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Maintenance Management of Aging Oil and Gas Facilities

*Riaz Khan, Ammeran B. Mad, Khairil Osman
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Abstract

Oil and gas operators are now being driven to now operate beyond their originally conceived design life and field life. Asset life extension (ALE) beyond these thresholds presents unique safety and business risk challenges for the oil and gas industry. With aging equipment and facilities, operators face increasing challenges in maintaining equipment reliability and integrity as well as operational safety. Aging factors do not only involve hardware but also human and organizational factors. Factors include corrosion, erosion, fatigue, equipment obsolescence, normalization of deviance (accepting degraded conditions as being normal), changes in codes and standards and lack of data to forecast future risks. The challenge is magnified if there is a large fleet or large amount of aging assets that needs to be managed. In this chapter, a responsible approach to ALE, where assets can continue to be operated safely and resources are adequately managed, is provided herein.

Keywords: maintenance management, asset life extension, integrity management, safety critical element, oil and gas producers

1. Introduction

Oil and gas facilities range from both upstream and downstream assets to include offshore structures, onshore tank farm facilities. Offshore structures may include the typical fixed offshore structures, monopods, guyed wire caissons to the more complex deep water assets including Floating Production and Storage Offloading (FPSO), Mobile Offshore Production Unit (MOPU), Tension Leg Platform (TLP) and semi-submersible structures (**Figures 1 and 2**).

Extending operation facilities beyond design life presents safety risks, business risks and operational challenges to the oil and gas industry. These risks affect significant business decisions and need to be quantified and managed as we strive for continuous operations of aging assets. Aging assets and equipment present increased challenges in maintaining equipment integrity and hence, will need to be managed accordingly. These could be because of a cumulative degradation and risks over time, which includes:

- Degraded materials of construction due to corrosion related mechanisms;
- Erosion, wear, fatigue or cracking mechanisms;

- ‘Slow burn’ degradation mechanisms;
- Obsolescence of equipment leading to potential lack of spares, high cost of spares, etc.;
- Normalization of deviance associated with human factors (i.e. accepting degraded conditions as being the new normal);
- Lack of data trending to forecast future risks to safety and business continuity;
- Failure to record the accurate status of safety critical elements (SCE) over time;
- Changes to engineering codes and standards;
- Loss of technical competence (qualifications + training + experience) in the industry;
- Introduction of foreign materials into the production systems (e.g. Chemicals for Enhanced Oil Recovery (EOR), downhole sand consolidation, chemical tracers, off spec water injection, etc.).

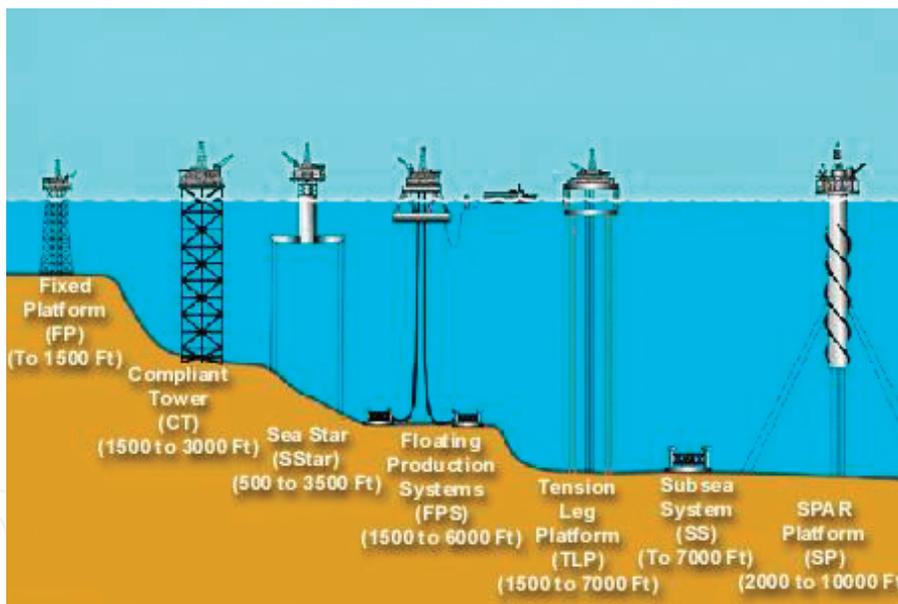


Figure 1.
Typical offshore structures [1].



Figure 2.
Typical onshore tank farm facility [2].

Assets are required to predict and understand the effects of deterioration, or changing conditions associated with life extension and be prepared to intervene to ensure that this demand can be met without adverse effect on asset integrity and safety. Asset life extension (ALE) for a given design life expiry, refers to a condition whereby an asset is approaching its intended design life. The main aging factors that need to be considered when developing an ALE program are material degradation (Figure 3), obsolescence and organizational issues. This is provided within Figure 4.

The status of the known degradation mechanisms applicable for safety barriers should be evaluated and documented. The basis for acceptance of deviations and management of change (MoC) is reviewed in as a justification for the new mode and timeframe for continuous operations. The engineering evaluations of all changes and eventually mitigation measures against all operating risks must be documented. OGP must review, evaluate assess all damage mechanisms or defects that may impact the facilities or individual operating systems for the life extension period. This is generally applicable to damage or defects where a temporary MoC has been accepted due to a limited period of use and this period has since been changed as a result of ALE considerations. The OGP is then required to re-assess the basis for acceptance to verify that this is still valid for the new period. Components or systems with a high consequence of failure, which are not available for inspection must be identified, evaluated, analyzed, and qualified for life extension. It is required that OGP evaluate the consequence in case of failure, monitors



Figure 3.
Degradation of offshore structural component [3].

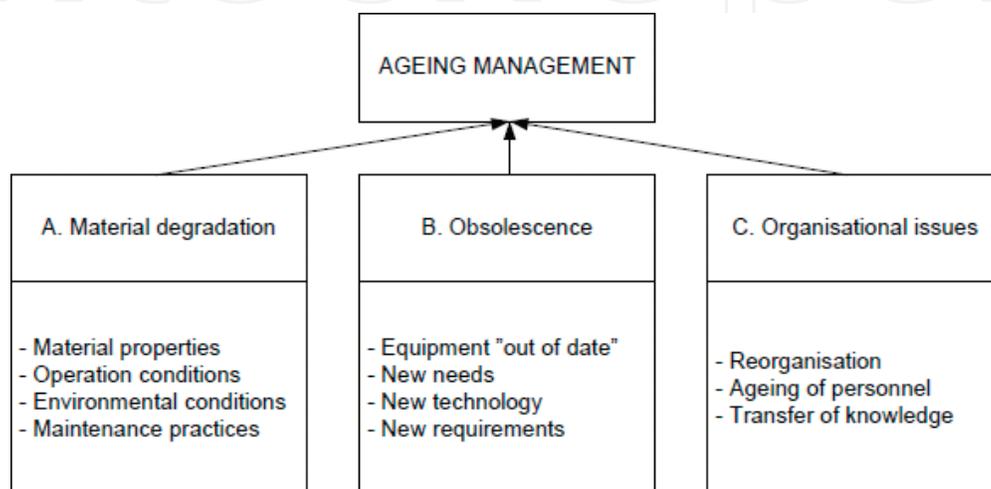


Figure 4.
Aging management [4].

indications of failure and have plans for compensating actions if indications of failure are found. Latest knowledge related to degradation and life extension shall be applied.

A case study is provided within Section 11, to demonstrate a simple application of the ALE framework and possible outcomes.

2. Operational context

As the Asset ages, there is increasing challenge to maintaining equipment and installation integrity, compliance with Regulatory requirements and improve economic hydrocarbon recovery from depleted fields. As such, life extension analysis and evaluations must be based on the planned use of the facilities during the life extension period. Changes to the operational conditions that can have an impact on the efficiency of resource exploitation, the risk profile as well as the performance of the barriers due to aging, must be considered. The potential changes to the operational conditions that influence the degradation of barriers must be identified and used as basis for life extension evaluations.

Based on Norwegian Oil and Gas Recommended Assessment and Documentation for Service Life Extension of Facilities, Rev1, 2012 [5] and operational data and requirements, the following should, among others, be considered:

- reservoir depletion causing subsidence of the facility
- shallow gas detection and mitigation
- changes in climatic conditions resulting in changes to environmental loadings and operating conditions
- Increased changes in fluid compositions that can adversely affect the corrosion rates in certain systems
- Changes to the original design assumptions as provided in QRA etc.
- Well and drilling factors
- Plans for increased gas flow
- Need for new process or utility equipment due to changed flows, chemistry, pressure, injection or chemicals
- Changes to the SCEs on the facility
- New methodologies to simulate damage and degradation.
- Changes to equipment usage.

3. An asset life extension program

The basis for the design and design life of facilities with its associated platform, wells, subsea systems and pipelines may be different. When facilities are planned to be used beyond design life, OGP should define the life extension period for which

the different parts of the facilities are planned to be used. An ALE framework outlining the main tasks as a six (6) step process is proposed and provided below on **Figure 5**.

3.1 Data and information

The collection of data and information is often the most challenging aspects of commencing an ALE study. It is recommended that records be securely placed within an electronic database generally used to manage asset integrity and reliability solutions. The availability and accuracy of information should be evaluated for each facility considered. The information should constitute design basis and specifications, design and as built drawings, design/(re-) analysis reports, inspection reports, maintenance and repair records and specifications. Once these records have

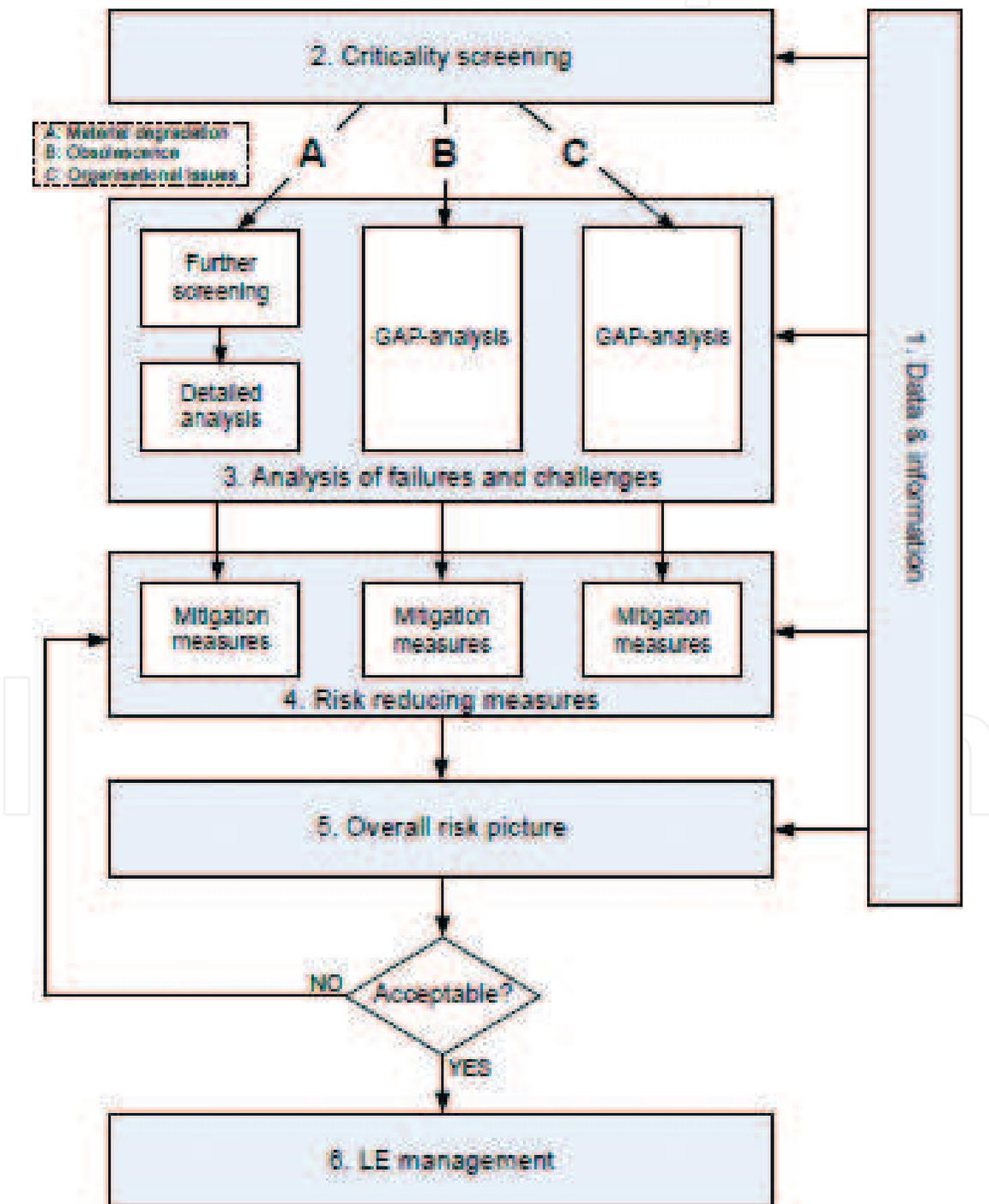


Figure 5.
Asset life extension process [6].

been complied, data quality measures should ensure the appropriate data for screening. In some cases, the data analytics and trending measures give a better representation of the data set and how this can be used effectively in an ALE program.

3.2 Gap assessment

Gap assessment is the second stage of an ALE process. Identifying gaps can be broken down to several steps, which includes:

- Identify hazards and critical barriers.
- Check integrity and functionality of barriers.
- Assess current performance of barrier against intent.
- Review historic performance of barriers.
- Review current state of maintenance and gaps.

The gap assessment shall focus on the barrier functions and the factors that influence the barrier elements. This includes technical, organizational and operational elements. The gap assessment and recommendations are performed based on the major inspection findings, root cause failure analysis reports, modification implemented on the equipment, bad actor list, history of incidents, maintenance report, overhaul findings, reliability data, operating and maintenance philosophy and any condition monitoring recommendation. Any life extension recommendation must take the future technical condition, operating parameters and mode of operation into consideration. The assessment should also include review of the forecasted production profile, exploiting synergy with other related equipment such that key assets and system infrastructure can be rationalized, optimized or expanded. A process for the identification and correction of gaps is provided within **Figure 6**.

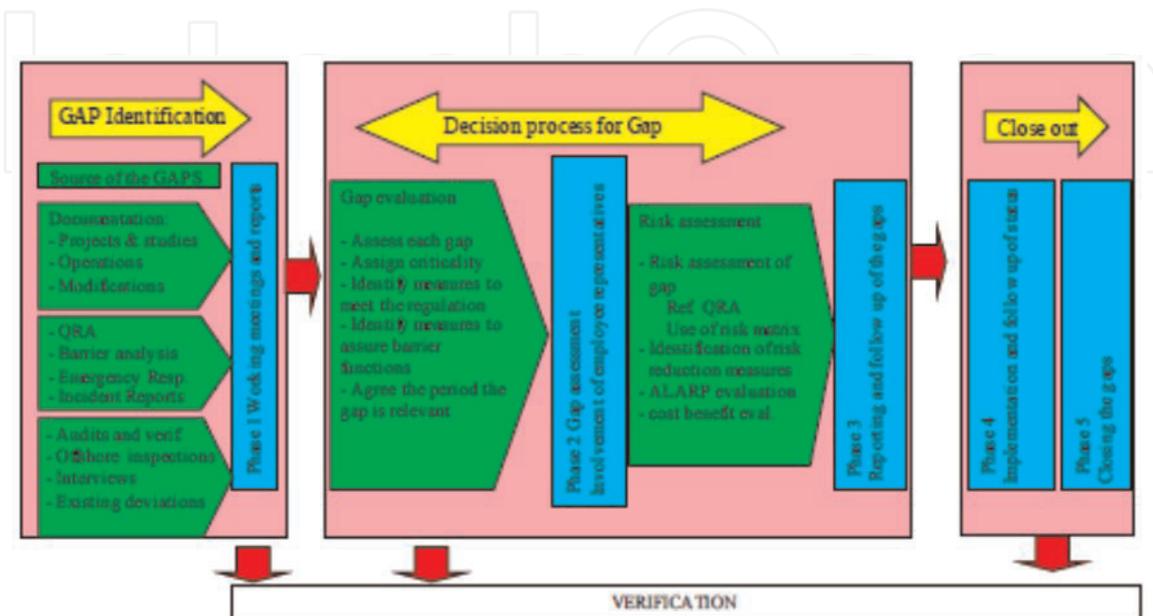


Figure 6. Process for identification and correction of gaps [5].

The recommendations from the gap assessment are to cover all the remedial actions necessary to prevent the risk associated with spare strategy, obsolescence related to the equipment and spare parts, remnant life analysis and prediction of future failures modes and degradation mechanism especially related to aging during the extension period. The benefits of applying new technology in addressing the gaps shall be evaluated. This could help mitigate or close gaps with less modifications or compensating measures. The Health and Safety Executive, UK (2013) KP4 Report [7] outlined the following safety management systems as being the barriers on the facilities that are not to be breached. They include:

- Structural integrity;
- Process integrity;
- Fire and explosion;
- Mechanical integrity;
- Electrical, control and instrumentation;
- Marine integrity;
- Pipelines;
- Corrosion;
- Human factors.

In addition to the above mentioned the following systems may be considered

- Cranes and lifting equipment
- Telecommunication facilities
- Subsea systems
- Life-saving equipment

Oil and gas producers (OGPs) are to perform analyses and evaluations to demonstrate and understand of how the time and aging processes will affect HSE, the facilities barriers including technical operational and organizational aspects and resource exploitation. They shall also identify measures required to mitigate the impact of the time and aging processes (**Figure 7**).

The Norwegian Oil and Gas Recommended Assessment and Documentation for Service Life Extension of Facilities, (2012) [5] provides good guidance on the processes, resources and methodologies used in the ALE approach to find the “as is” condition and re-qualification for life extension and how to implement and document. Safety critical elements (SCEs) such as wells, subsea jacket structures, pipelines, risers, mechanical equipment etc. are to be qualified for the continuous operations and asset life extension. Quantitative and qualitative assessments are generally employed for equipment where known degradation mechanisms are prevalent and where quantitative models exist to calculate degradation, remaining margins and prediction of remaining service life. Quantitative analysis including

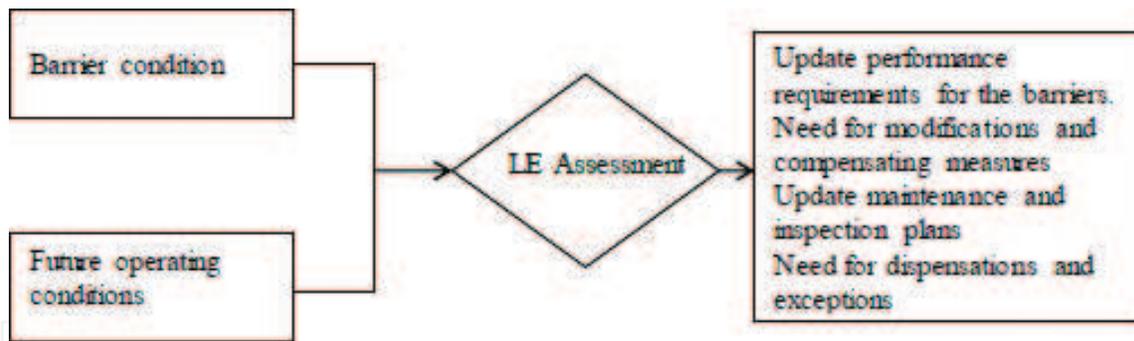


Figure 7.
Recommended life extension assessments of barriers [5].

probability of failure (PoF) is generally employed for structures, pipelines, position mooring, and flexible or steel catenary risers etc. and requires string technical expertise and often specialist software packages. Qualitative assessments is also possible but must be supported by effective data management and operating historical data to make good engineering assessments.

3.3 Risk factors and assessments

Risk assessments must be performed to verify that the facilities risk level is within acceptable limits in the period of life extension and As Low as Reasonably Practicable (ALARP). The principle of ALARP is in widespread use in the oil and gas industry. The following risk evaluations shall be performed based on the context defined for life extension:

- Accumulation of Operational Risk Assessments (ORA), as some of which may be decoupled because they have been considered in isolation and not in combination, potentially resulting in unknown increased risks
- Risk assessment of major accident risk, Quantitative/Qualitative Risk Analysis (QRA)
- Emergency preparedness and response
- External environment
- Occupational safety, health and working environment.

Ensuring risks have been reduced to ALARP means balancing the risks against the costs to further reduce it. The decision is weighted in favor of health and safety because the presumption is that OGP should implement the risk reduction measure. It is expected that the latest available technology and knowledge related to analysis of major accidents is applied. The conservatism level and any assumptions made in risk assessments are to be assessed and evaluated for all continuous operations. The vulnerability, actual and expected effectiveness of the barrier function, including technical, organizational and operational elements shall be included in the risk assessment.

The OGP risk matrix consists of a consequence axis and a likelihood axis. The consequences are those of credible scenarios (taking the prevailing circumstances into consideration) that can develop from the release of a hazard. The potential worst case consequences, rather than the actual ones (that may have occurred

PoF					
CoF	1	2	3	4	5
1	Green	Green	Green	Green	Yellow
2	Green	Green	Green	Yellow	Yellow
3	Green	Yellow	Yellow	Yellow	Red
4	Yellow	Yellow	Red	Red	Red
5	Yellow	Red	Red	Red	Red

Figure 8.
 Typical risk matrix used by oil and gas producers (OGPs).

previously), are used. After assessing the potential outcome, the likelihood on the vertical axis is determined on the basis of historical evidence or experience that such consequences have materialized within the industry, the entity or a smaller unit (Figure 8).

3.4 Maintenance management system

Effective inspection and maintenance are important in ensuring asset integrity and reliability. In developing the maintenance management systems an initial review is required determine status and how the aging processes is covered in the existing maintenance program. The review is to evaluate the need for updating the integrity, reliability, vulnerability and consequence analysis for continuous operations in the future. Experience and knowledge from documented failures and lessons learnt shall also be part of the evaluation and be used to improve the maintenance management system. In principle, the maintenance management system should be within a computerized database with detailed history of the operating, design, assessment, inspection and maintenance records accessible to all key personnel.

4. Emergency preparedness

A review of the current emergency response systems must be performed, including an evaluation of how operational changes and new requirements will be met in the period of life extension. If there is a change in operating philosophy, HSE Case shall be revisited. OGPs are to evaluate any likely operational or organizational changes to the facilities that will affect the emergency preparedness and response systems.

5. Organizational and human factors

Human factors area comprises methods and knowledge which can be used to assess and improve the interaction between people, technology and organization to realize efficient and safe operations. The factors should include organizational

structure, competency or training requirements, and succession planning. Human factors analysis shall be performed where changes are made or where extended life challenges the established human, technology and organizational context. Organizational system is also a factor to be considered, which aspects include engineering design, contract and procurement management. Engineering design and related procurement activities require a thorough and careful consideration of asset aging and life extension factor. The risk from each finding and the overall potential (future) risks shall be evaluated before deciding on the implementation of measures.

6. Assurance and verification

The OGP is to ensure that experience on lifetime extension from other installations and operating areas is applied to the analyses and evaluations carried out for the application. Any specific relevant information shall be included in the application document. OGPs are to ensure that the analyses and evaluation work has been carried out in accordance with the regulations, the relevant company standards and have been verified by the appropriate technical discipline authority.

7. Occupational health

The OGP will evaluate the status of working environment factors that are relevant for life time extension, prior to the commencement of implementing ALE. Factors that should be include considerations for chemical/radiation exposure, lightning and ventilation, ergonomics, noise/vibration pollution, material handling and storage, outdoor operations and accommodation facilities.

The main objective of the evaluation is to provide a status of the working environment according to both technical and operational requirements. The assessment/evaluation are appropriately based upon existing conditions at the facility, and if necessary, follow-up with new evaluations and assessments as required. The operational risks of each from each finding and the future risks shall be evaluated before deciding on the implementation of measures for improving working environment.

8. Engineering design

All assets are required to have design documentation available and accessible, which supports effective design at all stages of the asset life cycle and in relation to the management of aging life extension. All engineering activity to be undertaken throughout the anticipated service life of an asset should properly address life extension considerations.

9. Asset life extension for fixed offshore structures

Zettlemoyer [8] provides a template for the asset life of fixed offshore structures. In general, the main source of interest or ALE involves the jacket substructure which are essentially made up of tubular steel sections welded together to form a truss system. For fixed offshore structures, the jacket template or truss system is

considered as a structural safety critical element (SCE), so the integrity must always intact (**Figure 9**).

The jacket template substructure is to be assessed for ALE in terms of ultimate strength of the structure and fatigue life assessments. The values for the ultimate strength results are represented in terms of an RSR (Reserve Strength Ratio). The RSR is the ratio of the base shear at collapse/base shear at the 100 Yr environmental loading (i.e. the design condition). Ultimate strength analysis is also called a pushover analysis or collapse analysis and involves non-linear analytical methods (**Figure 10**).

For new structures a RSR value is generally over 2.0. As platforms operate for some time, degradation due to corrosion, damage due to accidental damage (vessel collision, dropped objects) is possible. Offshore structures are inspected and anomaly management is performed to detect and repair damage based on severity levels over its operations. It is expected that the RSR may be compromised and reduced if damage is unmitigated.

For every operating region the acceptance criteria need to be determined as it varies from region to region for varying levels of environmental loading. In the Gulf of Mexico (GoM) minimum acceptance criteria based on API RP2A are provided in **Table 1**.

The operations for fixed offshore structures can be extended if the platform in principle has greater than its minimum RSR values. For asset life extension, it is expected that all severe damage to structures has either been repaired or reduced to a manageable condition, prior to the migration to ALE. In essence the topsides of the fixed offshore needs to be appropriately assessed. This is generally done by using a risk based maintenance (RBM) program where anomalies are rectified due to severity levels. These topside RBM should be aligned to other topsides programs including piping, equipment skids and vessels to ensure that the maximum use can be made of allocated resources.

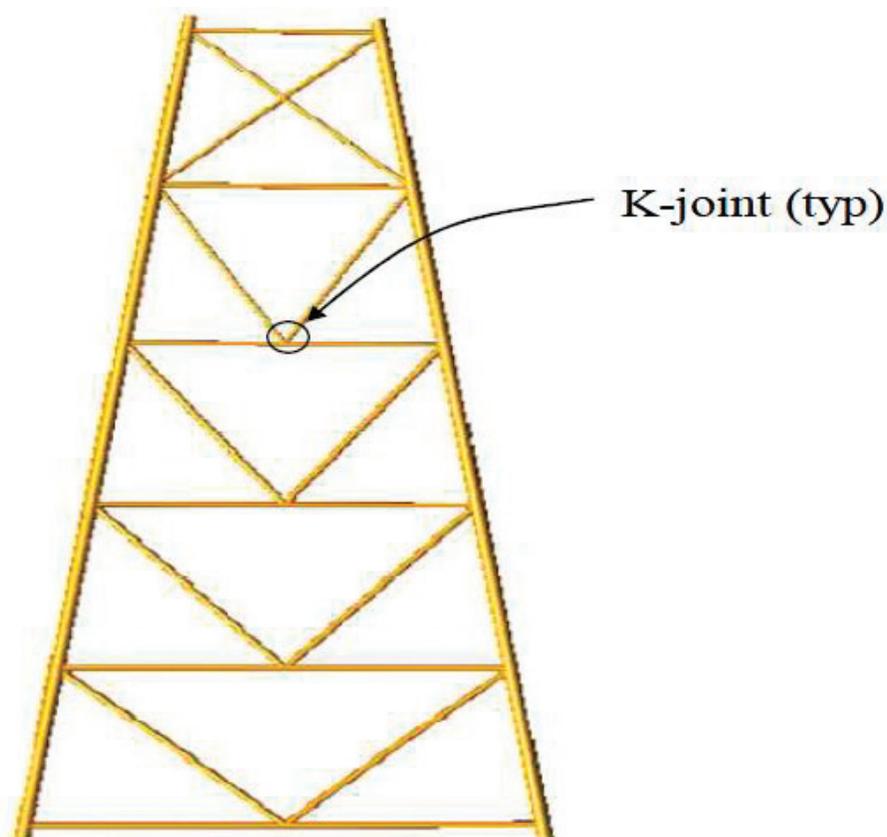


Figure 9.
Typical jacket substructure for a fixed offshore structure [8].

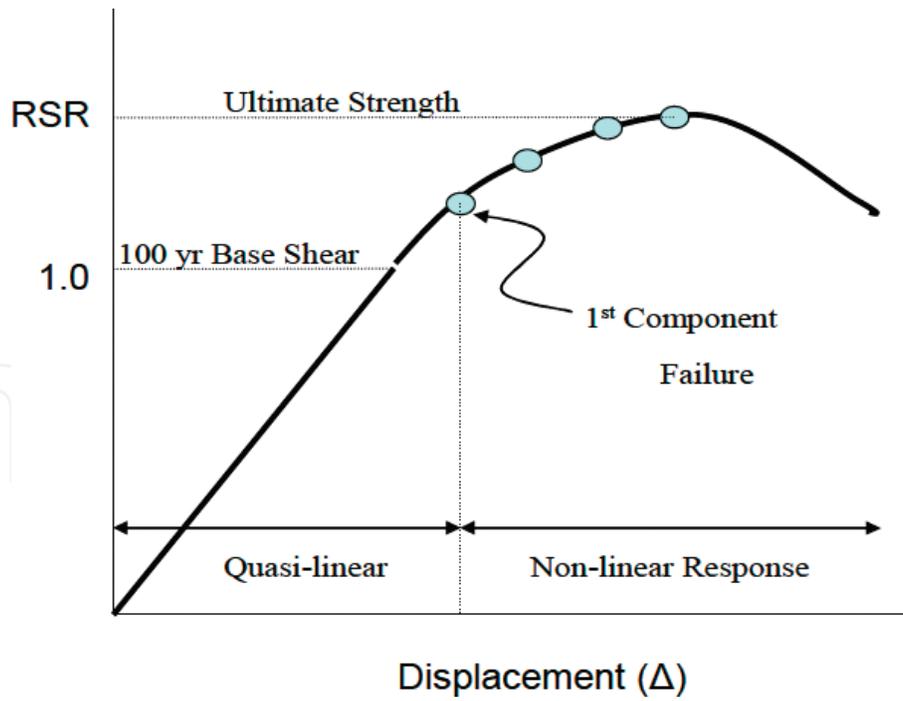


Figure 10. Typical schematic for load displacement curve—ultimate strength [8].

Assessment Category	Minimum RSR	
	GoM	West Coast
A-1	1.2	1.6
A-2	0.8	X
A-3	0.6	X

Table 1. Minimum RSR values for the Gulf of Mexico (API RP 2A, 2014) [9].

The other key performance indicator for tubular joints is fatigue life prediction. In recent years through the use of proper joint configuration in design, use of joint flexibility approaches in analysis, the issue of fatigue life estimation has been argued away. In principle the acceptance criteria for ALE for a fixed offshore structure is the exceedance of the minimum RSR values. In recent years, integrity management codes of practice including API RP2SIM (2014) [10], ISO 19902:2007 [11] provide guidance on the ALE for fixed operating steel structures.

10. Case study

10.1 Aging electrical component

Facilities are designed typically with a life span of 20–25 years. However, it is becoming common for facilities, both on-shore and off-shore, to be operated beyond its life span. While assets are designed for 20–25 years, equipment age differently and suffer from different age-related failure mechanisms. Other than aging, electrical, control and instrumentation equipment suffer from obsolescence. This is primarily due to unavailability of components and end of hardware/software support.

10.2 Situation

A downstream refinery experienced control issues with its two reactor and regenerator slide valves on its Residue Fluid Catalytic Cracker (RFCC) unit. The symptom, initially, manifested as valve hunting. This progressively worsened to the point where the valves had to be put on manual hand wheel control. While this action temporarily stopped the valve hunting, it made control of the reactor and regenerator catalyst level very difficult as operators had to be on-site to adjust the valve opening manually. Left unresolved, the likely consequence of this situation was a process upset and RFCC unit trip. This would also cause a cascade effect, resulting in the shutdown of other units, incurring significant production losses and HSE exposure (**Figure 11**).

10.3 Problem analysis

The problem was initially thought to be due to a failure of the HPU control module. However, the problem was traced, eventually, to a failing DC power supply unit (PSU) which powers the control module. Once the problem was identified, replacement of the power supply unit resolved the issue. What should be noted from this seemingly straightforward problem is that both reactor and regenerator HPU units had suffered from the same problem. On closer inspection, both power supply units were of the same make and had been first installed (as part of the HPU units) at around the same time. At the time of the incident, the power supply units



Figure 11.
A typical FCCU slide valve actuator (left) and HPU control module (right) [12].

were estimated to be 10 years old. Aging was attributed as the cause of the problem, as within 6 months, another slide valve HPU had also suffered from an almost similar problem.

There are several failure mechanisms that are typically found due to aging. Unfortunately, a detail inspection of the power supply unit was not carried out to identify the aging mechanism. **Table 2** shows common aging mechanism for primary containment (piping, vessels, heat exchangers), structures, safeguarding systems and electrical, control and instrumentation (EC&I) [HSE UK RR823 Plant Aging Study] [8].

10.4 Solution

The multiple failures within a short period of time was a strong indication of an age related failure, as opposed to a random failure. As a result, several actions were taken:

- All HPUs with PSU of similar make and type were identified.
- PSUs were replaced (like-for-like replacement).
- A Preventive Maintenance (PM) plan was created in PMMS to replace the PSUs every 8 years.
- Learnings (failure mode, failure mechanism, failure rectification) were incorporated into the technician training program for future ease of troubleshooting.

Due to the potentially high consequence of production loss from this failure, other components of the HPU were also scrutinized. Other critical components, and possible single points of failure, were identified. These were parked for future improvements for the next asset refresh cycle. A similar exercise to this would be to perform a failure mode, effects and criticality analysis.

To ensure these upgrades were implemented in the next possible opportunity, the equipment upgrade was parked into the refinery's 5-year CAPEX plan. The site's

Ageing Mechanism	Primary Containment	Structures	Safeguards	EC&I
Corrosion	✓	✓	✓	✓
Stress Corrosion Cracking	✓	✓	✓	
Erosion	✓	✓	✓	✓
Fatigue	✓	✓	✓	
Embrittlement	✓	✓		✓
Physical damage	✓	✓	✓	✓
Spalling		✓		
Weathering		✓	✓	
Expansion/ contraction due to temperature changes (process or ambient) or freezing	✓	✓	✓	✓
Instrument drift				✓
Dry joint development				✓
Detector poisoning				✓
Subsidence		✓	✓	

Table 2.
Typical aging damage mechanism (HSE UK RR823 Plant Aging Study) [13].

Equipment Obsolescence Masterplan was also updated. This is typically reviewed on a yearly basis to manage overall life cycle of aging EC&I assets. **Figure 12** is an example of an equipment obsolescence dashboard which lists EC&I equipment asset, obsolescence status and remedial plan.

This case study highlights several important aspects of managing aging assets:

- Information is in the data. Useful insights can be obtained through data analysis. Equipment failure rate, for example, will show whether an equipment is approaching end-of-life. However, quality data is essential and data clean-up often is required before analysis can be done.
- Obsolescence management is essential for EC&I equipment. All equipment should be captured in an asset list and the aging strategy should be clearly defined. This could be through various way which include replacement, upgrade, life extension (through supplier extended support), life extension (with available spares) or run-to-fail.
- EC&I equipment typically will have shorter life-cycle than an asset overall design life. Therefore, EC&I aging strategy has to be put in place much earlier than other assets such as structures and mechanical equipment. With E&CI equipment, analysis down to the major component level (e.g. PSU) should be done. This may need to also include supporting equipment such as interface modules, equipment communicators and workstations as well as software.
- Remediation of aging asset can be based equipment criticality and/or actual equipment condition. There are various methodologies that can be employed to determine equipment criticality such as failure mode, effects and criticality

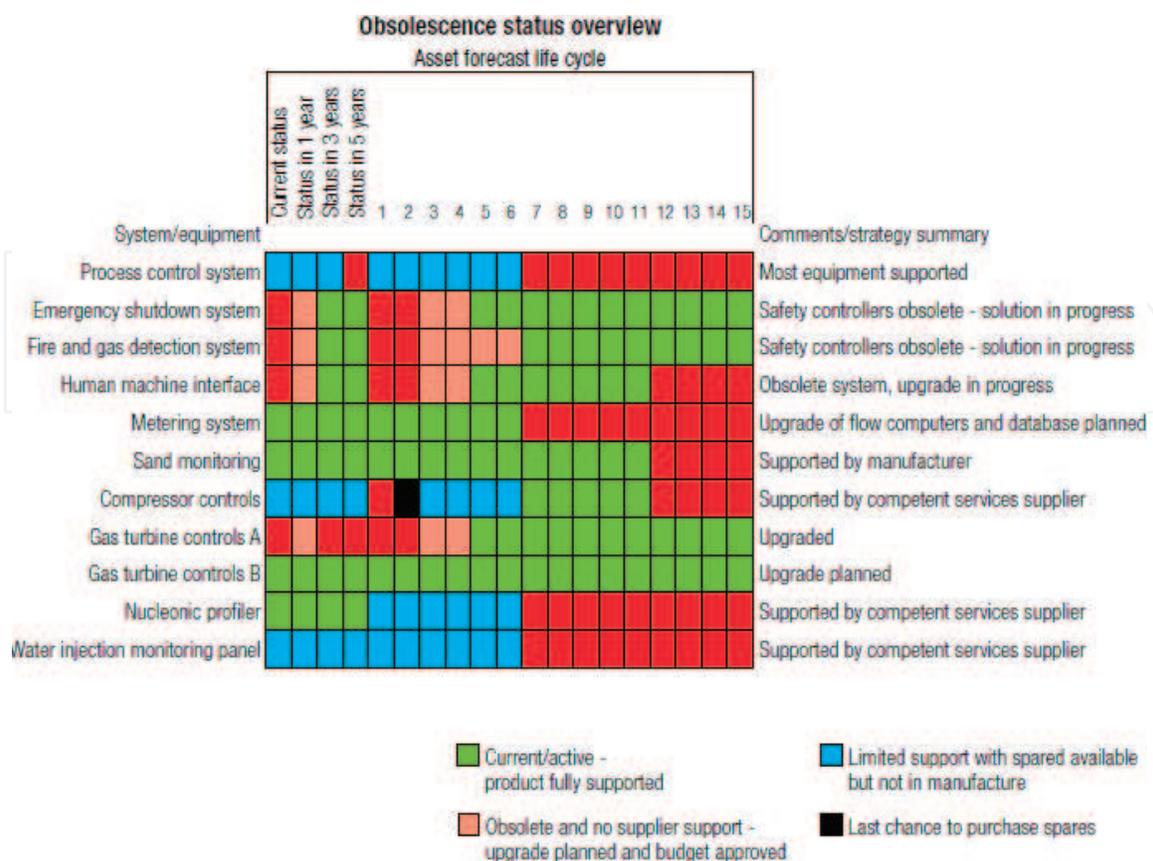


Figure 12. Example of an equipment obsolescence dashboard (HSE UK KP4 report) [7].

analysis (FMECA), reliability availability and maintainability (RAM) analysis, and even layers of protection analysis (LOPA), among others. Each methodology puts a different focus on equipment reliability and integrity.

- The human aspect of managing aging asset should not be under-estimated. Knowledge is lost when people move or retire. Therefore, knowledge retention is key in ensuring assets can continue to be managed safely and reliably.

11. ALE reporting requirements

As a minimum, OGP's should establish the following in their submission of ALE Study Consent for Extension Report:

- Clarity on how the asset is to be operated during the extension period.
- Clarity on Fitness for Service to run up to Design Life, Remnant Life Assessment, and Life Extension requirement and Gap Closure requirement for the Asset
- Economic Analysis is performed with the following scenarios:
 1. No Further Production Enhancement Action, for three (3) different options of Crude Oil Price.
 2. Shortest Extension Period, for different options of Crude Oil Price.
 3. Longest Extension Period based on the longest remnant life of a discipline assessed, for different options of Crude Oil Price.
 4. Three further scenarios of extension period in between shortest and longest period for different options of Crude Oil Price.
 5. Sensitivity analysis for Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) for a variety of scenarios.

12. Conclusions

Oil and gas producers are often driven to continue operations beyond its design facility and are required to operate safely. There are many factors to consider when providing an asset life extension solution to aging offshore or onshore facilities. This chapter presents the key issues to consider and a prescribed methodology follow in justifying asset life extension for an aging facility. At all stages of the asset life extension, assets are required to satisfy the As Low as Reasonably Practicable criteria as a minimum for each discipline and demonstrate fitness for purpose.

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