IRIS

Industrial Safety and Life Cycle Engineering

Technologies / Standards / Applications

Lifetime

Capacity

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2
3
4
5
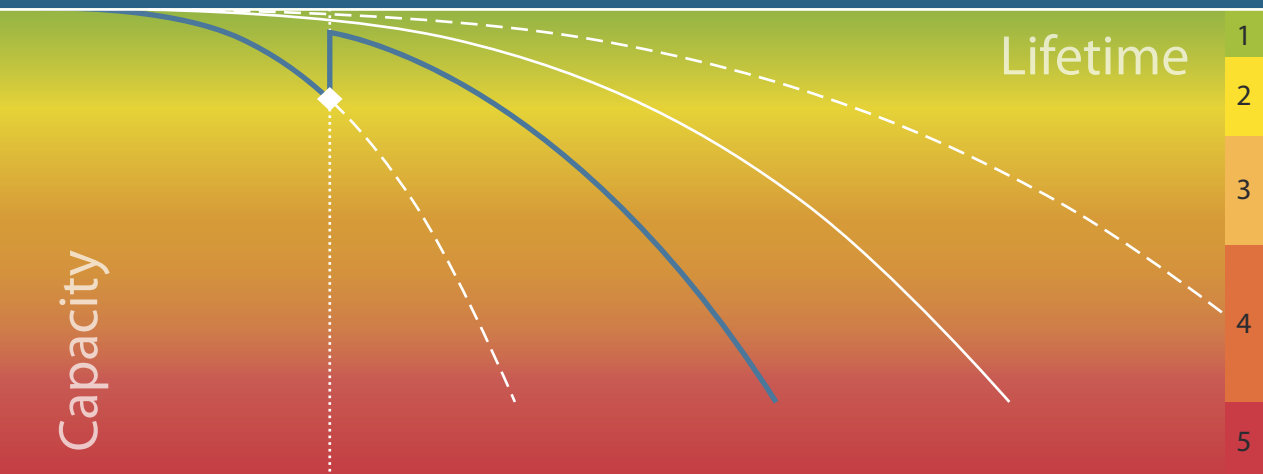
Foreword

The activities involved in value chain based production have become more complex with an increasing amount of interdependencies, new technologies and materials that introduce new risks in an ever changing environment. At the same time our society has become more risk averse.

Until the start of the IRIS project in 2008 very little had been done to identify industrial risk factors in a systematic manner and risk assessment and management was largely characterized by its methodical diversity and fragmented approach. A shift to a new safety paradigm was therefore required in order to combine a more competitive, innovative and better risk informed industry with a safer society in mind.

This is exactly what IRIS has done in a systematic and structured way as duly illustrated through several large-scale demonstrations performed together with the industry. The demonstrations have been done to cover and visualize as many aspects of potential risks in the industry as possible, while keeping the users safety in mind, in order to better mitigate future risks.

The main concept of IRIS was to focus on diverse industrial sectors' main safety problems as well as to transform its requirements into integrated and knowledge-based safety technologies, standards and services. The IRIS Risk Paradigm is based on three steps: 1) System modelling; 2) Risk quantification; 3) Uncertainty estimation. It is a comprehensive generic framework for risk management with the use of several interconnected tools.

The demonstrations of the value of the IRIS Risk Paradigm have been very impressive indeed, some at a nearly unprecedented scale for an EU project (e.g. the destructive testing of an existing bridge on motorway A1 in Austria) and have led to new CEN standardization in the area. The data obtained through the demonstrations have led to results that can be applied globally and have yielded a technical competitive expertise in Europe that will have long lasting consequences for the industrial safety as well as public safety. This is exactly the kind of results that are targeted in the European Framework Programme for Research and provides the "reason d'etre" for its existence.

A project like IRIS is of course not possible without a team of world class experts in the field. In the case of IRIS this team consisted of 37 different partners from 14 countries in the European Union and 3 global partners as well as many more collaborators outside the project. All bound together and catalysed by the efficient and competent management from the Coordinator Johannes Kepler University Linz and VCE that enabled the team to deliver all the envisioned objectives. Every team has a champion. For the IRIS project this champion was Dr. Helmut Wenzel, without whom the project would never have even started and without whom it would not have been possible to achieve such a successful outcome. On behalf of DG RTD and the European Commission I would like to congratulate the consortium with such an excellent outcome and hope that the obtained results will have a lasting impact on our future.

On behalf of DG Research & Innovation, G2 – New Generation of Products
Jose-Lorenzo Valles, Head of Unit

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Acknowledgements

The success of the IRIS project has many fathers. Without the vision of Dr. George Katalagarianakis who supported ETPIS and the Industrial Safety topic and carefully organized the process IRIS would not exist. Søren Bowadt of the European Commission has been very helpful and patient in overcoming administrative problems with partnership verification and the fact that an SME intended to lead such a large project. The officer Antonio Cipollaro and the reviewer Michalis Loupis accompanied the project with understanding and advice.

Without the funding by the European Commission under Agreement number CP-IP 213968-2 this development combining deep basic research with real on-site requirements would not have been possible. The IRIS Project was lucky to receive the right size of support and funding for this important subject. This framework has been rated excellent by "jealous" researchers worldwide.

Special thanks go to the Johann Kepler University Linz, which in order to overcome the administrative deadlock by taking over the administrative coordination, have saved the project from collapse before kick-off. This was realized under the burden of having to trust in private management practice. The frictionless performance of coordination under these difficult circumstances has been highly appreciated.

Finally, the consortium has to thank all the excellent individuals that contributed to the success of the project. Unprecedented engagement, in combination with the clear determination to follow the rules of the project's steering committee, allowed targeted development work and contributed the required pieces to the IRIS technology puzzle. A comprehensive list of authors is provided in chapter 31.

We hope that the trust given to the consortium is awarded by the achievements made and the numerous applications in industry, not only in Europe but worldwide.

1

Introduction to Industrial Safety and Life Cycle Engineering

Author:
Helmut Wenzel

1-1   Introduction

European industries are challenged by competition from low cost economies and ageing problems. Innovative approaches are required to harmonize competitiveness with end of design life issues as well as safety concerns. These are directly addressed by the research and development work presented here.

Coordinated industrial research enables the reduction of fatalities and injuries and increases the competitiveness keeping key industrial jobs in Europe.

The Consortium conducting the large European Collaborative Research Project IRIS (CP-IP 213968-2) was driven by the motivation that current practices in risk assessment and management for industrial systems are characterized by their methodical diversity and fragmented approaches. In retrospect these risk and safety paradigms resulted from diverse industries driven and limited by available knowledge and technologies. The need for a change based on industrial research and development work has been identified. This formed the basis for IRIS.

At present the European industry recognizes their obligation to reconsider risk and safety policies, having a more competitive industry and more risk informed and innovative accepting society in vision. The IRIS project has identified, quantified and mitigated existing and emerging risks to create societal cost benefits, to increase industrial safety and to reduce impact on human health and environment. The project was led and driven by industry consolidating and generating knowledge and technologies which enable the integration of new safety concepts related to technical, human, organizational and cultural aspects. More than 300 researchers participated in an industrial consortium that represented over one million workers.

IRIS focused on diverse industrial sectors to transform their specific requirements into integrated and knowledge based safety technologies, standards and services. This book displays a relevant portion of the results produced by IRIS between 2008 and 2012.

An overview of the conception for the various industries and the expected impact is given in F.1-1.

1-2 Success Factors and Historical Background

Large collaborative research projects represent an exceptional management challenge. The usual success factors teaming and participation have to be coached actively. It needs the right team as well as it needs the team right. IRIS was able to select among the top researchers and institutions in this domain and it was important to allow everyone the suitable position within the team.

The desire to get participation right and to achieve the right participation was satisfied as well. A core group of well experienced elder experts formed the executive board and a large group of selected hungry young researchers have been motivated to give their best. The fact that the coach has been an expert insider as well enabled the desired top performance. It shall be particularly acknowledged that this did not happen by accident but was enabled by trust and understanding between the main stakeholders, the European Commission (funding agency), industry (organized through a targeted net-

Integration of industries and objectives · F.1-1

	Nuclear Industry SP1	Chemical Industry SP2	Construction Industry SP3	Mining and Oil SP4	Energy Production SP5
Industrial sector with	**Nuclear Industry**	**Chemical Industry**	**Construction Industry**	**Mining and Oil**	**Energy Production**
Problem and focus	Natural Disasters	Major Accidents	Worker Safety	Environment Disasters	Material Life Cycle
Leading industrial pool	EDF	DOW Chemical	VCE	KGHM CUPRUM	WBI
Main S&T objectives and innovations	Integrated Methodologies for Pioneering Risk Assessment and Management				New Safety Paradigms
	New Knowledge-Based Safety Concepts				33 % less fatal accidents
Impact 2020	Total Safety of Industrial Systems and Networks				100 % integrated approach
	Knowledge and Technologies for Risk Identification and Reduction				15 % more economic designs
	Online Monitoring with Decision Support Systems			Increased risk awareness	−20 % down time
	Demonstration & Technology Transfer, Standardization & Training Activities				50 % less accidents

work) and the research community identified through well prepared work programmes in targeted research frameworks.

The transition from analogue to digital concepts opened a wide range of opportunities for innovation. The framework programmes of the European Commission appreciated these opportunities and called for proposals in this domain regularly. Partners of the IRIS consortium performed a number of successful projects in various constellations which have been ranked among the top projects in the EC's NMP programmes since 1995.

> // The HARIS project (BRPR-CT95-0072) coordinated by VCE in the Brite-EuRam Programme developed innovative isolation systems for high-speed railways. It led to a multi-billion contract for the Taiwan high-speed rail project led by European industry.
> // The CasCo project (GRD1-1999-11095) followed concentrating on vibration and noise emission on railway bridges and tunnels. Monitoring became part of the procedure.
> // The IMAC project (G1RD-CT-2000-00460) developed an innovative methodology to assess cables which has led to a European dominance in this domain. The methodology is now applied worldwide.

As a consequence of these successful individual projects in the 5th Framework Programme the European Commission decided to fund a targeted network on monitoring assessment and control of structures.

> // The SAMCO Network (FP5 G1RT-CT-2001-05040) enabled the identification and consolidation of the respective community and issued the first standards in this domain. It has been extended successfully to global scale with the SAMCO international supplement. The resulting publications "Ambient Vibration Monitoring" and "Health Monitoring of Bridges" are mainly based on SAMCO results. They comprise bestsellers in the very competitive international technical publication market.
> // The project SAFEPIPES (Contract no.: 003766) in the 6th Framework Programme focused on the implementation of the technologies to industrial pipelines. A wide industrial participation has been achieved. The door to key industries was opened.

Thanks to the foresight of the European Commission with the backup of the demand of an ageing European industry, proposals for projects in the industrial safety domain have been called in the early stage of the 7th Framework Programme. The consortium of 38 partners performed the project from late 2008 till mid-2012. Details are sustainably kept under www.vce.at/iris for information and download.

	IRIS consortium and core competences			T.1-1
No.	**Organizwation name**	**Org. type**	**Role in IRIS**	**Country**
1 C	Johannes Kepler University Linz (JKU)	RES	Financial coordinator, decision support systems, cyber infrastructure	Austria
2	EDF	IND	World largest nuclear power operator, natural hazard assessment, safety	France
3	DOW Deutschland	IND	Safety in chemical industry	Germany
4	EGNATIA	IND	Management and supervision, construction safety	Greece
5	KGHM Cuprum	SME	Mining control, environmental monitoring	Poland
6	RWE	IND	Energy production issues, life-time estimation	Germany
7	WBI	SME	Standardization, safety conception NPPs	Germany
8	USTUTT	RES Inst.	Testing, evaluation, safety assessment	Germany
9	CEA	RES Inst.	Nuclear laboratory, proliferation issues	France
10	JRC ELSA Laboratory	RES Inst.	Structural safety and security	EU
11	INRIA	RES Inst.	Pattern recognition	France
12	POLITO	RES	Embedded sensor development, monitoring	Italy
14	TU Braunschweig (TUB)	RES	Galileo, tracking of workers	Germany
15	AUTH	RES	Risk and safety concept	Greece
16	MEGA Risk	IND	Operational risk management systems	Germany
17	BBT	IND	Tunnel construction, monitoring of workers	Italy, Austria
18	Kozloduy NPP	IND	New member state NPP	Bulgaria
19	ICEMENERG	RES Inst.	Energy research and development, environmental factors	Romania
20	RISKENG	IND	Risk engineering	Bulgaria
21	CTU	RES	Cyber infrastructure	Czech R.
22	DTCDM	Stake-holder	National civil protection	Hungary
23	ERF	SME	Online monitoring	Germany
24	BAGF	SME	Remote sensing technology	Germany
25	BAM	RES Inst.	Testing of infrastructure	Germany
27	Aplica	SME	Computational fluid dynamics, engineering	Austria
28	VR Vis	RES	Virtual reality and visualization	Austria
29	University Genoa	RES	Permanent monitoring	Italy
30	University of Manchester	RES	Geotechnical research	UK
31	University of Cartagena	RES	Monitoring of mining activities	Spain
32	TU Lulea	RES	LIDAR technology for vulnerability assessment	Sweden
33	Fraunhofer	RES	Guided waves	Germany
34	CVS	SME	Safety of industrial components	Russia
35	BARC	RES	Reactor safety – health, safety and environment	India
36	CAS	RES	Micro scale mechanics and microsystems mechanics	China
37	University of Shefflied	RES	Damage detection, assessment, localization	UK
38	VCE	SME	Technical coordinator, online monitoring, decision support system	Austria
39	TU Delft	RES	Geotechnical research	Netherlands

1-3   Main S&T Objectives of the IRIS Project

For the success of European industry and the benefit of European society the following objectives, which are to be integrated into a sustainable development context, have been identified:

// Integrated methodologies for pioneering risk assessment and management to combine practical operation with risk management.
// New knowledge based safety concepts through refinement of the risk identification, assessment and control processes to continuously improve economics obeying safety concerns.
// Total safety of industrial systems and networks to understand systemic interdependencies and identification of risks in the increasing complex value chain based production activities.

Project context with reasonable allocation of Work Packages (integration)   **F.1-2**
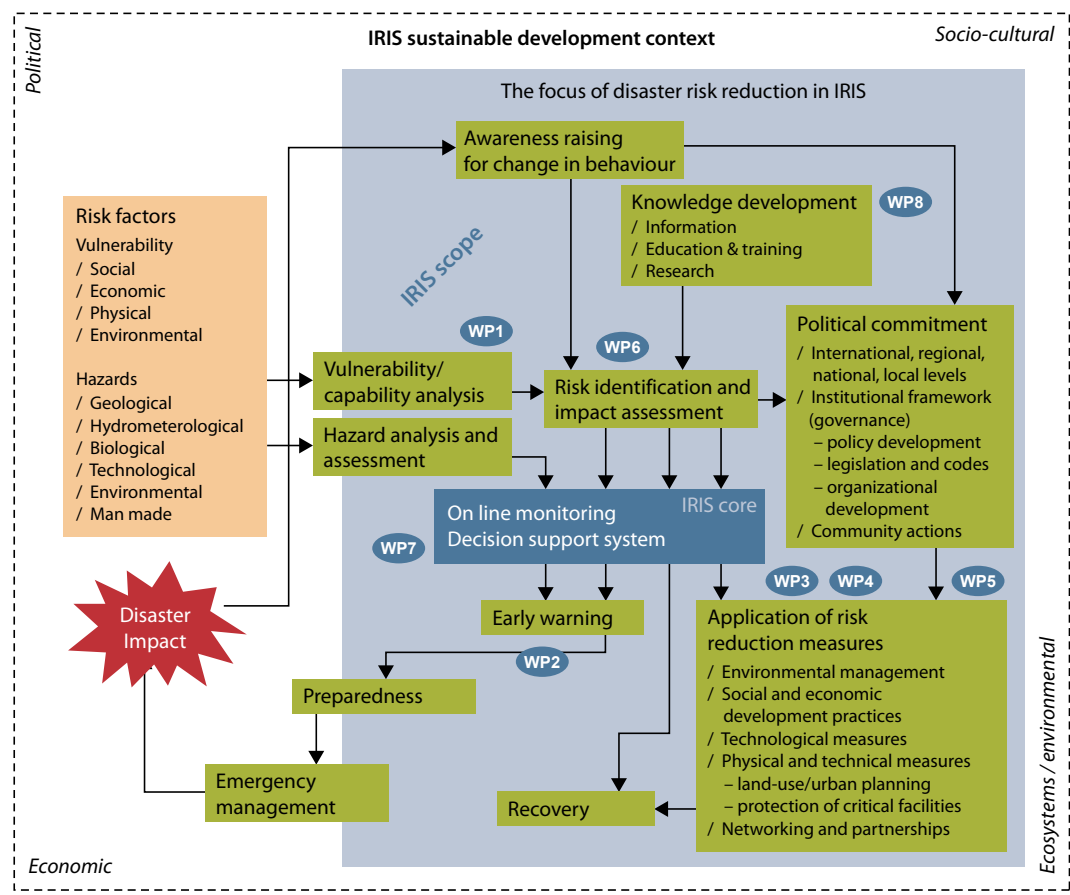
// Knowledge and technologies for risk identification and reduction to consider the re-assessment of exposure and vulnerability of environment, society, industry and to mitigate the impact of natural, technical and man-made hazards.
// Online monitoring and decision support systems to enable continuous risk assessment by online monitoring of the interactions in the industrial systems during their life cycle.
// Pattern recognition in signal processing to identify system parameters and attributes characterizing evolving damages in materials and systems. This includes the transfer from parameters to key performance indicators (KPIs).
// Demonstration, technology transfer, standardization and training activities. The intention has been to apply the developments directly in industry and to standardize successful technologies.

The figure graphically represents the flow and inter-dependencies of activities and highlights the IRIS scope within this wider context. Around the IRIS core comprising the online monitoring and decision support system the eight work packages (WP1–WP8) are situated contributing to the various activities.

1-4   Summary of IRIS Results

The desire to fill the gaps existing in current applications has driven the IRIS development. Besides the many detailed results significant breakthrough has been achieved. The overarching fields of development have been:

// The **IRIS Risk Paradigm**
// Filling the technology gaps for **risk assessment**
// Innovative **risk identification** and mitigation technologies
// **Standardization** and application

For risk based decision making risks have to be quantified. Derived from the various international approaches towards condition assessment of structures a multi-dimensional risk framework has been erected. It produces an index allowing intuitive quantified recognition of risk situations. The quantification procedure is a combination of the individual assessment of identified key performance indicators (KPIs). A harmonized glossary for the terms involved has been elaborated out of which the risk formulation is derived. It has been recognized that a large variety of terms is used in this domain, which nevertheless, in combination, produce the same result. For example the hazard domain used in IRIS is described under the term exposure in relevant other elaborations. Nevertheless, the components involved are the same enabling comparable results. In this respect the IRIS development goes far beyond current practice and pioneers risk quantification. Harmonization in this domain is a strong demand for future development work.

The new IRIS Risk Paradigm comprises a closed definition of the elements of risks. The input usually generated by separated individual expertise is combined to excitation (load model), structural (i.e. FEM) and a performance model introducing time as an additional

dimension. The involved parameters come along with specific uncertainties which are summarized in logic combinations. The formulation is open to any kind of input for which a model can be erected knowing the boundaries of uncertainties. In a normalization process the result can be fitted into a commonly used colour scheme. Using the degradation law standardized in the project prediction on development over time is feasible providing early warning and defining the remaining time till intervention. By the variation of individual parameters, sensitivity studies can be performed as a basis for decision making. The methodologies for comparative risk assessment (CRA) are directly supported by these results and allow the introduction of an innovative risk management that fits into the ISO 31 000 framework.

It is recognised that in practice the excessive density of regulations seems to exclude such an innovative approach even so the usefulness and charm is appreciated by all players involved. To overcome this difficulty a first step towards standardization of the degradation law has been performed within the project successfully in a CEN Workshop (CEN WS63).

The subsequent figure gives a graphic representation of the new IRIS Risk Paradigm with its models and uncertainties involved. Details are described in chapter two of this publication.

Concept of the new IRIS Risk Paradigm   F.1-3
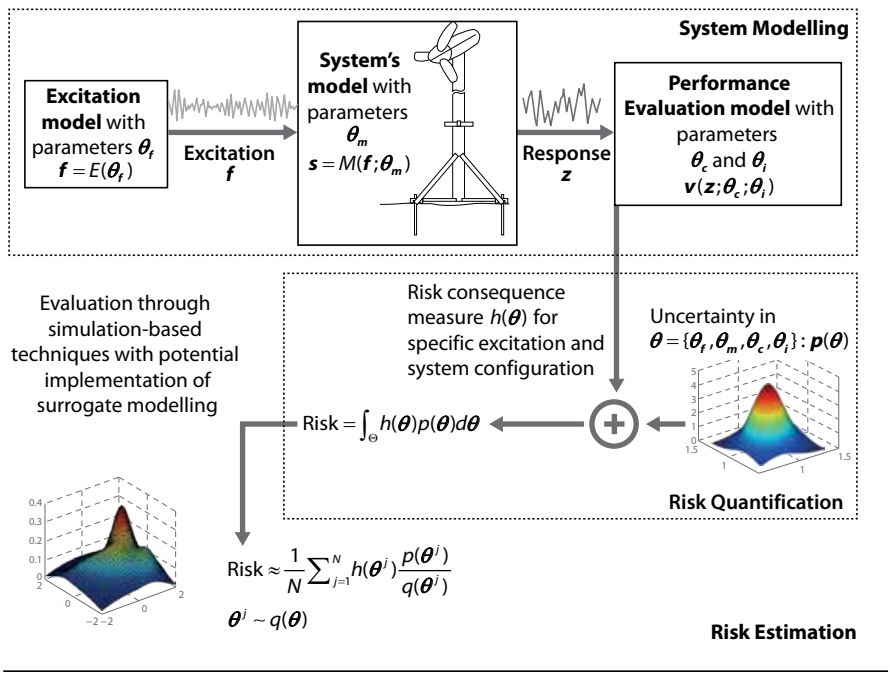
Risk is described in a simple formulation as a combination of hazard, vulnerability and consequences. The individual information used is targeted towards these elements.

The determination of the final risk index is symbolized by the following figure showing how the individual results of the risk components led to an individual risk index.

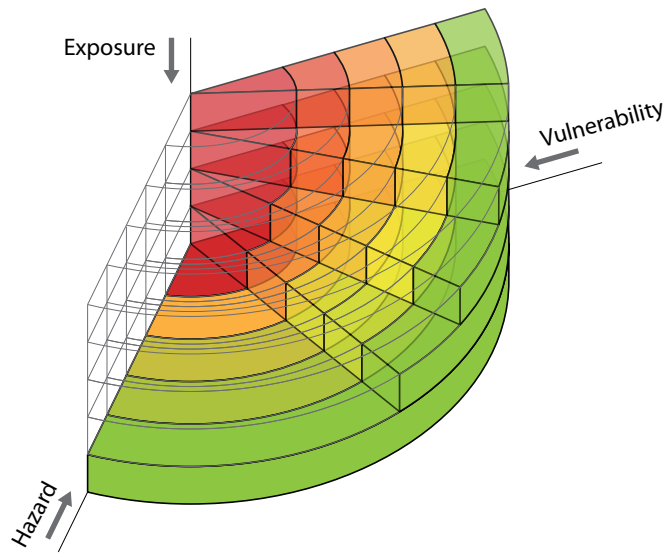Elements of risk   F.1-4
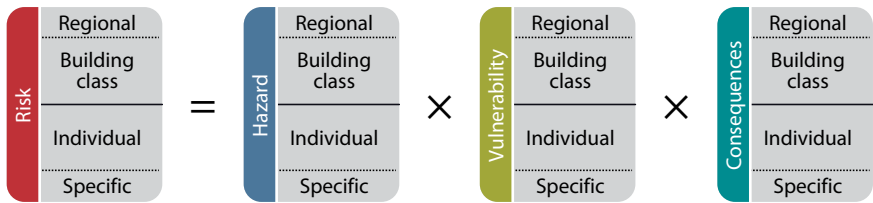
Risk quantification scheme   F.1-5

It has been found during the course of this project that the individual industries require tailored applications for their individual cases. This is reflected in the selection of parameters that are finally used as key performance indicators and in the weighting of issues in the individual complex procedure. For this reason a mathematical formulation (one size fits all) is not feasible. An individual element consisting of engineering input and sometimes subjective expertise remains necessary. Nevertheless, this fact gives the process managers and operators sufficient control over the process to satisfy the definition of their experience and steering role.

1-5   Individual Results

A selection of individual project results has been made enabling understanding the features and background of the technology highlighting remarkable achievements.

Chapter 2: describes the new IRIS Risk Paradigm. The previously fragmented way creating problems with interfaces and quantification has been replaced by a consistent methodology providing a conceptual framework for harmonized risk assessment and quantification.

Chapter 3: describes the IRIS damage assessment methodology, a major desire of the SHM community. The idea that the condition of a structure is represented in the character of its dynamic system response converts monitoring data into Life Cycle Information.
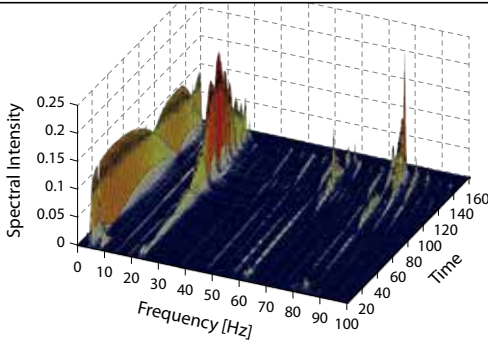
Chapter 4: describes the application to Life Cycle Cost optimized monitoring systems for offshore wind turbine structures. The efficient operation of offshore wind parks based on monitoring results showing Life Cycle Cost benefit analysis is addressed.


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Chapter 5: addresses the complex identification of linear time invariance by output only measurement under consideration of statistical uncertainty. The application to en-large full scale field test, S101 bridge case, is used for verification.

Chapter 6: describes the application of the IRIS Risk Paradigm to experimental testing of a masonry arch bridge model subject to damage. The proof of concept has successfully been given in this laboratory test.

Chapter 7: provides an overview on SHM and adaptivity concepts for risk reduction in structures. A conclusive solution for the European transportation infrastructure is presented.

Chapter 8: concentrates on integrity assessment, identification and reduction of pipe vibrations in industry. Very specific applications in the chemical, energy and nuclear industry are addressed.
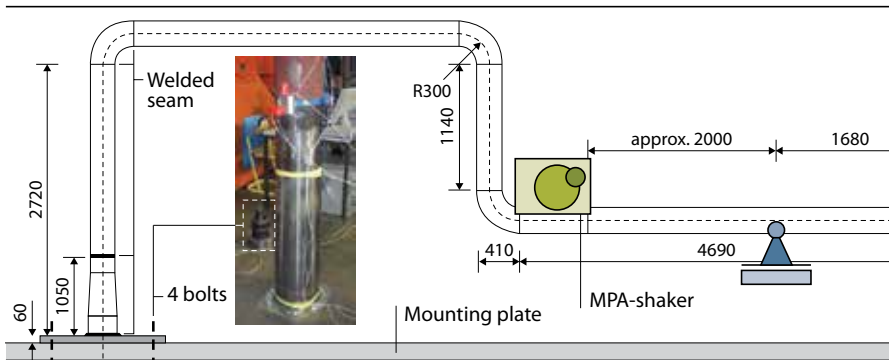
Chapter 9: contributes with stability problems of large Chinese hydropower dams. It concentrates on sub-structure issues with high uncertainties involved. It represents the Chinese contribution to the IRIS project.
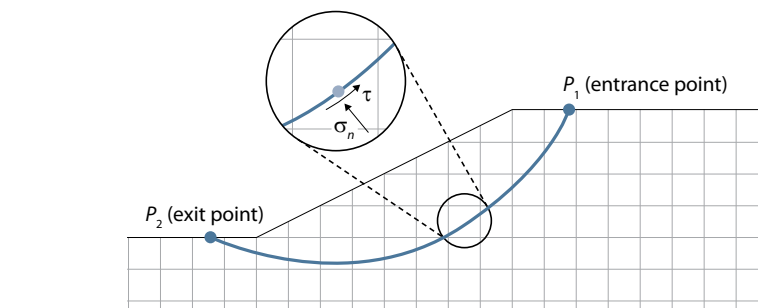

Chapter 10: Lessons learned from the earthquakes in Kashiwazaki (2007) and Fukushima (2011) revealed insufficient knowledge in actual shear behaviour of thick concrete walls. A comprehensive monitoring and testing campaign has been designed and performed at JRC in Ispra.

Chapter 11: describes a comprehensive set of tools that are used in risk management based on remote sensing technologies embedded in a tool box featuring a GIS environment interface for practical handling.

Chapter 12: describes the developed IT-platform EQvis (European Earthquake Visualization System) which has been made fit for industrial application and multi-risk assessment. The Open source software platform is freely available for download including a comprehensive tutorial.

Chapter 13: describes the IRIS active vibration absorber (AVA) and its application to a vibrating reactor system in a European chemical plant.
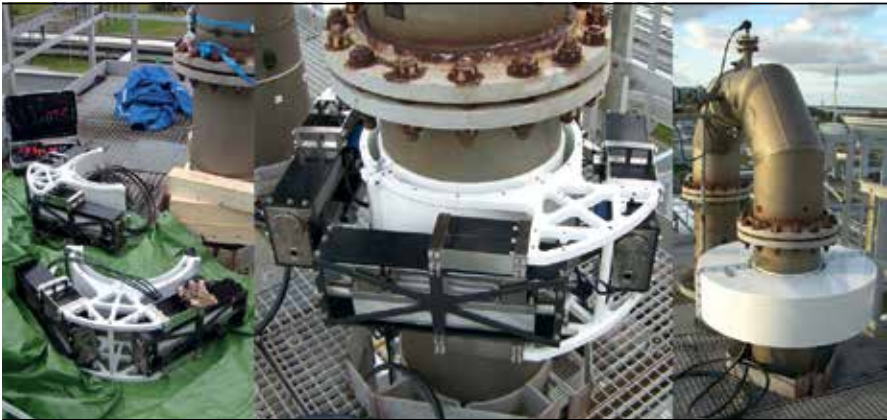

Chapter 14: informs about the unique application of monitoring of hot pipes (up to 700 °C) at a power plant in operation. Besides the evaluation technology new sensors for hot pipe application have been developed.

Chapter 15: describes the application of an outlier analysis to the S101 Bridge full scale destructive test. This contribution of the University of Tokyo provides a very welcome proof of concept.
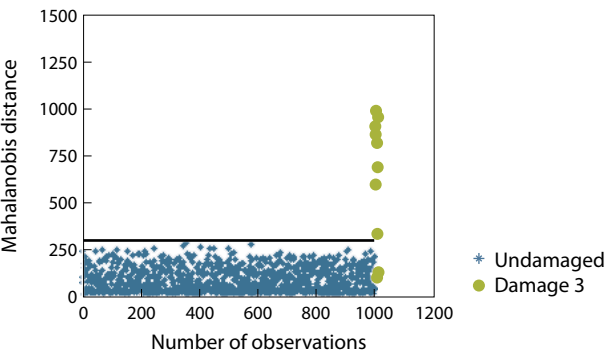

Chapter 16: addresses various aspects of worker safety in the construction industry. It comprises the management of risks at scaffolds as well as worker allocation and warning in situations with the presence of moving vehicles.
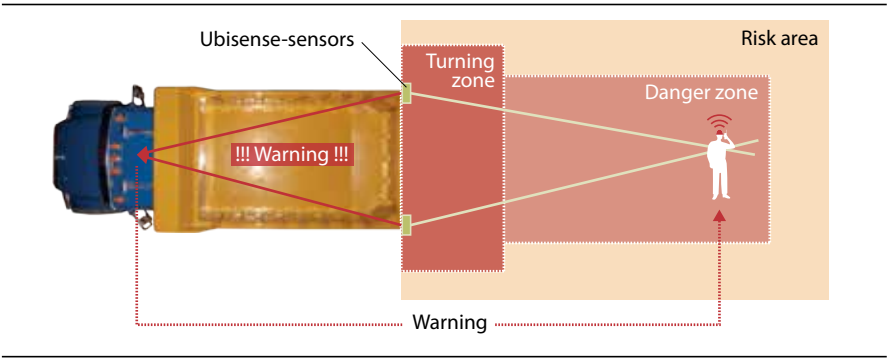
Chapter 17: describes the ontologies to integrate heterogeneous decision support systems into the process. It summarizes part of the IT-development performed within the IRIS project.

Chapter 18: describes a specific application of risk reduction in human and ecosystems in historic mine tailing ponds in Spain.

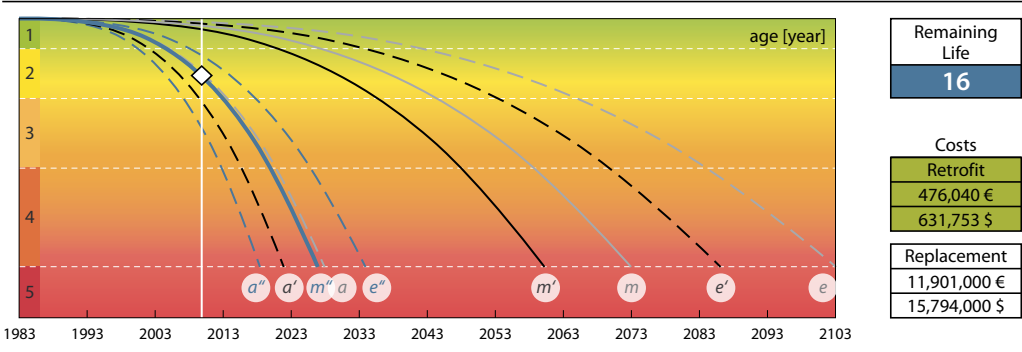Chapter 19: comprises the assessment of the soil-structure interaction based on the dynamic monitoring methodologies applied in the project. A unique experiment has been performed.
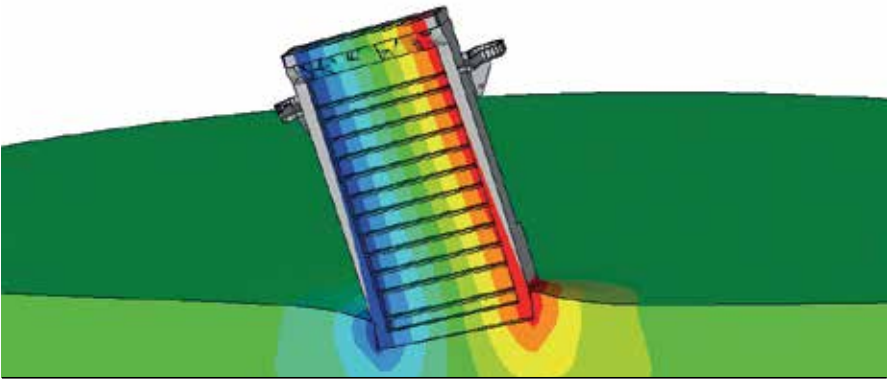
Chapter 20: The opportunity for comprehensive, destructive testing of an existing bridge in Austria (S101) on motorway A1 has been taken to collect well proven damage data. The dataset has been extensively used by many research teams.
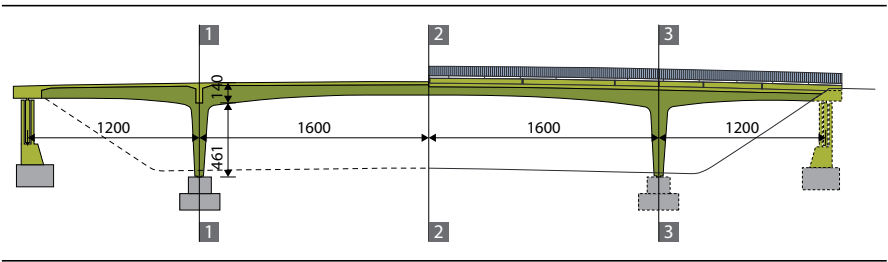
Chapter 21: reports about the results of a global harmonization activity at the New Jersey Bridge Study performed by 18 parties from IRIS, America, China, Japan and Korea. The new IRIS Life Cycle Approach has been demonstrated successfully.

Remaining Life		
16		
Costs		
Retrofit		
476,040 €		
631,753 $		
Replacement		
11,901,000 €		
15,794,000 $		

Chapter 22: describes the application of the IRIS technologies to the Tamar Bridge in the United Kingdom where through an extensive monitoring campaign the feasibility of reducing uncertainties in key structures has been demonstrated.

Chapter 23: shows a major demonstration case at the Egnatia Motorway in Greece. The combination of a landslide with an earthquake hazard is successfully demonstrated.

Chapter 24: describes the demonstration of IRIS technologies to an earthquake damaged bridge in Taiwan in collaboration with the National Center for Research on Earthquake Engineering (NCREE) in Taipei, Taiwan, Republic of China. This has been a very successful proof of concept.


Chapter 25: concentrates on the stochastic approach to slope stability analysis with in-situ data where inherent heterogeneous geo materials are properly modelled.

**Chapter 26:** reports about a unique application of the IRIS Life Cycle Technology to the blast of two arch bridges within the Austrian motorway system.

Chapter 27: represents the results of the CEN-workshop 63 "Condition, determination for integrated lifetime assessment of constructed facilities and components". The generic degradation law developed within IRIS has been standardized. It serves to determine the

design life or the residual life of existing structures and helps to assess the real degradation process enabling the development of optimized maintenance plans.
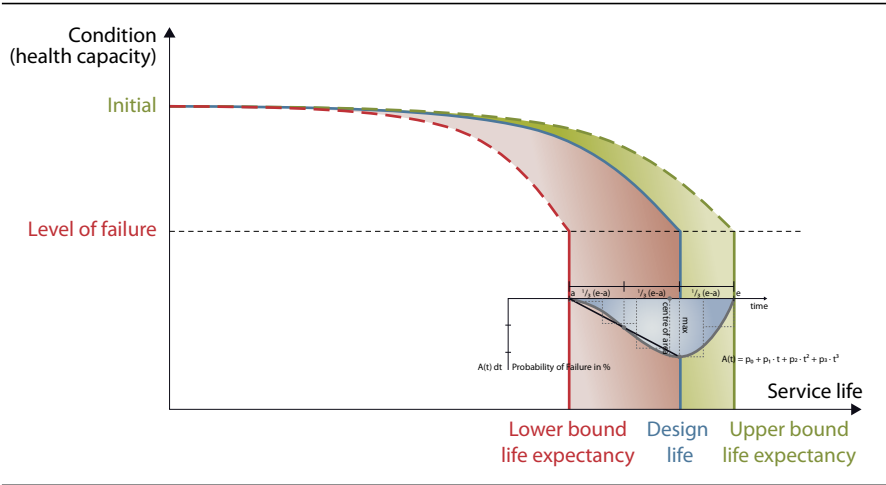
Chapter 28: describes the application of the IRIS technology for reliability bases control of post-tension containment structures exemplarily executed at the Kozloduy Nuclear Power Plant in Bulgaria. This is a worldwide unique industrial demonstration that confirmed the applicability of innovative assessment methods in strongly regulated sectors. Further applications for the benefit of the European energy policy and society are expected.
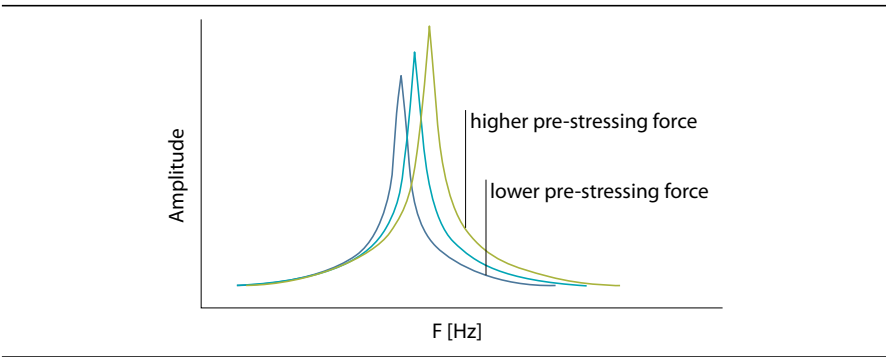
Chapter 29: The opportunity to collaborate on global scale was realized in the collaboration with the partners from India. A series of tests has been performed with vice versa participation and comparison of test results.

Chapter 30: describes the results of the large IRIS demonstration in Hungary in 2011. In an exercise comprising over 500 participants the feasibility of application of the methodology to complex disaster management scenarios including life images from targeted satellites has been demonstrated.

Last but not least short CVs of the researchers involved are presented.

It is acknowledged that without the generous support of the European Commission within the NMP programme of the 7th Framework Programme research on this level of size and complexity would not have been feasible. IRIS is an excellent example how this combined effort can make huge impact on Europe's position in the global competition within various industrial sectors. It is a fact that Europe has gained the definite lead in this domain despite the considerably smaller budgets made available for this sectorial research.

IRIS has been an example that large well-coordinated projects are able to produce superior results compared to previous concepts or other global approaches. Our thanks particularly go to the wise steering of this process by the respective scientific officers and management of the 7th Framework Programme.

1-6   Open Issues and Recommendations for Further Development

Every answer to a scientific question usually comes along with another question and ideas for further improvement. It therefore becomes essential to keep the momentum of such a successful development and invest into further improvement. What needs to be done can be highlighted in a few sentences:

// The **IT-component** has been considerably underrepresented in the IRIS Project. A joint ICT-NMP project would be necessary in order to transform the theoretical results into a generally applicable IT-solution.
// The individual methodologies developed within the IRIS project are based on very specific cases available to the consortium. Further **generalization and extension to other cases** is desirable. This includes the introduction of the results of other European projects which could usefully contribute to an improvement of the technology.
// Further effort has to be put into **standardization** particularly in the risk quantification domain. The various heterogeneous approaches have to be harmonized and standardized subsequently.
// There is a wide open field for further **damage detection technologies**, sophisticated concepts for monitoring and assessment and harmonization in data management and elaboration.
// There are still considerable gaps in **Life Cycle Engineering** which has been introduced to this process recently. Future work will have to concentrate on innovative methodologies and approaches towards an adaptive sustainable application.

Finally it has to be mentioned that the IRIS work mainly addresses the industrial concerns directly. Efforts to support the underlying political and juristic environment are important as well. The sector of consequences has to be treated with priority including a wide range of social sciences.