ISSN 1840-4855
e-ISSN 2233-0046

Original scientific article
http://dx.doi.org/10.70102/afts.2026.1836.867

DEVELOPING A COMPREHENSIVE HEALTH SCORING SYSTEM FOR STATIC, ROTATING, AND ELECTRICAL EQUIPMENT IN OIL REFINERIES

Agustinus Pindoan Panjaitan[1], Ranu Fauzan[2], Eko Sunarno[3], Dedi Apriadi[4], Rachman Setiawan[5]*

[1]Kilang Pertamina Internasional, Jakarta, Indonesia.
e-mail: agustinus.pp@pertamina.com, orcid: https://orcid.org/0009-0005-9241-1599
[2]Kilang Pertamina Internasional, Jakarta, Indonesia.
e-mail: ranu.muslim@pertamina.com, orcid: https://orcid.org/0009-0007-4083-843X
[3]Kilang Pertamina Internasional, Jakarta, Indonesia. e-mail: enarno@pertamina.com, orcid: https://orcid.org/0009-0006-8827-1404
[4]LAPI Ganesha Utama, Bandung, Indonesia. e-mail: dedia@itb.ac.id, orcid: https://orcid.org/0009-0001-3779-6896
[5]Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Bandung, Indonesia. e-mail: r.setiawan@itb.ac.id, orcid: https://orcid.org/0009-0003-2124-3781*

Received: June 10, 2026; Revised: July 20, 2026; Accepted: August 27, 2026; Published: September 29, 2026

SUMMARY

The proper functioning of static, rotating, and electrical equipment plays a vital role in ensuring the safety and uninterrupted production process within an oil refinery environment. In this research, an all-encompassing framework of an Equipment Health Score (EHS) will be formulated through a combination of lifecycle condition, operations data, maintenance records, and equipment reliability into a 0–100 score. This method will incorporate the use of initial health, modifier health, and reliability measures as the basis for evaluating different assets within an oil refinery environment. Different equipment-related scores will be based on the following data. The methodology is illustrated using selected refinery equipment, including storage tanks, piping systems, and pumps. The storage tank attained the highest health score of 85.99, with the piping system scoring 80.64, whereas the pump attained the lowest health score of 66.70. The low health score attained by the pump shows that having a good current condition score does not mean good health if other criteria such as lifecycle and reliability are not well met. The developed methodology can therefore be used for the purposes of easy comparisons among different classes of equipment, prioritization of equipment maintenance, and risk-based decisions. The developed methodology has also provided a platform for integration with condition-based maintenance, computerized maintenance management system, and asset readiness evaluation. Future research will concentrate on the validation of the methodology over a long period of time in various refinery plants, fine-tuning of weighting factors and thresholds, and integration with machine learning and predictive maintenance.

Key words: *health scoring, reliability, condition monitoring, equipment health scores, asset readiness index, sustainability.*

INTRODUCTION

The operations in oil refineries require high levels of mechanical, thermal, electrical, and chemical stresses, and thus the reliability of equipment becomes a critical factor for safety, efficiency of production, and operational reliability. The presence of risks in occupational and operational areas in oil refining processes makes systematic monitoring of equipment and management of risks relevant [8]. Old installations and sophisticated process technologies add to the complexity of the degradation of equipment before its failure. Conventional reactive maintenance is done after the breakdown of equipment, while fixed maintenance is not always adequate to the real state of equipment [2].

Condition monitoring has evolved into an essential component of maintenance due to the possibility of detecting degradation using certain measurable parameters [5]. Monitoring of rotating electrical machinery through automated systems helps in identifying abnormal operating conditions continuously [7]. Predicting health index of equipment using machine learning techniques has been shown to be effective for petrochemical equipment [4]. AI applications are increasingly used in the oil and gas industry for improving predictions and decision-making processes [9]. Digital twin and IoT-based monitoring help in integrating equipment condition and process information [1]. AI-powered maintenance systems may also help in integrating instrumentation and maintenance planning processes [6].

Useful life prediction is another significant source of knowledge about degradation apart from the current operational indicators [3]. Intelligent oilfield systems prove the significance of integration of sensor technology, automation, and digitized information in oil and gas production [13]. Systems for integrated facility management also illustrate the consolidation of heterogeneous engineering data for asset management [15]. Risk management principles help to prioritize significant operational conditions in a transparent manner [14]. Studies on sustainable business performance also underscore the significance of balancing operational efficiency with organizational goals [18].

The health scoring tool was developed to analyze three major types of equipment that are widely available in oil refineries:

1. **Static Equipment:** This type of equipment includes storage tanks, heat exchangers, and pipes; storage tanks are used for storing the raw materials and products. Heat exchangers are used for heat exchange between two media with different temperatures, and pipes are used for transporting fluids from one vessel to another.
2. **Rotating Equipment:** This type of equipment includes pumps, compressors, and turbines.
3. **Electrical and Instrumentation Equipment:** This type of equipment includes generators, motors, transformers, control valves, and other similar equipment.

Each type of equipment is linked to specific EHS indicators, which have their own weights depending on the effect on equipment performance. The health scoring algorithm includes not only current equipment condition assessment but also takes into consideration performance history.

The case study of the proposed health scoring system application for Refinery Facilities is provided in order to emphasize the advantages and practicality of the approach, and it is stated that the health scoring system could help in detecting equipment with deteriorating health status, optimize maintenance planning and prevent unplanned downtime, and also improve equipment reliability [16]. The health scoring system could also be used in asset readiness indices calculation, which is crucial for assessing plant readiness.

This paper's contribution to the field of reliability engineering in the oil refining industry consists of a structured method of evaluation of the health of equipment, and the proposed health scoring system will contribute to better decision-making as well as support the sustainability of important assets in order to ensure the reliability, efficiency, and flexibility of the refineries to fit the needs of the industry.

The rest of this paper is organized as follows: Section 2 covers the methodology used in the development

of the health scoring system, and the identification and weighing of the EHSs, and Section 3 demonstrates the use of the health scoring system for static, rotating, and electrical equipment as well as a case study of the Refinery Facilities. Section 4 covers the findings of the proposed system, and Section 5 concludes the paper.

LITERATURE REVIEW

This research therefore proposes an all-embracing framework to assess the condition of static, rotating, and electrical refinery equipment [10]. This framework will incorporate condition monitoring data, design details, operating history, maintenance information, lifecycle parameters, and reliability data into one EHS. Multicriteria condition rating techniques illustrate the importance of incorporating heterogeneous indicators in one decision support system [11][12]. In addition, standardized assessment methods underscore the importance of clearly defined indicators and measurement procedures [17].

As far as rotating machinery is concerned, vibration, temperature, pressure, lubrication, and diagnosis information can be used to measure the operational condition directly [5]. As for electrical machinery, the automatic health monitoring process makes use of measurable electrical and mechanical indicators to carry out assessment [7]. Machine learning-based health index prediction can further improve the analysis of equipment condition [4]. Reliability-centered maintenance links the health indicators with maintenance activities and intervention planning [2]. Remaining Useful Life assessment brings a lifecycle angle to separate the operating condition from the deterioration process [3].

Such an EHS will be a dynamic means for comparing different refinery assets, detecting equipment that is becoming obsolete, allocating maintenance efforts, and making decisions based on risks. The use of digital-twin technology can contribute to more efficient real-time equipment monitoring [1]. Artificial intelligence can help in predicting equipment health [9]. Intelligent oilfield technologies represent a way forward towards wider digitalization of refinery activities [13]. Facility-management systems can assist in better consolidation of equipment data [15]. Structured verification procedures can serve as an appropriate methodological foundation for improving the transparency and reliability of the suggested scoring model [19]. Standardized measurement frameworks can further improve assessment efficiency and consistency [20].

According to the literature reviewed, asset management of the refineries is now being conducted by means of condition monitoring, reliability assessment, life cycle analysis, and smart decision support techniques. However, almost all such techniques are limited to certain pieces of equipment or individual criteria. This justifies the relevance of the current study that combines condition, maintenance, performance, and reliability data into an integral EHS.

METHODOLOGY

Figure 1 below represents the general flow process of the health scoring system starting from data collection to EHS calculation and dashboard display.

Classification of Equipment used in Refinery Facilities Under Study:

a) Static Equipment: Includes storage tanks, heat exchangers, jetties, and pipes.

b) Rotating Equipment: Includes pumps, compressors, and turbines.

c) Electrical and Instrumentation Equipment: Includes generators, motors, transformers, and control valves.

Each group has distinct degradation modes and monitoring requirements, and thus, specific EHS.

EHS are measurable or inferred parameters that directly reflect the health, functionality, and failure risk of equipment assets. For a health score to be both meaningful and actionable, EHS must be derived from reliable data sources, including real-time sensors, maintenance logs, and operating conditions. Each EHS is normalized on a 0–100 scale, allowing aggregation into composite health scores.

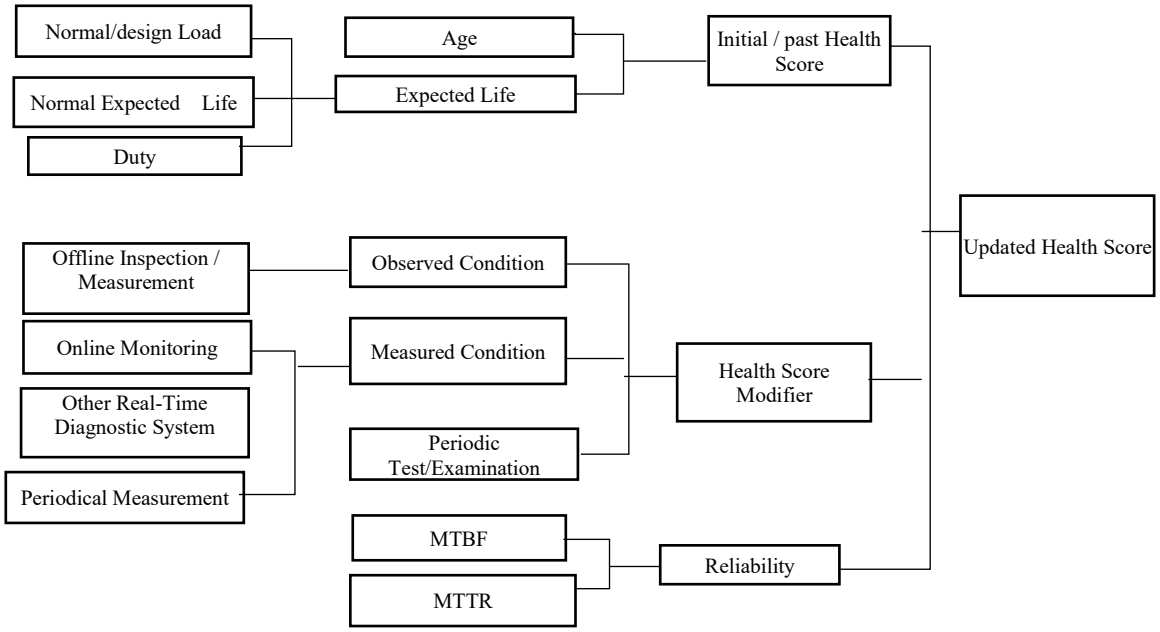

Figure 1. The health scoring system architecture

EHS are grouped into four categories: Condition, Maintenance, Operational, and Risk, each with distinct acquisition strategies. Table 1 shows EHS by equipment type. Recommended sensors and data sources for the associated EHS are presented in table 2.

Table 1. EHS applicability by equipment type

Equipment Class	Equipment Type	Applicable EHS
Static	**Jetties**	Structural fatigue (and expected lifetime), vibration from mooring, signs of marine corrosion.
	Storage Tanks	Temperature Trend, Corrosion Rate, Leak Detection, MTBF, MTTR, CM/PM Ratio, Overdue Maintenance, Run Hours, Safety Criticality, Environmental Impact
	Heat Exchangers	Vibration, Temperature Trend, Pressure Deviation, Corrosion Rate, Leak Detection, MTBF, MTTR, CM/PM Ratio, Overdue Maintenance, Run Hours, Safety Criticality, Environmental Impact
	Piping Systems	Temperature Trend, Pressure Deviation, Corrosion Rate, Leak Detection, MTBF, MTTR, CM/PM Ratio, Overdue Maintenance, Run Hours, Safety Criticality, Environmental Impact
Rotating	**Pumps**	Vibration, Temperature Trend, Pressure Deviation, Leak Detection, MTBF, MTTR, CM/PM Ratio, Overdue Maintenance, Run Hours, Start/Stop Cycles, Trip Frequency, Safety Criticality, Environmental Impact
	Compressors	Same as Pumps: Vibration, Temperature, Pressure, Leak Detection, MTBF, MTTR, CM/PM Ratio, Overdue Maintenance, Run Hours, Start/Stop, Trip Frequency, Safety, Environment
	Turbines	Same as Compressors
	Power Generators	All Pump EHS **plus** Insulation Resistance (critical for windings), highly sensitive to Trip Frequency
	Motors	Vibration, Temperature, MTBF, MTTR, CM/PM Ratio, Overdue Maintenance, Insulation Resistance, Run Hours, Start/Stop, Trip Frequency, Safety, Environment
Electricals & Instrumentations	**Transformers**	Temperature Trend, Insulation Resistance, MTBF, MTTR, CM/PM Ratio, Overdue Maintenance, Trip Frequency, Safety, Environment
	Control Valves	Vibration, Temperature, Pressure, Leak Detection, MTBF, MTTR, CM/PM Ratio, Overdue Maintenance, Run Hours, Start/Stop, Trip Frequency, Safety, Environment

Table 2. Recommended sensors and data sources for EHS

EHS	Measurement Method	Sensor Type / Device	Notes
Vibration	Direct measurement of displacement, velocity, or accel.	Accelerometer, Velocity Sensor, Proximity Probe	Commonly used for rotating equipment (pumps, turbines)
Temperature Trend	Surface or internal temp over time	RTD (Resistance Temp Detector), Thermocouple, IR Sensor	Applicable to all equipment types
Pressure Deviation	Pressure variance from normal range	Strain Gauge Pressure Sensor, Differential Pressure Transmitter	Common in exchangers, valves, compressors
Corrosion Rate	Thickness loss over time	Ultrasonic Thickness Gauge, Corrosion Coupon, ER Probe	Static assets: tanks, jetties, piping
Leak Detection	Acoustic anomalies or fluid/gas loss	Ultrasonic Acoustic Sensor, Infrared Gas Detector, Mass Flow Meter	Infrared and acoustic for static assets; flow meters for pipelines
Insulation Resistance	Electrical insulation degradation	Megohmmeter (Offline), Motor Analyzer, Online IR Sensor	Key for motors, transformers, generators
MTBF / MTTR	Historical failure and repair timing	CMMS, DCS Logs (indirect)	Calculated from failure and repair data
Corrective-to-Preventive Ratio	Maintenance record analysis	CMMS (SAP, Maximo)	Calculated from number and type of work orders
Overdue Maintenance %	Ratio of late PM tasks	CMMS report	High value reduces health score
Run Hours	Total accumulated operational time	Hour Meter, Control System Runtime Counter	Available in DCS/PLC logs
Start/Stop Cycles	Number of power or process cycles	Digital Counters, PLC Input Logs	Important for motors, pumps, generators
Trip Frequency	Protective trip/lockout frequency	DCS Alarm Logs, Relay Logs, Safety System Logs	High trip count indicates operational stress
Safety Criticality (SIL Level)	Design-based criticality classification	Safety Instrumented System (SIS) Docs, LOPA	Qualitative; influences score weighting
Environmental Impact	Risk to surrounding area	HAZOP, RBI software, Environmental Monitoring Logs	Usually qualitative or semi-quantitative

Where Sensors are NOT Available,

- **MTBF**, **MTTR**, **C/M Ratio**, and **Overdue Maintenance** are not measured with sensors but computed from **historical data in CMMS** systems.
- **Safety Criticality** and **Environmental Impact** come from **design basis documentation** (e.g., LOPA, HAZOP, RBI), not real-time measurement.

The refinery facility being studied has gradually fitted its assets with various sensors and data acquisition systems according to the categories of sensors and data acquisition types listed in table 2 above. This includes vibration and proximity probes on rotating machines, RTD temperature sensors, temperature trending using thermocouples, differential pressure transmitters for process deviation, ultrasonic thickness testing to monitor corrosion and wall loss, and megohmmeters to assess motor and transformer electrical insulation. Records of historical maintenance activities, work orders, and failures are captured within the Computerized Maintenance Management System (CMMS), and the data within it serves as the main source of information for reliability-related EHS measures such as MTBF, MTTR, and the ratio between corrective and preventive maintenance, while the proposed health scoring system uses real-time sensor measurements, scheduled inspections, and data from the CMMS records to compute the EHS using one computational tool. The ability to gather all of these data types allows the process not to rely heavily on manual data collection anymore, while health scores could be continuously updated upon receipt of new measurements, results of inspections, and maintenance activities that provide management with an up-to-date and data-driven picture of the condition of each asset.

Scoring Formulation

The proposed health scoring model evaluates refinery equipment through three principal components: the initial health score H_{init}, the health modifier score H_{mod}, and the reliability score H_R. The overall EHS is therefore expressed as (Equation 1):

$$H_i = w_{\text{init}} H_{\text{init},i} + w_{\text{mod}} H_{\text{mod},i} + w_R H_{R,i} \quad (1)$$

$$\text{where } w_{\text{init}} + w_{\text{mod}} + w_R = 1.$$

For each health component, multiple EHSs are integrated using data availability, indicator importance, and normalized condition scores (Equation 2):

$$H_{k,i} = \frac{\sum_{j=1}^{n} A_{ij} W_{ij} S_{ij}}{\sum_{j=1}^{n} W_{ij}} \quad (2)$$

where A_{ij} represents data availability or confidence, W_{ij} is the indicator weight, and S_{ij} is the normalized EHS value on a 0–100 scale.

Equipment aging is represented through remaining useful life (Equation 3):

$$H_{\text{init},i} = \left(1 - \frac{L_{a,i}}{L_{e,i}}\right) \times 100 \quad (3)$$

where L_a and L_e denote actual and expected equipment life, respectively.

Reliability is obtained from the probability of failure-free operation over a mission period (Equation 4):

$$H_{R,i} = R_i(t_{\text{mission}}) \times 100 \quad (4)$$

For Weibull reliability,

$$R_i(t) = \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right] \quad (5)$$

Equation 5 where α and β are the scale and shape parameters.

This formulation enables condition, age, reliability, and incomplete data to be incorporated into a unified and comparable EHS.

Piping Systems

Piping systems are important static equipment in oil refineries as they transport process fluids from one unit to another within the plant under different levels of pressure, temperature, and corrosivity. The condition of pipes is primarily influenced by the thinning of walls, corrosion, cracking, fatigue, and mechanical damage. Some common forms of degradation are erosion-corrosion, flow-accelerated corrosion, corrosion under insulation, vibration fatigue, thermal fatigue, and stress corrosion cracking. These forms of degradation lead to a reduction in pipe wall thickness and hence increase the risk of leakage or even bursting of pipes. For this reason, risk-based inspections are carried out (Table 3).

The health score for the piping system is obtained through the use of the general health scoring methodology. The initial health score will be based on the design life, commissioning information, and the age of the operation, whereas the modifier health score is based on the inspection measurements such as the wall thickness and corrosion rate.

Table 3. Major failure mechanisms of piping systems

Failure mechanism	Typical condition	Components most at risk
Erosion/erosion-corrosion	High-velocity or two-phase flow	Elbows, tees, reducers
Corrosion under insulation	Insulated piping exposed to cyclic wetting	Low points and damaged insulation areas
Stress corrosion cracking	Aggressive chemical and thermal environments	Welds and heat-affected zones
Vibration-induced fatigue	Piping near rotating equipment	Small-bore connections and supports
Thermal fatigue	Repeated hot-cold cycling	Mixing tees and dead legs
External corrosion	Weather and coating degradation	Supports and exposed piping

Pumps

Pumps form one of the most critical types of rotating equipment in the operation of refineries. Even though there are many different pump designs employed within the petroleum industry, centrifugal pumps are the most common design used in the refinery and petrochemical industries. Consequently, they will serve as the benchmark of rotating equipment in this paper. Pump degradation usually occurs due to mechanical seal failure, bearing wear and tear, cavitation, erosion-corrosion, shaft fatigue, impeller damage, and vibration. This can occur due to poor lubrication, contamination, misalignment, suction issues, or corrosion (Table 4).

Table 4. Major failure modes of centrifugal pumps

Failure mode	Main affected components	Typical root causes
Mechanical seal failure	Seal faces and elastomers	Dry running, cavitation, misalignment
Bearing failure	Bearings and housing	Contamination, lubrication problems, imbalance
Cavitation	Impeller and casing	Inadequate NPSH and low suction pressure
Erosion/corrosion	Impeller and casing	Abrasive solids and corrosive fluids
Shaft fatigue	Shaft and coupling	Misalignment, vibration, cyclic stress
Vibration-driven wear	Bearings, seals and foundation	Resonance, imbalance and off-design operation

The baseline pump health score is established using design specifications and commissioning records. The score is subsequently updated using condition-monitoring indicators such as vibration, bearing condition, temperature, pressure, and seal leakage. Maintenance history, MTBF, and MTTR provide the reliability component of the assessment.

Transformers

Transformers can be considered exemplary electrical equipment as they have an impact on refinery power distribution and process operations. The oil-filled power transformers and oil-filled distribution transformers are widely used in petroleum plants; however, dry-type transformers can be used if there is a risk of fire or explosion. The most common failures in transformers are connected to dielectric breakdown, thermal hotspots, winding distortion, tap changer malfunctions, bushing problems, and cooling system malfunctions. The causes of such failures include moisture penetration, insulation aging, electrical transients, overload, stress, and improper cooling (Table 5).

The initial health score for transformers is determined based on their design, installation, commissioning, and age of operation data. The modified health score will be calculated on the basis of conditions that include oil testing, winding temperature, insulation resistance, bushing condition, and partial discharges. Reliability will be calculated through maintenance history and failures.

Table 5. Major failure modes of transformers

Failure mode	Main components	Typical root causes
Dielectric breakdown	Windings, insulation, oil, bushings	Moisture, aging, contamination, electrical surges
Thermal hot spots	Windings and core	Overloading and cooling-system failure
Mechanical deformation	Windings and supports	Through-fault forces and vibration
Tap-changer failure	OLTC contacts and mechanism	Contact wear, oxidation and thermal stress
Bushing failure	HV/LV bushings	Moisture, pollution and partial discharge
Cooling-system failure	Fans, pumps and radiators	Wear, corrosion and blocked cooling paths

Integration with CMMS and CBM Systems

The scoring system has been configured for easy integration into any computerized maintenance management system and CBM system, and pipelines have been created in order to automatically pull out work orders, event logs, alarms, and real-time sensor readings. The historical failures are aligned with the failure codes from the ISO 14224 standard for consistency in coding and analysis.

Algorithm 1. Equipment Health Score Calculation

Input: Equipment data, sensor/inspection data, maintenance records, MTBF and MTTR.

Output: Overall EHS (0–100).

1. Identify equipment type.

2. Select applicable health indicators.

3. Collect lifecycle, condition, operational, and maintenance data.

4. Normalize each indicator to a 0–100 score.

5. Calculate Initial Health Score from age and expected life.

6. Calculate Modifier Score from inspection and condition data.

7. Calculate Reliability Score using MTBF, MTTR, and failure history.

8. Combine the three scores using assigned weights.

9. Compute the final Equipment Health Score.

10. Rank equipment for maintenance based on the final score.

The algorithm rates refinery equipment by analyzing information on lifecycle, condition, operation, maintenance, and reliability. The appropriate indicators are chosen and normalized to a range from 0 to 100. The initial, modifying, and reliability values are computed based on age, inspection data, MTBF, MTTR, and failures, respectively, and then summarized for the Equipment Health Score.

HEALTH SCORING SYSTEM APPLICATIONS

The health scoring process tailors the assessment to each equipment type based on its place in the process, major failure mechanisms, and EHS, using ISO 14224 terminology and ISO 17359 measurement approaches to define the appropriate health indicators. The EHS are either taken directly from sensors or calculated based on inspection data, operational data, and CMMS information.

Applications for Equipment Units

Health scoring for each piece of equipment is performed according to the standard algorithm factors are also adjusted based on equipment criticality and the availability of data. Then, all the results are consolidated in one reliability dashboard. An example of such a dashboard is shown for static equipment and pumps in figure 2.

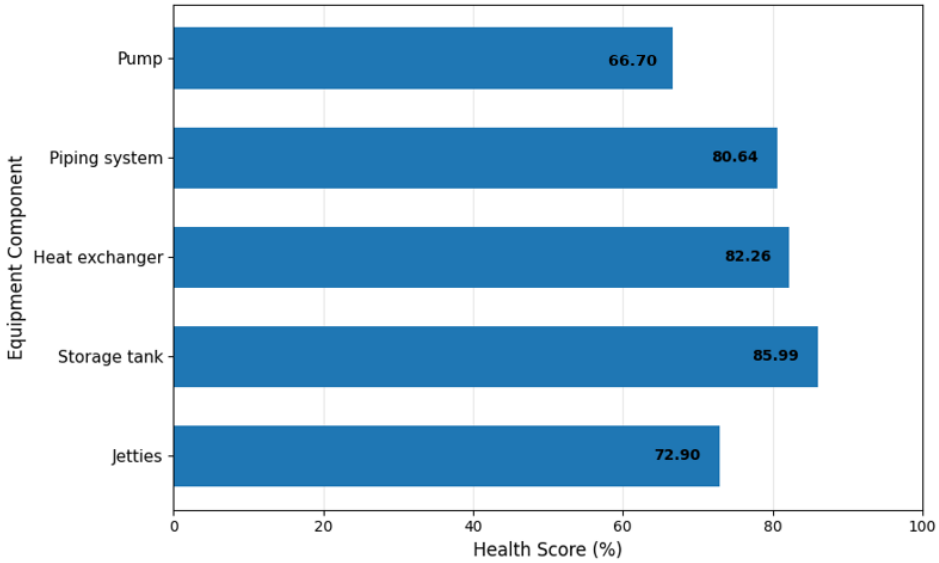

Figure 2. EHS dashboard on static equipment + pump

Storage Tank Health Assessment

For the storage tank, the total health score is 85.99, the highest total health score among all the other tanks and therefore suggests good structural and operational performance. The initial health score is 90.00, the modifier score is 91.41, and the reliability score is 80.00. A high modifier score implies that the conditions of corrosion were relatively acceptable.

Table 6. Storage tank health score

Health Score Component	Symbol	Value
Initial Health Score	H_{init}	90.00
Modifier Health Score	H_{mod}	91.41
Reliability Health Score	H_R	80.00
Total Health Score	H	**85.99**

The total score was calculated as (Equation 6):

$$H_{\text{Tank}} = 0.20H_{\text{init}} + 0.35H_{\text{mod}} + 0.45H_R \quad (6)$$

Table 6 demonstrates that the storage tank performed best among the other evaluated assets with regard to its health condition. The high initial and modifier scores suggest good lifecycle and inspection conditions, respectively, while the reliability score of 80 implies stable historical performance. The obtained score of 85.99 implies relatively low immediate maintenance needs.

Piping System Health Assessment

The piping system obtained a health score of 80.64. While its initial health score was equal to 60.00 as it is quite old compared to its service life expectancy, the high modifier score of 93.26 implies that the wall thickness is close to the design one. The reliability score of 80.00 indicates acceptable operational performance.

Table 7. Piping system health score

Health Score Component	Symbol	Value
Initial Health Score	H_{init}	60.00
Modifier Health Score	H_{mod}	93.26
Reliability Health Score	H_R	80.00
Total Health Score	H	**80.64**

The total piping health score is (Equation 7):

$$H_{\text{Piping}} = 0.20H_{\text{init}} + 0.35H_{\text{mod}} + 0.45H_R \quad (7)$$

Table 7 shows that the condition of the piping system is relatively healthy even with its mature service age. The modifier score of 93.26 indicates the good state of the wall, and the lower initial score indicates the deteriorating state due to the lifecycle. The total score of 80.64 indicates operation with proper inspection and monitoring.

Pump Health Evaluation

The pump had the lowest total health score of 66.70, making it the key asset for maintenance priorities. The initial health score of the pump was zero since the operating age exceeded the design life. While the modifier score was still relatively high (98.30), the reliability score decreased to 25.70 due to an MTBF of 473.85 days and an MTTR of 8.7 days.

Table 8. Pump health score

Health Score Component	Symbol	Value
Initial Health Score	H_{init}	0.00
Modifier Health Score	H_{mod}	98.30
Reliability Health Score	H_R	25.70
Total Health Score	H	**66.70**

For pumps, greater emphasis is assigned to actual operating condition (Equation 8):

$$H_{\text{Pump}} = 0.10H_{\text{init}} + 0.60H_{\text{mod}} + 0.30H_R \quad (8)$$

It is clear from table 8 that the pump requires maximum attention in terms of maintenance. Despite its high modifier score, its zero initial health score and low reliability score make its overall health score drop to 66.70. Thus, it is important to use both condition assessment and life cycle and history of failures to assess the current state of equipment.

Consolidated Health Assessment of Evaluated Equipment

Table 9 below provides a health score evaluation of all refinery equipment used in the comparison presented in figure 2. The storage tank has the best EHS of 85.99, followed by the heat exchanger, which has an EHS of 82.26, while the piping system has an EHS of 80.64, the jetty having 72.90, and finally the pump with the worst EHS of 66.70. Calculations at the component level are provided for the storage tank, piping system, and pump. However, the heat exchanger and jetty only had total EHS provided in the case study dataset.

Table 9. Consolidated health assessment of evaluated refinery equipment

Equipment	H_{init}	H_{mod}	H_R	Total EHS
Storage Tank	90.00	91.41	80.00	85.99
Heat Exchanger	NR	NR	NR	82.26
Piping System	60.00	93.26	80.00	80.64
Jetties	NR	NR	NR	72.90
Pump	0.00	98.30	25.70	66.70

The heat exchanger has an overall EHS value of 82.26, which means that its health condition is relatively better compared to the storage tank, but still inferior to the piping system. The jetty has an EHS of 72.90, meaning that it has a relatively worse health condition and requires more monitoring and inspection than the other two assets. Since there was no separate value for the lifecycle, modifier, and reliability components for these two assets in the dataset, only their EHS is reported.

The value of EHS of the refinery assets under evaluation was found to be 85.99 for the storage tank, 82.26 for the heat exchanger, 80.64 for the piping system, 72.90 for the jetty, and 66.70 for the pump. The component-specific analysis could be done for the storage tank, piping system, and pump, whereas the heat exchanger and jetty had been assessed on the basis of their total EHS values. Electrical assets have not been analyzed in this case study due to unavailability of datasets.

Comparative Analysis with Existing Asset Assessment Approaches

In order to assess the practicality of the developed framework for the EHS, its applicability has been evaluated by comparison with similar frameworks from other studies. Refinery and asset management literature has been concentrating mostly on choosing KPIs for maintenance, readiness, sustainability measures, asset integrity, or condition monitoring. Such frameworks provide valuable decision-making support information; however, they tend to deal only with particular performance aspects instead of providing a holistic health score of the equipment.

Table 10. Comparison of the proposed health scoring framework with existing approaches

Study/Approach	Main Assessment Focus	Integrated EHS	Unified Health Score	Risk-Based Maintenance Support	Main Limitation
[5]	Maintenance KPI selection	Partial	No	Moderate	Focused mainly on maintenance performance indicators
[7]	Asset operational readiness	No	Readiness score	Moderate	Developed for project/equipment readiness rather than continuous refinery health monitoring
[8]	Refinery sustainability performance	Partial	Performance-oriented	Limited	Emphasizes economic, environmental, and social KPIs rather than equipment degradation
[11]	Asset integrity and process safety	Partial	No unified EHS	High	Primarily framework-based without cross-equipment quantitative health scoring
Proposed EHS Framework	Condition, lifecycle, operation, maintenance, and reliability	Yes	Yes, 0–100	Direct	Requires further multi-site and long-term validation

Table 10 shows that the suggested framework improves upon the earlier methods by combining condition monitoring data, life cycle data, maintenance history, and reliability performance measures in one common 0-100 grading framework. In the case of the refinery, for instance, the storage tank scored the highest in terms of health at 85.99, the heat exchanger was second (82.26), the pipes third (80.64), the jetty fourth (72.90), and finally the pump at 66.70. These health scores enable a clearer definition of maintenance priorities, with some assets being prioritized based on their lower total health scores despite acceptable operating conditions. Hence, the proposed EHS framework enables a clearer link between equipment condition, reliability, and risk-based maintenance planning as compared to the reviews.

Rotating Equipment Health Assessment

Health evaluation for compressors and turbines shall take into consideration the operating condition, reliability, and maintenance history of the machines. For compressors, health check could include discharge pressure, lubrication alarms, valve functioning, vibration readings, trips, and DCS information. Reciprocating compressors usually have high longevity in their structures, but axial and centrifugal compressors have a lifespan of about 20 years, where MTBF is highly dependent on maintenance and replacement of components. Health evaluation for turbines would rely more on duty cycles, quality of fuel or steam, environmental factors, and maintenance practices. Usually, gas turbines have a life expectancy of 25-30 years, and the steam turbines can last up to 30-40 years.

Electrical Equipment Health Assessment

Generators, motors, and transformers need to have their health monitored through electrical and thermal means. Some of the ways of analyzing generators may be through battery cycles, start failures, voltage variances, fuel systems, and test run compliance. Motors, on the other hand, are assessed using insulation resistance, start-stop cycles, overloads, temperatures, and MCSA analysis. Transformers are mostly affected by aged insulation and thermal conditions. Such indications as dissolved gases analysis, bushings, partial discharges, hot spot temperatures, and overdue diagnostics are important. Electrical devices formed part of the EHS, but lacked sufficient case study information. For that reason, transformers, generators, and motors were not analyzed numerically but rather saved for future validation.

Expected Impact on Reliability and Availability

With the current state of development of the suggested health scoring framework, the framework will be employed to make strategic decisions related to asset maintenance and will help to prioritize maintenance actions depending on the calculated health of assets rather than depending on predetermined schedules and a failure-based approach. As the framework has not been implemented over an extended period of time yet, there is not enough information from practical operations that could be used to measure the improvements resulting from implementation of the framework. Thus, the improvement of reliability and availability due to the implementation of the suggested framework can be described in the following way: if the total health score of a piece of equipment or any of its EHS measures falls below a certain pre-defined threshold, it will be possible to schedule asset maintenance before it fails. For instance, the pump described in Section 4.1.5 has a health score of 66.7, an MTBF of 473.85 days, and an MTTR of 8.7 days, implying that the asset's availability is approximately 98.2%. However, despite the relatively good availability of the asset, the fact that its temperature and flow rates have zero scores shows that the asset has started deteriorating. In the case where maintenance actions are taken based on this early indication, the modifier score is anticipated to improve, failure frequency to decrease, and MTBF and availability levels to be maintained or improved in the next period of operation. A more extensive quantitative validation exercise for all the equipment categories will be carried out in future studies after full deployment and collection of enough post-maintenance operation data.

Ablation Study of the EHS Framework

Table 11 shows the results of the numerical ablation analysis; it can be seen that the elimination of any one of the health indicators leads to the loss of comprehensiveness of the final assessment. The greatest loss occurs when the modifier score is removed, which shows the significance of the information about current condition monitoring.

Table 11. Ablation study of the proposed equipment health score framework

Model Configuration	Storage Tank EHS	Piping EHS	Pump EHS
Full EHS Model	**85.99**	**80.64**	**66.70**
Without Initial Health	82.45	75.21	63.18
Without Modifier Health	76.82	71.36	54.92
Without Reliability Health	79.64	74.83	58.47

CONCLUSION

A comprehensive EHS model that incorporates all information about static, rotating, and electrical equipment used in oil refineries was created in this research through the use of lifecycle condition, operational measurements, maintainability, and reliability information within an integrated 0-100 scoring model. This model helps to evaluate equipment specifically while maintaining a common ground to compare various equipment in heterogeneous oil refineries. From the analysis of the case study, it can be observed that the storage tank scored the highest EHS score of 85.99, followed by the piping system, which scored 80.64, while the pump scored the lowest score of 66.70. The pump has a very critical role since it scored 98.30 as a modifier score but scored zero for initial health score and 25.70 for reliability. This framework thus provides a solid foundation for maintenance planning, condition-based intervention, and risk-oriented asset management. With regard to real-time measurements, inspection information, CMMS data, MTBF, MTTR, lifecycle factors, and reliability measures, this technique provides a clearer picture of the equipment condition compared to methods using individual indicators. The comparative study shows that the framework developed enhances the existing asset assessment techniques in the sense that it combines all these variables into a single health score. Future research efforts should be aimed at long-term validation of the method at other refinery facilities and using bigger samples of equipment. The weights in the health score formula and the decision thresholds can be adjusted with the use of historical failure data and post-maintenance information. Machine learning can also be used to adjust the weights, predict equipment degradation, and remaining useful life. Combining the model with digital twin technology, automated CMMS/CM techniques, and real-time dashboards can allow health scores to be updated continuously. The post-implementation effect of improved failure rate, MTBF, availability, maintenance costs, and risks should also be investigated.

REFERENCES

[1] Barua MK. Digital-Twin And IOT-Based Condition Monitoring for Rotating Machinery and Process Equipment in Petrochemical and Industrial Environments. American Journal of Scholarly Research and Innovation. 2026 Apr 11;5(01):382-428. https://doi.org/10.63125/mwdnjv55

[2] Sarkar S, Dhanekula A. Reliability-centered maintenance optimization using multi-objective AI algorithms in refinery equipment. American Journal of Scholarly Research and Innovation. 2023 Dec 28;2(01):389-411. https://doi.org/10.63125/6a6kqm73

[3] Animah I, Shafiee M. Condition assessment, remaining useful life prediction and life extension decision making for offshore oil and gas assets. Journal of loss prevention in the process Industries. 2018 May 1;53:17-28. https://doi.org/10.1016/j.jlp.2017.04.030

[4] Khrakhuean W, Chutima P. Real-time induction motor health index prediction in a petrochemical plant using machine learning. Engineering journal. 2022 May 31;26(5):91-107. https://doi.org/10.4186/ej.2022.26.5.91

[5] Muthanandan S, Nor KA. Condition monitoring and assessment for rotating machinery. InRotating machineries: Aspects of operation and maintenance 2018 Sep 26 (pp. 1-22). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-13-2357-7_1

[6] Almazer MS. AI-Driven Integrated Maintenance for Rotating Equipment: Connecting Condition Monitoring, Instrumentation, and Diagnostic Systems. InSPE Kuwait Oil and Gas Show and Conference 2026 Feb 3 (pp. SPE-231015). SPE. https://doi.org/10.2118/231015-MS

[7] Kande M, Isaksson AJ, Thottappillil R, Taylor N. Rotating electrical machine condition monitoring automation—A review. Machines. 2017 Oct 19;5(4):24. https://doi.org/10.3390/machines5040024

[8] Eyayo F. Evaluation of occupational health hazards among oil industry workers: A case study of refinery workers. IOSR J Environ Sci. 2014 Dec;8(12):22-53. https://doi.org/10.9790/2402-081212253

[9] Sircar A, Yadav K, Rayavarapu K, Bist N, Oza H. Application of machine learning and artificial intelligence in oil and gas industry. Petroleum Research. 2021 Dec 1;6(4):379-91. https://doi.org/10.1016/j.ptlrs.2021.05.009

[10] Laurent P, Moreau C. Ethical Leadership and the Mitigation of Unethical Pro-Organizational Behaviour.

International Academic Journal of Organizational Behavior and Human Resource Management. 2026;13(3):43-55.

[11] Qasem A. Performance Assessment Model for Petrol Stations Using a Multi-Criteria Condition Rating Index. Sustainability. 2025 Mar 7;17(6):2355. https://doi.org/10.3390/su17062355

[12] Perveen R, Kishor N, Mohanty SR. Off-shore wind farm development: Present status and challenges. Renewable and Sustainable Energy Reviews. 2014 Jan 1;29:780-92. https://doi.org/10.1016/j.rser.2013.08.108

[13] Temizel C, Canbaz CH, Palabiyik Y, Putra D, Asena A, Ranjith R, Jongkittinarukorn K. A comprehensive review of smart/intelligent oilfield technologies and applications in the oil and gas industry. InSPE Middle East Oil and Gas Show and Conference 2019 Mar 15 (p. D042S087R001). SPE. https://doi.org/10.2118/195095-MS

[14] Farhood AS. Analyze the efficiency of banking risk management in banks operating in the local environment through the application of Basel standards in financial risk management. International Academic Journal of Social Sciences. 2023;10(2):39-52. https://doi.org/10.9756/IAJSS/V10I2/IAJSS1011

[15] Hou L, Wang Y, Wang X, Maynard N, Cameron IT, Zhang S, Jiao Y. Combining photogrammetry and augmented reality towards an integrated facility management system for the oil industry. Proceedings of the IEEE. 2014 Jan 20;102(2):204-20. https://doi.org/10.1109/JPROC.2013.2295327

[16] Nautiyal A, Mishra AK. Machine learning approach for intelligent prediction of petroleum upstream stuck pipe challenge in oil and gas industry.Environment, Development and Sustainability. 2025 Oct;27(10):24167-93. https://doi.org/10.1007/s10668-022-02387-3

[17] Abbasi H, Seyedi M, Mozafaripour E, Bayati M, Nobari H, Shams A, Rohani H. Development and validation of the observational static posture assessment tool (OSPAT): a holistic approach to postural evaluation. Sport Sciences for Health. 2025 Jun;21(2):1071-9. https://doi.org/10.1007/s11332-025-01345-6

[18] García J, Fernández L. Corporate social responsibility and sustainable business performance: Evidence from emerging economies. International Academic Journal of Humanities. 2024;11(2):24-32.

[19] Wanasinghe TR, Wroblewski L, Petersen BK, Gosine RG, James LA, De Silva O. Digital twin for the oil and gas industry: Overview, research trends, opportunities, and challenges. IEEE Access. 2020 Jan 1;8:104175-104197. https://doi.org/10.1109/ACCESS.2020.2998723

[20] Rose M, Bjorner JB, Gandek B, Bruce B, Fries JF, Ware Jr JE. The PROMIS Physical Function item bank was calibrated to a standardized metric and shown to improve measurement efficiency. Journal of clinical epidemiology. 2014 May 1;67(5):516-26. https://doi.org/10.1016/j.jclinepi.2013.10.024