

Critical Safety Elements in Subsea Asset Integrity Framework

Ramasamy, Jeyanthi,^{a,*} and Yusof, Sha'ri M,^b

^{a),b)}UTM Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia.

*Corresponding author: jeyanthi.ramasamy@shell.com

Paper History

Received: 30-October-2015

Received in revised form: 15-December-2015

Accepted: 30-December-2015

ABSTRACT

Safety incident provides valuable lessons learned for us to avoid similar situations from recurring. The 2010 BP Macondo incident set high impact in managing asset integrity in minimizing risk exposure. Asset integrity is defined as the ability of an asset to perform its required function effectively and efficiently whilst protecting health, safety and the environment. Asset integrity management is a continuous process throughout the project lifecycle. Few subsea related oil and gas landmark accidents showcased that asset integrity must be maintained at the highest possible standard at all times. Due to the unique nature of subsea and high cost involvement, subsea asset integrity should be given high attention from the beginning of a project's lifecycle. Based on extensive literature review, critical safety elements such as performance standard, risk evaluation and mitigation, competency safety culture are identified. Existing asset integrity frameworks are only focused on asset in operation stage and there is no robust subsea asset integrity framework during project phase. For further study existing asset integrity framework model will be studied to develop suitable asset integrity frame for subsea asset during project phase.

KEY WORDS: *Asset Integrity; Subsea, Project; Safety; Life Cycle*

1.0 INTRODUCTION

Managing asset integrity is vital for oil and gas companies because it is part and parcel of managing the risk portfolio. The 2010 BP Macondo incident set a precedent for many oil and gas companies to reevaluate their facility's asset integrity in managing their risk exposure. The downstream business has focused on asset integrity for a long time but the upstream sector has only recently shifted focus on asset integrity [33].

Exploring fossil fuel is getting ever more challenging whereby the search for new sources has expanded to complex geographical locations. Among all types of field developments, subsea developments have gained popularity. Expenditure for drilling and completing subsea wells, floating production platform and pipelines in the Asian region is expected to increase by 8% from year 2011 until 2015 [13]. Unlike topside facilities, subsea assets do not provide the same level of direct control of asset condition and only can have very little human interaction and intervention [40]. Subsea development is ever more challenging in deeper water and therefore close attention should be given during project execution phase. Subsea facility integrity management plan can be developed during the project phase when the designer's input and information on construction-led design changes can be obtained directly and easily incorporated [10].

2.0 LITERATURE REVIEW

2.1 Why Asset Integrity?

Every single incident provides valuable lessons learned for us to avoid similar situations from recurring. On 20th April 2010, an uncontrolled flow of water, oil mud, oil, gas and other materials rushed out of the drilling riser and drilling pipe on a dynamically positioned drilling vessel at approximately at 5000ft of water in the Northern Gulf of Mexico, the coast of Louisiana. Methane gas from the well under high pressure shot up in the drill column, expanded onto the platform, then ignited and exploded. This explosion caused the deaths of 11 workers, severe injuries to

many others and the release of crude to sea. The leak continued for 87 days with spills of 4 million barrels and caused massive environmental damage [9]. A series of incident investigations were carried out to determine cause of the incident. Analysis of the available evidence indicates that when given the opportunity to save time and money, tradeoffs were made for certain things such as production because it was perceived that there are no downsides associated with the uncertainties [12]. The importance of asset integrity was neglected and it caused the downfall of Deepwater Horizon.

On 10 August 2011, an oil leak was reported from the Garnet F field resulting from the failure in a subsea flow line, 176km east of Aberdeen [14]. An initial investigation by Health and Safety Executives revealed that an audit of the safety management system for the leaking pipeline was due in 2008 and had not been carried out before the incident [6]. From the causal investigation carried out on the leak, Shell has increased awareness on reducing hydrocarbon leaks within operations and increased tremendous focus on asset integrity of subsea asset [42].

The Ekofish Brovo accident that occurred on 22 April 1977 recorded the largest oil spill in the North Sea. The production Christmas tree valve was removed and a Blowout preventer was not installed; the well kicked and an incorrectly installed downhole safety valve failed [29]. The failed safety valve resulted in an oil and gas release. The blowout resulted in a continuous discharge of crude oil through an open pipe 20 meters above the sea surface with estimated rate of 1170 barrels per hour, approximately 202,380 barrels of oil escaped before the well was finally capped 7 days later [23]. The official inquiry into the blowout determined that human error was a major factor which led to the mechanical failure of the safety valve including faults in the installation documentation and equipment identification and misjudgments, improper planning and improper well control [29]. Based on the investigation finding, there were a series of asset integrity requirement which were neglected and caused the accident.

These are few examples of oil and gas landmark accidents happened in the past decades with devastating consequences and showcased that asset integrity must be maintained at the highest possible standard at all times. Due to the unique nature of subsea and its' remoteness, asset integrity should be given high attention from the beginning of a project's lifecycle.

2.2 Definition

An asset is an entity from which the economic owner can derive a benefit in future accounting period by holding or using the entity over a period of time [21]. The Institute of Asset Management defines asset management as a set of systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan [31]. UK Health and Safety Executive (2009) KP3 program defined asset integrity as the ability of an asset to perform its required function effectively and efficiently whilst protecting health, safety and the environment [52]. Subsea production systems can be defined as range in complexity from a single satellite well with a flowline linked to a fixed platform, to several wells on a template producing to a floating facility. Typical subsea production systems consist of wellheads and trees, sealines

and end connections, controls, control lines, single-well structures, templates and manifolds, remote operating vehicle (ROV) and completion/workover and production risers [2].

2.3 Asset Integrity

Asset integrity can be divided into design integrity, technical integrity and operation integrity as illustrated in figure 1. Design integrity provides assurance that facilities are designed in accordance to governing standards and meet specified operating requirements without compromising on safety, accessibility, operability and maintainability [5]. Any facility asset integrity must evolve from the design phase and the integrity management plan is developed with incorporating hardware barriers [7].

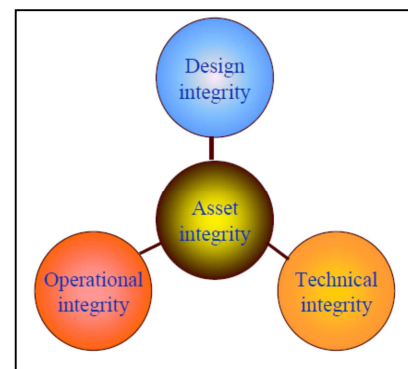


Figure 1: Sub groups of asset integrity [17]

Technical integrity is defined as the development of a design that is carried out by well trained personnel, who have been assessed to be competent in accordance with recognized, sound practices and procedures with adequate provision for reviews and audits to ensure the design intent is unimpaired in any way that could cause undue risk or harm to people or damage to the environment [19]. Asset technical integrity refers to a condition where the technical state of assets incorporates all related operations and business processes as one process to ensure that there will be no harm done to people, property or the environment [36].

Operational integrity addresses operating within an asset's operating envelope, as defined by technical barriers. Appropriate knowledge, required experience, adequate manning, competence manpower and reliable data for decision making are essential to operate the plant as intended throughout asset lifecycle [5]. Oil and gas companies have to manage assets without any incidents by managing the governance and integrity of its assets [39].

The objectives of asset integrity are to compliant to all national requirement, regulatory, company policies and standards; adapted to industry requirement and international standard and regulation; stay fit for purpose safe and operational under all circumstances; ensure all assets operate in safe manner, reliable within design parameter and efficient in its operation mode; ensure all suitable check, process and review in place to safeguard the asset ;ensure the asset design, construct, install, operate and maintain to a risk level tolerable to the ALARP concept; protect company reputation; achieve planned production forecast and follow operating and maintenance philosophy [18].

2.4 Asset Integrity Management

Most oil and gas companies use asset integrity management to manage asset integrity activities in various stage of an asset's lifecycle. Department of Mines and Petroleum refer to asset integrity as fitness for purpose (FFP) and used Figure 2 to illustrate asset integrity management [50]. The asset lifecycle can be divided into five phases; design, installation, commissioning, operation and decommissioning. The asset integrity strategies, policies, procedure and scheme are developed in early stage of assets when the failure frequencies are decreasing. During operation phase the asset design requires reappraisal and for the design life extension additional measure should be taken place. After the initial design life, asset failure frequency will increase.

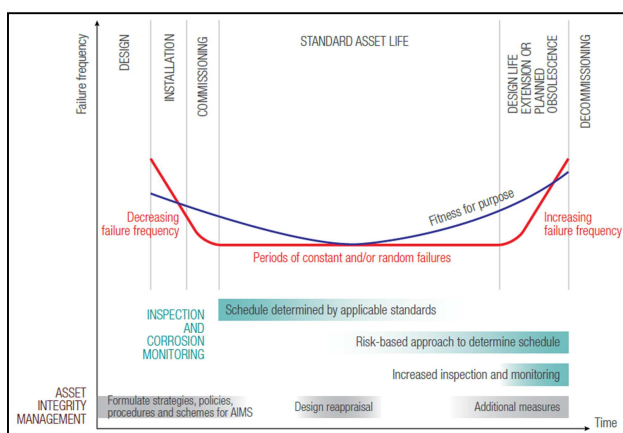


Figure 2: Fitness for Purpose graph

Asset lifecycle begins when a project opportunity enters the project funnel process. Careful consideration should be given between short term and long term benefits, between risks and reward profiles and associated costs when dealing with all stages of the asset life cycle to ensure the best value for money is achieved with asset integrity management. Phased project management processes, also known as stage and gate management processes (SGMP), is commonly used in macro and micro projects from early evaluation, to sanction the project and close it out [3]. At each project phase, the project team shall meet the requirements to move the project from current phase to next phase. In general, the SGMP aims to improve the decision making process by helping to manage the level of uncertainty and increase the quality of projects [41]. Table 1 shows the project phases associated with asset lifecycle.

Table 1: Project phases that associated with asset lifecycle

Scholar	Project Phases (Based on stage and gate management processes)				
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Walkup Jr & Ligon [46]	Feasibility /Identify	Identify (broader development plan)	Definition (detailed development plan)	Execution	Operation
Alsayari, Lauritzen, & Alqurais [26]	Concept Investigation	Strategic consensus	Strategic implementation	Installation & Evaluation	Closure
Adibhatla & Wattenbarger [4]	Screen candidate processes	Evaluate in depth	Field test uncertainties on	Commercial evaluation	Implementation, surveillance, operation

Asset integrity management is a continuous process throughout

the project lifecycle. On average there are five phases in an asset's lifecycle including identify, evaluate, concept definition, execute, and operate as illustrated in Figure3. Heavy emphasis on design integrity should be made at the concept selection and concept definition phases to establish asset integrity. Upon starting the project execute phase, the focus will be on technical integrity. The process will be continued even after project has been handed over to the operation team in the operate phase. In the operate phase, the asset definitely needs to be maintained in order to maintain the integrity of the asset.

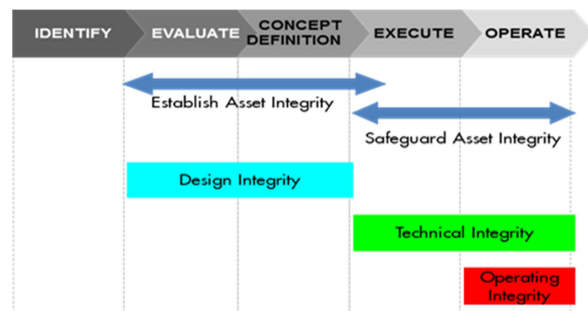


Figure 3: Illustration of asset integrity during asset lifecycle in project phases

3.0 CRITICAL SAFETY ELEMENTS

3.1 Performance Standard

In the asset integrity world, performance standard is defined as a measurable statement, expressed in qualitative or quantitative terms, of the performance required of a system, item of equipment, person or procedure and that is relied upon as basis for managing a hazard [51]. The performance standard themselves are compilation of references forming a continuous link from design standards employed to achieve the stated objectives of the barrier to the final audit functions and document location used to assure their proper implementation [11].

Performance Standards are divided into two groups; (1) initial application in the design, construction and commission phase and (2) ongoing application in the operational phase [15]. The specification can be combination national regulation, company policies and standard, industry requirement and international standard and regulation. Any deviation from performance standard requires stringent evaluation process with critical impact assessment. As cost cutting measure engineers or contractor always use excuses to deviate from performance standard. Therefore any deviation request carefully studied by panels before accepted for implementation. At each stage of asset lifecycle, after performance standards are developed the assurance process shall kick in. The verification scheme provides assurance that the suitable safety critical equipment has been identified and provided that they remain fit for purpose and are maintained in an operable and reliable condition to meet defined performance standard [25]. In some operators, the quality department oversees the assurance process with help of appointed specialist such as coating inspectors, welding inspectors, and HSE inspectors.

3.2 Risk Evaluation and Mitigation

Besides maintaining compliance with required standard, many companies' face additional challenges on managing risk profiles by deploying effective risk management programs. Large risks with small returns are typically avoided and conversely, opportunity with perceived low or manageable risks and large gains are developed and added to the portfolio [35]. Structured risk analyses are performed using processes such as hazard and effect management process (HEMP), failure and effect analysis (FMEA), bow tie diagram, quantitative risk assessment (QRA) and qualitative risk assessment identifying hazards, assessing risk, selecting control and recovery measure and comparing the resultant risk to ALARP [47]. HEMP is one of the effective tools which identify hazard and potential risk, implements control measures, and maintains a documented demonstration that HSE risk have been reduced to level that is as low as reasonably practicable (ALARP) [37]. Recent study carried out classification of risk to distinguish decision scenarios into strategic decision, operational decision, instantaneous decision and emergency decision as way to improve decision makers to understand when term of "risk" used [48].

3.3 Competency

In the petroleum industry, operators demand rigorous safety standards and risk management to avoid any mistakes that put their reputation in danger. Therefore skilled workforce becomes crucial in managing risk in oil and gas projects. Asset integrity depends on a skilled workforce doing the right thing on a daily basis. Based on analysis of definition, it concluded that competencies are permanent characteristics of person, made manifest when performing a task or doing a job, related to the successful performance of a activity either work or of another kind, have causal relationship with job performance and can be generalized to more than a activity [1]. Each stage of asset requires competencies which may deal with a person's behavior in an office environment like soft skills and abilities in business and technical skills [20]. The industry code and local regulation define the minimum competency requirement for personnel who undertake some critical activities such as crane driver, professional engineer, welding inspector and so on. Failing to comply to the requirements, companies can face serious penalties. The competent people can ensure flawless asset delivery with due diligent asset integrity management.

Competency based development is method deployed by many companies to evaluate and recognize competency and training requirement for the employees. The competency based development process involves (1) generating required job description, (2) building a competency model with set of skills (3) assessing each employee against competency model to identify gaps which competency level do not meet the standard require by the job and (4) generating and executing an individual development plan the closes the gaps [27]. Beside organizational capacity to provide adequate resources, it is important to provide sufficient diversity of perspectives to ensure that technical integrity problems are identified despite the cost and schedule pressures [22]. Most companies encourages their employee to undertake regular training which normally referred as 'Continued Professional Development' to sharpen the skills or to deepen knowledge to keep up to date with emerging technology or recognized best practices [32].

3.4 Safety Culture

Leadership is an important factor in achieving safety culture in organizations. According to Blair, Culture is often described as "the way we do things around here" or "unwritten rules" and culture arises from shared norms of behavior [49]. Corporate culture describes shared values within organizations which has strong influence among the member's attitude, value and beliefs in relation to safety and is now accepted to have strong influence over workplace accidents and injuries [8]. Safety culture that demonstrated by leaders can be very powerful mechanism to drive employee's behavior in performing daily tasks. Employee must feel empowered to do the right despite pressure completing given task.

Value can be divided as intrinsic and extrinsic. Monetary value like promotions and bonuses is referred as extrinsic value; whereby belief, ethics and environmental concern are regarded as intrinsic value. A great safety leader is sensitive to intrinsic values and is deeply committed to health and safety [49]. A leader's action will reflect the value he or she believes. For example, leader must willing to spend resources as necessary for safety activities despite being tight budgeted, always engaging teams on safety initiatives despite a tight delivery schedule, participate in daily events like toolbox talks and being supportive of team intervention that could lead to delays on construction. By demonstrating the intrinsic value beyond the monetary value will influence the employee safety culture in organization.

The corporate culture of risk taking and cost cutting as highlighted in Mocondo blowout must be avoided [12]. A leader must refer as a safety coach or reference without fear as they "walk the talks" and not just provide lip service for safety including asset integrity. Having well documented procedures and specifications alone will not promise delivery of asset integrity. Competent personnel should be key part of integrity process and should able use their skills and knowledge to fix small, routine problems as they arise than wait and hope for system deal with later.

4.0 ASSET INTEGRITY FRAMEWORK

A framework for asset integrity will be useful for achieving the goal of ensuring assets meet its full life cycle usage or intention. Subsea asset integrity framework requires the systematic and continuous monitoring of activities from concept selection, detail engineering, procurement, manufacturing, construction, installation, commissioning, operation, inspection and maintenance to meet asset integrity objectives. The ultimate aim of the framework is for asset owner to demonstrate that the assets are safe and to prove that to various stakeholders.

According to Suyanto, subsea asset integrity management is defined as the management of subsea system or asset to ensure that it delivers the design requirements and do not harm life, health or the environment throughout the required life [44]. Subsea facilities are unique and require special attention because the equipment doesn't have direct and manual access like topside equipment. Specific precautions have to be taken at the design stage to ensure that the adopted design solutions will not compromise the long term safe operation and also to develop monitoring techniques that will allow indirect conditions to be followed up, compensating for the lack of direct access for

traditional inspection means [40].

Through extensive literature, the safety critical elements safety culture, competency, performance standard, risk evaluation and mitigation are discovered as part of asset integrity framework. As shown in Table 2, it can be concluded that existing asset integrity frameworks are only focused on asset in operation stage, there is a lack of standardization on asset integrity frameworks, and there is no available subsea asset integrity framework during project phase. For further study existing asset integrity framework model will be studied intensively to develop suitable asset integrity frame for subsea application during project phase.

Table 2: Asset integrity framework by various scholars

Asset phase	International Association of Oil & Gas Producers [24]	Rahim, Refsdal, & Kenett [36]	Rocher, Perrollet, & Muir [40]	Sri-amorntham, Chingpongpan, & Chamsakram [43]	Wenman & Dim [47]	Dutta & Madi [18]	Refsdal & Ostby [38]
Design	X		X		X	X	
People	X		X	X	X		X
Plants	X		X	X	X	X	
Community				X		X	
Processes	X			X	X		X
Competence		X	X			X	X
Compliance		X			X		
Communication		X	X			X	
Collaboration		X					
Control		X	X		X	X	
Data collection			X		X	X	

4.1 Issues on Achieving Asset Integrity

Implementing and achieving asset integrity at any stage of asset life cycle can be very challenging. There are predominantly visible and invisible parameters that may impede the delivery of asset integrity. Many scholars conducted studies or compiled lessons learnt about asset integrity mainly during the asset's operation lifecycle. Bale & Edwards reported non-user-friendly procedures; poor handling of management of change, lack of experience, incompetent engineers, human error, improper training and lack of design review during the design phase can challenge the implementation of effective asset integrity management [19].

Generally in projects, lack of compliance, incompetent engineering, communication breakdown, lack of collaboration within teams are key challenges to asset integrity [36]. Poor data and knowledge transfer from construction to operation, varying quality of risk management, inadequate maintenance and safety work practice and lack of continuous process improvement can impact asset integrity of facilities [34]. In subsea field applications, Suyanto stressed on new technologies, harsher environments, complex technical issue, high cost for inspection and intervention, limited inspection intervals and longer lead time for repair are impacting the subsea asset integrity [44]. Developing suitable and efficient subsea asset integrity frameworks alone will not guarantee effective asset integrity management implementation to safeguard the asset. The research will be focused existing challenges to create efficient framework to overcome the challenges.

4.2 Subsea Development and Asset Integrity challenges

Subsea developments in shallow, deep and ultra-deep water have become a cornerstone when compared to other development options. According to the DNV GL survey, 52% of respondents expect subsea technologies to absorb the strongest investment in the coming years [16]. However subsea developments have their unique nature. The subsea development in deeper water depth presents increasing challenges in higher development cost. Operational costs with subsea installation and intervention on subsea wells are increasing at a higher rate than the cost the hardware [45]. Ratio of installation or intervention cost of hardware has increased from 1:1 for shallow water to 3:1 for deeper water. Poor asset integrity management resulting in intervention or repair work would tremendously increase costs for an asset throughout its lifecycle. To avoid heavier costs during the operation phase and lower profit margins, the asset integrity should be managed effectively from the project phase. It is believed that the right combination of people, processes and technology can safeguard asset integrity and maximize profitability. Accidents in the oil and gas industry highlighted how important it is to have appropriate asset integrity management in place to prevent them before they become a reality [28].

5.0 CONCLUSION

The primary aim of a subsea asset management framework is to detail out strategies to manage the risks associated with assets in a very systematic manner with regards to retaining asset integrity throughout its life. Many studies carried out on oil and gas asset integrity happen during the operation phase after project teams have handed over the asset and for ageing assets, during a life extension program. Very little emphasis and studies were carried out about asset integrity during the project stage inclusive of concept design, detailed engineering, manufacturing, installation and pre-commissioning stages.

Asset integrity only focused on operating assets is not ideal and should be revisited for system effectiveness from the start of an asset's life cycle. Therefore, the existing asset integrity management framework and its implementation need to be analyzed to establish an asset integrity framework for subsea assets during the project phase. The objectives of the further research are to determine how project organizations can assure subsea asset integrity at the project phase, to identify obstacles of implementing subsea asset integrity during project phase and to develop asset integrity framework for subsea asset during project phase.

Current operation phase asset integrity implementation poses many challenges as reported in Table3 are requisite for the development of subsea asset integrity framework during project phase. Asset integrity assurance processes will be intensively focused on concept selection, pre-FEED, FEED, detailed design, manufacturing, installation and commissioning activities. The obstacles that can influence the successful implementation of subsea asset integrity will be studied. Based on the outcome of obstacles, the weakness and best practices of asset integrity will be evaluated for subsea asset integrity strategy. The identified strategy will be integrated to develop a subsea asset integrity framework for project phase. Robust and rigorous subsea asset

integrity framework will safeguard subsea asset and provide assurance that subsea asset to perform its required function effectively and efficiently whilst protecting health, safety and the environment.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Higher Education of Malaysia for providing the scholarship for this study. R.J would like also like to provide her sincere gratitude to her husband Mr. Raj Thangavelu and her family for their fullest support throughout this study.

REFERENCES

- Antonio, R. S., Isabel, O.-M., Gabriel, P. S., & Angel, U. C. (2013). A proposal for improving safety in construction projects by strengthening coordinators' competencies in health and safety issues. *Safety Science*, 92-103.
- API 17A. (2002, September). *Recommended Practice for Design and Operation of Subsea Production System*, 4-5.
- Azzarone, D., & Bruni, T. (2008). Real Option Theory Complements the Stage and Gate Process: the Value of Information. *2008 SPE Europe/EAGE Annual Conference and Exhibition*. Rome: Society of Petroleum Engineers.
- B.L.Adibhatla, & Wattenbarger, R. (2009). Staged Design of an EOR Pilot. *International Petroleum Technology Conference*. Doha, Qatar: International Petroleum Technology Conference.
- Baby, R. (2008). Integrity Management during Design Stage. *2008 Abu Dhabi International Exhibition and Conference*. Abu Dhabi, UAE: Society of Petroleum Engineers.
- BBC News. (2012, February 20). *BBC News*. Retrieved May 8, 2014, from BBC News Website: <http://www.bbc.com/news/uk-scotland-north-east-orkney-shetland-17095379>
- Botto, A., Rees, J., & Hull, M. (2011). Holistic Approach to Subsea Integrity Management and Reliability and Their Application to Greenfield and Brownfield Projects. *Offshore Technology Conference*. Rio de Janeiro, Brazil: Offshore Technology Conference.
- Chib, S., & Kanetkar, M. (2014). Safety Culture: The Buzzword to Ensure Occupational Safety and Health. *Procedia Economics and Finance* 11, pp. 130-136.
- Christou, M., & Konstantinidou, M. (2012). *Safety of offshore oil and gas operations: Lessons from past accident analysis*. Italy: European Union.
- Cook, H. H., Dopjera, D. E., Thethi, R., & Williams, L. (2006). Riser Integrity Management for Deepwater Developments. *2006 Offshore Technology Conference*. Houston: Offshore Technology Conference.
- Cooke, S. J. (2012). Performance Standard Enhance Asset Integrity Assurance. *SPE Middle East Health, Security, and Environment Conference and Exhibition*. Abu Dhabi: Society of Petroleum Engineers.
- Deepwater Horizon Study Group. (2012). *Final Report on the Investigation of the Macondo Well Blowout*. Deepwater Horizon Study Group.
- Deepwater Sector Update. (2013, May/June). *Petromin*, pp. 48-52.
- Department of Energy & Climate Change. (2011, August 15). *Gov uk*. Retrieved May 5, 2014, from Gov. uk Website: <https://www.gov.uk/government/news/statement-on-oil-leak-from-pipeline-at-the-gannet-alpha-platform>
- Dhar, R. (2011). Performance Standards For Safety Critical Elements- Are We Doing Enough? *SPE European Health, Safety and Environmental Conference in Oil and Gas Exploration and Production*. Vienna: Society of Petroleum Engineers.
- DNV GL. (2014). *Challenging climates: The outlook for the oil and gas industry in 2014*. Norway: DNV GL.
- Mohamed, D., Mohamed, A., Drahb, S. & Badyab, A., 2012. ADCO's assets integrity requirement during projects execution. Abu Dhabi, UAE, Society of Petroleum Engineers.
- Dutta, R., & Madi, M. (2014). Best Practices in Asset Integrity Management System. *International Petroleum Technology Conference*. Doha, Qatar: International Petroleum Technology Conference.
- E.A.Bale, & D.W.Edwards. (2008). Technical Integrity-An Engineer's view. *Trans IChemE*, Vol 78, Part B.
- Fassihi, M. R. (2005). Competency- Based Training and Development. *SPE Annual Technical Conference and Exhibition*. Dallas: Society of Petroleum Engineers.
- Harrison, A. (2006, Feb 8). *United Nation statistics division*. Retrieved from United Nation website: <https://unstats.un.org/unsd/nationalaccount/aeg/papers/m4Ec onAssets.PDF>
- Hayes, J. (2012). Operator competence and capacity - Lessons from the Montana blowout. *Safety Science* 50, pp. 563-574.
- Incident News. (1977, April 22). *Incident News*. Retrieved May 11, 2014, from Incident News Web Site: <http://incidentnews.noaa.gov/incident/6237>
- International Association of Oil & Gas Producers. (2008). *Asset integrity-the key to managing major incident risks: Report No.415*. International Association of Oil & Gas Producers.
- Lauder, B. (2012). *Major Hazard (Asset Integrity) Key Performance Indicators in use in the UK Offshore Oil and Gas Industry*. United Kingdom: Oil & Gas UK.
- M.Alsayari, S., E.Lauritzen, J., & M.Alqurtas, A. (2011). Workflow automation of a 5-stage Gate Upstream Technology Pilot Process. *SPE/DGS Saudi Arabia Section Technical Symposium and Exhibition*. Al-Khobar, Saudi Arabia: Society of Petroleum Engineers.
- Ogle, K. C., Burley, S. D., Magan, T., Senapati, N. K., & Cornor, J. (2012). Building Technical Excellence: E&P Competency Development in India. *International Petroleum Technology Conference*. Bangkok: International Petroleum Technology Conference.
- Oil & Gas iQ*. (2014, April 11). Retrieved from Oil & Gas iQ Web site: <http://www.oilandgasiq.com/integrity-hse-maintenance/articles/addressing-asset-integrity-at-bp/>
- Oil Rig Disasters*. (2014, May 11). Retrieved May 11, 2014, from Oil Rig Disasters website: http://home.versatel.nl/the_sims/rig/ekofiskb.htm

30. Opsintegrity.com. (2014, April 12). Retrieved from Opsintegrity.com Web site: <http://www.opsintegrity.com/2012/08/01/255/>
31. PAS 55-1:2008 Asset Management. (2008). The Institute of Asset Management.
32. Pickering, J. G., & Sengupta, S. (2013). Achieving Digital Oilfield Competency . *SPE Middle East Intelligent Energy Conference and Exhibition*. Dubai: Society of Petroleum Engineers.
33. Pillai, V. (2013, September/October). Asset Integrity the Buzzword in Asia... *Petromin*, p. 6.
34. Pirie, G. A., & Østby, E. (2007, December 4). A Global Overview of Offshore Oil & Gas Asset Integrity Issues. Miami, Florida, USA.
35. R.Trammell, S., & D.Wright, R. (2014, April 3). *Evaluation of System Design Using Risk Assessment*. Retrieved from One Petro Website: <https://www-onepetro-org.proxy1.athensams.net/download/conference-paper/ASSE-00-026?id=conference-paper%2FASSE-00-026>
36. Rahim, Y., Refsdal, I., & Kenett, R. S. (2010). The 5C model: A new approach to asset integrity management. *International Journal of Pressure Vessels and Piping*, 88–93.
37. Rao, A., S.S.Rao, Sharma, T., & Krishna, K. R. (2012). Asset Integrity Management in Onshore & Offshore-enhancing Reliability at KGD6. *SPE Oil and Gas India Conference and Exhibition*. Mumbai: Society of Petroleum Engineers.
38. Refsdal, I., & Ostby, E. (2014). A Step Change In Managing Technical Integrity In The Oil And Gas Industry - A Case Study. *Offshore Technology Conference*. Kuala Lumpur: Offshore Technology Conference Asia.
39. Risktec. (2010). An Introduction to Modern Asset Integrity Management. *RISKworld*, 2.
40. Rocher, A., Perrollet, C., & Muir, K. (2011). Asset Integrity Management- From General Requirement to Subsea Facilities: Total Block 17 Experience. *Offshore Technology Conference*. Houston,Texas: Offshore Technology Conference.
41. Safra, E. B., Peru, R., Antelo, S. B., & Bolivia, R. (2010). Integrated Project Management Applied in World-Class Gas-Field Development Projects: From Theory to Practice. *SPE Latin American & Caribbean Petroleum Engineering Conference* . Lima: Society of Petroleum Engineers.
42. Shell U.K. Limited. (2012). *2012 Annual Environmental Statement For Shell U.K. Upstream Operations*. U.K.: Shell U.K. Limited.
43. Sri-amorntham, A., Chinpongpan, R., & Chansakran, A. (2012). SI Asset Integrity Model and Management System. *International Petroleum Technology Conference*. Bangkok: International Petroleum Technology Conference.
44. Suyanto, A. (2011). Subsea Integrity Management System a brief overview. *OCEANO 2011*. Surabaya: OCEANO 2011.
45. Vernotzy, R. (2013, April). Deepwater: Subsea Technology. *World Oil online*, p. Vol. 234 No.4.
46. Walkup Jr, G. W., & Ligon, J. R. (2006). The Good, the Bad and the Ugly of Stage-Gate Project Management Process in the Oil and Gas Industry. *SPE Annual Technical Conference and Exhibition*. San Antonio: Society of Petroleum Engineers.
47. Wenman, T., & Dim, J. (2012). Pipeline Integrity Management. *Abu Dbahi International Exhibition & Conference*. Abu Dhabi: Society of Petroleum Engineers.
48. Yang, X., & Haugen, S. (2015). Classification of risk to support decision-making in hazardous processes. *Safety Science* 80, pp. 115-126.
49. Blair, S., 2013. Beyond PSM: Integrating Culture and Leadership Into Process Incident Prevention. London, Society of Petroleum Engineers.
50. Department of Mines and Petroleum, 2012. Evaluation of asset integrity management system (AIMS), Perth: Department of Mines and Petroleum.
51. Anon., 2008. PAS 55-1:2008 Asset Management, s.l.: The Institute of Asset Management.
52. Offshore Division, 2009. Key Programme 3 Asset Integrity Programme, United Kingdom: HSE's Offshore Oil and Gas.