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CAN AGEING AND OBSOLESCENCE MANAGEMENT BE INTEGRATED?

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ABSTRACT

In industries with extended operational lifespans, challenges of ageing and obsolescence are ever-present and interdependent. Both phenomena, if unaddressed, pose risks to safety, efficiency, and regulatory compliance. This paper explores the potential integration of ageing and obsolescence management, emphasizing their shared reliance on accurate data, proactive monitoring, and strategic planning. Integrated approaches leverage advancements in data analytics, machine learning, and real-time monitoring to detect ageing-related degradation and forecast obsolescence trends. The implementation of dedicated management software and data-driven decision-making is critical to advancing integration. By adopting a unified approach, nuclear facilities can minimize resource duplication, ensure long-term operational reliability, and adapt to evolving technological landscapes.

INTRODUCTION

In industries with long operational lifespans, such as nuclear energy, two persistent challenges emerge: obsolescence and ageing. These phenomena, while distinct, often intersect in ways that amplify risks and operational inefficiencies. Understanding their commonalities is critical to developing effective strategies for their management. Obsolescence refers to the loss of functionality, relevance, or support due to technological, regulatory, or market changes. As new technologies emerge, older systems and components may become outdated, even if they remain physically intact. In contrast, ageing describes the physical or material degradation of components over time, leading to a decline in performance and an increased likelihood of failure. Despite their differences, they can share several common characteristics and consequences. (Murakami and Sekimura, 2023) Both can lead to operational disruptions, higher maintenance costs, and safety risks if not addressed proactively. They also require organizations to allocate significant resources for monitoring, evaluation, and strategic planning. This article explores the commonalities between obsolescence and ageing management and examines whether they can be effectively handled through integrated approaches.

KEY SIMILARITIES

Obsolescence and ageing share fundamental traits that necessitate integrated management strategies. While each presents distinct challenges, their overlap in risks and resource demands makes integrated approaches both efficient and essential for long-term system reliability. These activities are based on accurate and reliable data, and proactive monitoring and evaluation is essential. Early detection and continuous evaluation help to prevent risks from escalating into critical issues. For instance, predictive maintenance tools and data-driven analytics play a crucial role and can be instrumental in identifying ageing-related deterioration while also forecasting obsolescence trends. (IAEA, 2022).

Components nearing the end of their operational lifecycle often exhibit physical degradation, while technological lifecycles may render them incompatible with modern systems. Addressing lifecycle dependencies requires careful planning for timely upgrades and replacements to ensure continued functionality and reliability. (NEA, 2021) This relationship is illustrated in Figure 1., which shows that degradation (ageing) and technological incompatibility (obsolescence) require timely interventions, such as upgrades or replacements, to maintain operational integrity.

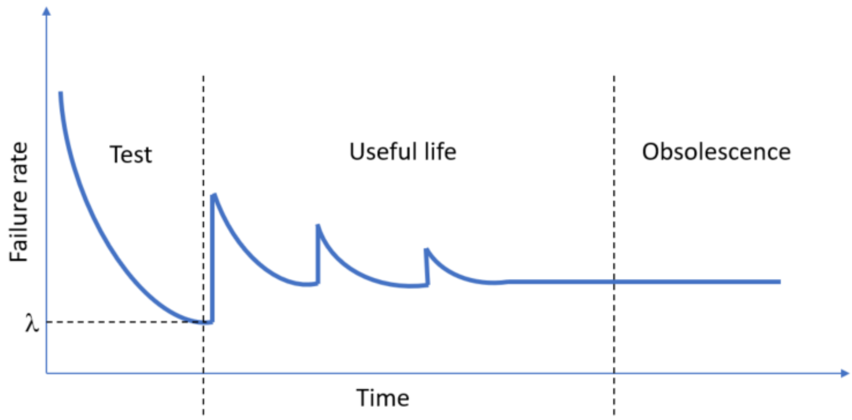

Figure 1.: System failure rate with frequently upgrade (own work)

Risks posed by unaddressed obsolescence and ageing are significant, both must align with stringent regulatory standards. Operational disruptions, safety incidents, and regulatory challenges can result if these issues are not managed effectively. By integrating strategies, it is possible to mitigate potential hazards and maintain compliance with strict safety standards. Managing both requires significant financial in spare parts, modernized systems, and human resources as training personnel are critical. *(Murakami and Sekimura, 2023*) Integrated management strategies help organizations adhere to these regulations efficiently while mitigating risks associated with non-compliance.

Although ageing and obsolescence share significant overlaps and can benefit from an integrated management strategy, it is crucial to acknowledge their inherent differences and manage them accordingly. If ageing and obsolescence are treated identically without adequate differentiation, several risks emerge:

- *Inappropriate Resource Allocation:* Resources might be misdirected, applying excessive maintenance efforts to components that are technologically obsolete yet physically sound, or neglecting critical physical deterioration in favour of premature technological upgrades.
- *Incorrect Risk Assessment*: Treating both issues identically can skew risk assessments, potentially underestimating physical degradation threats or overstating the immediacy of obsolescence-driven replacements.
- *Operational Inefficiencies:* Identical management strategies may lead to ineffective maintenance practices, where resources are not optimally allocated, causing increased operational downtime and higher costs due to redundant or ill-timed interventions.
- *Regulatory Non-Compliance:* Regulatory standards often differentiate clearly between physical ageing-related issues and obsolescence-related updates. Failure to distinctly recognize these can lead to non-compliance risks or inefficient allocation of compliance-related efforts.

Therefore, while integration is beneficial in terms of shared data frameworks and monitoring tools, effective management strategies must differentiate clearly between ageing and obsolescence to ensure that the appropriate interventions are implemented at the right time.

STRATEGIES FOR INTEGRATED MANAGEMENT OF OBSOLESCENCE AND AGEING

To effectively address the intertwined challenges, the nuclear industry must adopt a comprehensive and integrated management approach. These strategies involve technological advancements, operational planning, and collaboration across stakeholders to ensure safety and reliability over time.

Predictive Maintenance and Data Utilization

The foundation of integrated management lies in predictive maintenance systems that leverage accurate and real-time data. These tools can detect early signs of physical degradation and potential obsolescence, allowing operators to act before significant issues arise. For instance, sensors and analytics can monitor component performance and predict failure timelines, minimizing operational disruptions. *(IAEA, 2022)*

Modernization Programs

Upgrading ageing infrastructure and systems to incorporate modern technologies is another vital strategy. Modernization not only addresses physical wear and tear but also ensures compatibility with current and future technologies. A prominent example is the transition from analogue to digital instrumentation and control systems.

Collaboration with Stakeholders

Collaboration among industry operators, regulators, and technology providers is essential to develop and implement robust management frameworks. Stakeholders must share best practices, align on technological standards, and ensure compliance with evolving regulations.

Lifecycle Cost Analysis

Decision-making processes in integrated management should incorporate lifecycle cost analysis. This involves assessing the total cost of ownership, including initial investments, maintenance, and eventual decommissioning. By prioritizing investments with long-term value, organizations can optimize resources while maintaining safety and reliability.

Workforce Training and Development

Addressing ageing and obsolescence requires skilled personnel who understand both the challenges and the technologies used to mitigate them. Investing in workforce training ensures that employees are equipped to manage advanced systems and implement effective management practices.

THE ROLE OF RELIABLE AND ACCURATE DATA

Reliable and accurate data are fundamental. High-quality data enable early detection of component degradation, facilitate predictive maintenance, and support informed decision-making processes. Robust data collection and analysis are essential for developing strategies to address ageing and obsolescence issues. *(IAEA, 2022b)* Sensors, digital twins, and IoT devices play a critical role in gathering real-time data on equipment conditions. This data enables the identification of patterns, such as wear rates and performance deviations, which are vital for predicting failures and planning upgrades.

Implementing advanced data analytics and artificial intelligence (AI) techniques enhances the performance and accuracy of predictive maintenance systems. These technologies increase autonomy and adaptability in complex and dynamic environments, allowing for more precise forecasting of equipment failures and timely interventions. *(Hardik et al., 2023)* By applying machine learning algorithms and statistical models, operators can forecast potential risks and prioritize maintenance activities. Moreover, the integration of machine learning algorithms in predictive maintenance frameworks enables the analysis of heterogeneous data from various sensors. This approach facilitates the early identification of potential failures, thereby improving safety and operational efficiency. *(Ucar et al., 2023)* From operational planning to strategic investments, reliable information allows organizations to prioritize actions that minimize risks and maximize value. Despite its importance, managing data presents challenges, including ensuring cybersecurity, addressing data silos, and maintaining data quality over time.

In conclusion, accurate and reliable data is not just a supporting element but a core enabler of successful obsolescence and ageing management strategies. By leveraging modern tools and practices for data collection, analysis, and integration, these processes can ensure safety, compliance, and operational operation.

THE S-CURVE OF ACCURACY

In managing dataset, the concept of the S-curve in Figure 2. illustrates how improvements in data accuracy can yield diminishing returns if not aligned with practical usefulness. While increasing accuracy is critical for decision-making, there is a point where additional precision may no longer provide proportional value and could even hinder timely actions.

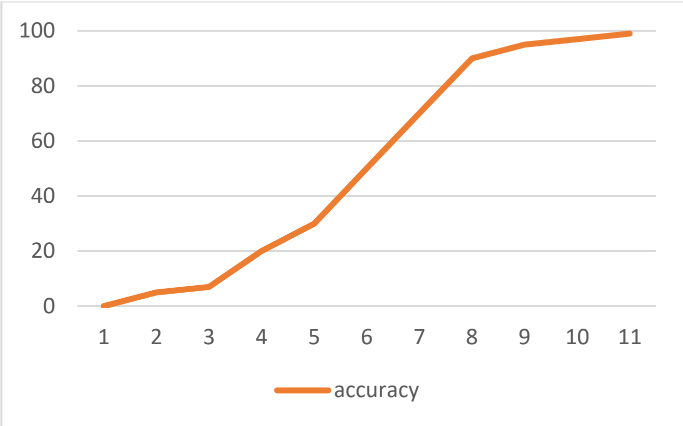

Figure 2.: Accuracy in relation to added value of dataset (own work)

This method highlights to align resource investments with practical needs. High accuracy is essential for long-term planning, such as forecasting ageing and obsolescence, but operational decisions often rely on timely and relevant data rather than exhaustive precision. By following the principles of the S-curve, it is possible to optimize data management strategies, focusing on utility and applicability.

PRACTICE OF PAKS NPP

Paks NPP, Hungary's sole nuclear facility started to develop further its Equipment Reliability (ER) program at 2023 to improve internal operations. It involves comprehensive surveys and data collection on components and systems, which can support two critical pillars: Ageing Management (AM) and Obsolescence Management (OM). Together, these elements create a robust framework for operational reliability as visible in Figure 3.

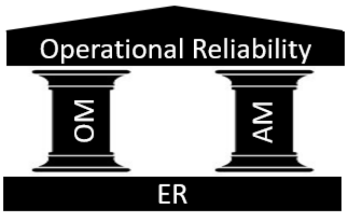

Figure 3.: Main pillars of Operational Reliability (own work)

For instance, its Unit Capability Factor has consistently exceeded the median value reported by WANO from 2016 to 2022. This achievement reflects the plant's effective maintenance and operational practices (MVM Paks NPP Ltd, 2022).

Equipment Reliability works as backbone, ensuring that critical systems function safely and efficiently. It is focused on systematically identifying important components, collecting data about their performance, and developing optimized maintenance schedules. Each component is evaluated for its role in safety, reliability, and plant performance, allowing for a targeted approach to maintenance planning. Historical performance data, failure reports, and maintenance logs are then collected and analyzed to understand the operational behavior of these components. In addition to historical data, real-time condition monitoring tools, such as vibration sensors and thermal imaging, provide continuous feedback about the state of critical equipment. This data-driven approach ensures that maintenance efforts are both effective and resource-efficient.

Ageing management has been a cornerstone of operational reliability for many years. Given the plant's operational start in the early 1980s, ageing management efforts have been ongoing for decades. These long-term efforts have been guided by international best practices and include systematic reviews and mitigation strategies for critical systems such as the RPV, Steam Generators, MCPs, and primary piping. These programs highlight how Paks has been proactive in addressing ageing risks long before extended operation became standard practice, ensuring that degradation mechanisms are managed effectively to maintain safety and reliability (IAEA, 2004). To handle technological obsolescence, a key example is the replacement of turbine condenser tubing with stainless steel, enabling the use of high pH secondary circuit water chemistry. This upgrade reduces erosion and corrosion in the feed-water system and prevents the deposition of corrosion products in steam generators, thereby enhancing system reliability (Máté, 2012). However, the broader challenge of systematically addressing obsolescence across all plant systems - including reactor control systems, instrumentation, and electrical components - remains a work in progress.

Obsolescence Management is a structured, ongoing effort to address the risks associated with outdated technologies and unavailable replacement components. With the plant operating well beyond its original design life, the logistical aspects of OM, such as stockpiling critical spare parts and engaging suppliers, are already well-established. Leveraging data from the Equipment Reliability program, Paks has identified high-risk components and supply chain bottlenecks to ensure continuity, however the engineering side of OM is still under development. Modernization of outdated systems, such as control systems and instrumentation, is a key area requiring further planning and execution, and a dedicated management software solution is currently being implemented. With the logistical framework in place and the management software under implementation, Paks NPP is steadily advancing toward a comprehensive obsolescence management strategy.

FUTURE DIRECTIONS

Addressing obsolescence and ageing in the future will require leveraging emerging technologies, fostering collaboration, and prioritizing sustainability. Advances in artificial intelligence, machine learning, and big data analytics will transform how these challenges are managed. Tools like digital twins can offer real-time simulations, improving predictive maintenance and enabling proactive decision-making. These technologies will help forecast degradation, optimize maintenance schedules, and extend the lifecycle of components.

Collaboration among nuclear operators, regulators, and technology providers will become increasingly important. Shared databases, international standards, and joint research initiatives will streamline best practices and accelerate innovation. Regulatory frameworks must evolve to support these advancements, balancing the need for flexibility with stringent safety standards. Risk-informed approaches will likely become central to achieving this balance.

Sustainability will also play a critical role. The adoption of circular economy principles, minimizing waste, and resource-efficient technologies such as 3D printing for spare parts can reduce environmental impacts. Workforce development will be equally vital. Training personnel to manage advanced systems and encouraging interdisciplinary expertise will ensure that the nuclear industry adapts to emerging demands while maintaining reliability and safety.

CONCLUSION

Managing obsolescence and ageing is a complex but vital task to ensure safety, reliability, and efficiency in long-term operations. These challenges, though distinct, share commonalities that necessitate integrated management strategies based on accurate data, proactive planning, and modernized systems. By leveraging predictive maintenance tools, fostering collaboration among stakeholders, organizations can effectively prioritize actions that address these issues without compromising timeliness or practicality.

Future advancements in technology, such as artificial intelligence and digital twins, combined with a focus on sustainability and regulatory evolution, will redefine how the nuclear sector approaches ageing and obsolescence. Workforce development and interdisciplinary expertise will also play a critical role in ensuring that these strategies are successfully implemented.

Integration is not without challenges, but ageing and obsolescence management can be integrated through shared data frameworks, predictive maintenance systems, and collaborative modernization efforts. Integration not only minimizes duplication of resources but also enhances overall system reliability and operational efficiency.

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