COST Action
TU 1402

Quantifying the Value of Structural Health Monitoring

SHORT TERM SCIENTIFIC MISSIONS OVERVIEW

Final TU1402 Conference, BAM Berlin, Germany, February 18th and 19th, 2019

Prof. Alan O'Connor & Prof. Ana Mandić Ivanković

Short Term Scientific Missions (STSM)

- institutional visits aimed at supporting individual mobility and fostering collaboration
- with the scientific scope which supports the Action in achieving its scientific objectives
- supporting COST policies on promoting gender balance, enabling Early Career Investigators (ECI), broadening geographical inclusiveness

COST Action TU 1402 STSMs

- altogether 17 STSMs performed, with currently more underway/in preparation
- 18 different countries involved:
  Switzerland, Macedonia, Portugal, Italy, Denmark, Norway, France, Poland, Ireland, France, Australia, Slovenia, Croatia, Spain, Scotland, Sweden, The Netherlands, Germany
- >15 conference/journal papers published, several under preparation
- basis for case studies, for further development of scientific methodologies, for practical guidelines

OVERVIEW CONTAINS

- STSM participant and home institution
- Host & reason for choosing this host
- Aim of the STSM
- Tools & Methods used in preparation and during course of the STSM
- Main results
  within the COST TU 1402 Scope, including scientific publications and inputs for practical guidelines
- Outreach
  future developments and exploitation/implementation potential
- Main figural/visual schematic representations of the contributions

1. The Value of SHM for the Structural Behaviour of Masonry Structures under Varying Environmental Effects

- STSM participant and home institution: Maria Giovanna Masciotta (mg.masciotta@gmail.com) University «G.d'Annunzio» of Chieti-Pescara, Italy

- Host & reason for choosing this host: University of Minho, Portugal – The host University, in particular the HMS (Historical and Masonry Structures) research group, is very active and internationally recognized in the field of interest for this STSM.
- Aim of the STSM: Shed light on how the information collected through monitoring systems can be exploited for assessing the structural performance of masonry historical buildings under varying environmental conditions, making more effective asset management decisions.
- Tools & Methods used in preparation and during the STSM: Diagnostic investigations and monitoring-based quantitative methods aimed at collecting field-recorded data on the structural health for subsequent processing and analysis.
- Main results:

1. Masciotta M.G., Ramos L.F., Lourenço P.B., Matos J.A.C., Development of Key Performance Indicators for the Structural Assessment of Heritage Buildings, E-Journal of Non-Destructive Testing, 21(8), ISSN 1435-4934, Proc. 8th European Workshop on Structural Health Monitoring (EWSHM), Bilbao, Spain, 12 pp. (2016).

1. The Value of SHM for the Structural Behaviour of Masonry Structures under Varying Environmental Effects

- Outreach: Development of SHM-based forecasting models for heritage structures in order to predict aging effects.
- Main figural/visual schematic representation of the contributions:

2.

A novel bi-component SHM strategy for deriving global models of operational Wind Turbines

- STSM participant and home institution: **Simona Bogoevska (monana19@yahoo.com),** Home Institution: Ss. Cyril and Methodius University, Skopje, FYR Macedonia

- Host & reason for choosing this host: Eleni Chatzi, ETH Zurich, Switzerland

3. APPLICATION OF B-WIM MEASUREMENTS IN ASSESSMENT OF EXISTING BRIDGES

- STSM Participant: **Dominik Skokandić** (dskokandic@grad.hr), University of Zagreb, Faculty of Civil Engineering, Croatia

- Host: Aleš Žnidarič, Slovenian National Building and Civil Engineering Institute (ZAG), Slovenia, as a expert on B-WIM technology, and also a main developer associated with the world leading B-WIM system, SiWIM®.

- Aim of the STSM: The main purpose of the STSM was to study and analyze application of Bridge Weigh-in-Motion (B-WIM) measurements as a part of SHM tools, in load carrying capacity assessment of existing road bridges.

- Tools & Methods used in preparation and during STSM: Extensive literature review on the theoretical background of WIM technology was done prior to my STSM, followed by field measurements on selected Case Study bridge in the first part of STSM. Second part of STSM consisted of data post-processing, development of FEM model of Case Study Bridge and its reliability assessment using probabilistic approaches.

3. APPLICATION OF B-WIM MEASUREMENTS IN ASSESSMENT OF EXISTING BRIDGES

- Main results: STSM results clearly show the quantification of B-WIM measurements as a type of SHM in assessment of existing bridges, and are presented in the following papers:
  1. Ana Mandić Ivanković, Dominik Skokandić, Aleš Žnidarič, Maja Kreslin: ***Bridge performance indicators based on traffic load monitoring***. Structure and Infrastructure Engineering 12/2017
  2. Dominik Skokandić, Aleš Žnidarič, Ana Mandić Ivanković, Maja Kreslin: ***Application of Bridge Weigh-in-Motion measurements in assessment of existing road bridges***. JOINT COST - IABSE Workshop, Zagreb, Croatia; 03/2017

- Outreach: STSM research and conclusions were a basis for Case Study development, and additional STSM, where economical aspects of B-WIM implementation in terms of costs and benefits were researched using VoI analysis.

- Main visual schematic representation of the contributions:

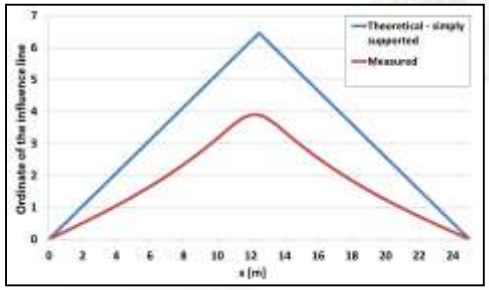


Figure 1: *Difference between measured and theoretical influence line*

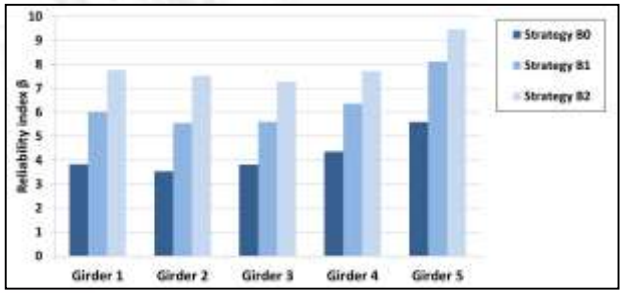


Figure 2: *Reliability assessment with and without additional SHM data*

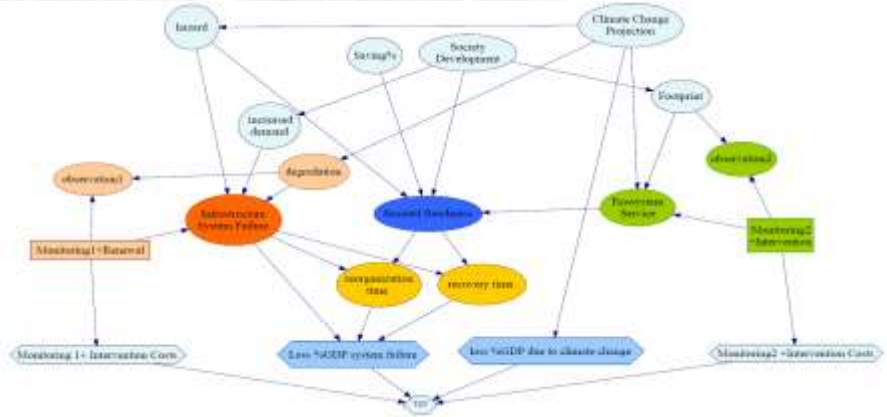
4. VALUE OF INFORMATION IN SYSTEM RESILIENCE MODELLING

- STSM participant and home institution: **Simona Miraglia** (smi@civil.aau.dk), Technical University of Denmark (DTU)
- Host & reason for choosing this host: Mark G. Stewart, Centre for Infrastructure Performance and Reliability (CIPAR)-The University of Newcastle, NSW-AU. Prof Stewart is the director of the CIPAR and an internationally recognized expert in evaluating the impact of climate change on risks to infrastructure, as well as the cost-effectiveness of engineering adaptation strategies and policy-making.
- Aim of the STSM: The STSM activity is related to both WG1- Theoretical Framework and WG4- Case Studies Portfolio. The aim was to investigate the application of VoI to system resilience modelling and to demonstrate how VoI can be applied in a broader sense to different monitoring strategies which comprises socio-environmental performance indicators in addition to SHM and for assessing the sensitivity of the system performance to the monitored indicators.
- Tools & Methods used in preparation and during STSM: A generic system is used as case study to model system performance in terms of resilience. The decision problem is modelled using a Bayesian Network where the VoI analysis is performed on the classic risk analysis indicators of system vulnerability and robustness and extended to indicators of ecosphere and socio-economic capacity.

4. VALUE OF INFORMATION IN SYSTEM RESILIENCE MODELLING

- Main results: Results were presented and published at 12th International Conference on Structural Safety & Reliability-ICOSSAR2017, held in Vienna on 6-10 August 2017.
- Outreach: The VoI analysis can be used as a decision support tool in evaluating monitoring policies over different indicators and scenarios. In particular VoI can be used as a substitute for sensitivity analysis of the system resilience performance over the (monitored) variables. A new version of the model is under development using a new dataset for modeling socio-economic and environmental indicators together with recalibration of parameters for technical system.
- Main figural/visual schematic representation of the contributions:

Representation of the multiple dimensions of resilience of the built environment



Influence diagram for the representation of the built environment

5. Use of meta-models in SHM

- STSM participant and home institution: **Peter El Hajj (Peter.ElHajj@mottmac.com)**, University of Nantes (now working at Mott MacDonald – Information Consultant)

- Host & reason for choosing this host: Prof. Alan O'Connor, common interest in understanding the impact of uncertainty of SHM techniques on decision making and lifecycle management of critical infrastructure through a risk based approach.

- Aim of the STSM: Investigate the use of degradation meta-models based on a formulation of correlated state-dependant stochastic processes (gamma processes in this study) in a structural health monitoring context.

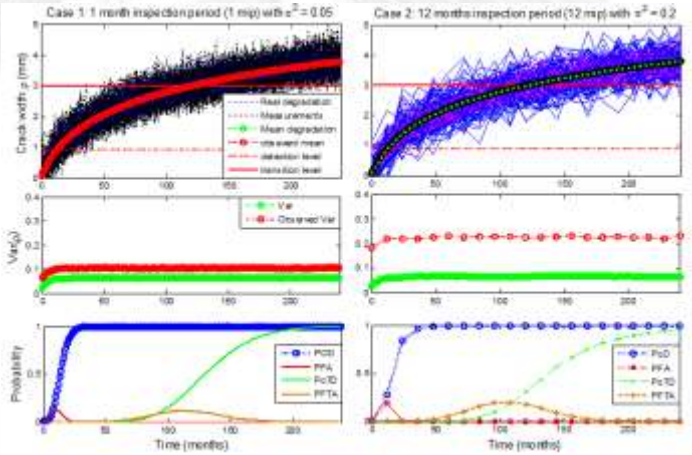
- Tools & Methods used in preparation and during STSM:
  State-dependent stochastic processes
  Correlated gamma processes
  Stochastic Estimation Maximisation algorithm
  Simulation were carried out through Matlab

5.

Use of meta-models in SHM

- Main results :
  1. Identified an approach to integrate environmental-effects in degradation meta-models
  2. Modelled the SHM assessment by means of probabilities of detection and false alarms
  3. Illustrated the calibration framework based on the Stochastic Estimation Maximisation while considering different lifetime of the sensors
- Outreach: Further investigation on the use of degradation meta-modelling in an SHM context
- Main figural/visual schematic representation of the contributions:

Two inspection scenarios and the impact on probabilities of detection (PoD) and false alarm (PFA), and on probabilities of transition detection (PoTD) and false transition alarm (PFTA)



6.

Strategies of structural health thermal monitoring and condition assessment with thermal monitoring of earth dams and levees

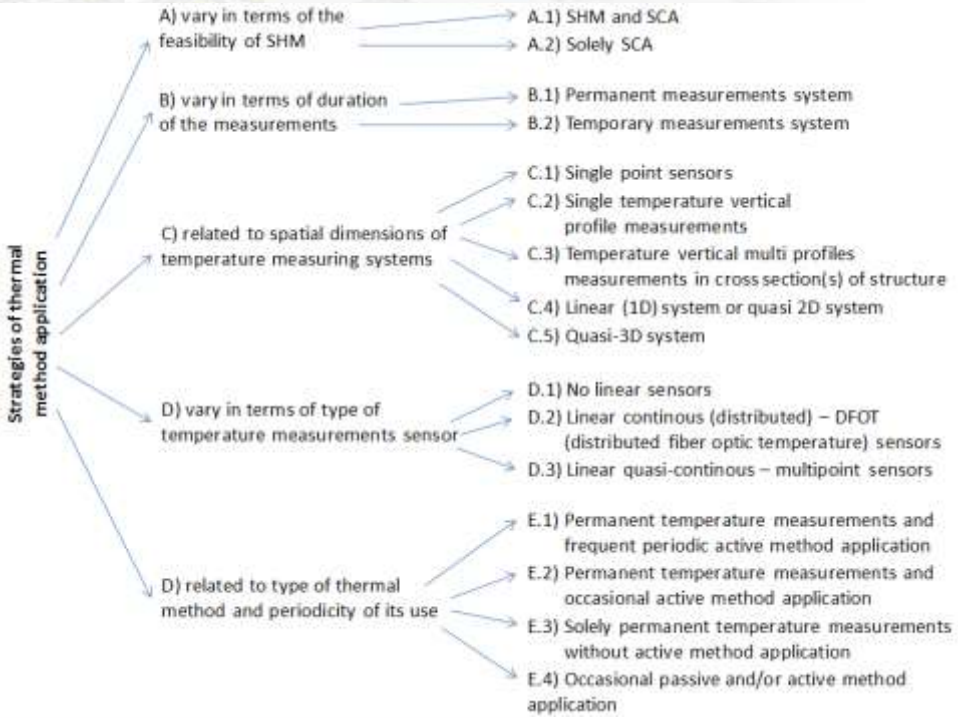
- STSM participant and home institution: PhD Eng. **Krzysztof Radzicki** (krzysztof.radzicki@iigw.pl) from Cracow University of Technology
- Host & reason for choosing this host: Irstea – National Research Institute of Science and Technology for Environment and Agriculture is a public research institute in France focusing on land management issues. It is one of the key institutions in France involved in the assessment of the technical condition of the damming structures. It conducts research and development works developing technologies for this purpose, including the termomonitoring method.
- Aim of the STSM: preparation of optimal strategy of structural health thermal monitoring and condition assessment with thermal monitoring of earth dams and levees.
- Tools & Methods used in preparation and during STSM: Bibliographic analysis & Analysis and comparing of research results and application experiences for thermal monitoring method of Cracow University of Technology (Home Institution) and Irstea (Host Institution).
- Main results :
  1. Defining and describing key basic components used to build a strategy for the thermal monitoring method
     a) developed by Cracow University of Technology (CWT) and IRSTEA
     b) defined on the basis of the bibliographic analysis
  2. Describing multivariate strategies of structural health thermal monitoring and condition assessment with thermal monitoring of earth dams and levees and principal elements for strategies decisions making.

6.

Strategies of structural health thermal monitoring and condition assessment with thermal monitoring of earth dams and levees

- Outreach:
  Developed methodology is used in structural health thermal monitoring and condition assessment of damming structures as dams and dikes

- Main figural/visual schematic representation of the contributions:



7.

Structural Health Monitoring for Large Structural Systems

- STSM participant and home institution: **Prof. Bernt J. Leira** (bernt.leira@ntnu.no), NTNU, Norway
- Host & reason for choosing this host: DTU due to the excellent research environment and extensive experience from system modelling and reliability analysis. This applies to civil engineering as well as offshore structures.
- Aim of the STSM: To explore the potential for application of enhanced Monte Carlo simulation methods for large structural systems within the area of structural health monitoring.
- Tools & Methods used in preparation and during STSM: A comprehensive data set of chloride diffusion profile samples from a coastal bridge in Northern Norway was analyzed in order to provide statistical models to enable a system reliability analysis. In order to address chloride attack on the entire bridge, a system model with 90 components was applied. This model was utilized in order to perform reliability updating based on observations at a number of sites along the bridge. The computations are performed by application of the so-called Enhanced Monte Carlo simulation method.

7.

Structural Health Monitoring for Large Structural Systems

- Main results (within the COST TU 1402 Scope, including scientific publications and inputs for practical guidelines):

1. Leira, B. J.; Thons, S.; Faber, M. H.: "Reliability assessment of a bridge structure subjected to chloride attack", Structural Engineering International 2018 ;Volume 28.(3) pp. 318-324.

2. Leira, B. J.; Thons, S.: System Reliability of Concrete Structures Subjected to Chloride Ingress. I: Safety & Reliability, Theory and Applications. CRC Press 2017 ISBN 978-1138629370. s. 2305-2312

- Outreach : Presentation of results at COST-action Workshop in Zagreb (2017) and at ESREL Conference in Slovenia (2017). Potential for future applications within the area of monitoring and inspection planning for large structural systems.

- Main figural/visual schematic representation of the contributions:

Fig. 1: The Gimsøystraumen Bridge in northern Norway (Lofoten area) (Photo: Per Smerkl, Wikipedia)

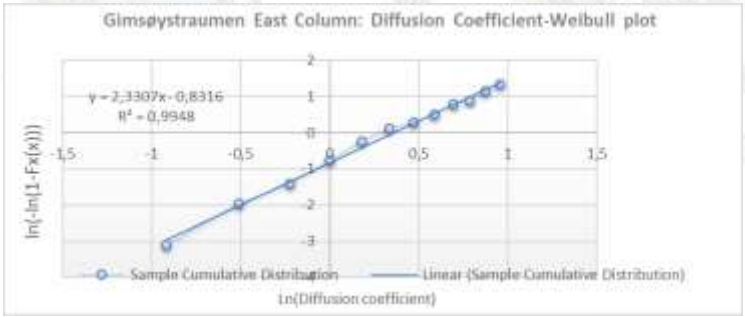


Fig. 2: Comparison between the sample distribution function and the fitted Weibull distribution for the diffusion coefficient of the east column

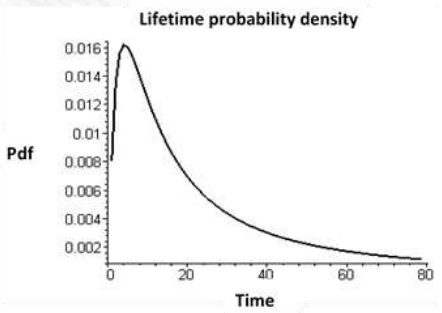


Fig. 7: Probability density function obtained by differentiation of the distribution function

8. Model for the structural health monitoring of concrete structures under fatigue loads, considering material and structural uncertainties

- STSM participant and home institution: Dr. Luis Saucedo Mora (luis.saucedomora@materials.ox.ac.uk), Instituto de Ciencias de la Construcción Eduardo Torroja, Spain
- Host & reason for choosing this host: Prof. Sebastian Thöns, DTU, Denmark. He is a researcher specialized on risk analysis, and it was ideally for me to get new skills.
- Aim of the STSM: To apply risk modeling to the fatigue damage of concrete, and develop a probabilistic model with the pre-posterior and prior decision models.
- Tools & Methods used in preparation and during STSM: Risks analysis and a fatigue theory.

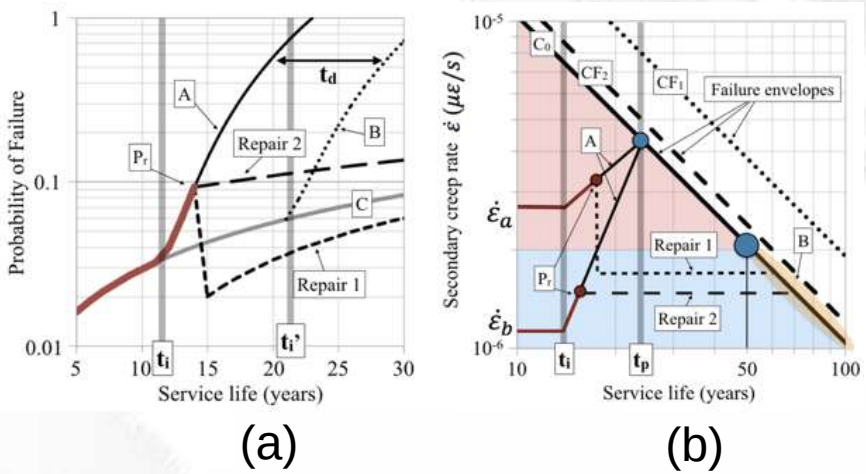


Figure: (a) shows the probability of failure evolution considering the repairs and the different pathologies modeled. (b) is the same information of the Figure (a) but in the secondary creep rate space, which is the main indicator of the model.

8.

Model for the structural health monitoring of concrete structures under fatigue loads, considering material and structural uncertainties

- Main results : a probabilistic model that considers fatigue, corrosion and freeze and thaw damages
- Outreach : scientific papers are under preparation.
- Main figural/visual schematic representation of the contributions:

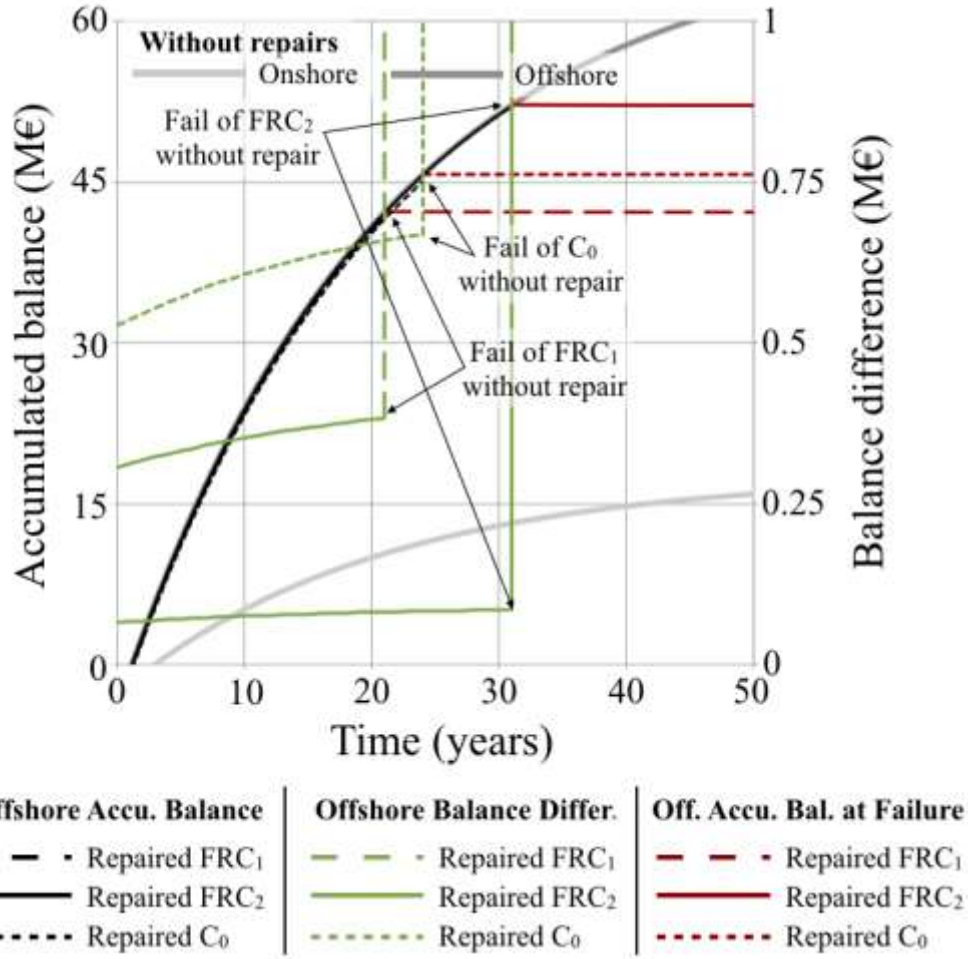


Figure showing the accumulated balance for 3 materials (plain, steel fiber and polypropylene fiber reinforced concrete. As an output of the risk analysis considering fatigue, corrosion and freeze and thaw cycles.

9. Development of a Digital Image Correlation technique as indicator of the structural integrity

- STSM participant and home institution: Dr. **Luis Saucedo Mora** (luis.saucedomora@materials.ox.ac.uk), University of Oxford (UK)

- Host & reason for choosing this host: Prof. Luis Oliveira Santos, LNEC, Portugal, he is a researcher of the Structures Department, involved on the structural health monitoring of several structures. It made a good framework to explore the potentiality of the Digital Image Correlation in SHM.

- Tools & Methods used in preparation and during STSM: We implemented the technique in some pictures of the International Guadiana Bridge.

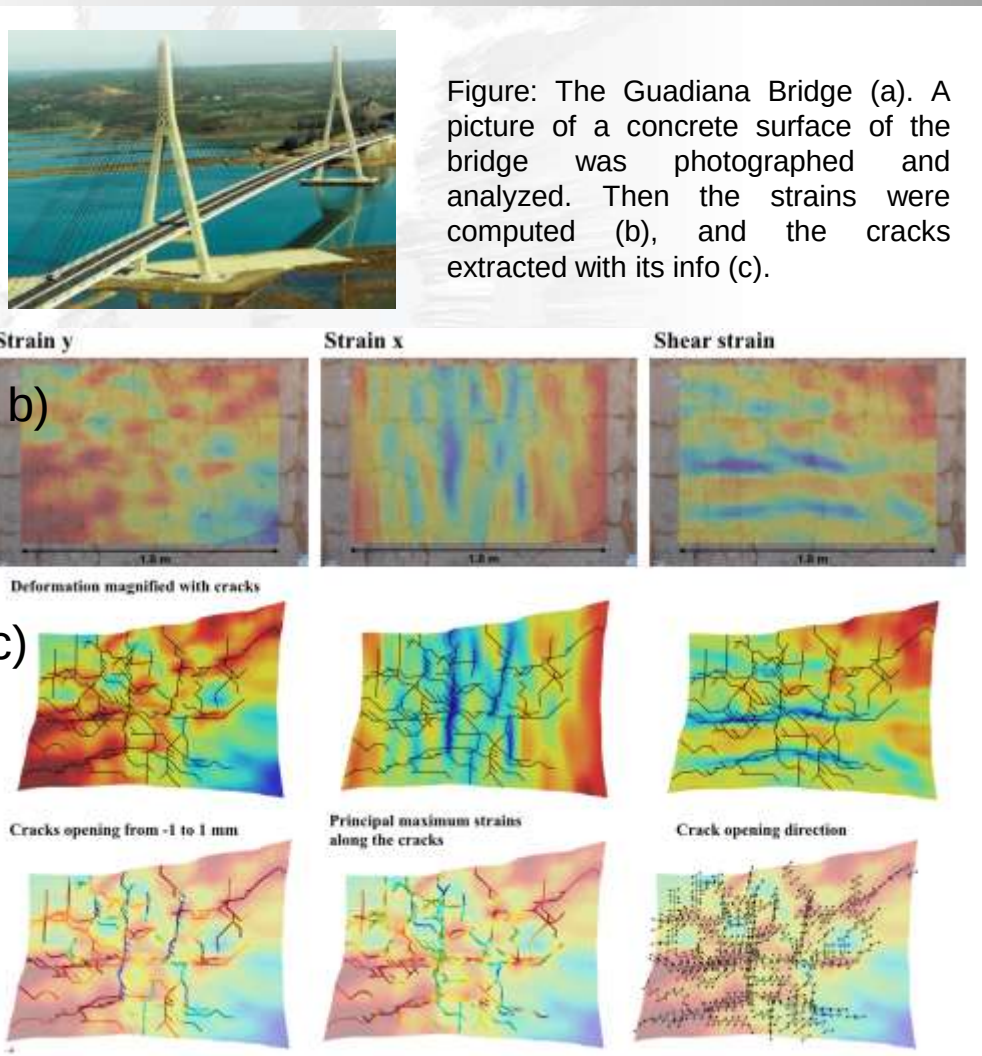


Figure: The Guadiana Bridge (a). A picture of a concrete surface of the bridge was photographed and analyzed. Then the strains were computed (b), and the cracks extracted with its info (c).

9. Development of a Digital Image Correlation technique as indicator of the structural integrity

- Main results : the aim is to publish a scientific paper.
- Outreach: to extend the methodology towards a global application
- Main figural/visual schematic representation of the contributions:

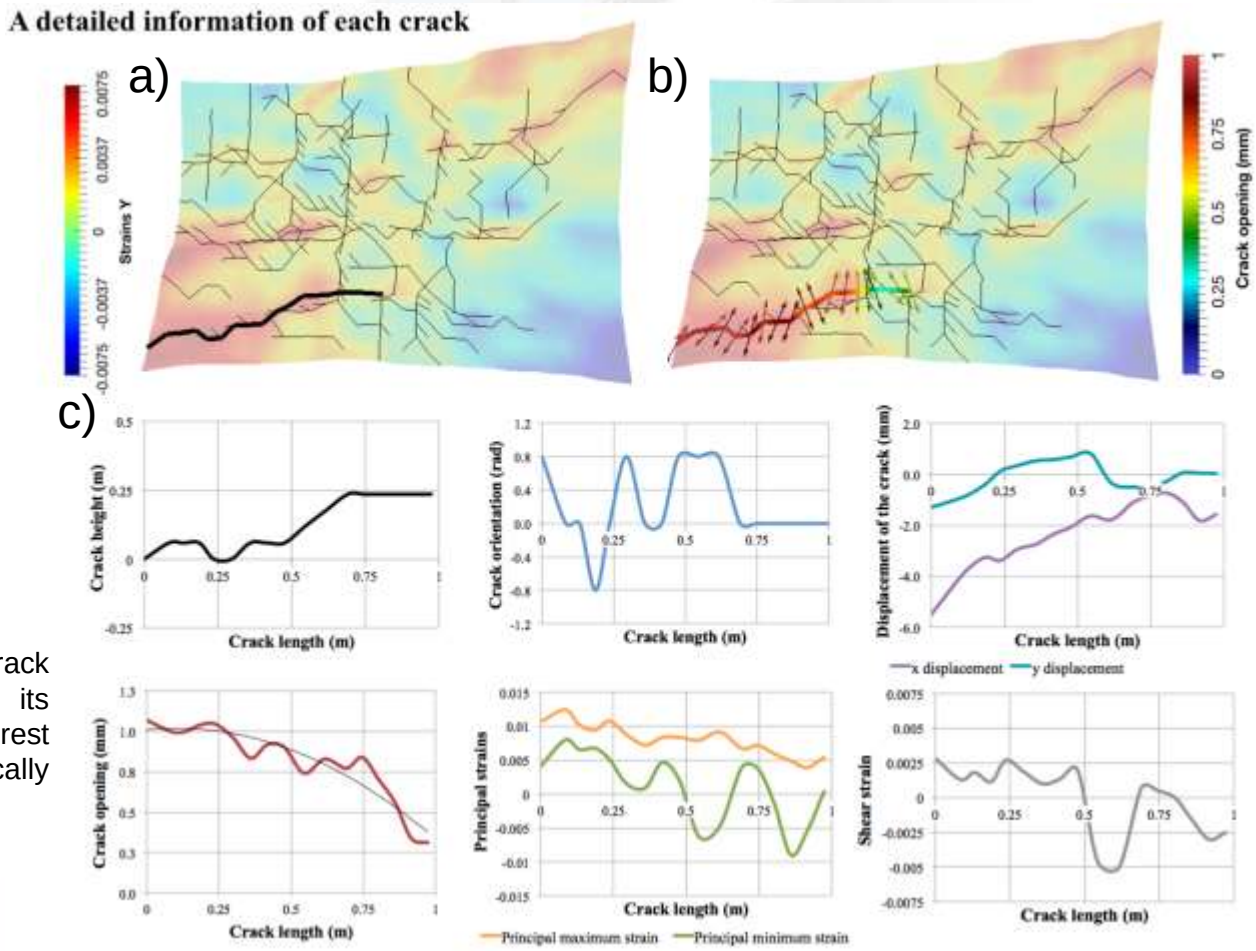


Figure: A crack from the crack pattern is selected (a) with its opening direction (b), and the rest of the info was automatically extracted (c).

10.

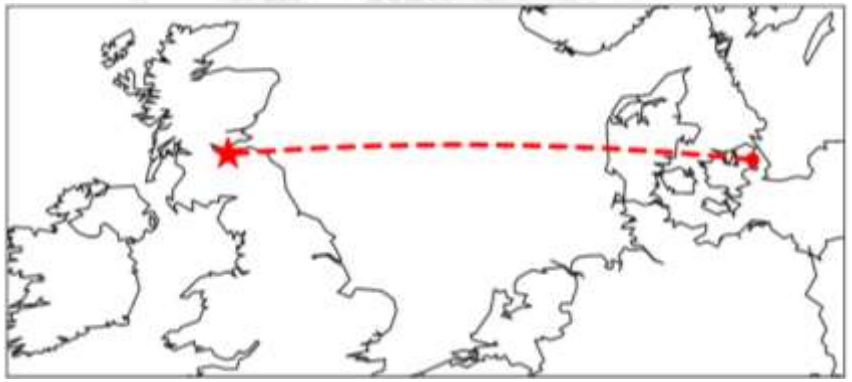
Proof load testing decision framework

- STSM participant and home institution: **Henning Brüske, (henbrr@dtu.dk)**, Technical University of Denmark, Lyngby, Denmark

- Host & reason for choosing this host: Dimitri Val, Heriot-Watt University, Edinburgh, Scotland; Great experience in value of information analysis, proof load testing, structural reliability

- Aim of the STSM: Development of a decision framework for proof load testing. Depending on the structure and its utilization, different parameters for the proof load test or even other testing may be optimal and may provide a greater value of information.

- Tools & Methods used in preparation and during STSM: Value of information analysis, structural reliability analysis



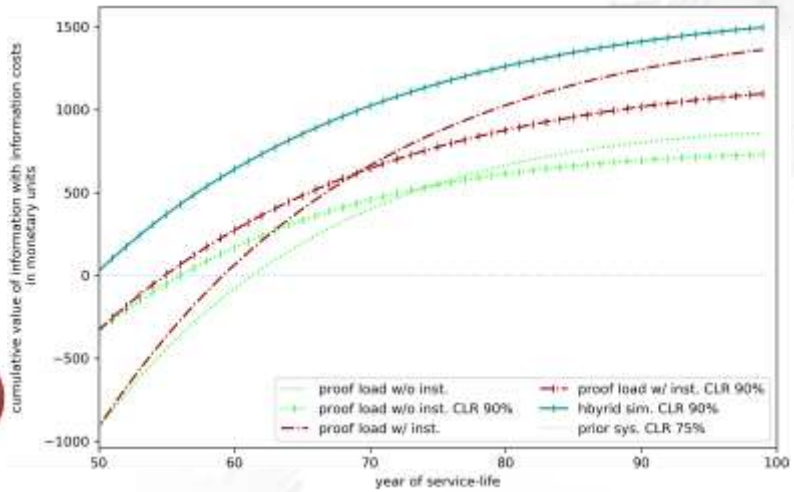
10.

Proof load testing decision framework

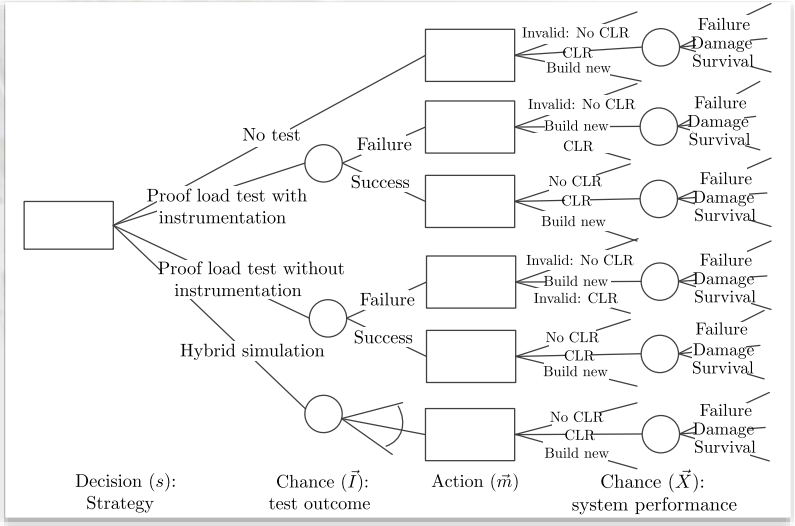
- Main results:
  1. Article submitted to Structural Safety
  2. Providing an example as basis for applications.

- Outreach: Potential follow-up research considering hybrid-simulation

- Main figural/visual schematic representation of the contributions:



VoI developing over time

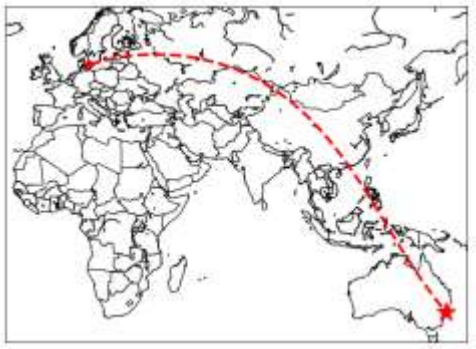


Example tree of decision framework

11.

Assessment of Risk Mitigation Strategies for Attacks on Bridges

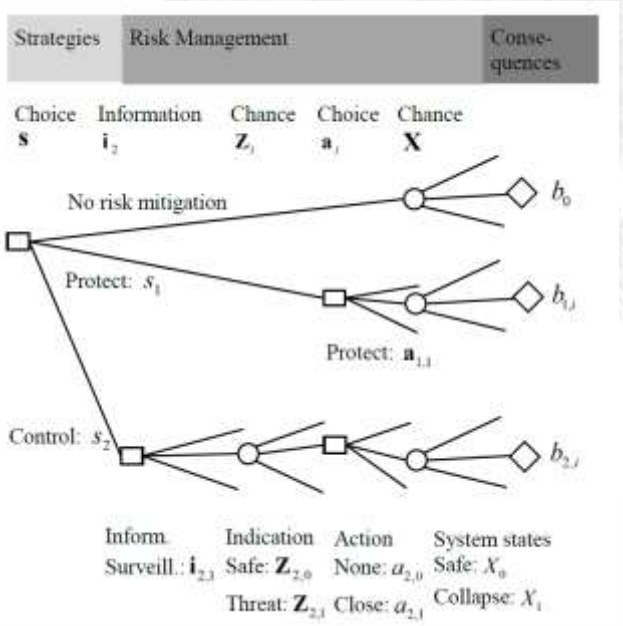
- STSM participant and home institution: Prof. **Sebastian Thöns** (sebt@byg.dtu.dk), Technical University of Denmark
- Host & reason for choosing this host: Prof. Mark G. Stewart, University of Newcastle
- Decision scenario: We analyse the value of risk mitigation measures for terrorist attacks with Improvised Explosive Devices (IEDs) for an iconic bridge structure.
  - Decision maker: Public authority responsible for the societal safety of the infrastructure.
  - Decision point in time: Design phase (protect), Operation (control)
  - Life cycle phases: Design and 100 years of operation
  - Performance: Terrorist attack with an improvised explosive device
  - Objective: Minimisation of risks and expected costs
  - Methods: Bayesian prior and pre-posterior decision analysis



11.

Assessment of Risk Mitigation Strategies for Attacks on Bridges

- Main results: Evidence of cost efficiency of protection and surveillance strategies for relatively high threat probabilities (1 conference and 1 journal paper, 1 journal paper in preparation).
- Outreach: Identification of efficient strategies for a safer build environment with least resources.
- Main figural/visual schematic representation of the contributions:



12.

STRUCTURAL HEALTH MONITORING OF A TENDON SUPPORTED LARGE SPAN ROOF OF THE MULTIARENA IN GLIWICE, POLAND

- STSM participant and home institution: **Tomasz Howiacki (MSc), (howiacki.tomasz@gmail.co**
  Cracow University of Technology, Poland

- Host & reason for choosing this host:
  Miroslav Sykora (PhD), Czech Technical University in Prague, Czech Republic
  Common interests in the topic of large span roof snow loading, cooperation between experts on structural mechanics (Cracow) and reliability and risk analysis (Prague)

- Aim of the STSM: reliability and risk analysis involving FE model and in situ data on the example of real multiarena case study, showing the way of how to proceed in similar cases

- Tools & Methods used in preparation and during STSM:
  Finite Element Method, Probabilistic methods (FORM, SORM, Monte Carlo Simulation), Decision tree, Cost – Benefit analysis, etc.

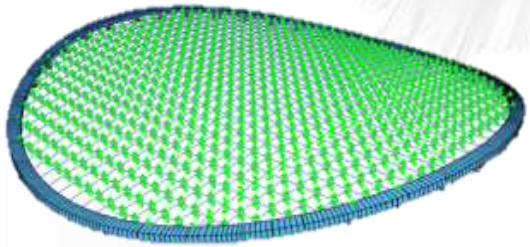
12.

STRUCTURAL HEALTH MONITORING OF A TENDON SUPPORTED LARGE SPAN ROOF OF THE MULTIARENA IN GLIWICE, POLAND

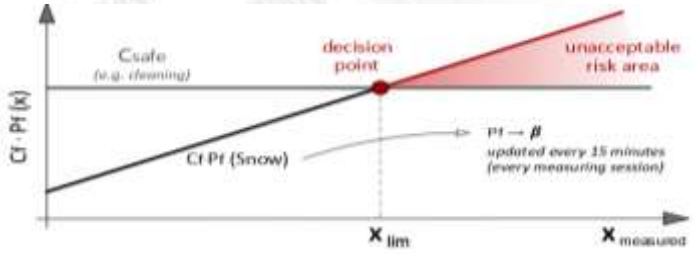
- Main results:
  1. *Howiacki T., Sieńko R., Sýkora M.,* ***Reliability Analysis of Serviceability of Long Span Roof Using Measurements and FEM Model*** *, ICNAAM 16th International Conference of Numerical Analysis and Applied Mathematics, Rhodos, Greece, 13-18.09. 2018*
  2. *Maślak M., Pazdanowski M., Howiacki T.,* ***Value of information in the maintenance of a tendon supported large span roof*** *, 40th IABSE Symposium, 19-21 September 2018, Nantes, France*

- Outreach:
  1. managing procedure for a real multiareana
  2. calculation scheme for similar case studies

- Main figural/visual schematic representation of the contributions:



FEM model for anlyzed tendon large span structure



The idea of cost-benefit specification of thresholds

13. IMPLEMENTATION OF VoI ANALYSIS WITH PROBABILISTIC ASSESSMENT METHODS OF EXISTING BRIDGES

- STSM Participant: **Dominik Skokandić** (dskokandic@grad.hr), University of Zagreb, Faculty of Civil Engineering, Croatia

- Host: Prof. Sebastian Thöns, Technical University od Denmark (DTU), Denmark, as an expert on Value of Information analysis and probabilistic updating using additional information

- Aim of the STSM: Main purpose of the STSM was to implement a Value of Information analysis (VoI) to quantify costs and benefits of application of Bridge Weigh-in-Motion measurements in assessment of existing road bridges.

- Tools & Methods used in preparation and during STSM: Prior to my STSM, I conducted initial literature review on VoI analysis and probabilistic updating, which was followed by definition of decision scenarios and development of probabilistic model for the calculation of system states. In second part of my STSM, we developed a probabilistic model for different SHM strategies using a computational software and define all the parameters for performance of VoI analysis.

13. IMPLEMENTATION OF VoI ANALYSIS WITH PROBABILISTIC ASSESSMENT METHODS OF EXISTING BRIDGES

- Main results: Research conducted on my STSM provides great basis for further development of Case Study, and is a part of my ongoing Phd thesis, and will also be presented on the upcoming IABSE conference with a paper titled:
  1. Skokandić Dominik, Mandić Ivanković Ana, Žnidarič Aleš, Thöns Sebastian: ***Quantifying the value of B-WIM: Assessing costs and benefits for Value of Information Analysis***

- Outreach: STSM research and conclusions are a part of Case Study within the action, and its final results in terms of costs and benefits comparison for different monitoring strategies will provide great insight for bridge owners, and will contribute to overall objectives of this COST Action.

- Main visual schematic representation of the contributions:

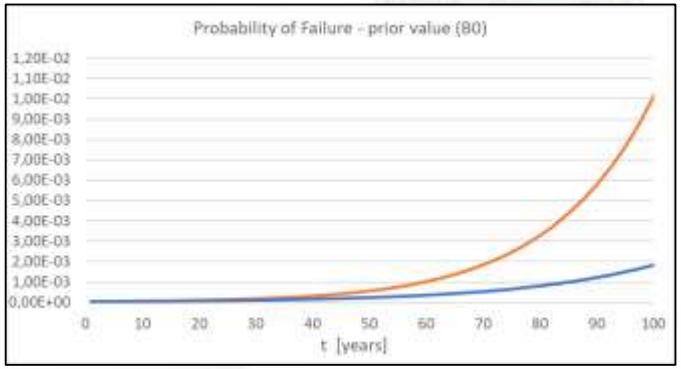


Figure 1: *Probability of failure progression trough service life*

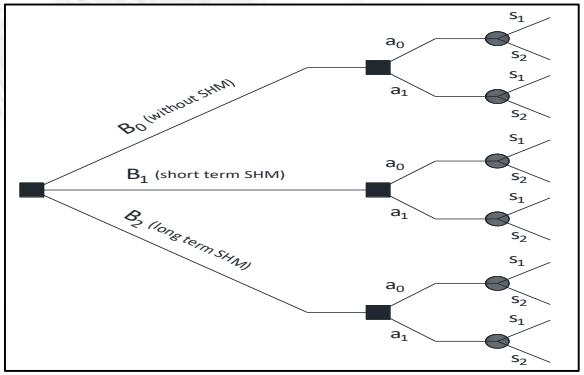


Figure 2: *Decision tree for VoI analysis of Case Study Bridge*

14. IMPLEMENTATION OF VALUE OF INFORMATION ANALYSIS WITH PROBABILISTIC ASSESSMENT METHODS OF EXISTING TIMBER HALL

- STSM participant and home institution: Mislav Stepinac (mstepinac@grad.hr), University of Zagreb

- Host & reason for choosing this host: Daniel Honfi, RISE Research Institutes of Sweden. Dr. Honfi was chosen as a host because he is deeply involved in timber structures and has a knowledge in reliability and VoI methods for existing structures

- Aim of the STSM: A wide variety of methods exist to assess timber structures, however, their frequency and scope, the decision making approach concerning safety and the necessary interventions are far from being agreed upon. Over the past years, a multitude of guidelines on how to approach the inspection and maintenance of existing timber structures have been published, however, only a few countries have published applicable code-type documents for the assessment of existing structures. The STSM work was on how pre-posterior decision analysis can help quantifying the Value of Information (VoI) obtained by the condition assessment of timber structures and thus help select appropriate assessment procedures and subsequent maintenance actions. As a case study a timber exhibition hall in Zagreb, Croatia is investigated in the context of VoI analysis.

- Tools & Methods used in preparation and during STSM: Case sudy documentation, GeNiE software

14.

IMPLEMENTATION OF VALUE OF INFORMATION ANALYSIS WITH PROBABILISTIC ASSESSMENT METHODS OF EXISTING TIMBER HALL

- Main results: As VoI is relatively new in the field of timber structures, STSM introduced the methods and benefits to the community of timber engineers. Two papers were accepted for IABSE Conferences:
  1. 1. Stepinac, Mislav; Rajčić, Vlatka; Honfi, Daniel. *Condition Assessment of Timber Structures – Quantifying the Value of Information* // Proceedings of the 40th IABSE Symposium, Nantes, 2018
  2. 2. Stepinac, Mislav; Rajčić, Vlatka; Honfi, Daniel. *Decision analysis and scenarios for the assessment of existing timber structures* // IABSE Guimaraes 2019

- Outreach: Results of the STSM can have implementation in the assessment of timber structures

- Main figural/visual schematic representation of the contributions:

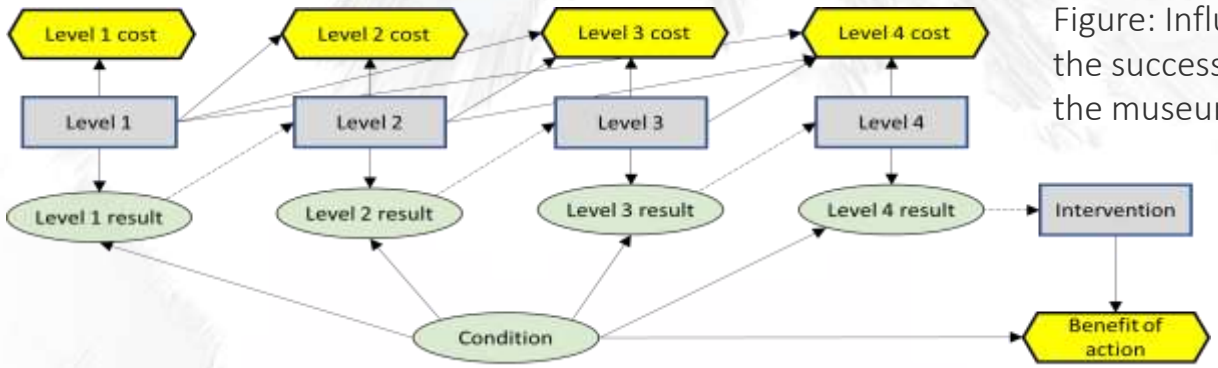


Figure: Influence diagram for the successive assessment of the museum

15.

Development of a novel pro-active SHM tool devoted to bridge maintenance based on damage identification by FE analysis and probabilistic methods - Application to the Lezíria Bridge -

- STSM participant and home institution:

  Dr Helder Sousa (mail@hfmsousa.com), HS Consulting / BRISA Group, Portugal

- Host & reason for choosing this host:

  TNO – Innovation for Life, The Netherlands, which holds wide expertise on FE analysis and probabilistic methods applied to asset management in the Netherlands

- Aim of the STSM:

  To give evidence of the VoI applied to prestressed concrete bridges, supported by a well-documented testbed with extensive field data available – the Lezíria Bridge owned by BRISA (Portugal)

- Tools & Methods used in preparation and during STSM:

  Advanced Finite Element modelling, Bayesian methods and decision analysis methodology

15.

Development of a novel pro-active SHM tool devoted to bridge maintenance based on damage identification by FE analysis and probabilistic methods - Application to the Lezíria Bridge -

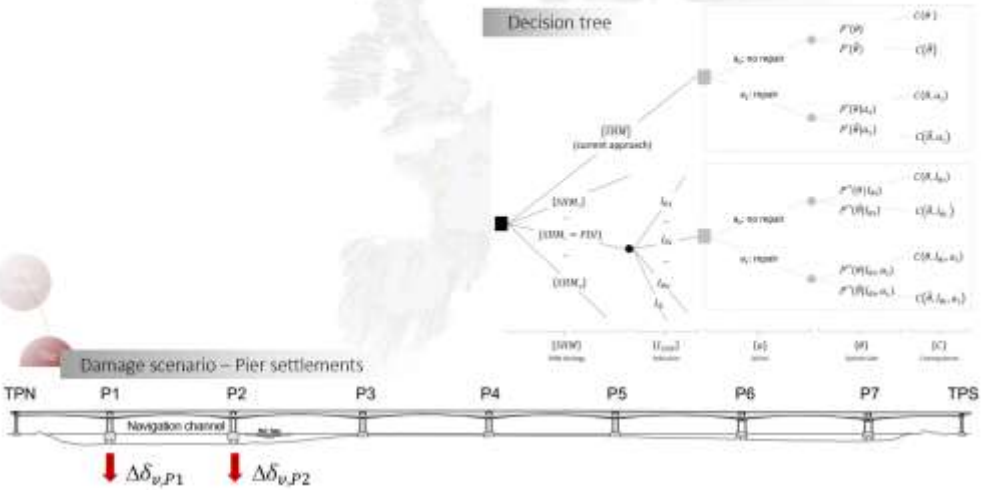
- Main results:

  1 internal report, 1 conference paper (IABSE, Guimarães), 2 journal papers (1 submitted + 1 under finalization)

- Outreach:

  Utilization of the obtained results on the benefit of asset management of the Lezíria Bridge

- Main figural/visual schematic representation of the contributions:



16. VALUE OF INFORMATION IN SEISMIC EMERGENCY MANAGEMENT OF BRIDGES

- STSM participant and home institution: **Pier Francesco Giordano** (pierfrancesco.giordano@polimi.it), Politecnico di Milano, Italy.

- Host & reason for choosing this host: Simona Miraglia, Aalborg University, Denmark. The Reliability and Risk Analysis Research Group of Aalborg University carries out world-leading research activities spanning risk assessment, decision theory, resilience, and sustainability in the varied fields of construction and industry.

- Aim of the STSM: To carry out a Value of Information (VoI) analysis for visual inspections and Structural Health Monitoring (SHM) in the context of emergency management of a motorway bridge under seismic hazard. The VoI can be used to decide if the installation of a SHM system on the bridge is worth in light of a future seismic event.

- Tools & Methods used in preparation and during STSM: The critical aspects in the VoI analysis are in the definition of 1) utility function, 2) prior probabilities, and 3) likelihood functions. The utility function is expressed as a monetary value of consequences (direct and indirect) of the bridge collapse or traffic restrictions. Prior probabilities of damage states are estimated by means of fragility curves. The formulation of likelihood functions implies a probabilistic representation of the output of the visual inspection and SHM.

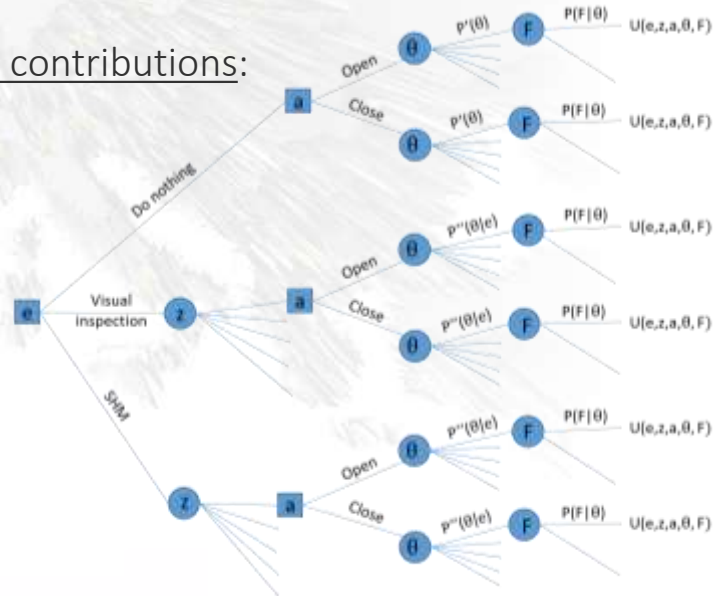
16. VALUE OF INFORMATION IN SEISMIC EMERGENCY MANAGEMENT OF BRIDGES

- Main results: The STSM activity is related to WG4 - Case Studies Portfolio and WG5 - Development of Guidelines of the COST Action TU1402. A paper related to the topic of the STSM will be presented at 9th International Conference on Structural Health Monitoring of Intelligent Infrastructure, 2019 – St. Louis, Missouri (USA).

- Outreach: Future works include the study of VoI of different SHM strategy related to the global dynamic characteristic of the structure .

- Main figural/visual schematic representation of the contributions:

The studied bridge



Decision tree

17. SEQUENTIAL DECISION FRAMEWORK FOR DESIGN DECISIONS INCLUDING LIFE-CYCLE CONSIDERATIONS

- STSM participant and home institution: **Jorge Mendoza (jorge.m.espinosa@ntnu.no)** (NTNU).

- Host & reason for choosing this host: Daniel Straub and Elizabeth Bismut (ERA Group in TUM). Experience and strong theoretical background in Bayesian Networks and risk-based decision models for inspection and maintenance optimization.

- Aim of the STSM: Develop the mathematical framework for an extended design decision scenario in which operation and maintenance (O&M) decisions could be reflected in the design. A case study is to be developed for the following purposes: (1) to gain insight into the impact of considering O&M decisions at the design phase in terms of safety and economical savings (2) to test the model in terms of computational efficiency.

- Tools & Methods used in preparation and during STSM: Hierarchical Dynamic Bayesian Networks.

17. SEQUENTIAL DECISION FRAMEWORK FOR DESIGN DECISIONS INCLUDING LIFE-CYCLE CONSIDERATIONS

- Main results: This STSM is currently under development. Results focus on quantifying the economical impact of the following features on the life-cycle management of structures: inspectability of a structural detail; element importance regarding system structural integrity; relative cost of a safety measure.

- Outreach: Code calibration of design standards for different maintenance strategies.

- Main figural/visual schematic representation of the contributions:

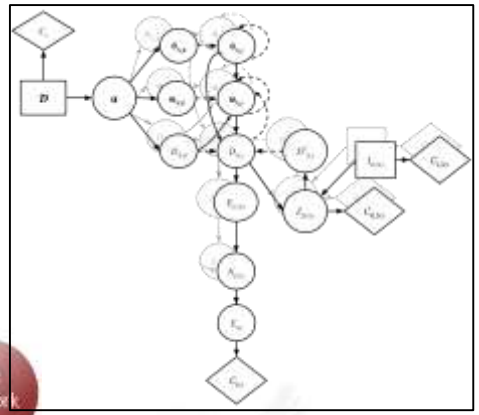


Figure 1. Hierarchical ID

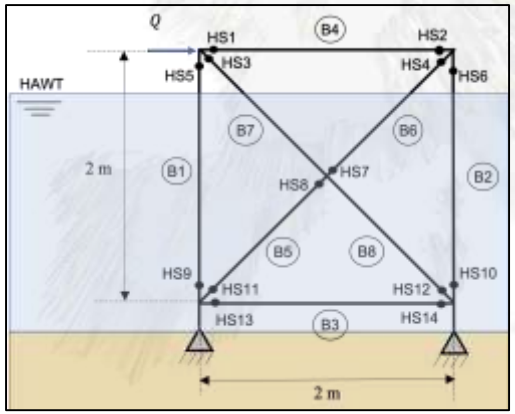


Figure 2. Case study structure

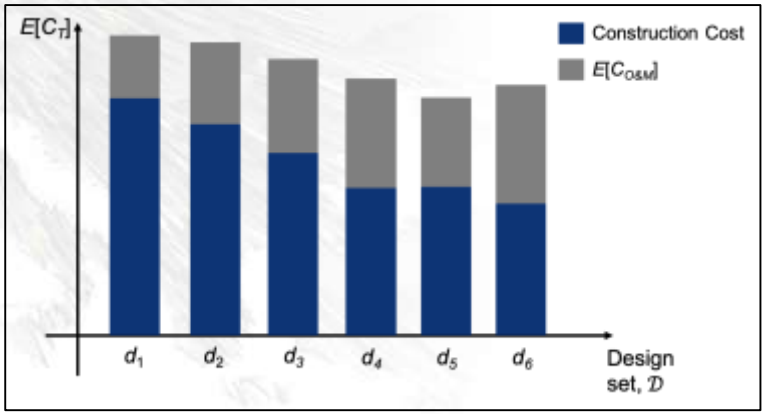


Figure 3. Example of trade-off between investment into construction and O&M

CONCLUDING REMARKS:

- COST Action TU 1402 was very successful in organising and performing STSMs. Results show benefit and potential in quantifying the Value of SHM:

1. for different type of structures
   - ✓ masonry structures,
   - ✓ bridges,
   - ✓ wind turbines,
   - ✓ dams,
   - ✓ large span roofs,
   - ✓ timber halls, …

2. under different loads and influences:
   - ✓ environmental effects,
   - ✓ under chloride attack,
   - ✓ traffic loads,
   - ✓ fatigue loads,
   - ✓ terrorist attacks,
   - ✓ seismic hazard, …

3. considering different inspection or monitoring methods:
   - ✓ visual inspection based condition assessment,
   - ✓ digital Image Correlation technique,
   - ✓ proof load testing,
   - ✓ B-WIM,
   - ✓ thermal monitoring,…

4. by developing different methods and tools for:
   - ✓ system resilience modelling,
   - ✓ structural behaviour modelling ,
   - ✓ SHM strategies,
   - ✓ degradation meta-models,
   - ✓ risk mitigation measures, …
   - ✓ considering material, structural and load uncertainties

5. for quantifying costs and benefits and decision making:
   - ✓ within asset management,
   - ✓ emergency management and
   - ✓ life-cycle management of structures in general.

COST Action
TU 1402

Quantifying the Value of Structural Health Monitoring

SHORT TERM SCIENTIFIC MISSIONS OVERVIEW

Final TU1402 Conference, BAM Berlin, Germany, February 18 and 19, 2019

Thank you for your attention!

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