Risk-Based Inspection in Offshore Structures: A Systematic Approach

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Abstract. The Risk-Based Inspection (RBI) is a component of the whole asset integrity management. The RBI procedures grant a reasonable base for inspection of projects and efficient tools to support the operation. This study aims to overview the performance aspects of RBI from the perspective of offshore structures. Therefore, a structured review study was adopted to get an idea about the extent of the industry's achievement in this domain. Using Scopus database and specific designed keywords combination, a total of 80 papers were downloaded, out of which 26 papers were finalized for in-depth analyses. The review revealed fatigue inspection, RBI procedural improvements, pipelines, corrosion management, and offshore structures as most frequent areas being focused on the sorted articles. It was concluded that in reference to RBI methods and procedures, the oil and gas industry is up to date with advanced modification as a strong bond has been observed between industry and academia.

Keywords: Inspection · Maintenance · Risk Assessment · Oil and Gas · Safety

1 Introduction

Risk-based Inspection (RBI) proves to be a feasible strategy for applying an assessment process that delivers to maintenance actors to assess the probability of risk level, the effect of failure, and actions leading to risk management of structures [1]. There are various ways to implement RBI procedures, leading to cost-effective measures, which offer encouraging advancements to change structures maintenance management from a reactive to a proactive sphere [2]. For the last few years, implementing the RBI methodology for risk assessment in the offshore oil and gas structures has been up-to-date and advanced as it has been found to apply efficient risk measures effectively. The RBI procedures provide outcomes with foreseeable, extra authentic, safe systems with more economical standards for scrutiny and safeguarding activities. In addition, RBI procedures enhance the learning prospects of the pipeline's system integrity [3]. Whereas RBI strategy demands a comprehensive examination of the pipeline, the degradation means

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other than inspection-based performances, which facilitates identifying the highly risked and weak areas in the pipeline system. The proper application of RBI procedures significantly improves safety compared to traditional code-based inspection techniques. The RBI methodology is useful in the risk assessment of large-scale oil and gas structures for ascertaining the tolerable risk and core inspection period [4].

Many oil and gas structures related to renewable energy platforms and production facilities have been positioned under extreme operating circumstances in the marine environment, consisting of low visibility, strong currents, large wave heights, high wind speed, and various other known and unknown factors. Such scenarios speed up the usual material degradation rate. In return, these aforementioned facts shorten the structural failure time, which may cause serious environmental damage, huge financial consequences, and in the worst-case, loss of human life [5]. In the 1970s, probabilistic risk analysis techniques were applied for the first time in the nuclear industry. In contrast, the first overview document on RBI principles was issued by “American Society of Mechanical Engineers” (ASME) [6]. Following this, in the 1990s, the “American Bureau of Shipping” (ABS), “Det Norske Veritas” (DNV), and “American Petroleum Institute” (API), designed RBI software and methodology, which have been improved over time in a fast pace till date [7]. However, RBI was proved to be an exceptional procedure that improves the perception of integrity management for oil and gas subsea pipelines. Still, the procedures have observed weaknesses, such as findings, statistics, and inaccurate computations, which may cause disastrous outcomes by failing the operations. Therefore, to overcome these limitations, an extended RBI technique has been introduced. The basic theory behind the extended method is to transfer the uncertainties to the administration by adopting an extensive improbability computation which combines the results from the uncertainty investigation and risk analysis [3].

In the environment of process industries, the purpose of risk assessment techniques is to predict probable scenarios leading to accidents and execute suitable safety procedures and mitigation strategies to prevent such incidents [8]. Several terminologies have been devised to signify such operations and safety devices, i.e., ‘layer of protection’, ‘countermeasure’, and the most popular term is ‘safety barrier’ [9]. The significance of examining the performance of safety barriers is continually growing. Technical barrier elements may face fatigue-induced collapse or failures due to degradation over time. Considering these unstable performance characteristics, there is a need for frequent inspections and testing. Likewise, organizational and operational barrier components’ competence and performance may vary with time; therefore, requirements must be validated according to the defined regulations [10]. With the advancement of Internet of Thing (IoT) and sensing technologies, the oil and gas industry in moving toward real-time RBI analysis in which the inspection plans can be updated promptly when any changes occur. A structured review study has been performed to overview the implementation of RBI processes and procedures, impacts, and scope [5]. This study helps to assess the performance level and achievement of RBI attained in the offshore structures related to the oil and gas industry.

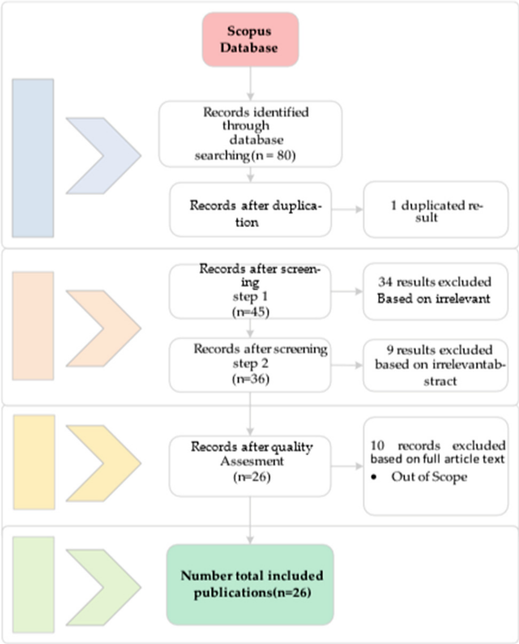

Fig. 1. PRISMA Research Flowchart

2 Methodology

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), a systematic review technique suggested by various researchers for review purposes has been followed in this study [11, 12]. PRISMA statement follows the identification, screening, quality assessment and inclusion steps that have been incorporated while extracting the relevant articles to review, the details of which are provided in Fig. 1.

2.1 Identification Criteria

To assess the initial articles on the selected title, the following keywords ("Risk Based Inspection" AND "OFFSHORE") were used in the Scopus database, which showed 80 articles, comprised of research articles and conference papers. The 80 articles were gathered by applying the 10 years of limitations, along with the "Engineering" subject area and "English" language articles limitations.

2.2 Screening Criteria

Upon getting 80 articles, initial screening based on titles and abstracts were performed which reduced the articles firstly to 45 numbers and then the number was reduced to 36 articles. The title and abstract screening help to eliminate 34 and then 9 articles.

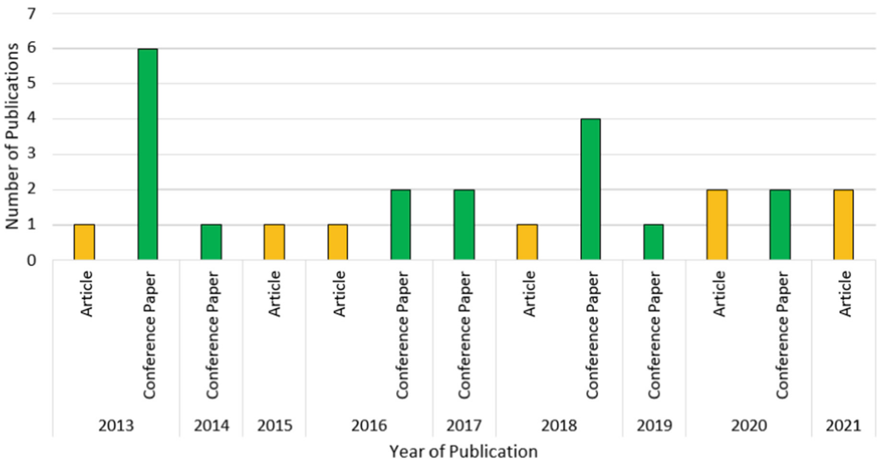

Fig. 2. Summary of Final Extracted Articles.

2.3 Quality Assessment and Inclusion Criteria

The third step which is quality assessment criteria was followed where the full-text reading of the remaining articles was performed which provided the 26 articles for final assessment to review. Here, 10 articles were eliminated based on the type of scope. The details of the remaining articles to review are presented in Fig. 2. It can be seen that with time a slight increase has been observed for the number of journals-based studies in this domain.

3 Results and Discussion

Overall, 26 articles were finalized for review and evaluation to assess the role and impacts of RBI in offshore structures part of the oil and gas industry. Table 1 illustrates the summary of the collected study for their focused area, published year and related information.

It can be observed from Table 1 that researchers have been working on RBI processes focusing on various aspects, parameters, and areas related to offshore structures. The selected can be divided into the following broad categories based on focused topics: 1) fatigue inspection, 2) RBI procedural improvement, 3) pipelines, 4) corrosion, and 5) offshore structures.

Literature defines fatigue deterioration as a phenomenon that impacts the loss of structural integrity in the form of propagation and cracks. Fatigue is a regular occurrence under cyclic loading for welded structural systems, such as offshore structures and ships. Cracks normally originate at welded details containing initial flaws or local stress concentration areas and then spread swiftly under continuous stress cycles. Zou, et al. [14] proposed the RBI approach to attain a complete decision-making framework to counter maintenance, inspection, and uncertainties related to fatigue-sensitive components. This methodology benefited operational maintenance, structural scantling, and

Table 1. Year of Publications and Focused Area.

S. No	Focused Area	Year	Authors	Cited by
1	Safety barriers	2021	Hosseinnia Davatgar, et al. [8]	3
2	RBI process (integrity management)	2021	Hameed, et al. [3]	2
3	Qualitative RBI (QRBI) process	2020	Eskandarzade, et al. [13]	0
4	Fatigue inspection	2020	Zou, et al. [14]	1
5	RBI planning inspection	2020	Ozguc [15]	3
6	RBI process (review)	2020	Shafiee and Soares [5]	0
7	Magnetic tomography method	2019	Kamaeva, et al. [16]	2
8	Vibration-induced fatigue	2018	Crowther and Loneragan [17]	0
9	Corrosion management program	2018	Mohamed, et al. [18]	0
10	Small diameter piping	2018	Ferdous, et al. [19]	0
11	Flexible pipes	2018	Hameed, et al. [19]	0
12	Microbiologically influenced corrosion	2018	Singh and Pokhrel [20]	19
13	Fatigue inspection	2017	Faber [21]	9
14	RBI planning inspection	2017	Agusta, et al. [22]	10
15	Static mechanical equipment	2016	Ayele and Barabadi [23]	8
16	RBI process	2016	Kamsu-Foguem [2]	19
17	FLNG Hull	2016	Ilahi, et al. [24]	1
18	Membership functions (MFs)	2015	Ratnayake [25]	6
19	Jacket platform structure	2014	Wang, et al. [26]	0
20	Wind turbines	2013	Guédé, et al. [27]	1
21	Aged offshore pipelines	2013	Stadie-Frohbös and Lampe [28]	7
22	RBI process (review)	2013	Goyet, et al. [29]	13
23	RBI dynamic inspection	2013	Cong, et al. [30]	1
24	RBI process	2013	Daniel, et al. [31]	0
25	FPSO	2013	Altmann and Nezamian [32]	6
26	Fatigue inspection	2013	Lassen [33]	13

risk mitigation to reduce life cycle costs and optimum resource utilization. Crowther and Loneragan [17] discussed the vibration-induced fatigue that may cause the failure of more than 20% of the piping system. The study reflects on the guideline, i.e., Energy Institute's "Guideline for the Avoidance of Vibration Induced Fatigue Failure in Process Piping" and explains its practical implementation. Moreover, a productive screening process in combination with innovative vibration data management has been explained, strengthening operators all over the facility lifecycle and lowering the costs for integrity teams. Faber [21] proposed a primarily conceptual model assessing key advances in risk identified offshore structures for structural integrity management by highlighting advantages and challenges linked with this. In comparison, Lassen [33] discussed RBI planning calculations and procedures for fatigue-based cracks in welded steel structures.

Various studies overview and examine the RBI related processes. As already discussed, RBI is equated to Asset Integrity Management (AIM). The RBI procedures effective practical inspection plans and tools to assist them. Hameed, et al. [3] suggested the enhanced RBI procedures for pipeline systems to verify the related integrity management and focused on flexible and steel pipelines. Zou, et al. [14] discussed the evolution of the Qualitative RBI (QRBI) method along with related trends in mechanization. Moreover, "Gray Relational Analysis (GRA)" method and GRA applications in mechanizing the QRBI process were discussed. Ozguc [15] attempted to fix the step-by-step inspection procedure for RBI planning and discussed various guidelines to maintain and prepare RBI activity. However, Kamsu-Foguem [2] incorporated maintenance and inspection of delicate facilities related to production systems. The suggested methodology could enhance the maintenance management strategies for related RBI procedures and facilities. On the other hand, studies performed by Ferdous, et al. [19], Hameed, et al. [19], and Stadie-Frohbös and Lampe [28] covered the application and implementation RBI process for small diameter piping, flexible pipes, and aged offshore pipelines, respectively.

Various elements used on offshore and onshore gas systems are exposed to degrading mechanisms such as erosion and corrosion. As a result, the systems may lose their structural integrity with period and causing in ruptures, bursts, and leakages. Such losses cause financial impacts, affect the production process, and, most importantly, cause hazards to health, safety, and the environment. Singh and Pokhrel [20] proposed a fuzzy logic framework with a methodology for carbon steel pressure vessels, static equipment, and pipes for assessing the rate of "microbiologically influenced corrosion". Moreover, procedures were suggested for estimating the probable failure necessity, possibility, and optimum inspection time. Likewise, Mohamed, et al. [18] executed the corrosion management program for "PETRONAS Floating Liquefied Natural Gas Satu" and delivered corrosion monitoring and mitigation recommendations for some related mechanisms using software named CARAT. Researchers also covered RBI procedures considering various offshore and onshore oil and gas industry related structures, such as Ilahi, et al. [24] discussed the FLNG Hull by following the systematic maintenance methodology for structural integrity. On the other hand, Wang, et al. [26] a thorough RBI procedure for in-service jacket platform structure. Guédé, et al. [27] developed a RBI framework for planning for wind turbines. Altmann and Nezamian [32] discussed "Floating structures for production, storage and offtake (FPSO)" and presented procedures related to survey plans and determined inspection in the combination of industry expertise and RBI analysis. Literature also revealed that various researchers have also worked on other related areas and parameters to RBI about the oil and gas sector and associated structures. Hosseinnia Davatgar, et al. [8] highlighted the safety barriers to RBI, as they are crucial aspects leading to accident situations and decreasing the occurrence of undesirable incidents. Kamaeva,et al. [16] discussed the "magnetic tomography method" that allows the remote identification of areas of irregularities with metal flaws but also indicates mechanical stress levels in reference to factual loads.

Overall, this structured literature review has given insight into the aspects and procedures being adopted and related to RBI methodology. The oil and gas sector are advancing quickly and is a highly important sector for oil- producing countries. The aforementioned fact can be observed by the sudden updating of related procedures with time. Also, the industry's involvement with academia in these related matters is proving beneficial in this progress, which is a very positive image. Therefore, RBI methods are effective and updated based on the activity type and need, as strong bonds have been observed between industry and academia in this domain. This study suggests devising RBI-based guidelines for each identified domain, i.e., fatigue inspection, RBI procedural improvement, pipelines, corrosion, and offshore structures.

4 Conclusion

This study presents an overview of RBI of offshore structures by following a structured literature review PRISMA methodology. Related articles were collected from the Scopus database using relevant keywords, and 26 articles were sorted for in detail analysis. Five major areas were identified on which researchers are focusing for RBI procedures, i.e., fatigue inspection, RBI procedures improvement, pipelines, corrosion, and random offshore structures. However, it has been concluded that RBI methods are effective and updated based on the activity type and need. Moreover, the research community is effectively active in responding to the issues and overcoming discrepancies related to RBI procedures for the oil and gas sector.

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References

1. Bai Y, Bai Q. Risk-Based Inspection. In: Bai Y, Bai QBT-SPI and RM, editors. Subsea Pipeline Integrity and Risk Management [Internet]. Boston: Elsevier; p. 213–32(2014).
2. Kamsu-Foguem B. Information structuring and risk-based inspection for the marine oil pipelines. Appl Ocean Res [Internet]. :132–42 (2016 Mar);
3. Hameed H, Bai Y, Ali L. A risk-based inspection planning methodology for integrity management of subsea oil and gas pipelines. Ships Offshore Struct [Internet]. :687–99 (2021 Aug 9);
4. Shuai J, Han K, Xu X. Risk-based inspection for large-scale crude oil tanks. J Loss Prev Process Ind. :166– 75 (2012);
5. Shafiee M, Soares CG. New advances and developments in risk-based inspection (RBI) of marine structures. 30th Eur Saf Reliab Conf ESREL 2020 15th Probabilistic Saf Assess Manag Conf PSAM 2020. :4485–92 (2020);

6. Selvik JT, Scarf P, Aven T. An extended methodology for risk based inspection planning. Reliab Theory Appl. :115–26 (2011);
7. Inspection R-B. Development of guidelines (Vol. 1 general document). CRTD-Vol. 20–1. Am Soc Mech Eng New York. (1991);
8. Hosseinnia Davatgar B, Paltrinieri N, Bubbico R. Safety Barrier Management: Risk-Based Approach for the Oil and Gas Sector. J Mar Sci Eng [Internet]. :722 (2021 Jun 30);
9. Paltrinieri N, Haskins C. 7. Dynamic security assessment: benefits and limitations. In: Security Risk Assessment. De Gruyter; p. 131–41(2017).
10. Petroleum Safety Authority Norway. Principles for barrier management in the petroleum industry.:34(2013);
11. Rahim AAA, Musa SN, Ramesh S, Lim MK. A systematic review on material selection methods. Proc Inst Mech Eng Part L J Mater Des Appl. :1032–59 (2020);
12. Sidani A, Dinis FM, Sanhudo L, Duarte J, Santos Baptista J, Pocas Martins J, et al. Recent tools and techniques of BIM-based virtual reality: A systematic review. Arch Comput Methods Eng. :449–62 (2021);
13. Eskandarzade M, Chandima Ratnayake RM, Najafi Ershadi M. Mechanization of Qualitative Risk Based Inspection Analysis. In: 2020 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM) [Internet]. IEEE; p. 401–6(2020).
14. Zou G, Faber MH, González A, Banisoleiman K. A holistic approach to risk-based decision on inspection and design of fatigue-sensitive structures. Eng Struct [Internet]. :110949 (2020 Oct);
15. Ozguc O. A new risk-based inspection methodology for offshore floating structures. J Mar Eng Technol [Internet]. :40–55 (2020 Jan 2);
16. Kamaeva SS, Kolesnikov IS, Eremin NA, Khusnutdinov LA. Remote inspection by the magnetic tomography method (MTM) to prevent the risks imposed by exploitation of Arctic offshore pipelines. IOP Conf Ser Mater Sci Eng [Internet]. :012051(2019 Nov 1);
17. Crowther P, Loneragan B. Integrating an RBI Approach for Vibration-Induced Fatigue into a Mechanical Integrity Programme. In: Day 3 Thu, March 22, 2018 [Internet]. OTC; (2018).
18. Mohamed NA, Mahani Z, Razak LAA. Approach to Corrosion Management Program and Risk Based Inspection Development for the World's First Floating LNG. In: Day 1 Tue, March 20, 2018 [Internet]. OTC; p. 1–12(2018).
19. Ferdous CMR, Kulhawy A, Farrell J, Beaudin C, Payoe A, Li L. Risk Assessment for Small Diameter Piping for Liquid Pipeline Facilities. In: Volume 2: Pipeline Safety Management Systems; Project Management, Design, Construction, and Environmental Issues; Strain Based Design; Risk and Reliability; Northern Offshore and Production Pipelines [Internet]. American Society of Mechanical Engineers; p. 1–7(2018).
20. Singh M, Pokhrel M. A Fuzzy logic-possibilistic methodology for risk-based inspection (RBI) planning of oil and gas piping subjected to microbiologically influenced corrosion (MIC). Int J Press Vessel Pip [Internet].:45–54 (2018 Jan);
21. Faber MH. Risk Informed Structural Systems Integrity Management: A Decision Analytical Perspective. In: Volume 9: Offshore Geotechnics; Torgeir Moan Honoring Symposium [Internet]. American Society of Mechanical Engineers; p. 1–8(2017).
22. Agusta A, Thons S, Leira BJ. Value of information-based inspection planning for offshore structures. In: Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE. p. 1– 8(2017).
23. Ayele YZ, Barabadi A. Risk based inspection of offshore topsides static mechanical equipment in Arctic conditions. In: 2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM) [Internet]. IEEE; p. 501–6(2016).
24. Ilahi M, Kar S, Mukherjee K, Ayob MSB. Risk Based Integrity Management System for FLNG Hull Structure. In: Day 3 Thu, March 24, 2016 [Internet]. OTC; p. 1–16(2016).

25. Chandima Ratnayake RM. Estimation of maximum in-service inspection intervals based on risk: A fuzzy logic based approach. Int J Performability Eng. :23–32 (2015);
26. Wang YT, Ren HL, Yu JJ, Cui BB. Risk-Based Inspection Analysis of Jacket Platform. Appl Mech Mater [Internet]. :18–27 (2014 Aug);
27. Guédé Z, Bigourdan B, Rouhan A, Goyet J, Renard P. Framework for Risk-Based Inspection of an Offshore Wind Farm. In: Volume 2B: Structures, Safety and Reliability [Internet]. American Society of Mechanical Engineers; p. 1–8(2013).
28. Stadie-Frohbös G, Lampe J. Risk Based Inspection for Aged Offshore Pipelines. In: Volume 2B: Structures, Safety and Reliability [Internet]. American Society of Mechanical Engineers; p. 1–10(2013).
29. Goyet J, Boutillier V, Rouhan A. Risk based inspection for offshore structures. Ships Offshore Struct [Internet].:303–18 (2013 Jun);
30. Cong GP, Gao JJ, Hou B, Zhu J, Zhang BW. Study on the Dynamic Inspection for Decreasing the Losses and Costs Caused by Accidents of Fixed Equipment in Petrochemical Plants. Adv Mater Res [Internet].:1511–25 (2013 Dec);
31. Daniel G, Silva M, Junior JSP, Barros M, Krzonkalla VC de S, Costa V, et al. Risk Based in Inspection Applied to a Semi-Submersible Platform. In: All Days [Internet]. OTC; p. 1593–8(2013).
32. Altmann J, Nezamian A. Optimized Structural Integrity Management System and Inspection Program for a Converted FPSO. In: All Days [Internet]. OTC; p. 660–72 (2013).
33. Lassen T. Risk based Fatigue Inspection Planning – State of the Art. Procedia Eng [Internet].: 489–99 (2013);