Quantifying the Value of Structural Health Information for Decision Support

GUIDE FOR OPERATORS

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May 2019

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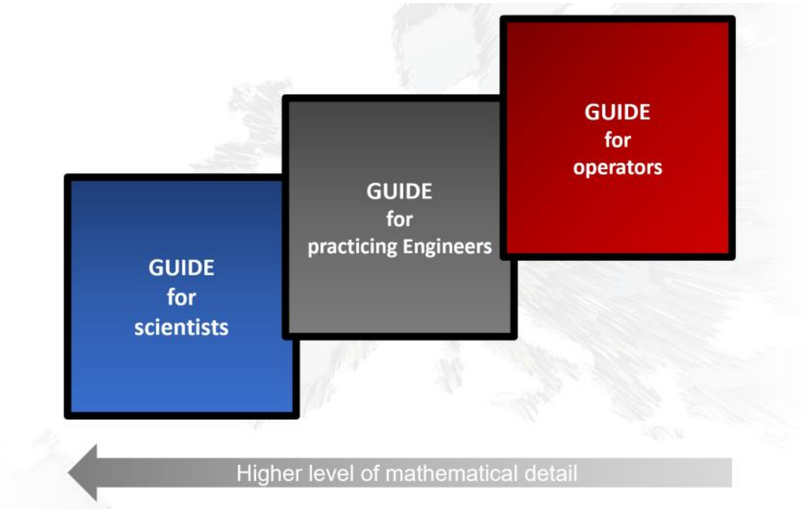
Preface

Having in mind the ultimate mission in promoting, disseminating and exploiting the subject *Quantifying the Value of Structural Health Information*, a set of three complementary guides are presented with the aim in targeting the broadest audience possible.

The Guides for Operators, Scientists and Practicing Engineers on Quantifying the Value of Structural Health Information (SHI) for Decision Support has emerged from the scientific networking project COST Action TU1402 (www.cost-tu1402.eu) in the period from 2014 to 2019. The guides are the result of the TU1402 Working Group 5 on Standardisation in conjunction with the work of the Joint Committee on Structural Safety (JCSS; www.jcss.co).

The Guide for Operators contains recommendations for the use of SHI value analyses by infrastructure owners, operators and authorities aiming at an enhanced infrastructure performance and utility management in terms of costs, life safety and sustainability. The Guide for Scientists provides a consistent formulation of value of SHI decision scenarios encompassing probabilistic SHI system performance and cost models, probabilistic infrastructure performance and utility models and approaches for adapting infrastructure performance models with SHI. The Guide for Practicing Engineers aims to provide guidance in applying, implementing and using results of value of SHI analyses.



CONTENTS

Executive summary

This guide introduces the main results, derived recommendations and the potentials of the COST Action TU1402 on *Quantifying the Value of Structural Health Information*, mainly from the point of view of owners, operators and authorities of infrastructure systems.

Structural Health Information (SHI) encompass Structural Health Monitoring (SHM) strategies, inspections, damage detection, load testing and digital technologies. The value of SHI can be very high and may result in up to 90% reduction in the expected total costs and risks for infrastructure system design and operation. However, the value of SHI depends on several factors regarding: (i) the SHI system (e.g. technology, usage strategy, information type), (ii) and regarding the infrastructure system (e.g. reliability, risks and exposures) and the relevance of SHI for the infrastructure system integrity and risk management. Non relevant and not optimised SHI may result in unnecessary expenditures.

The main recommendation is to perform a quantification on the value of the SHI strategy (encompassing SHM strategies, inspections, damage detection, load testing and digital technologies) and the optimisation of any structural health information technology and strategy before implementation. The value of SHI quantification will ensure that the SHI strategies are cost efficient and that integrity management strategies can be optimised. In a wider sense value of SHI analyses facilitate (1) an impact of digital technologies and Industry 4.0 for the design and operation and asset management of infrastructure systems, (2) more competitive SHM-based strategies available in the market and (3) an increased competiveness in infrastructure system management.

Introduction

Western and developed societies are confronted with a vast amount of existing and aging infrastructures, limited economic and ecological resources and the incentives for industrial growth and societal wealth. In the last decade, there have been significant industrial and societal developments triggered by digital technologies and networks and artificial intelligence [1]. The industrial changes are driven by economic efficiency, which, however, should also account for societal, governmental and industrial necessities for human safety, wealth and environmental friendliness.

On the November 28th 2018, the European Commission introduced the long-term strategy for a prosperous, modern, competitive and climate-neutral economy by 2050 [2]. Such scenario is bringing challenges to asset management, since that after fossil fuels and land-use change, cement is one of the largest source of anthropogenic emissions of carbon dioxide [3] with its associated industry being the third largest carbon emitting industrial sector in the EU [4].

Under such European context, it becomes clear the necessity in enhancing efficiency in asset management of infrastructure systems across all Europe, which can only succeed by means of joint-efforts among all countries, based on (i) a learning process by means of (ii) sharing experiences related to (iii) the know-how that each country holds on the effective utilization of SHM in the context of SHI strategies applied to Civil Engineering infrastructures. The requirements for enhancing the associated efficiency is in line with the Sustainable Development Goal (SDG) *Industry, Innovation And Infrastructure* (SDG 9) and *Partnerships For The Goals* (SDG 17), defined in the 2030 Agenda for Sustainable Development. The relevance of this was clearly demonstrated in 2015 by the compromise of all countries in the United Nations towards a sustainable planet [5].

The outlined necessities for industrial efficiency, human safety, wealth and environmental friendliness of infrastructure systems require a holistic perspective and integration. This can be achieved with the utilization of system reliability, utility and decision analyses to quantify the value of structural health information - the topic of the COST Action TU1402[6]. TU1402 has developed the framework, methods, tools case studies and guidelines to quantify the value of structural health information in the period from 2014 to 2019. The TU1402 results build upon a strong and lively debate among experts from academia, industry and infrastructure owners, operators and authorities from 29 European countries plus China, USA and Australia.

This Guide for Operators on Quantifying the Value of Structural Health Information for Decision Support contains a scope and objectives, general recommendations for the utilisation of value of SHI analyses, specific recommendations of the utilisation of SHI strategies to achieve a high value and the documentation of the scientific evidence also in regard to performed case studies.

Scope and objective

This guide offers guidance to operators regarding the efficient performance, knowledge and utility management of infrastructure systems towards rational and efficient utilization of Structural Health Information (SHI), encompassing Structural Health Monitoring (SHM) strategies, inspections, damage detection, load testing and digital technologies. The objective here is to guide operators in the identification and effective utilization of SHI- strategies that are able to provide, efficiently, an increase of benefits together with a reduction of costs and risks in the lifecycle of an infrastructure.

General Recommendations

Infrastructure owners, operators and authorities are advised to perform a value of SHI quantification (encompassing SHM strategies, inspections, damage detection, load testing and digital technologies) and the optimisation of any structural health information technology and strategy before implementation. In case of already implemented SHM strategies, the value of these strategies may be assessed retrospectively and SHM strategy optimisation recommendations can be derived.

Value of SHI quantification should be performed already in the design phase of an infrastructure system. This will facilitate:

(1) The SHI system optimisation and the required SHI information can be aligned with the infrastructure integrity management procedures,
(2) The OPerational EXpenditures (OPEX) quantification and optimisation, and
(3) In perspective of the CApital EXpenditures (CAPEX), a joint optimization of the OPEX and risks in the design phase.

During the operation of infrastructure systems a value of SHI quantification should be performed to:

(1) Ensure that the implementation SHI strategies and integrity management strategies are cost efficient and
(2) Optimise the future SHI and integrity management strategies as above.

The value of a SHI strategy, either at the design or operation phase, is driven by the amount of:

(1) Enhanced benefit generation, sustainability and life safety,
(2) Reduction in the expected value of costs, and
(3) Reduction of structural and operational risks.

To ensure the effectiveness of the implementation of the targeted SHI system and integrity management strategy, it is recommended to check: (i) the readiness level of the involved technology and methods, (ii) the effective integration in existent management procedures and (iii) the alignment with codes, standards and regulations.

The value of a SHI quantification and optimisation will facilitate, on a medium- to long-term run perspective:

(1) The impact of digital technologies and networks and industry 4.0 in the design and operation of infrastructure systems,
(2) More competitive SHI systems and strategies available in the market and
(3) Increased competiveness in infrastructure system management.

Value evidence and utilisation recommendations

The ultimate goal of SHI has been understood in 2000s as providing damage prognosis, which is associated with tremendous life-safety and economic benefits [7]. However, it took almost a decade until these benefits were quantified [8, 9] and almost another decade until a comprehensive scientific evidence could be provided with the COST Action TU1402 [6].

The scientific evidence encompasses several scientific studies and case studies. A comprehensive quantification of the value of SHM for the risk and integrity management of infrastructure systems has been performed in [9]. Herein, the value of SHM has been quantified between 10 and 90 % for various structural system configurations and influencing parameters. The following practical implications can be provided:

(1) The value of SHI can be high for deteriorated systems due to risk reduction and postponing the necessity of maintenance actions.
(2) The value of SHI can include an increase of system benefit generation due the service life extension.
(3) The value of SHI can be high, when model uncertainties can be circumvented with measurements (e.g. for fatigue in steel).
(4) For very reliable system, where the reliability is enforced by frequent inspections, SHM can have a high value due to the reduction of integrity management costs.
(5) The value of SHI is low for very reliable system.

TU1402 case study portfolio

The above recommendations are supported by a portfolio of infrastructure systems that has been gathered and matured among the TU1402 community [10]. Table 1 shows the portfolio, including details on the structure type, the country where the structure is located and meaningful references for further details.

Further to the case studies listed in Table ,1 the respective evidences are summarized in Table 2. It is worth noting that this will be periodically updated in further versions of this guide and based on a cost-benefit evidence in the integration of SHI strategies encompassing SHM systems with current integrity asset management protocols.

Table 1. Portfolio of case studies of the COST Action TU1402.

#	Case study	Structure type	Country	References
1	Condition assessment of timber structures – quantifying the value of information	Building	Croatia	[11, 12]
2	Optimizing in-situ testing for historic masonry structures		Czechia	[13-15]
3	Head monitoring for flood defences	Dike	The Netherlands	[16]
4	The Söderström Bridge	Bridge	Sweden	[17-19]
5	Bridge maintenance strategy using SHM data		Croatia	[20-22]
6	Emergency Management of Highway Bridges		Italy	[23]
7	Value of Information of a pro-active SHM tool devoted to early damage detection on bridges		Portugal	[24, 25]
8	Assessment of Terrorism Risk Mitigation Measures for Iconic Bridges		Denmark, Australia	[26, 27]
9	Case Study on Offshore Wind Farm Foundation	Offshore wind-park	Norway	[28, 29]
10	Value of structural health information for the operation of wind parks		Denmark	[30]
11	Case study on the maintenance of a tendon supported large span roof	Roof	Poland	[31]
12	Optimizing Monitoring: application to assessment of roof snow load risk		Italy	[15, 32, 33]

Beyond the general guidance in the previous Section, Table 2 summarizes the evidence obtained in the case studies, based on a monetary and life safety basis.

Table 2. Selected evidences on the benefit associated with the utilization of SHM-based strategies.

#	Evidence [4]
7	The case study herein presented shows that for the case of four possible damage scenarios, it is possible to save up to 8.4 % in maintenance costs, if information from the SHM is properly used by means of the mentioned pro-active damage detection tool.
8	The value of terrorism risk mitigation strategies has been quantified and optimised resulting in 0 % to 48 %, depending on the threat probability.
10	The value of 3 load monitoring strategies for a wind park service life extension has been quantified between -1% and 33%.

[4] Based on the current state of the art according to the list of references given in Table 1

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