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RAMS + C informed decision-making with application to multi-objective optimization of technical specifications and maintenance using genetic algorithms

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Abstract

The role of technical specifications and maintenance (TSM) activities at nuclear power plants (NPP) aims to increase reliability, availability and maintainability (RAM) of Safety-Related Equipment, which, in turn, must yield to an improved level of plant safety. However, more resources (e.g. costs, task force, etc.) have to be assigned in above areas to achieve better scores in reliability, availability, maintainability and safety (RAMS). Current situation at NPP shows different programs implemented at the plant that aim to the improvement of particular TSM-related parameters where the decision-making process is based on the assessment of the impact of the change proposed on a subgroup of RAMS + C attributes.

This paper briefly reviews the role of TSM and two main groups of improvement programs at NPP, which suggest the convenience of considering the approach proposed in this paper for the Integrated Multi-Criteria Decision-Making on changes to TSM-related parameters based on RAMS + C criteria as a whole, as it can be seem as a decision-making process more consistent with the role and synergic effects of TSM and the objectives and goals of current improvement programs at NPP. The case of application to the Emergency Diesel Generator system demonstrates the viability and significance of the proposed approach for the Multi-objective Optimization of TSM-related parameters using a Genetic Algorithm.

Keywords: Reliability; Availability; Maintainability and safety (RAMS); Cost; Testing and maintenance; Multiple criteria decision-making; Multi-objective optimization

1. Introduction

The study of changes to TSM at NPP normally aims at finding the best solution feasible for a particular requirement or activity (Maintenance, SR, LCO, etc.), taking into account relevant criteria concerning the decision-making; that is for example, searching the appropriate set of particular parameters related to TSM of SRE to result in minimal risk, cost, etc.

In this way, one can find in the literature several analyses of changes to particular parameters related to TSM that have been performed at NPP taking as reference the information provided by the analysis of the risk impact of the changes proposed, which fall into the well know group of risk-informed applications to support decision-making. Among the application areas one can find risk-informed improvement or optimization of STI and AOT both within

Abbreviations: AOT, allowed outage time; CDF, core damage frequency; DBA, design base accident; DG, diesel generator; FSAR, final safety assessment report; EDG, emergency diesel generator; IMCDM, integrated multi-criteria decision making; ISI, in-service inspection; IST, in-service testing; LB, licensing basis; LCO, limiting conditions for operation; LMP, life management program; LRA, license renewal application; MOGA, multi-objective genetic algorithm; MOP, multiple-criteria optimization problem; MRI, maintenance rule implementation; NPP, nuclear power plant; PM, preventive maintenance; PAR, proportional age reduction; PSA, probabilistic safety assessment; RAM, Reliability, availability, maintainability; RAMS, RAM and safety; RAMS + C, RAMS and cost; RCM, reliability centered maintenance; RI-ISI, risk informed ISI; RI-IST, risk-informed IST; RI-LCO, risk informed LCO; RI-SR, risk informed SR; RI-TS, risk informed TS; SRE, safety-related equipment; SR, surveillance requirements; STI, surveillance test interval; SSC, structure, system and component; TS, technical specifications; TSM, technical specifications and maintenance.

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the Technical Specification. In addition, there are many works in the literature devoted to the analysis of changes or even optimization of maintenance-related parameters at NPP where the RAM of systems and components that overcome maintenance activities are adopted as decision criteria [1–3]. Furthermore, recent works often take into consideration additional acceptance criteria for the decision-making procedure; such as economical costs, human resources, etc., that yield to an IMCDM on changes to TSM-related parameters in many applications [4–7].

This paper briefly reviews the role of TSM to achieve appropriate levels of RAMS of NPP. Then, the ongoing programmes or those being currently considered for implementation at NPPs that aim at improving both maintenance practices and TS that justify the need of such IMCDM are introduced. Starting from the analysis of the current situation, a new IMCDM approach based on RAMS + C criteria to assess changes to TSM-related parameters is proposed. This approach extends the current concept of Risk-informed to a RAMS + C-informed decision-making integrating many of the TSM requirements, activities and multiple acceptance criteria at NPP. This methodology can consider other traditional criteria such as human resources, radiological doses, etc. The application performed on a safety system normally in standby of a NPP reveals the significance of the proposed approach and assesses the viability of the proposed methodology to solve this kind of engineering problems formulated as a multi-objective optimization problem.

2. RAMS and the role of TSM at NPP

Fig. 1 illustrates the basic concepts and the role of the requirements included into Technical Specification and Maintenance relative to RAMS of SRE at NPP. Reliability of SRE represents its capability to respond and sustain operation under specified conditions without failure during a given period or to a given age. Thus, failure is defined as an interruption of its functional capability or loss of performance below the threshold defined in the functional specification. In turn, degradation is defined as the loss of performances of characteristics in the limits of the specifications as time or age passes, which results in a failure just below the failure point defined in the functional specifications.

Natural reliability is the reliability of the equipment with no maintenance at all, which directly depends on its physical characteristics or design, while the intrinsic reliability is the value (in principle higher than natural) obtained with a normal amount of quality maintenance (usually preventive maintenance).

Maintenance represents all activities performed on equipment in order to assess, maintain or restore its operational capabilities. Maintenance introduces two types of positive aspects. Firstly, corrective maintenance restores the operational capability of the failed or degraded equipment and secondly preventive maintenance increases the intrinsic reliability of non-failed equipment beyond the natural reliability, for example, controlling its degradation below the failure point. Although the equipment is subjected to preventive and corrective maintenance it may degrade over age depending on the working conditions of the equipment and the effectiveness of the maintenance being applied (so called imperfect maintenance). So that, several activities are scheduled to control evolution of degradation mechanisms that fall into the categories of continuous monitoring or periodic predictive maintenance, which are responsible for launching on condition preventive or corrective activities when necessary.

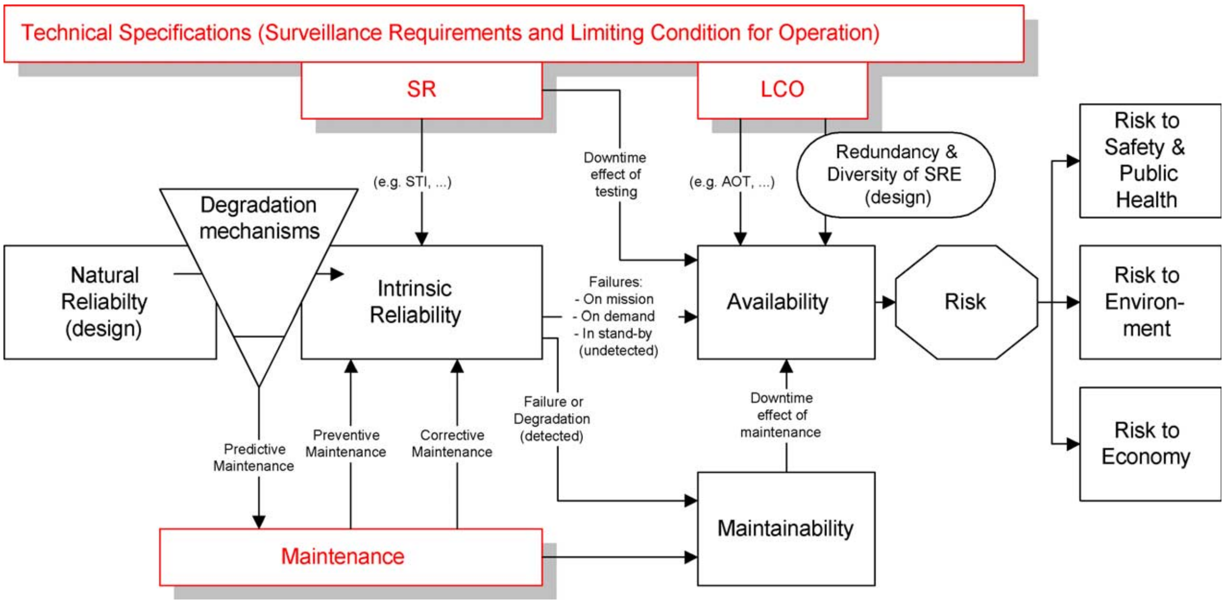

Fig. 1. Role of TSM and RAMS criteria.