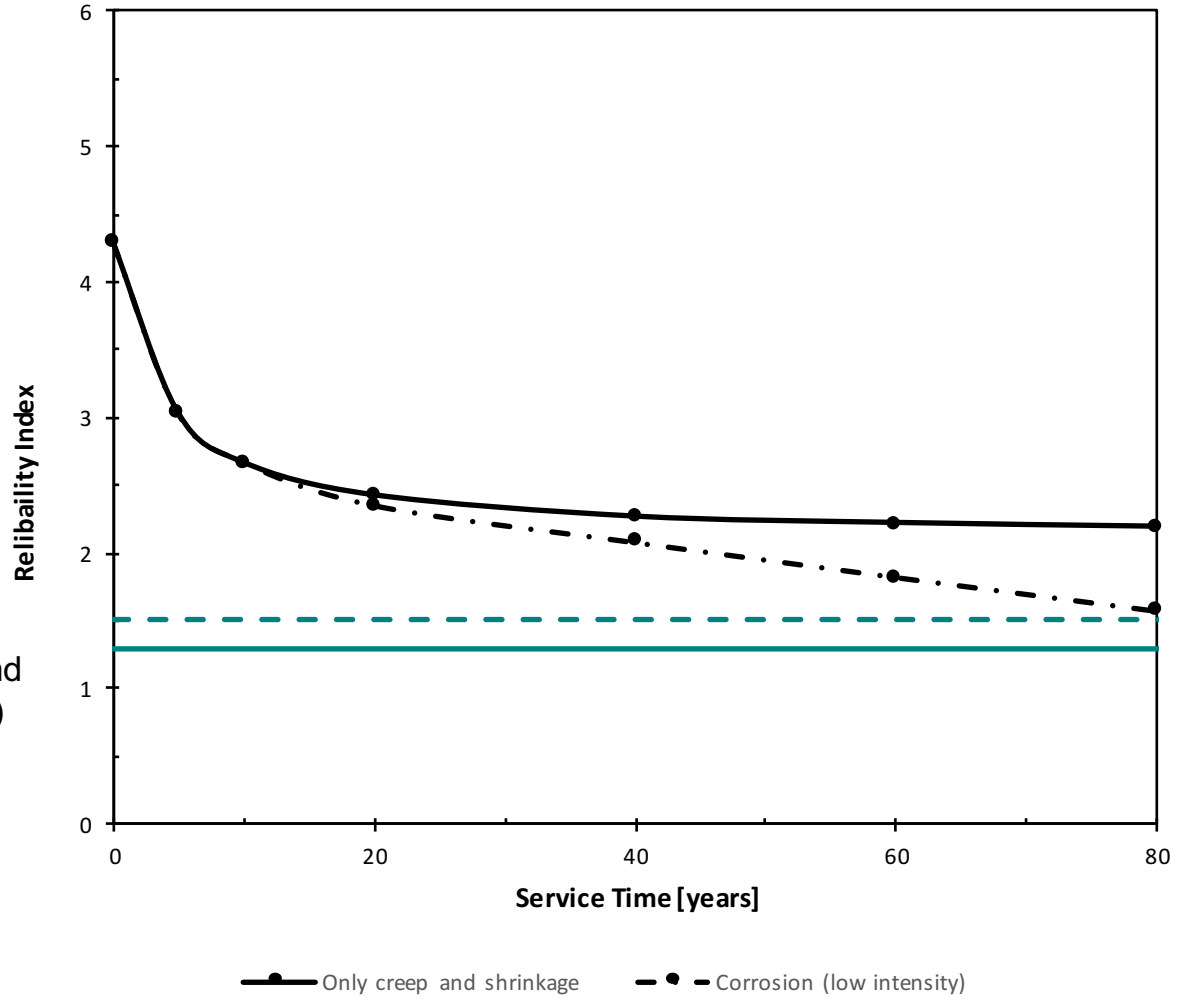


Target reliability based on Ghosn and Yang (2014)
NCHRP Report 776

Simply supported girder bridge

$\beta_{serv} = 1.3$

JCSS (2001) and ISO2394 (2015)

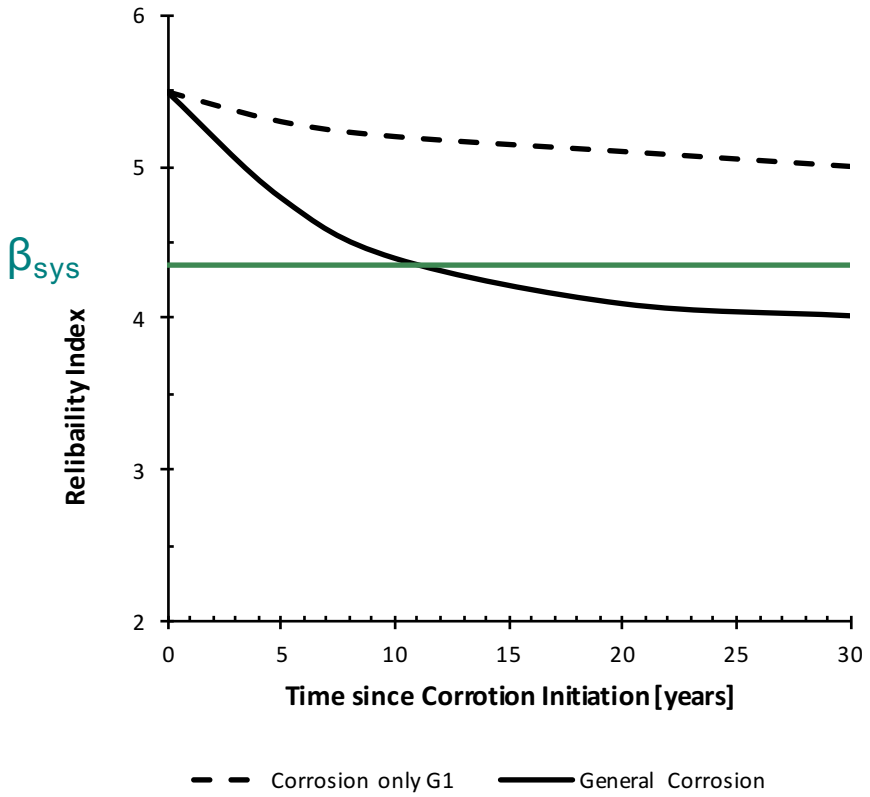


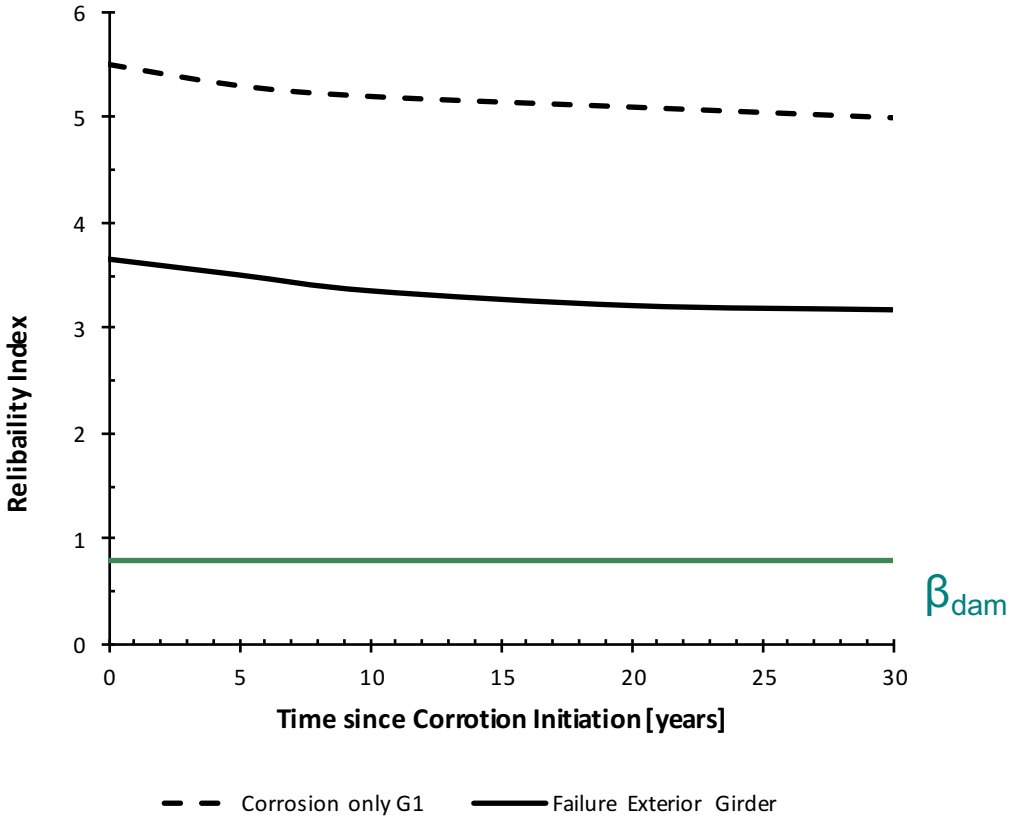
$\beta_{serv} = 1.5$

EN-1990 (2002)]

Tercenas Bridge

Tercenas Bridge

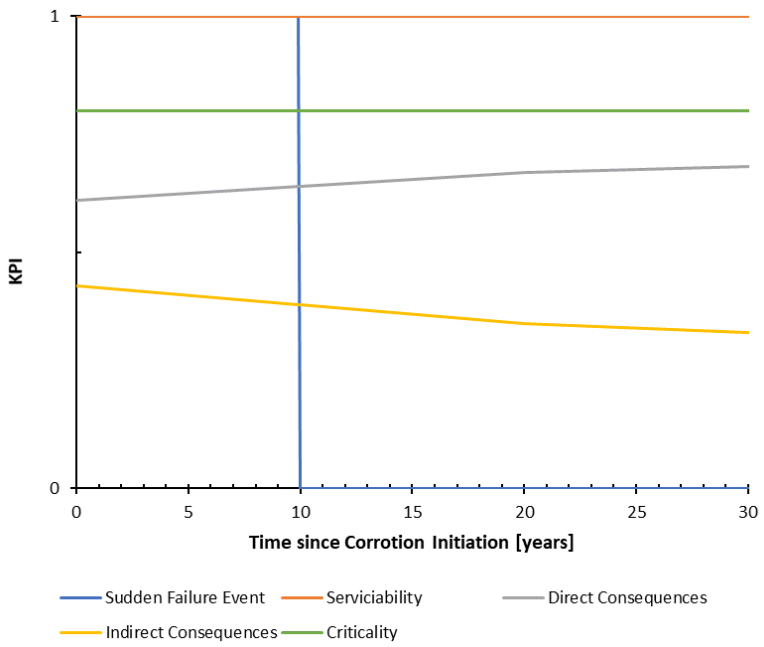




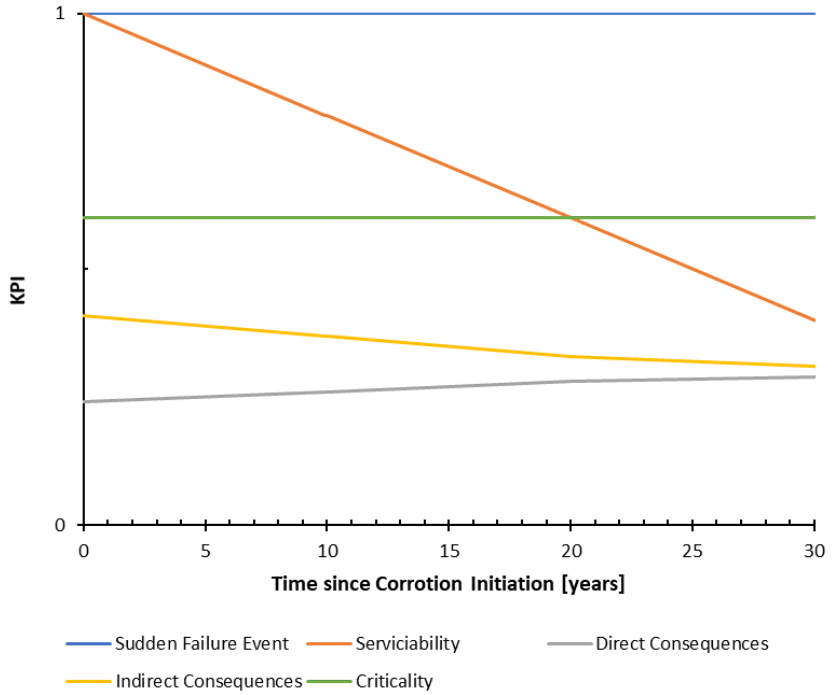
The structure presents a satisfactory reserve capacity and redundancy.

Comparing Performance

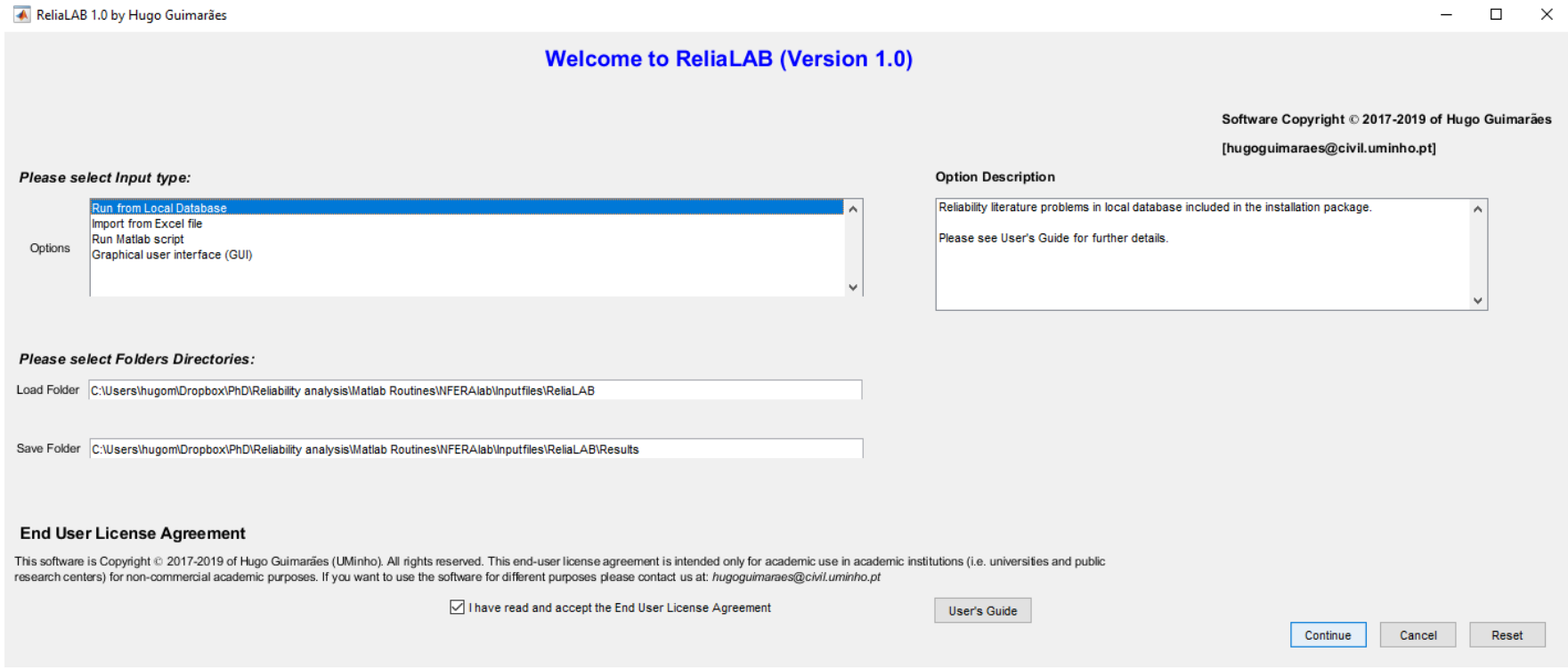
Simply supported bridge



Tercenas Bridge



Additional Contributions



Conclusions

- Research needs vs Research Goals
- Challenges and solutions in metamodeling-based reliability
- Alternative approach to prioritize maintenance actions in bridges
- Contributions to academical and practical environment

Future Developments and suggestions to research

- Introducing clustering algorithms to deal with multiple failure modes
- Performance metrics at network level can still be improved and include probabilistic nature (flow-based and topology-based)
- Extend and disseminate developed software
- Include multiobjective optimization in the proposed framework