*Hadi Ahmadi Vafa*[1,2], *Rasoul Ahmadpour-Geshlagi*[3], *Saeid Mousavi*[4], *Sorena Heidarpour Tabrizi*[5], *Seyed Shamseddin Alizadeh*[*6]

# ASSET INTEGRITY INDICATORS IN HSE MANAGEMENT: A SYSTEMATIC REVIEW

# POKAZATELJI INTEGRITETA OPREME U UPRAVLJANJU HSE: SISTEMATSKI PREGLED

Pregledni rad / Review paper
Rad primljen / Paper received: 22.01.2024
https://doi.org/10.69644/ivk-2025-02-0291

Adresa autora / Author's address:
[1)] Department of Health, Safety and Environmental Management (HSE), School of Public Health, Tabriz University of Medical Science, Tabriz, Iran
H.A. Vafa https://orcid.org/0000-0001-8599-5737
[2)] Health and Environment Research Center, Tabriz University of Medical Sciences, Tabriz, Iran
[3)] Department of Occupational Health Engineering, Health Faculty, Tabriz University of Medical Sciences, Tabriz, Iran
R. Ahmadpour-Geshlagi https://orcid.org/0000-0001-9540-438X
[4)] Department of Statistics and Epidemiology, School of Public Health, Tabriz University of Medical Sciences, Tabriz, Iran
S. Mousavi https://orcid.org/0000-0001-7424-5770
[5)] East Azerbaijan Province Gas Company, Planning Affairs, Maintenance Planning Office
[6)] Associate Professor, Department of Occupational Health Engineering, Health Faculty, Tabriz University of Medical Sciences, Tabriz, Iran [*]email: ss.alizadeh2013@gmail.com
S.S. Alizadeh https://orcid.org/0000-0002-9640-985X

**Keywords**
- asset integrity management
- critical asset
- asset integrity
- safety
- HSE

**Ključne reči**
- upravljanje integritetom opreme
- kritična oprema
- integritet opreme
- bezbednost
- HSE

*Abstract*

*Asset integrity is crucial for the safe and reliable operation of industrial facilities, avoiding accidents, equipment issues, and unexpected stops with financial and safety impacts. There is limited research on asset integrity, and a comprehensive investigation of asset integrity indicators is lacking. The study aims to analyse literature and find indicators of asset integrity for decision-making at different levels, ensuring optimal asset use and maintenance. A selection process is done on scholarly articles from 2000 to 2023, taken from databases like Web of Science, PubMed, and Scopus. Nineteen articles are chosen after examining their abstracts and complete texts. These selected articles underwent a thorough review process to extract indicators of asset integrity. Through a detailed analysis of the 19 articles in this study, we identify 68 distinctive indicators associated with asset integrity. These indicators provide insights into various factors that impact asset condition and well-being. Notably, three indicators 'reliability', 'environmental effects' and 'preventive and corrective maintenance' are most frequent. This finding highlights the importance of these indicators in the realm of asset integrity. With time and industrialisation, organisations are more focused on protecting their assets. Hence, it is important to recognise and prioritise the results from indicators while maintaining asset integrity.*

*Izvod*

*Integritet opreme je bitan za bezbedan i pouzdan rad industrijskih postrojenja, izbegavajući nesreće, probleme sa opremom i neočekivanim prekidima sa finansijskim i bezbednosnim posledicama. Postoje ograničena istraživanja o integritetu opreme, ali nedostaje sveobuhvatno istraživanje indikatora integriteta opreme. Cilj ovog rada je analiza literature i iznalaženje indikatora integriteta opreme za donošenje odluka na različitim nivoima, obezbeđujući optimalno korišćenje i održavanje imovine. Obavljena je selekcija naučnih članaka od 2000. do 2023, preuzetih iz baza podataka kao što su Web of Science, PubMed i Scopus. Nakon pregleda njihovih izvoda i kompletnih tekstova izabrano je 19 članaka. Ovi odabrani članci su prošli proces temeljne recenzije kako bi se izdvojili indikatori integriteta opreme. Detaljnom analizom 19 članaka u ovom radu, identifikovali smo 68 karakterističnih indikatora povezanih sa integritetom opreme. Ovi indikatori pružaju uvid u različite faktore koji utiču na stanje opreme i na bezbednost. Najčešća su tri indikatora „pouzdanost", „uticaji na životnu sredinu" i „preventivno i korektivno održavanje". Rezultati naglašavaju važnost ovih indikatora u domenu integriteta opreme. Tokom vremena uz industrijalizaciju, organizacije se sve više fokusiraju na zaštitu svoje opreme. Stoga je važno prepoznati i dati prioritet rezultatima indikatora uz očuvanje integriteta imovine.*

## INTRODUCTION

With the passage of time and industrialisation, more than ever, and the occurrence of calamities, such as the detonation that transpired in 1988 at the Piper Alpha oil platform located in the North Sea, approximately 120 miles northeast of Aberdeen, Scotland, whereby a significant volume of gas condensate was inadvertently released, followed by a series of consequential circumstances. Consequently, a total of 167 individuals tragically perished as a result of this particular occurrence. They seek to improve their organisational performance and manage their assets. The creation of the PAS 55 document in 2004 marked a response to incidents and the growing aspiration of organisations to effectively manage assets, enhance their efficiency, and promote safety and environmental performance. Serving as the inaugural official document on asset management practices, the PAS 55 framework encompassed a comprehensive set of tools aimed at optimising business processes to ensure heightened integrity and performance. This document garnered widespread ac-

ceptance and was made available to the professional community through extensive global consultation processes. In the sphere of asset management, the year 2014 witnessed publication of ISO 55000 standard series, built upon the PAS 55 document. A study conducted by Al Youssef and colleagues delved into the ramifications of implementing asset management on organisational performance, ultimately corroborating its efficacy /1, 2/.

Ossai et al. have expressed that the management of asset integrity (AIM) plays a vital and central role in the functioning of renewable energy generation facilities. This is primarily owing to its capacity to effectively tackle issues such as prolonged periods of inactivity, reduced energy output, and escalated costs linked to maintenance and reparations /3/.

In their study, while emphasising the integrity of assets, Shahri et al. /4/ invented a method to determine critical assets. They conducted the criticality of assets in a gas refinery using the proposed integrated approach of Analytical Hierarchy Process (AHP) and Fuzzy Inference System (FIS). They concluded that this approach is efficient and effective in determining the integrity of assets and their criticality.

In 2019, in their study, Sheikhalishahi et al. /2/, considering the importance of asset integrity, using asset integrity criteria, used the integrated approach of the analytic network process and data envelopment analysis to evaluate and optimise the performance of the petrochemical plant. They classified asset integrity criteria into three levels and used ANP to calculate the relative importance of the second level criteria and then used a DEA model to measure the efficiency of decision-making units. They concluded that the proposed approach improves overall performance and reduces operational losses.

Lima et al. in 2019 /5/, during their study regarding the importance of assets and their management, presented the Regulation-Oriented Model for asset management (AM-RoM) with the aim of increasing the efficiency and effectiveness of assets, which ISO 31000:2018 and ISO 55001: 2014 combined to rank the most critical requirements for compliance with the regulatory framework of multi-asset organisations. This model was implemented in a Brazilian company and the results of AM-RoM validation in the Brazilian company showed its relevance in inducing improvement and increasing the level of maturity of the asset management process while complying with the regulatory framework.

No research has been conducted globally to collect asset integrity indicators, as stated in the aforementioned studies. Considering the importance of assets in all organisations, our aim in this study is to systematically examine assets management and asset integrity to extract indicators in the articles. Because by using these indicators in all stages of design, production, purchase construction, operation and maintenance, and throughout the life of the equipment, we can have a proper view of the condition of our assets and be sure of their efficiency and effectiveness towards the purpose for which they are designed.

The concept of asset integrity has undergone a transformation over the course of time in order to effectively address numerous challenges associated with the maintenance of industrial assets and their ability to consistently perform and ensure safety throughout their entire lifespan. Asset integrity, in essence, pertains to the capacity of an asset to carry out its intended function in a manner that is both efficient and secure during the entirety of its existence. This entails the establishment of protocols that guarantee assets are designed, operated, and maintained in a manner that minimises the potential for failure, adheres to established regulations and standards, as well as maximises their overall lifespan. The management of asset integrity plays an incredibly pivotal role, particularly within industries such as oil, gas, and petrochemicals, where the failure of critical assets can have dire consequences in terms of safety, environmental ramifications, as well as financial losses. It is comprised of a plethora of activities that include but are not limited to risk assessment, inspection, maintenance, and continuous monitoring, all of which are undertaken to identify and mitigate potential risks that may arise, thus ensuring the sustained integrity of the assets /6, 7/.

## METHOD

A systematic review allows us to examine and integrate past studies to address gaps that exist on a specific topic. In this study, we are trying to find indicators of asset integrity by reviewing articles in the field of asset integrity in safety and HSE management. The Web of Science, PubMed and Scopus databases are used to search for articles from 2000 to 2023 to conduct a systematic review. Table 1 provides search strategies for the articles.

The inclusion and exclusion criteria are as follows.

The inclusion criteria included:

- an article related to asset integrity,
- an article related to asset integrity management,
- an article related to maintenance.

The exclusion criteria included:

- review articles and books,
- conferences and letters to editors,
- an asset integrity in economic field.

Initial evaluation of articles is conducted by examining the titles and abstracts. Subsequently, the articles that pertained to asset integrity are further assessed through a comprehensive analysis of their full texts. As a considerable number of the articles were not relevant to our specific subject matter and predominantly originated from the economic discipline, they were excluded from our study. The evaluation process was carried out independently by two individuals. The finalisation of findings was achieved subsequent to a thorough review.

Using search methodologies outlined in the method section, we conducted database searches and identified a total of 455, 2507, and 4325 articles in PubMed, Scopus, and Web of Science, in respect. After eliminating duplicate entries, we were left with a combined total of 6,838 articles. In terms of distribution PubMed accounted for 6.64 %, Scopus had 35.48 %, and Web of Science had 57.88 % of articles. Subsequently, we commenced the process of examining the titles of these articles. We eliminated those unrelated and grouped the relevant ones together based on their titles. By

removing articles at this stage, a total of 6461 articles were excluded, leaving us with 377 articles for abstract review. Following this abstract review, we identified 52 articles that warranted a full text review. Out of these, 22 are conference articles that were subsequently removed from consideration. Additionally, 4 articles are books, and 2 articles could not be accessed due to the unavailability of their text. Furthermore, 5 articles are deemed irrelevant and are subsequently excluded from the review process. As a result, 19 articles remained for full text review (Fig. 1).

Table 1. Search strategy, database, search year and results.

| Search strategy | Data base | Search years | Results |
|---|---|---|---|
| ("accident*"[All Fields] OR "insurance, accident"[All Fields] OR "accident proneness"[All Fields] OR "accidental injuries"[All Fields]) ((safety[All Fields]) OR (safety management[All Fields])) OR (Equipment Safety[All Fields]) ("HSE") OR ("health, safety and environmental management") OR ((incident*) OR (near miss*)) OR (close call*)AND "asset integrity"[All Fields] OR "asset management"[All Fields] OR "Asset integrity management"[All Fields] OR "Critical asset*" OR "critical equipment*" OR "critical faciliti*" AND (2000:2023[pdat]) | PubMed | 2000-2023 | 455 |
| ((((((((((((((((((TS=("accident*")) OR TS=("insurance, accident")) OR TS=("accident proneness")) OR TS=("accidental injuries"))) OR TS=("safety")) OR TS=("safety management")) OR TS=("Equipment Safety")) OR TS=("HSE")) OR TS=("health, safety and environmental management")) OR TS=("incident*")) OR TS=("near miss*")) OR TS=("close call*")) AND TS=("asset integrity")) OR TS=("asset management")) OR TS=("Asset integrity management")) OR TS=("Critical asset*" )) OR TS=("critical equipment*" )) OR TS=("critical faciliti*" ) | Web of Science | 2000-2023 | 4325 |
| (TITLE-ABS-KEY (= "accident*") OR TITLE-ABS-KEY ( = "insurance, accident" ) OR TITLE-ABS-KEY ( = "accident proneness" ) OR TITLE-ABS-KEY ( = "accidental injuries" ) OR TITLE-ABS-KEY ( = "safety" ) OR TITLE-ABS-KEY ( = "safety management" ) OR TITLE-ABS-KEY ( = "Equipment Safety" ) OR TITLE-ABS-KEY ( = "HSE" ) OR TITLE-ABS-KEY ( = "health, safety and environmental management" ) OR TITLE-ABS-KEY ( = "incident*" ) OR TITLE-ABS-KEY ( = "near miss*" ) OR TITLE-ABS-KEY ( = "close call*" ) AND TITLE-ABS-KEY ( = "asset integrity" ) OR TITLE-ABS-KEY ( = "asset management" ) OR TITLE-ABS-KEY ( = "Asset integrity management" ) OR TITLE-ABS-KEY ( = "Critical asset*" ) OR TITLE-ABS-KEY ( = "critical equipment*" )) | Scopus | 2000-2023 | 2507 |

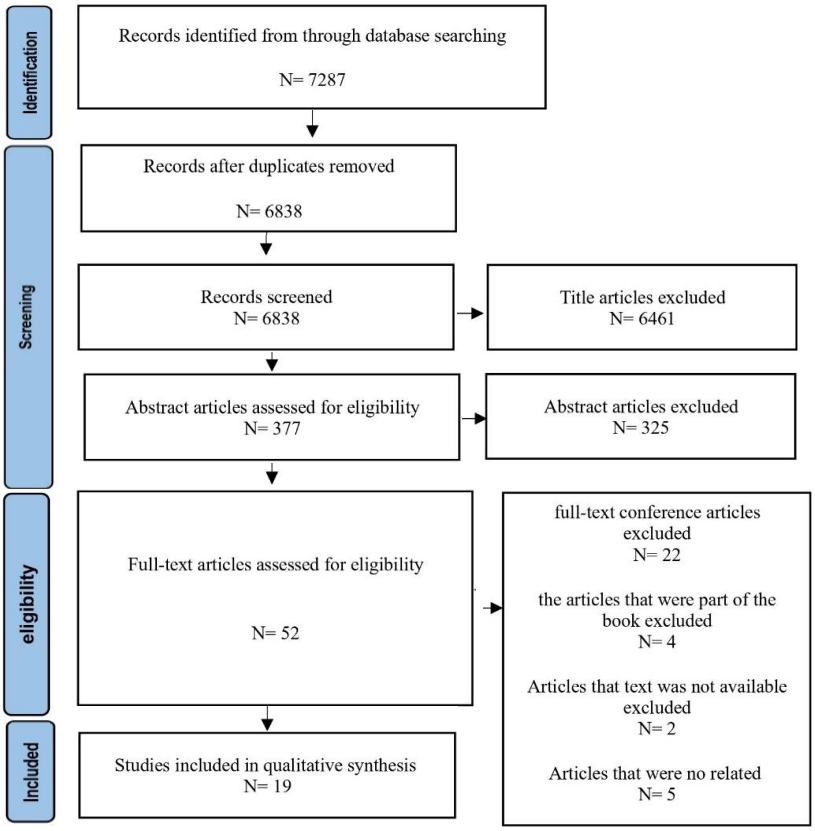


Figure 1. Flow chart of the systematic review and qualitative synthesis.

## RESULTS

By examining a total of 19 articles that are included in the investigation, a sum of 178 indicators are distinguished within the articles. Upon the elimination of duplicated indicators and the assimilation of similar ones, a collection of 68 distinct indicators is obtained.

As depicted in Table 2, it is ascertained that the indicator denoting 'reliability' is the most prevalent among aforementioned 68 indicators. This particular indicator is recurrently mentioned in 74 % of articles.

Moreover, the indicators pertaining to the 'effects on the environment' and 'maintenance practices for prevention and correction' are reiterated in 63 % of articles and hold the second position in terms of frequency. Additionally, indicators associated with 'availability,' 'plans for inspection,' and 'operational value of assets' have collectively secured third rank, each appearing 7 times and being cited in 36.84 % of articles.

Table 2. Indicators, frequency, percentage and references.

| No. | Indicators | Count | (%)* | References |
|---|---|---|---|---|
| 1 | Reliability | 14 | 7.865 | /3-16/ |
| 2 | Environmental effects | 12 | 6.742 | /2-4, 6-8, 10, 11, 14-17/ |
| 3 | Preventive and corrective maintenance | 12 | 6.742 | /3-7, 10-13, 15, 17, 18/ |
| 4 | Availability | 7 | 3.933 | /2, 4-8, 12/ |
| 5 | Inspection plans | 7 | 3.933 | /3, 4, 6, 7, 12-14/ |
| 6 | Operational value of the asset | 7 | 3.933 | /3, 6, 7, 9, 12, 17, 18/ |
| 7 | Quality | 6 | 3.371 | /2, 4, 6, 7, 9, 13/ |
| 8 | Investing in education | 6 | 3.371 | /2, 8, 10, 12, 15, 18/ |
| 9 | Stakeholders and their expectations | 5 | 2.809 | /3, 7, 9, 13, 17/ |
| 10 | Life cycle cost | 5 | 2.809 | /2, 5, 6, 16, 18/ |
| 11 | Sustainability or economic life of the asset | 4 | 2.247 | /3, 9, 12, 19/ |
| 12 | Inherent safety | 4 | 2.247 | /6, 8, 10, 14/ |
| 13 | Process safety | 4 | 2.247 | /10, 12-14/ |
| 14 | Management of change | 4 | 2.247 | /10, 12, 14, 15/ |
| 15 | useful life of the service | 4 | 2.247 | /3, 7, 12, 17/ |
| 16 | Availability of spare parts | 4 | 2.247 | /4, 6, 8, 14/ |
| 17 | Return on investment (ROI) | 3 | 1.685 | /1, 3, 15/ |
| 18 | Climatic factors | 3 | 1.685 | /3, 10, 19/ |
| 19 | Employee safety | 3 | 1.685 | /4, 7, 8/ |
| 20 | Expert force | 3 | 1.685 | /5, 7, 12/ |
| 21 | Rules and regulations | 2 | 1.124 | /2, 7/ |
| 22 | Accident rate | 2 | 1.124 | /2, 6/ |
| 23 | Incident rates | 2 | 1.124 | /2, 6/ |
| 24 | Improving the efficiency of the organisation | 2 | 1.124 | /1, 5/ |
| 25 | Reduce operating costs | 2 | 1.124 | /6, 9/ |
| 26 | Damage rate | 2 | 1.124 | /10, 15/ |
| 27 | Vibration | 2 | 1.124 | /6, 10/ |
| 28 | Production capacity | 2 | 1.124 | /4, 6/ |
| 29 | Community safety | 2 | 1.124 | /4, 7/ |
| 30 | Energy consumption | 2 | 1.124 | /3, 8/ |
| 31 | Greenhouse gas emissions | 2 | 1.124 | /3, 8/ |
| 32 | Support operations | 2 | 1.124 | /5, 18/ |
| 33 | Amount of waste | 2 | 1.124 | /8, 18/ |
| 34 | Optimum maintenance time | 1 | 0.562 | /2/ |
| 35 | Type of technology | 1 | 0.562 | /2/ |
| 36 | Training hours | 1 | 0.562 | /2/ |
| 37 | Effectiveness of training | 1 | 0.562 | /2/ |
| 38 | Uncertainty rate | 1 | 0.562 | /2/ |
| 39 | Improved output volume | 1 | 0.562 | /9/ |
| 40 | Cultural factors | 1 | 0.562 | /10/ |
| 41 | Mortality rate | 1 | 0.562 | /10/ |
| 42 | Frequency of fire and explosion | 1 | 0.562 | /10/ |
| 43 | Exposure to sound | 1 | 0.562 | /10/ |
| 44 | Ergonomic factors | 1 | 0.562 | /10/ |
| 45 | Exposure to mechanical hazards | 1 | 0.562 | /10/ |
| 46 | Exposure to electronic hazards | 1 | 0.562 | /10/ |
| 47 | Integrity of personnel | 1 | 0.562 | /10/ |
| 48 | Work arrangement | 1 | 0.562 | /10/ |
| 49 | Fatigue management | 1 | 0.562 | /10/ |
| 50 | Safety culture | 1 | 0.562 | /10/ |
| 51 | Permit to work | 1 | 0.562 | /10/ |
| 52 | Documentation | 1 | 0.562 | /10/ |
| 53 | Risk assessment | 1 | 0.562 | /10/ |
| 54 | Historical performance | 1 | 0.562 | /11/ |
| 55 | Effective record-keeping | 1 | 0.562 | /7/ |
| 56 | Inspection reports | 1 | 0.562 | /7/ |
| 57 | Accident reports | 1 | 0.562 | /7/ |
| 58 | Production losses | 1 | 0.562 | /5/ |
| 59 | Costs associated with operations | 1 | 0.562 | /12/ |
| 60 | Asset depreciation rate | 1 | 0.562 | /4/ |
| 61 | Limitation of technology use for political reasons | 1 | 0.562 | /6/ |
| 62 | Monitoring and control of corrosion | 1 | 0.562 | /3/ |
| 63 | In-service inspection | 1 | 0.562 | /3/ |
| 64 | Company's credit and reputation | 1 | 0.562 | /5/ |
| 65 | Assessment of suitability for services | 1 | 0.562 | /12/ |
| 66 | Company profitability | 1 | 0.562 | /12/ |
| 67 | Inspection effectiveness | 1 | 0.562 | /12/ |
| 68 | Location and installation conditions | 1 | 0.562 | /14/ |

* We have identified a total of 68 unique indicators ere repeated a combined 178 times in articles. The repetition count for each indicator is calculated as a fraction of the total count, specifically divided by 178.

The findings reveal that the trio of indicators, namely 'reliability,' 'environmental effects,' and 'preventive and corrective maintenance,' account for 22 % of overall frequency of all measures. These findings underscore the considerable significance of these three factors in ensuring the integrity of assets.

Table 1 illustrates that, as evident, the collective frequency of indicators, replicated at least five times, constitutes 45.5 % of the total count of extracted indicators, whereas the number of such indicators stands at a mere 10.

Conversely, indicators repeated less than five times encompass 54.5 % of all indicators. Consequently, the initial ten indicators must be taken into account when making asset integrity decisions and formulating plans.

Table 3 provides information about the articles studied and their characteristics, such as title, publication date, country, and results.

Within this tabular representation, we have endeavoured to consolidate the conducted investigations, their respective periods, countries of origin, and the contextual framework within which they are carried out. According to surveys, it is evident that 47.5 % of the studies focuses on the domains of oil, gas, and petrochemicals. The remaining subjects encompass a diverse range of sectors, such as infrastructure, water and electricity, and renewable energy.

Table 3. Articles and features.

| No. | Title | Year | Country | Type of industry | N* | Summary of results | Ref |
|---|---|---|---|---|---|---|---|
| 1 | Modelling a maintenance management framework for asset management based on ISO 55000 series guidelines | 2022 | Brazil | Different industries | 6 | The paper proposes a maintenance management framework for asset management (MMFAM) based on ISO 55000 series guidelines. By addressing the ISO 55000 series for asset management in depth, the MMFAM fills a gap in maintenance management literature. The aim is to assist maintenance practitioners and researchers in comprehending and disseminating a new maintenance management framework that is aligned with asset management. | /18/ |
| 2 | An integrated fuzzy inference system and AHP approach for criticality analysis of assets: A case study of a gas refinery | 2021 | Iran | Gas refinery | 11 | The proposed integrated approach of the analytic hierarchy process (AHP) and fuzzy inference system (FIS) is implemented in a gas refinery, and the results show its effectiveness and applicability in prioritising assets based on criticality criteria. The COA defuzzification method is employed to transform fuzzy values of consequences and probability into crisp values that can be used as inputs in the fuzzy inference system. | /4/ |
| 3 | Resistive maintenance and equipment criticality indexes | 2021 | Iran | Oil industry | 16 | The paper provides a formula for determining the equipment sensitivity index and resistive maintenance index for companies, especially in the petrochemical industry. Results of the study provide a method for determining the equipment criticality index (ECI) and planning maintenance, technical inspection, procurement, and operation measures based on the sensitivity of the equipment. | /6/ |
| 4 | A fuzzy DEMATEL-ANP-VIKOR analytical model for maintenance strategy selection of safety critical assets | 2021 | Iran | Distillation units of oil refinery plants | 10 | A fuzzy DEMATEL-ANP-VIKOR analytical model is presented in the paper to select maintenance strategies for safety critical assets in industries, such as aerospace, manufacturing, transport, and energy sectors. By utilising effective maintenance strategies, the proposed model aims to enhance the performance of safety critical equipment and facilities. | /8/ |
| 5 | Impact of ISO 55000 on organizational performance: evidence from certified UAE firms | 2021 | United Arab Emirates | ISO 55000 Certified organisations in the UAE | 2 | The study investigates the impact of implementing ISO 55000 on organisational performance in certified UAE firms. Through a literature review, the relevant asset management key performance indicators (KPIs) are identified and classified using the balanced-scorecard framework. | /1/ |
| 6 | Risk-based decisions: Implementing the asset integrity program | 2021 | Argentina | Oil & gas industry | 4 | A risk-based model approach is used in the paper to implement an Asset Integrity Management (AIM) programme in the Oil & gas industry. The paper emphasises the importance of establishing a baseline, conducting an auto-assessment, and defining a long-term implementation roadmap for AIM based on consequences analysis criteria, such as Loss of Primary Containment (LOPC). | /13/ |
| 7 | What is the value of asset management? | 2019 | UK | Different industries | 7 | The paper discusses the different perceptions of value and benefits associated with assets and their life cycle management, aiming to find common ground in terminology and practical measurement of impact for various stakeholders. The importance of understanding and measuring the value of assets and managing them is highlighted, taking into account the fulfilment of desires or expectations of identified beneficiaries. | /9/ |
| 8 | Combinatorial optimization of petrochemical plants by asset integrity management indicators | 2019 | Iran | Petro-chemical Plants | 13 | The paper proposes an integrated approach and consists of an analytic network process (ANP) and data envelopment analysis (DEA) to evaluate and optimise the performance of petrochemical plants based on asset integrity management criteria that aims to improve overall performance, reduce operational loss, safety issues, and incidents in petrochemical plants. | /2/ |
| 9 | Improving Asset Management under a regulatory view | 2019 | Brazil | Electric energy transmission sector | 11 | The Regulation-Oriented Model for Asset Management (AM-ROM) is presented in the paper, which ranks the most important requirements for compliance with the regulatory framework of the sector. The model is validated in a Brazilian company in the Electric energy transmission sector. | /5/ |
| 10 | Creating an effective asset integrity program | 2019 | USA | Chemical company | 8 | The paper emphasizes the importance of creating a leadership team at the appropriate level of management to establish an effective asset integrity management (AIM) programme. | /14/ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 11 | A review of the offshore oil and gas safety indices | 2018 | Malaysia | Offshore oil and gas platforms | 24 | The paper discusses the need for a composite index that integrates various aspects of safety, including cultural and climatic factors, to provide a more representative picture of offshore oil and gas platforms' safety performance. This would make it easier to benchmark performance and continuously improve safety management on the platforms. | /10/ |
| 12 | System to assess the reliability of critical equipment in the industrial sector | 2017 | Colombia | Plastic processing industry | 4 | The paper proposes a tool for evaluating the reliability of critical equipment in the industrial sector, with the aim of providing criteria for improving maintenance decision-making. The purpose of this procedure is to provide indicators for decision-making to prevent unplanned equipment shutdowns | /11/ |
| 13 | Fuzzy-based methodology for integrated infra-structure asset management | 2017 | Egypt | Municipal infra-structures | 3 | A fuzzy-based methodology is proposed for integrated infrastructure asset management, which involves analysing the condition, risk, and life cycle cost of water networks, sewer networks, and road networks. The methodology helps agencies in their short and long-term management plans. | /16/ |
| 14 | Asset integrity management: offshore installations challenges | 2016 | Norway | Oil and gas industry | 7 | The paper identifies and analyses the challenges and factors that could have an impact on the management of asset integrity in offshore installations. Organizations can use the identified challenges to address underlying AIM challenges, enhance their AIM strategy, and gain insights into current AIM practices in the petroleum industry. | /15/ |
| 15 | Sustainable asset integrity management: strategic imperatives for economic renewable energy generation | 2014 | Australia | Renewable energy generation plants | 14 | The paper develops a framework for sustainable asset integrity management (AIM) in renewable energy generation plants. The organizational model for sustainable AIM in renewable energy generation aims to satisfy stakeholder demands and enhance performance indicators. | /3/ |
| 16 | The evolution of asset management in the water industry | 2014 | USA | Water industry | 2 | Asset management in the water industry has evolved as a formal management approach over the past few decades, driven by constraints on financial resources and the need to optimize costs, risks, and performance over the life cycle of assets. | /19/ |
| 17 | The 5C model: a new approach to asset integrity management | 2010 | Italy, Norway, USA | Different industries | 16 | The paper presents a model called the 5C model, which is used to guide asset integrity management. The paper discusses the importance of asset integrity management in organizations, emphasizing the need to map the asset integrity business process, identify critical interfaces, and eliminate gaps and overlaps in processes. | /7/ |
| 18 | The rise, current position and future direction of asset management in utility industries | 2009 | UK | Utility industries | 5 | The paper discusses the rise in importance of asset management in utility industries over the last few decades. The paper suggests that as the age of asset databases grows, time series data will become more readily available, impacting deterioration models and curve fitting to individual asset data. | /17/ |
| 19 | Asset integrity management involving integrated RBI and RCM | 2003 | USA, SE Asia | Refinery and petro-chemical industry | 15 | The paper introduces the concept of streamlined Reliability Cantered Maintenance (RCM) and seamlessly integrated Risk Based Inspection (RBI) and RCM, offering quantitative predictions of plant risk, reliability, and availability. The paper discusses the requirements for software in successful asset integrity management, implementation of integrated RBI and RCM, and the need for interfacing with enterprise resource planning (ERP) systems like SAP. | /12/ |

## DISCUSSION

Asset integrity pertains to a company's capacity to uphold its operations and guarantee effective operation and security of its resources. This entails the identification of potential risks, shortcomings, and strategic asset goals, in addition to the maintenance of a comprehensive understanding of technical conditions and associated data, /7/.

In this systematic study, out of the 68 indicators that are extracted, the presence of indicators ‘reliability’ is detected in 74 % of the articles, while indicators ‘environmental effects’ and ‘preventive and corrective maintenance’ are observed in 63 % of the articles.

Reliability plays a pivotal role within the industrial sector since it guarantees the unwavering execution and operationality of pivotal machinery. This attribute aids in the reduction of periods of inactivity and disturbances in business functions, ultimately resulting in heightened levels of productivity and effectiveness /11/. Understanding and effectively addressing environmental ramifications holds the utmost significance in ensuring the safeguarding and preservation of facilities. Performance and dependability of equipment and structures can be adversely affected by environmental challenges, thereby engendering potential hazards to safety and disruptions in operational procedures. Consequently, AIM strategies necessitate the inclusion of an assessment

regarding the influence of environmental effects on asset integrity, along with the implementation of measures aimed at mitigating these impacts /15/. Maintenance endeavours, including periodic examinations, preventative maintenance, and remedial measures, aid in the identification and resolution of potential concerns prior to their progression into significant predicaments. Adequate maintenance has the potential to lengthen the serviceable lifespan of assets, diminishing the necessity for expensive substitutions and enhancing general cost-efficiency. Thus, maintenance is vital in guaranteeing the utmost efficiency, dependability, and security of industrial assets throughout their entire duration, /6/.

Hence, based on the aforementioned quantity of iterations, it is imperative to accord precedence to these elements throughout every phase of conception, procurement, fabrication, execution, and sustenance, encompassing the entire lifespan of machinery and resources. To establish the prioritisation of indices, both establishments and individuals ought to align their attention in accordance with the objectives and current policy of the organisation. In this systematic research, an endeavour is undertaken to aggregate indicators in the process of asset integrity with the purpose of their applicability in forthcoming scholarly research. It is recommended that these indicators have the potential to be utilised in the development of a software system that can assess the status of asset integrity among various industries, in alignment with the objectives and vision of the respective organisations.

## ACKNOWLEDGEMENTS

The authors appreciate Iranian East Azerbaijan Province Gas Company and Health and Environment Research Center of Tabriz University of Medical Sciences.

*Funding*

This work is supported financially by the Iranian East Azerbaijan Province Gas Company and Health and Environment Research Center of Tabriz University of Medical Sciences.

## REFERENCES

1. Alsyouf, I., Alsuwaidi, M., Hamdan, S., Shamsuzzaman, M. (2021), *Impact of ISO 55000 on organisational performance: evidence from certified UAE firms*, Total Qual. Manag. Bus. Excell. 32(1-2): 134-152. doi: 10.1080/14783363.2018.1537750
2. Sheikhalishahi, M., Karimi, M., Raghebi, R. (2019), *Combinatorial optimization of petrochemical plants by asset integrity management indicators*, Proc. Safety Environm. Prot. 127: 321-328. doi: 10.1016/j.psep.2019.05.017
3. Ossai, C.I., Boswell, B., Davies, I.J. (2014), *Sustainable asset integrity management: Strategic imperatives for economic renewable energy generation*, Renew. Energy, 67: 143-152. doi: 10.1016/j.renene.2013.11.024
4. Shahri, M.M., Jahromi, A.E., Houshmand, M. (2021), *An integrated fuzzy inference system and AHP approach for criticality analysis of assets: A case study of a gas refinery*, J Intell. Fuzzy Syst. 41(1): 199-217. doi: 10.3233/JIFS-201407
5. Lima, E.S., Costa, A.P.C.S. (2019), *Improving Asset Management under a regulatory view*, Reliab. Eng. Syst. Safety, 190: 106523. doi: 10.1016/j.ress.2019.106523
6. Hosseini, S.M.S., Shahanaghi, K., Shasfand, S. (2021), *Resistive maintenance and equipment criticality indexes*, Nexo Revista Cientifica, 34(2): 744-758. doi: 10.5377/nexo.v34i02.11559
7. Rahim, Y., Refsdal, I., Kenett, R.S. (2010), *The 5C model: A new approach to asset integrity management*, Int. J Pressure Vessels Piping, 87(2-3): 88-93. doi: 10.1016/j.ijpvp.2009.12.007
8. Arjomandi, M.A., Dinmohammadi, F., Mosallanezhad, B., Shafiee, M. (2021), *A fuzzy DEMATEL-ANP-VIKOR analytical model for maintenance strategy selection of safety critical assets*, Adv. Mech. Eng. 13(4). doi: 10.1177/1687814021994
9. Woodhouse, J. (2019), *What is the value of asset management?*, Infrastr. Asset Manag. 6(2): 102-108. doi: 10.1680/jinam.17.00040
10. Tang, K.H.D., Dawal, S.Z.M, Olugu, E.U. (2018), *A review of the offshore oil and gas safety indices*, Safety Sci. 109: 344-352. doi: 10.1016/j.ssci.2018.06.018
11. Gasca, M.C., Camargo, L.L., Medina, B. (2017), *System to assess the reliability of critical equipment in the industrial sector*, Inf. Tecnol. 28(4): 111-124. doi: 10.4067/S0718-07642017000400014
12. Tronskar, J.P. (2003), *Asset integrity management involving integrated RBI and RCM*, Hydrocarbon Asia, 13(2): 38-47.
13. Henao, F.A. (2021), *Risk-based decisions: Implementing the asset integrity program*, Proc. Safety Progress, 40(S1): S24-S31. doi: 10.1002/prs.12287
14. Moyer, L., Hedlund, M. (2019), *Creating an effective asset integrity program*, Proc. Safety Progress, 38(2): e12008. doi: 10.1002/prs.12008
15. Kusumawardhani, M., Kumar, R., Tore, M. (2016), *Asset integrity management: offshore installations challenges*, J Qual. Mainten. Eng. 22(3): 238-251. doi: 10.1108/JQME-06-2015-0023
16. Marzouk, M., Osama, A. (2017), *Fuzzy-based methodology for integrated infrastructure asset management*. Int. J Comput. Intell. Syst. 10(1): 745-759. doi: 10.2991/ijcis.2017.10.1.50
17. Brint, A., Bridgeman, J., Black, M. (2009), *The rise, current position and future direction of asset management in utility industries*, J Oper. Res. Soc. 60(sup1): S106-S113. doi: 10.1057/jo rs.2008.174
18. da Silva, R.F., de Souza, G.F.M. (2022), *Modeling a maintenance management framework for asset management based on ISO 55000 series guidelines*, J Qual. Mainten. Eng. 28(4): 915-937. doi: 10.1108/JQME-08-2020-0082
19. Jones, M., Williams, W., Stillman, J. (2014), *The evolution of asset management in the water industry*, J Amer. Water Works Ass. 106(8): 140-148. doi: 10.5942/jawwa.2014.106.0114