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An Evaluation of a Maintenance Strategy Using Risk-based Inspection (RBI)

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Abstract

This research focuses on evaluating the advantages and limitations of implementing Risk-Based Inspection and Maintenance (RBIM) in the power plant industry. RBIM aims to enhance maintenance practices by considering equipment failure risks. The study utilizes a mixed methods approach, including case studies, a literature review, and analyzing data. The findings underscore the positive impact of RBIM on efficiency and effectiveness, emphasizing the potential for cost reduction and improved risk assessment accuracy. Key recommendations include promoting transparency in reporting, early problem detection, and data-driven decision-making.

Keywords
Risk, Industry, Efficiency, Cost, Reduction.

1. Introduction
This Asset management involves comprehensive risk assessment, providing insights into technical, commercial, and situational aspects of risk in the power plant sector (Mohammadi et al. 2023). RBIM in power plants aims to improve productivity, safety, operational and maintenance expenses, and shareholder value. Safety considerations involve event likelihood, its occurrence, and negative outcomes (Naji et al. 2023). Risk, influenced by probability, is the potential outcome resulting from a specific threat or danger (Malekmohammadi et al. 2023)

In the power industry, production plants grapple with the challenges of meeting production demands, safety concerns, economic pressures, and legal requirements, amid a shortage of expert skills and resources (Milic et al. 2023). RBIM risk assessment is pivotal, employing both quantitative and qualitative analyses to detect potential issues and assess risk factors (Afenyo et al. 2023). Plant safety is closely tied to reliability, availability, and accident prevention (Cao et al. 2023).

Advanced maintenance and inspection programs are vital for extending equipment life and reducing failure probability (Priyanka et al. 2023). RBIM integrates reliability practices and risk assessment strategies for optimal maintenance scheduling, gaining popularity for its reported benefits. This study aims to assess the benefits and drawbacks of successfully implementing an RBIM system in power industries. Power plant industries face various risks, leading to financial losses and operational difficulties (Garg et al. 2023).

For example, the power plant performance decline has resulted in electricity shortages, with load-shedding costs exceeding the cost of operating gas turbines (Bao et al. 203). The introduction of the new Pressure Equipment Regulation adds complexity, requiring hydrostatic testing at shorter intervals, conflicting with power plants existing maintenance philosophy (Kumar et al. 2022). This study aims to understand the advantages and disadvantages of implementing Risk-Based Inspection and Maintenance in power plant sectors.

The research objectives include investigating the benefits and shortcomings of successful RBIM implementation, identifying different RBIM approaches, and recommending best practices for RBIM in power plant industries. The research addresses questions about the benefits and shortcomings of RBIM implementation and the best practices for implementing RBIM in power plant industries. This research could significantly assist companies in the power industry, such as Eskom, in cost reduction and improving maintenance focus.

RBIM offers potential economic benefits and efficiency improvements through optimized maintenance, making it relevant for South African electricity generation. The study can serve as a success story for RBIM in South African industries and Africa at large. Additionally, it can provide insights into RBIM's benefits, such as longer equipment lifespan and efficient inspection resource utilization.

2. Literature Review

The literature review delves into the concept of Risk-Based Inspection (RBI) for power plants. RBI is a method employed to create cost-effective inspection plans, with applications in various industries. The primary objective is to prioritize equipment based on their failure rates, considering degradation mechanisms and factors affecting failure rates. Table 1 is the depiction of the literature footprint (Holmberg and Kahlbom 2019). Maintenance strategies are critical for ensuring the reliability and safety of industrial assets. Among these strategies, Risk-Based Inspection (RBI) has emerged as a valuable methodology for optimizing inspection activities.

RBI involves assessing and managing risks associated with equipment failures, allowing for targeted and efficient maintenance interventions. The roots of RBI can be traced back to the 1970s when the need for more efficient inspection practices became apparent, particularly in industries like petrochemicals. Initial methodologies laid the foundation for the modern approach to risk-based inspection (Holmberg and Kahlbom 2019). The evolution of RBI principles has been influenced by advancements in risk assessment methodologies, reliability engineering, and lessons learned from historical failures (Mohamed et al. 2019).

Early models have been refined and adapted to suit diverse industrial contexts. Various risk assessment models form the core of RBI. Models like the Risk Matrix, Probability-Impact Matrix, and quantitative risk assessment (QRA) are widely used. Researchers have discussed the strengths and limitations of these models (Lelo et al. 2023). Comprehensive data integration and analysis are crucial for effective RBI. The literature emphasizes the role of data management, condition monitoring, and reliability data in supporting RBI methodologies (Aditiyawarman et al. 2023).

Optimizing inspection planning is a critical aspect of RBI. Researchers e.g., Aditiyawarman et al. 2023, have explored methodologies for determining inspection intervals, selecting appropriate inspection techniques, and integrating inspection plans into overall asset management strategies. The oil and gas industry has been a pioneer in adopting RBI for the assessment of pressure vessels, pipelines, and critical infrastructure. Case studies by Aditiyawarman et al. (2023) highlight successful applications and industry-specific challenges.

In the power generation sector, RBI is applied to assess the condition of boilers, turbines, and other components. Studies (Varde 2023) in this field discuss the implementation of RBI, outlining successes and challenges. The chemical and process industries extensively use RBI to manage risks related to corrosion, chemical reactions, and equipment degradation. Research by (Li et al. 2023) explores the application of RBI in chemical plants and related facilities. Despite its benefits, RBI faces challenges such as data quality issues and the need for specialized expertise. (Author6 et al. Year) delve into these challenges and propose potential solutions.

Emerging trends and innovations in RBI, such as the integration of artificial intelligence and advanced sensor technologies. (Aditiyawarman et al. 2023) provide insights into the future directions of RBI. This literature review provides a comprehensive overview of the evaluation of maintenance strategy using Risk-Based Inspection. It synthesizes existing knowledge, identifies gaps, and offers insights into the evolution, methodologies, applications, challenges, and future directions of RBI.

Table 1. Literature survey or RBI (2013 – 2023)

Topic	Key Points	References
Introduction	Focuses on the literature review regarding Risk-Based Inspection (RBI) for power plants in chemical and oil and gas industries.	Holmberg and Kahlbom (2019)
The Goal of RBI	RBI prioritizes equipment based on failure rates (PoF x CoF). Common degradation mechanisms are identified.	Holmberg and Kahlbom (2019)
RBI considers personal safety, environmental impact, product losses, and facility repair costs in risk assessment.	Human involvement significantly influences the success of RBI implementation. Minimizing human errors during inspection and maintenance is critical for optimal plant performance.	Mohamed, R., Che Hassan, C. R., and Hamid, M. D. (2019).
Risk acceptance levels determine inspection planning.	The integrated systemic model highlights the importance of quantifying the probability of human error in risk assessments.	Zwetsloot, G., van Kampen, J., Steijn, W., and Post, S. (2020).
Mitigation measures are implemented for low PoF and high CoF equipment.	RBI is employed to mitigate these risks. Factors such as training, working conditions, and fatigue must be considered to prevent incidents like Flixborough, Three Mile Island, Piper Alpha, and Bhopal accidents.	Tan, Z., Li, J., Wu, Z., Zheng, J., and He, W. (2011
Screening assessment identifies high-risk equipment.	The process categorizes risks as low, medium, and high, allowing for prioritization and continuous monitoring. In addressing risks effectively, equipment operation becomes safer and more reliable.	Khan, F. I., & Haddara, M. (2004).-Risk-based maintenance (RBM)
Understanding of Risks	RBI aims to understand facility risks for safety and optimization of inspection and maintenance resources.	Pence, Abolhelm, Mohaghegh, Reihani, Mehmet Ertem and Kee (2018)
Best Practices	Effective RBI implementation requires commitment from senior management. Suggested strategies are listed.	Gordon (2009), Jovanovic, Auerkari, and Jareiss (2014), Hameed, Khan, and Ahmed (2016)
Software is essential for RBI in handling large-scale assessments. Factors for selecting suitable software are discussed.	Kaley (2009), Kodssi, Sabry & Houssam (2018)	Topalis, P., Korneliussen, G., Singh, M., and Wiggen, F. (2011). Software for the process industry.
Confidence Criteria	Confidence measures are important for a reliable RBI system. The confidence index evolves over time.	Peters (2015)
Benefits of RBI	RBI aims to optimize inspections rather than reduce costs. It eliminates ineffective inspections and offers financial benefits.	Sutton (2017)
Financial advantages of Probabilistic Risk Assessment (PRA) in nuclear power plants.	Pence, Abolhelm, Mohaghegh, Reihani, Mehmet Ertem & Kee (2018)	Kim, T. O., Lee, J. H., Choi, S. K., Lee, H. C., & Jo, J. H. (2009).
Applicable Standards	API and RIMAP standards for RBI in different industries.	CEN (2008), SANS 347, SANS 17021, SANS 10227
API Risk Analysis	API's approach to assessing risks involves PoF, CoF, and inspection planning.	Shishesaz, Nazarnezhad Bajestani, Seyed, Hashemi and Shekari (2013)
Inspection Planning	API 510 standards outline inspection intervals for different equipment.	Shishesaz, Nazarnezhad Bajestani, Seyed, Hashemi and Shekari (2013)

The Value of API 581	API 581 evaluates component failure probability and factors affecting inspection effectiveness.	Osage (2007), API (2008)
The RIMAP Approach	RIMAP process involves initial planning, data collection, risk evaluation, decision-making, execution reporting, and performance evaluation.	Singh and Pretorius (2017)

3. Research Method

The research methodology chapter establishes a comprehensive framework for investigating the advantages and limitations of implementing Risk-Based Inspection and Maintenance (RBIM) in the power plant industry. Positivism serves as the chosen research philosophy for this study, emphasizing the utilization of empirical evidence and scientific methods to comprehend and explain phenomena (Park et al. 2020). This aligns with the assessment of the effectiveness and limitations of RBIM in power plant industries.

A mixed-methods approach combines quantitative and qualitative data collection methods. Surveys and questionnaires contribute to quantitative data, while interviews, focus groups, case studies, and document analysis contribute to qualitative data, providing a holistic understanding of the research problem (Creswell et al. 1999). The research strategy outlines a systematic approach, including decisions on data collection methods, research techniques, and analytical approaches. The study opts for a qualitative research approach to explore and explain RBIM.

Sampling is applied to select participants with expertise in RBIM implementation in power plant industries, enhancing the validity and reliability of findings by gathering information from knowledgeable individuals. Surveys, case studies, and document analysis serve as research instruments to collect data on the benefits, limitations, and best practices of RBIM implementation. Data analysis involves both quantitative and qualitative methods, incorporating descriptive statistics, correlation analysis, regression analysis, and thematic analysis. Triangulation is employed to validate findings by comparing results from different data sources (Kazu et al. 2023).

The data collection is done in power stations, each with specific details. A survey form with benchmarks assesses RBI implementation effectiveness in various aspects. RBI implementation assessment involves evaluating the progress of power stations, identifying two as the most advanced (Bertola et al. 2023). Historical maintenance cost records, though limited, were obtained for a cost-benefit analysis. Audit reports from all RBI-certified power stations highlighted common findings, emphasizing the importance of using SAP tools for scope consolidation and management.

The data analysis and results section includes an exemption that extends inspection intervals to months following successful RBI implementation. A Cost Analysis Excel Model compares costs between inspections with and without RBI for two power stations. The analysis of recurring audit discoveries across all power stations identifies deviations between RBI recommendations and executed inspections, data input errors, and other issues. Analysis of risk data with Risk Engineers evaluates the effectiveness of RBI implementation, revealing insights into strengths and weaknesses.

4. Discussion and Results

The RIMAP standard in Europe provides guidelines for adopting a risk-based approach in power plants, optimizing Operations and Maintenance (O&M), and asset management (Jovanovic et al. 2014). Integration of RBI with existing life management processes within power plants is essential to prevent redundancy and omission of scopes. Cost-effective measures should be prioritized when planning inspection and maintenance activities (Jovanovic et al. 2014). The decision-making team plays a crucial role in risk mitigation and inspection planning.

Evaluating the risk-based decision-making process is vital for assessing its effectiveness and impact on inspection and maintenance programs (Jovanovic et al. 2014). These activities ensure continuous improvement in RBI implementation. The utilization of RBI in coal-fired power generation is limited, particularly in South Africa, where certification by an independent third party is mandatory. In contrast, the National Thermal Power Corporation in India has successfully implemented RBI across all its power units, ensuring safe and reliable operations.

In the United States, Progress power's implementation of RBI has resulted in substantial cost savings. corrosion poses a significant threat in chemical process industries (CPI), and RBI is employed to mitigate these risks. The process

categorizes risks as low, medium, and high, allowing for prioritization and continuous monitoring. RBI allows for concentrated inspection resources, rationalization of inspections, and improved inspection quality. Additionally, it provides valuable data for degradation prediction, enhancing inspection rationalization and prediction models (Yang et al. 2023).

Human involvement significantly influences the success of RBI implementation. Minimizing human errors during inspection and maintenance is critical for optimal plant performance. Factors such as training, working conditions, and fatigue must be considered to prevent incidents. The integrated systemic model highlights the importance of quantifying the probability of human error in risk assessments. The exploration of Risk-Based Inspection (RBI) for power plants in this literature review delves into its objectives, optimal practices, advantages, relevant standards, and specific methodologies, (Heo et al. 2013) such as API and RIMAP.

RBI prioritizes equipment based on failure rates, taking into account degradation mechanisms, consequence of failure (CoF), and probability of failure (PoF). The primary goal is to optimize inspections rather than solely focusing on cost reduction. Large-scale assessments rely on software, and confidence measures play a crucial role in ensuring the reliability of the RBI system. Additionally, the article emphasizes the financial benefits of Probabilistic Risk Assessment (PRA) in nuclear power plants.

Applicable standards, such as API and RIMAP, cater to different industries. API's approach involves PoF, CoF, and inspection planning, while API 510 standards delineate inspection intervals for various equipment. API 581 evaluates component failure probability and factors influencing inspection effectiveness. The RIMAP process encompasses initial planning, data collection, risk evaluation, decision-making, execution reporting, and performance evaluation, aiming to optimize maintenance programs through risk assessments and continuous improvement (Bertola et al. 2023).

5. Results of the Study

Figure 1: Perceptions regarding the benefit of RBIM in SA (Source: Author)

The study revealed a high trust and confidence in the potential of RBIM and its ability of RBIM, when implemented, to produce great benefits for the SA power industry (fig.1) The highest percentage of confidence is seen in the ability of RBIM's potential to increase reliability, effectiveness, profitability and cost-effectiveness.

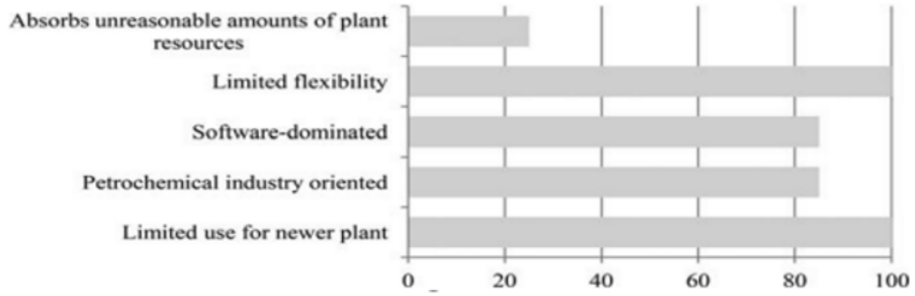

Figure 2: Perceptions regarding potential difficulties expected when implementing RBIM (Source: Author)

Regarding the potential difficulty when implementing RBIM, it is apparent that most organizations and experts believe that implementing RBIM will result in Limited flexibility and limited use for newer plants. There is a common fear that RBIM will be software-dominated, especially in petrochemical industry plants.

A benchmark of global RBI revealed the extent of implementation of RBI globally compared to the implementation and benefits in the South African power, petrochemical, steel, and rail industries. It is apparent that the South African power industry is still lagging behind in several key performance areas. The results presented below pertain to the power industry in South Africa and the global power generation industry. The key performance indicators applied in the comparison relate to profitability, effective operations, risk level, inspection interval, legal compliance, and societal expectations.

Table 2. Comparison of Benefits for Implementing RBI

Comparison of perceived benefits of implementing RBI approach by organizations in SA and Global			
Benefit Group	Benefit	Global Companies	SA Companies
Profitability	Decrease in the number of failures occurrences.	A	N/A
	Reduction in direct inspection cost.	A	N/A
	Fewer inspections.	A	N/A
	Ensure equipment longevity.	A	N/A
Effective Operations	Increase in plant availability.	A	N/A
	Elude unnecessary outages or system downtime.	A	N/A
	Minimum duration of shutdowns.	A	N/A
	Enhances understanding of integrity.		
	Enables to make informed decisions.	A	A
	Achieve operational excellence.		
	Increase the effectiveness of the inspection.	A	A
		A	N/A
		A	A
Risk Level	Reduction in the level of risk.	A	A
	More precise assessment.	A	A
	Understanding of concepts.	A	A
Inspection Interval	Tolerable inspection interval.	A	N/A
	Attain an optimum schedule.	N/A	N/A

Societal Expectation	Fulfil societal expectations	A	N/A
Legal Compliance	Maintain licensing permits. Avoid shutdown due to regulatory non-compliance.	A A	A A

Legend: A - Attainable
N/A – Not Attainable

The South African power generation industry lags regarding the following key performance indicators Inspection, interval, effective operations, societal expectations, and profitability. It was quite surprising to discover that the South African power generation industry is competitively at a similar level as the global power generation industry with respect to legal compliance and Risk level.

5. Conclusion and Recommendations

The study concludes by emphasizing the critical role of Risk-Based Inspection and Maintenance in enhancing the safety, reliability, and cost-effectiveness of power generation plants. While successful implementation offers numerous advantages, challenges such as management commitment, complex methodologies, and human factors must be addressed for continued success. Continuous monitoring and improvement are essential in the face of unexpected failures. A review of the perceived benefits reported by global organizations has been presented, followed by a discussion of results from a survey performed on South African organizations implementing the RBI approach.
However, the survey revealed that most of the benefits reported were short-term in nature. Benefits reported for global organizations are longer term when compared to the South African organizations. In the authors' opinion, the long-term benefits have not yet been realized among South African organizations because RBI implementation has not taken place in South African industries. Further improvements are necessary to enhance South African industries' skills and knowledge in RBI.

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