Risk, Reliability and Safety Engineering

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Advances in Risk-Informed Technologies

Keynote Volume (ICRESH 2024)

Springer

Risk, Reliability and Safety Engineering

In this era of globalization and competitive scenario there is a conscious effort to ensure that while meeting the reliability targets the potential risk to society is minimal and meet the acceptability criteria towards achieving long term targets, including sustainability of a given technology. The objective of reliability is not only limited to customer satisfaction but also important for design, operating systems, products, and services, while complying risk metrics. Particularly when it comes to complex systems, such as, power generation systems, process systems, transport systems, space systems, large banking and financial systems, pharmaceutical systems, the risk metrics becomes an overriding factor while designing and operating engineering systems to ensure reliability not only for mission phase but also for complete life cycle of the entity to satisfy the criteria of sustainable systems.

This book series in Risk, Reliability and Safety Engineering covers topics that deal with reliability and risk in traditional sense, that is based on probabilistic notion, the science-based approaches like physics-of-failure (PoF), fracture mechanics, prognostics and health management (PHM), dynamic probabilistic risk assessment, risk-informed, risk-based, special considerations for human factor and uncertainty, common cause failure, AI based methods for design and operations, data driven or data mining approaches to the complex systems. Within the scope of the series are monographs, professional books or graduate textbooks and edited volumes on the following topics:

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- Risk and Reliability standards and Codes
- Industrial Safety

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Preface

In this evolving global world-order where apart from economics and sustainability as the two major indicators, there are overriding factors, like ‘de-risking’—that covers random as well motivated or intended components of risk (safety and security)—and ‘reliability’ that form an integral part of dependability metrics. The current engineering systems, having their roots in technological evolution, are essentially governed by rules or specifications, best-practices, hands-on learning, experience, and peer-reviewed and enforcement systems. Here, the scope for interpretation, at times, is limited towards arriving at decisions.

We witness phenomenal progress in science and technology that is also reflected in advanced technologies that not only support but effectively enhance safety and reliability objectives. The advancement in safety and reliability technology in safety-critical systems, viz., structural, process, space, nuclear, water transport, and rail and road transport are a testimony or tribute to the success of state of the art in science and technology. However, if we look at the history of accidents and societal challenges, we still see that further efforts are required. One of the major observations has been that the human factor is one of the major contributing factors to accidents and unrest, and one still wonders—‘a lot has to be done even now’.

If the present international eco-system is any indicator, then it is evident that for true progress and happiness, we need a profound value-based system where ‘consciousness or to be more precise conscience-driven value system is the need of the hour’. Of course, ‘quality’ metrics is effective to a great extent ensuring desired performance and dependability-related aspects for engineering and social systems as a starting point. Here come risk and reliability attributes that have potential to ensure product, system and service overall performance employing quantitative goals and criteria, to a large extent, in perpetuality.

However, the challenge is the science and technology of risk and reliability is yet to achieve the higher level of considerations, e.g., demands for higher capability in terms of capturing dynamic, common cause failure, human factor and data and models with an acceptable level of uncertainty, for improved acceptability, and further become part of risk-informed and further risk-based engineering. Here, the risk also covers loss of availability and reliability that might lead to loss of production and compromised services that eventually and adversely impact the business bottom-line.

The state of the art in PRA is generally considered as matured enough to form a part of risk-informed evaluation. The reason is, PRA provides an integrated, structured and quantified model with provision to characterize uncertainty, documented required for any review and evaluation. Here, the Probabilistic Risk Assessment (PRA) provides a needed platform to either complement or supplement the existing deterministic methods as part of a risk-informed approach or as an alternate or standalone approach for not only risk assessment but also for the development of risk-based applications requiring identification and prioritization, e.g., risk-based in-service inspection, generally one-time activities—ageing management and routine maintenance management, safety significance identification to support prioritization of regulatory review management, etc. The increasing interest in the use or adoption of risk-based or risk-informed approach and effective solutions that can be seen in the open literature shows that these tools and methods will become an integral part of design, operation and regulation.

In the present context, there appears a silver lining in the context of de-risking our systems, structures and components. The phenomenal growth of advanced technologies including digital, complex computing, artificial intelligence & machine learning coupled with availability of data and experience is creating an eco-system for advanced research and development, towards addressing real-time engineering challenges. This is truly a promising development for further consolidating the effectiveness of the risk-informed approach and further development or improving risk-based technology as applicable to complex system engineering systems. The objective is to support various stages of development right from conceptualization, design, commissioning, operation, regulation and finally disposal as part of tracking sustainability.

The above discussion provides the background for identifying the title and theme of this book entitleds *Advances in Risk-Based Approach for Complex Engineering Systems—Transformative Role of Evolving Technologies*. Even though the plenary sessions of International Conference on Reliability, Safety and Hazard-2024 (ICRESH-2024) proceedings comprised seventeen keynote talks, this volume covers only 12 full-length papers. The four manuscripts were not available due to time and logistic constraints. The keynote talks in ICRESH-2024 covered a wide spectrum of topics dealing with the application of advanced tools and methods right from risk and reliability assessment, role of digital technology in general and digital twins in particular for the simulation to support, training, performance and model development, artificial intelligence and machine learning approaches as operator support aids, data-driven-based prognostics and management, etc. There is a dedicated chapter on organizational and safety technology management aspects, through an integrated approach to safety, touching upon international practices to support national regulatory objectives. Apart from this, the integrated view of asset management employing transformative technologies towards addressing Industry-4 requirements also formed a part of the conference proceedings.

It can be argued that the treatment of the subject is not exhaustive; however, the major objective of plenary sessions, i.e., to discuss the core evolving technologies and its implementations, has been met. As such, this volume can be considered to complement the contributory book volume, comprised of full-length papers as part of ICRESH-2024 proceedings. Further, pre-conference tutorial lectures provide an improved perspective on the subject, i.e., the role of reliability and risk in eliminating or reducing the potential hazard for complex engineering systems, through the development of insight on prevention, enhanced tolerance(s) and/or removal of the failure(s) or consequences of failure.

We sincerely thank our keynote speakers, many of whom have come from a long distance in India and abroad to grace the ICRESH-2024 and enlightened the participants and organizers of the event. We thank them for their support and for presenting their excellent work capturing their R&D and professional experience.

Special thanks to Springer team, Ms. Priya Vyas, Senior Editor, and colleagues for the development and management of the tasks associated with this volume and for bringing out the keynote talk book of ICRESH-2024, well in time.

Mumbai, India
November 2023

Prabhakar V. Varde
Manoj Kumar
Mayank Agarwal

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About the Editors

Prof. Prabhakar V. Varde started his carrier at Bhabha Atomic Research Centre in 1983 as nuclear engineering trainee of BARC Training School in 27th Batch and joined erstwhile Reactor Operations and Maintenance Group now Reactor Group and served initially as commissioning and later operations engineering for Dhruva—a 100 MW research reactor at BARC and rose through the administrative ladder and retired in 2019 as Associated Director, Reactor Group. During his service, he completed his Ph.D. from IIT, Bombay in 1996 in AI based operator advisory system and later focused his research on nuclear safety in general and Risk-based engineering in particular, while working for reactor related services responsibilities.

Alongside his regular duties he continued R&D in the area of Risk and Reliability and Academics. He also served as Senior Professor, Guide and Member of the Board of Studies in Engineering Sciences of Homi Bhabha National Institute, Mumbai. He also served as Indian specialists/experts, to International Atomic Energy Agency (IAEA), Vienna, and Nuclear Energy Agency (OECD/NEA) France. He has been on select Panel for recruitment/promotions and Ph.D. and M.Tech. Examiner at IITs and Universities.

He did his postdoctoral research at KAERI, South Korea and served as Visiting Professor at CALCE University of Maryland, USA. He has over 250 research publications at national and international level which also includes co-authored/edited 18 books, technical reports and proceedings. Recently, he has published a book entitled 'Risk-conscious Operations Management'. He received many awards and recognition. Presently, he is serving as DAE Raja Ramanna Fellow, at BARC. He is founder of (Society for Reliability & Safety) and presently serving as President, SRESA and Editor-in-Chief for SRESA's International Journal for Life Cycle Reliability and Safety.

Dr. Manoj Kumar received his B.Tech. (Electronics & Communication) from JMI, N. Delhi (1998) and Ph.D. (Engg.) from IIT Bombay (2008). He has been with Control Instrumentation Division of Bhabha Atomic Research Centre (BARC), Mumbai as Scientific Officer since 1998. He is currently working in the area development & dependability analysis of computer based systems for safety applications and prognostics of electronic systems. He is associated with BRNS (Board of Research in Nuclear Science) in its activities as project collaborator and reviewer. He is also associated with HBNI (Homi Bhabha National Institute) as guide for its post graduate programs. He has over 30 research papers to his credit and has supervised fifteen M.Tech. thesis. He has authored two books in the area of dependability modelling and accelerated life testing of electronic systems. At present he is guiding one Ph.D. candidate of HBNI in the area of prognostics of electronic systems. He is on the editorial board of three international journals and managing editor of Journal—Life Cycle Reliability and Safety Engineering. He was also the member of working group for IEEE Std1856-2017 (IEEE standard Framework for Prognostics and Health Management).

Mayank Agarwal is a mechanical engineer. After successful completion of training from 51st batch of BARC training school, he joined Bhabha Atomic Research Center, Mumbai. completed his M.Tech in Nuclear Science Engineering. As part of his M.Tech. thesis he worked on a project on development of a prototype of a Risk Monitor named as 'Risk-based Operation and Maintenance Management System'. He also worked with a team involved in developing a risk-based approach for regulatory re-licensing of a reprocessing plant. Based on the experience and research insights, he also contributed as to writing a departmental report and finally co-authored a paper on the subject in a reputed international journal.

He is working as Mechanical Maintenance Engineer for a Research Reactor at Bhabha Atomic Research Reactor. He has expertise in maintenance of Safety and Safety Related Equipments, HVAC system of nuclear facilities and Fuelling Machine.

Chapter 1
Tends in Engineering Asset Management: The Impact of Transformative Technologies on Risk and Reliability Management

Uday Kumar

Introduction

In recent years, technology has played an increasingly vital role in revolutionizing the management of risk and reliability in engineering assets, presenting both unprecedented opportunities and unforeseen challenges. However, with the advent of transformative technologies, the engineering asset management paradigm has shifted dramatically. This transformation is driven by the recognition that proactive, data-driven approaches can significantly enhance the operational performance of assets while mitigating risks and ensuring reliability. Further, these technologies empower engineering managers to make informed decisions while simultaneously minimizing operational costs. Consequently, asset managers across industries have eagerly embraced digital technologies, with the aim of achieving operational excellence. The deployment and use of industrial Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), and 5G communications, has provided the asset managers with tools for near perfect cost optimization and risk elimination. As we look into the future, it is evident that technologies will continue to evolve like living organism, providing even more advanced solutions for engineering asset management.

The convergence of AI, IoT, and 5G communication is expected to open new frontiers in real-time monitoring and predictive maintenance. Furthermore, advancements in data analytics will enable asset managers to extract deeper insights from their data, leading to more informed decision-making. For high-risk industry, RAMS (Reliability, Availability, Maintainability and Safety) engineers must get used to new tools and technologies that will reduce the risk and eliminate unforeseen reliability

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and safety issues. Further, during the last two decades the area of PHM (Prognostics and Health Management) has been evolving and complementing the area of RAMS to eliminate technical and financial risks from asset operation with deployment of transformative technologies.

RAMS (Reliability, Availability, Maintainability and Safety) & PHM (Prognostics and Health Management)

RAM management traditionally focuses on reducing failure occurrences and devising cost-effective maintenance programs to mitigate associated safety, business, and societal risks, considering the entire asset lifecycle. A well-structured RAMS program has become an indispensable driver of sustainable asset management for all organizations and plays a pivotal role in adapting to the challenges posed by climate change. It holds the key to ensuring competitiveness, the safe delivery of services, and the attainment of sustainability objectives. RAM parameters are determined and dimensioned during an asset's design phase, allowing for objective testing, verification, and certification. In a broader life cycle perspective, RAM assurance programs contribute to product support strategies aimed at mitigating total business risks while accounting for the unique operational context. This phase deals with population-level considerations.

PHM is operationalized during the operational phase and revolves around individual assets or engineered objects. RAM assists in planning PHM programs during operations, while the availability of PHM programs aids in the dimensioning of RAM parameters during the design phase. The overarching goal of a PHM program is to enhance asset availability by affording early proactive maintenance planning, thereby averting the consequences of unforeseen failures. PHM programs encompass detection, diagnostics, prognostics, and the identification of the Best Possible Solution (BPS) in the presence of various sources of risks and uncertainties.

Traditional reliability techniques harness probability models to characterize failure arrival rates, identify critical failure modes, and assess their severity through programs like Failure Modes and Effects Criticality Analysis (FMECA). These insights are instrumental in developing PHM algorithms. PHM algorithms, in turn, enhance classical reliability efforts by lowering the bounds on design reliability. In essence, a well-structured PHM program or tool obviates the need for extra reliability provisions, such as redundancies or additional costs. Maintenance serves to compensate for deficiencies in reliability by leveraging maintainability characteristics, thereby reducing maintenance action durations. PHM further facilitates accurate estimation of Remaining Useful Life (RUL) and the formulation of cost-effective maintenance tasks and policies leading to minimization of total asset operational risks. Figure 1.1 illustrates the concept of RUL.

The paper aims and underscores the profound significance of digital and enabling technologies in modern engineering asset management. It explores the associated challenges and opportunities, offering insights into how these technologies can reshape the future of asset management.

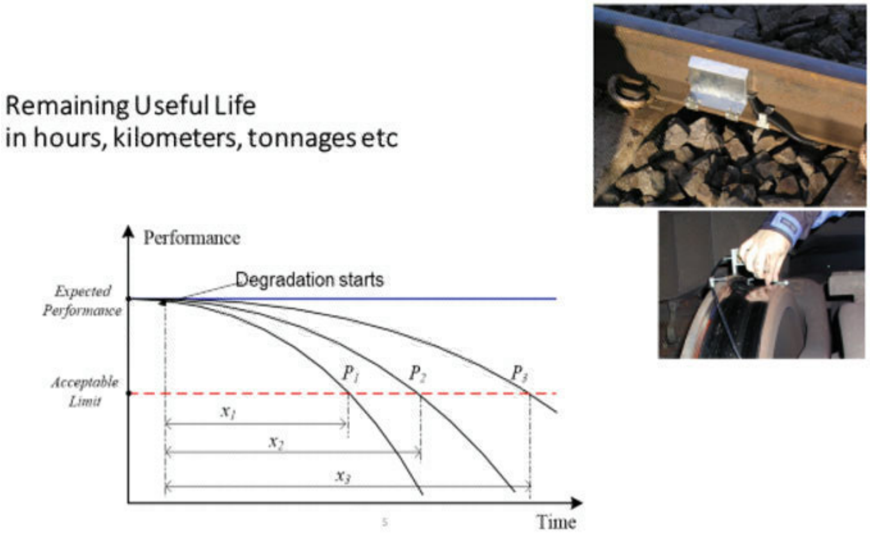

Fig. 1.1 Estimation of remaining useful life

New Technology for Asset Monitoring and Maintenance

The transformative technologies facilitate or are expected to facilitate correct decisions and actions at the lowest possible cost using the power of predictive and prescriptive analytics by the asset managers. These are expected to support organisations' digital transformation journey and operations goals. These technologies can be broadly classified as supporting, optimizing and transformative technologies, as outlined in Fig. 1.2, and collectively provide the foundation for the predictive technologies, being used for the estimation of the Remaining Useful Life (RUL) of assets. Condition monitoring, Multiphysics simulation, RAMS (Reliability, Availability, Maintainability and Safety) modelling, LCC (Life-Cycle Costs) analysis, etc. arrive at the correct optimal maintenance decision form the core of supporting and optimizing technologies. Other technologies such as Virtual Reality (VR), Augmented Reality (AR), predictive and prescriptive analytics, Industrial Internet of Things (IIoT), 5G communication technologies can offer near perfect solutions (even in real time) for the management of new or existing assets and are collectively termed as transformative technologies. For successful implementation domain knowledge is critical and expert with deep insight into the engineering system design and operation must be part of the technology deployment and implementation team.

Furthermore, for the successful development and implementation of transformative technologies and solutions, there is a spoken need for the convergence of the Operational Technology (OT) and Information Technology (IT).

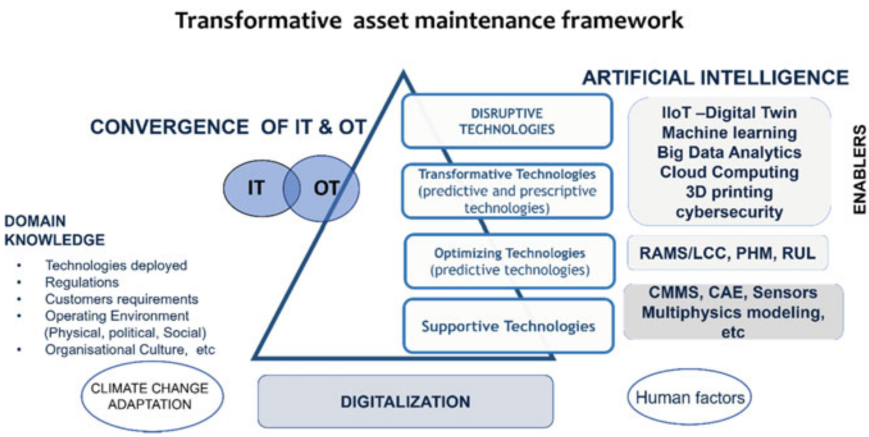

Fig. 1.2 Transformative asset maintenance framework

Digitization and Digitalization

The effort to develop and implement new technology is founded on digitalization of assets. The digitalisation process in industry and the corresponding implementation of AI technologies require availability and accessibility of both data and models. Data and models are considered digital assets that affect system's dependability during its whole lifecycle.

It provides directions for digitization, digitalization and digital transformation of maintenance process.

- Digitization is the process of converting continuous information to digital format. It is the conversion of information (i.e., objects, images, sounds, documents, data, etc.) into an electronically stored digital format that can be accessed with right tools, authorization and infrastructures.
- Digitalization is the process of leveraging value hidden in the data to improve business processes. Digitalization facilitates use of digital technologies and data to visualize the physical health of the asset and develop optimal solution for the operation and maintenance.

In short Digitization encompasses technologies that are aimed to enable the process of transforming analogue data to digital data. Digitalisation on the other hand encompassed to the provision of digital services which creates value to its user.