Asset Integrity Management

Challenges, planning and implementations

by

Mayang Kusumawardhani

Thesis submitted in fulfillment of
the requirements for degree of
PHILOSOPHIAE DOCTOR
(PhD)

University of
Stavanger

Faculty of Science and Technology

Department of Mechanical and Structural Engineering and Materials Science

2016

University of Stavanger
N-4036 Stavanger
NORWAY
www.uis.no

ISBN: 978-82-7644-665-4

ISSN: 1890-1387

PhD thesis no. 306

Abstract

The emergence of asset integrity management (AIM) in the petroleum industry has been encouraged by the demand for a safer and more sustainable workplace with respect to health, safety, environment, value generation and reduced risks. However, despite the current AIM development, literature shows that AIM practices in organizations still often fail and in troubled times some organizations may choose to rearrange the priorities of AIM activities, while in reality the integrity of these installations needs to be maintained at all times, regardless of the fluctuating market situation.

This study is divided into three consecutive phases that built the entire study. The first phase of the study was performed to identify and map the existing research approach in AIM. The study also proposed a structured framework as a guideline for designing AIM research. The second phase identifies the gaps between the theory and practices of AIM. The focus is to identify various challenges in volatile market conditions and how organizations can continuously ensure the safety and integrity of their offshore facilities. The study is continued by the third phase that addresses the organizational challenges identified in the second phase. The purpose is to continually develop AIM practices in organizations.

The three main challenges identified are the organizational challenges, human resources challenges, and the knowledge management and information technology (IT) challenges. When addressing the area of knowledge management and IT, the study discussed the survey findings and proposed the use of service providers to tackle the challenges in this area.

The study also addressed the organizational challenges by proposing structured planning and implementation of AIM in petroleum projects and in the organizational level. For petroleum projects, the operational readiness and assurance (ORA) is proposed as a solution to establish the AIM foundation before operations phase. This study elaborates the requirements for ORA planning and implementations, including the main elements in ORA, organizational structure, manpower and tasks planning and also ORA work structure.

For the organizational level, the survey findings were developed to improve a structured approach in planning and implementing AIM in the organizational context. Different approaches from respondents were also elaborated to give insights of how different petroleum organizations are planning and implementing AIM.

Keywords – Asset integrity management**,** Asset management, Petroleum industry, Oil and gas industry, Strategy, Strategic planning, Life cycle approach, Operational readiness, Research approach, Research design, Asset challenges.

Mayang Kusumawardhani
Stavanger, 01 August 2016

Preface and acknowledgement

This thesis is submitted as a partial fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) at the University of Stavanger (UiS), Norway. The research work was carried out in Stavanger, Oslo, Houston and Singapore in the period from August 2013 to May 2016. The compulsory courses were given and attended at the UiS. The work was funded by Norway´s Ministry of Education and Research (*Kunnskapdepartmentet*).

This work would not be possible without the support from people around me. First is my supervisor, Professor Tore Markeset, to whom I would like to give my sincere gratitude for all his patience, guidance and tireless support. Extended thanks are due to his family, Milanie, Isabella and Juliana, for the warmth they have showed me during our stay in Houston.

I would also like to thank my co-supervisor, Dr. Rajesh Kumar, who has supported my work and the surveys in between his busy work. Thanks are also due to Dr. Knut Erik Bang, who helped me to come to my decision to take this PhD in the first place. My appreciation also goes to Professor Jayantha P. Liyanage, Chair of CIAM, for valuable support during my study.

There is a special thank you for Professor Matthew Franchek, Director of the Subsea Engineering Program at the University of Houston, without whose support, the research in Houston would not be possible. To Airindy Felisita, Dr. Charlotte Botter, Dr. Izaskun Muruzábal-Lecumberri, Etienne Cheynet, Roy Zydeman, Joshua Lomes, Pål Gilde, Dag Årtun, Oeyvind Nerland and all my colleagues at UiSDC, SiN, University of Stavanger, University of Houston, Trancergy and Yinson Production, thank you for the valuable support. My thanks are also extended to Elisabeth Stornes Fiskå, Anne Karin Rafos and other members of the administration staff at the UiS.

I am grateful to family: my parents, Maria Sri Yatmini and Drs. Awang Anwaruddin, my sisters, Citra Mustikaningrum and Dyah Wulan together with James Anderson for their support. My appreciation goes to Shahen Akbari, Marina Davidian and Masoud, Icha and The Jongejan family for all the family warmth they have given me. Last but not least thanks go to Dodo, Peggy, the Indonesian community in Rogaland, and Arthur Almenräder.

Definitions

Asset	An asset is defined as a physical item or entity that has potential or actual value for an organization (ISO 55000, 2014).
Asset integrity management (AIM)	Asset integrity management is the development, implementation and execution of a coordinated plan together with managerial control and organizational activities, to ensure that the physical asset is performing its intended function in a safe, effective and efficient manner over its entire life cycle, in order to achieve the organizational objectives (Kusumawardhani et al., 2016).
Integrity	in this study refers to technical integrity, which is the state of being intact or the condition of being unified or complete (Murray, 2013). Technical integrity can also be described as the overall state of confidence in terms of functionality, operability and reliability (Rahim et al., 2010).
Maintenance	Maintenance is a combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function. Services like lubrication, cleaning, oil and filter change, and calibration, adjustments, etc. are included in the maintenance concept (DIN EN 13306:2010).
Operation readiness and assurance (ORA)	Operation readiness and assurance can be defined as the development and execution of a coordinated plan together with managerial control and organizational activities, to ensure that the physical asset and its supporting organizations are ready to operate and perform its intended function in a safe, effective and efficient manner (Kusumawardhani and Markeset, 2016).

Table of contents

List of appended papers

Paper 1 Kusumawardhani, M., Gundersen, S. and Markeset, T. (2015), "Mapping the research approach of asset management studies in the petroleum industry", Accepted for publication in *Journal of Quality in Maintenance Engineering*.

Paper 2 Kusumawardhani, M., Kumar, R. and Markeset, T. (2016), "Asset integrity management: offshore installations challenges", Accepted for publication in *Journal of Quality in Maintenance Engineering*.

Paper 3 Kusumawardhani, M. and Markeset, T. (2015), "Asset integrity knowledge management: a case study from the petroleum industry", *Operations and Supply Chain Management,* Vol. 8 No. 3, pp. 146–53.

Paper 4 Kusumawardhani, M., Kumar, R. and Markeset, T. (2016), "Establishing operational readiness and assurance for petroleum projects", Accepted for publication in *Journal of Quality in Maintenance Engineering*.

Paper 5 Kusumawardhani, M., Kumar, R. and Markeset, T. (2016), "Development of strategic asset management planning in the petroleum industry", Accepted for publication in *Journal of Quality in Maintenance Engineering*.

Additional papers, not included

Paper 6 Kusumawardhani, M. and Markeset, T. (2014), "Asset integrity of deepwater petroleum production facilities", *the Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management (IEEM2014)*, Kuala Lumpur, Malaysia, December 09-12th, IEEE Geoscience and Remote Sensing Society.

Paper 7 Kusumawardhani, M. and Markeset, T. (2014), "Research design for industrial service studies", *the Proceedings of the 6th International Conference on Operations and Supply Chain Management (OSCM 2014)*, 10-12 December 2014, Bali, Indonesia.

Paper 8 Kusumawardhani, M. and Markeset, T. (2014), "Information system challenges in managing asset integrity of petroleum production facilities", *the Proceedings of the 6th International Conference on Operations and Supply Chain Management (OSCM 2014)*, 10-12 December 2014, Bali.

Paper 9 Kusumawardhani, M. and Markeset, T. (2014), "Sourcing strategy for asset management support services of petroleum production facilities", *the Proceedings of the 6th International Conference on Operations and Supply Chain Management*, 10-12 December 2014, Bali.

PART I

THESIS SUMMARY

1 Introduction and background

The emergence of asset integrity management (AIM) in the petroleum industry has been encouraged by the demand for a safer and more sustainable workplace. This demand was mainly stimulated by the potentially high consequences of failure for health, safety and environment (HSE), as well as the high cost of technical failures, repairs and downtime. For example, the Piper Alpha accident and the fall in the oil price in the 1980s were said to be the catalyst for the rise in asset management in the petroleum industry (Woodhouse, 2007). Years later, history has repeated itself when AIM resurfaced following the Macondo blowout in 2010 and the low oil price after 2014.

Nowadays, petroleum organizations implement AIM under the fear of these major catastrophes and to save costs, amongst other motivations. Nonetheless, Ciaraldi (2012) observed that AIM practices often fail.

1.1 Asset integrity management

The term 'asset' was initially used in the financial and accounting field (Amadi-Echendu et al., 2010), but over the years the term has also been adapted to the management of physical resources (Woodhouse, 2007; ISO 55000, 2014). Following the latter, the term 'asset' in this study focuses more on managing physical entities. Thus, for the purpose of this study, the term 'asset' is defined as a physical item or entity that has potential or actual value for an organization (ISO 55000, 2014). In this study, 'asset' is associated with the petroleum related physical resources (e.g. production installations, drilling installations, wells, refineries, equipment, etc.) that are controlled by legal entities (e.g. companies, etc.) and provides economic benefits (e.g. profits).

The integrity of an asset

The term 'integrity' has several similar definitions and thus several applications. Within the scope of this study, the term 'integrity' refers to technical integrity, which is the state of being intact or the condition of being unified or complete (Murray, 2013). Technical integrity can be also described as the overall state of confidence in terms of functionality, operability and reliability (Rahim et al., 2010).

Defining asset integrity management

Within petroleum studies, the technical integrity of an asset (i.e. petroleum related physical resources) is associated with the ability of the asset to perform its required function in a safe, effective and efficient manner, particularly regarding the ability to safely contain or process hydrocarbons and other related substances according to the defined function and stated requirements.

Asset integrity studies in petroleum industry are mostly addressing a particular area, such as studies in life cycle integrity, life extension and especially in degradation of an asset (e.g. pipeline, machinery, structural) (see for example Tennyson et al., 2005; Baker, 2011; Lind, 2013).

Asset integrity management (AIM) involves both organizational and technical aspects, since intangible assets have a supplementary role in managing the physical asset (Nastasie et al., 2010). Therefore, AIM is considered as multi-disciplinary in nature and it manifests itself in a complex sociotechnical environment between the organization, asset, personnel, technology and systems that are integrated to achieve specific objectives.

The AIM objectives mainly focus on safeguarding life, the environment and maximizing the financial benefits from the asset. In order to achieve this, the organization needs to have holistic control and integration of the asset, organization, objectives and the means (methods):

- the asset, which is the tangible asset in conjunction with the intangible asset, and its related activities (Nastasie et al., 2010; El-Akruti and Dwight, 2013);
- the organization, which is the integration between different levels, departments and decision-makers (Amadi-Echendu et al., 2010; El-Akruti and Dwight, 2013);

- objectives, which is the integration of the individual, group and overall organizational objective (El-Akruti and Dwight, 2013); and
- the means (methods), which is the integration of planning, control and other managerial activities in the organization (Amadi-Echendu et al., 2010; El-Akruti and Dwight, 2013).

Thus, AIM can be defined as: "*the development, implementation and execution of a coordinated plan together with managerial control and organizational activities, to ensure that the physical asset is performing its intended function in a safe, effective and efficient manner over its entire lifecycle, in order to achieve the organizational objectives*" (Kusumawardhani et al., 2016).

1.2 Research disposition and research area

AIM is a known topic in the petroleum industry. However , AIM has often been misunderstood as a mere financial burden (Tsang, 2002), which might relate to the old school of thought that high maintenance cost is a necessary evil. This phenomenon could potentially be one of the factors affecting AIM practices, especially for installations that have a higher breakeven value.

A petroleum asset will degrade due to aging or other factors and it can only perform its required function if maintained properly over its life cycle (Schuman and Brent, 2005). To be able to sustain the desired integrity level, an organization needs to balance the asset's capabilities against the AIM constraints and the associated risks over its life cycle.

During fluctuating situations, some organizations may choose to rearrange the priorities of several AIM activities to a certain degree; however, questions are raised as to whether these decisions would compromise the HSEQ (health, safety, environment and quality) and integrity of the installation (NITO, 2016), while, in reality, most offshore petroleum installations are still operating regardless of price fluctuations, which demonstrates that the installation's integrity needs to be continuously maintained at all times.

AIM strategic planning

The term 'planning' has a clear and definite meaning as the process or activity of making plans. However, the terms 'strategic' and 'strategic planning' (SP) seem to be vague and are understood differently by scholars and practitioners (Nag et al., 2007; Carr and Smeltzer, 1997). The term 'strategic' is often related to the organizational interests or important matters that could affect the well-being of the organization, whilst SP is related to the planning of that important matter (Steiner, 1979).

Different scholars have also suggested that SP is part of the long-term corporate planning. However, regardless of the different views on SP, most of the definitions describe SP as an organizational process that attempts to anticipate future decision-making by forecasting the probability of consequences that arise from current action and knowledge (Capon et al., 1987; Miller and Cardinal, 1994; Al-Turki, 2011). The SP process is formulated in strategies and planning that will drive and allocate the organization´s resources to achieve the organization´s objectives.

Another characteristic of SP is that it is a form of a continuous systematic process that begins by defining organizational aims and then goes on to establish strategies to achieve them (Steiner, 1979). The process is continuous in order to be able to adapt to the changes in the internal and external environment, especially with the fluctuating fossil fuel price and the rapidly changing technology in the petroleum industry (Kusumawardhani and Markeset, 2015).

From the discussion, we understand that SP is a way for an organization to deal with uncertainties. Additionally, SP is essentially a process of identifying opportunities and threats that are significant to the organization´s objectives. The SP process facilitates organizations in performing decision-making processes to secure their competitive advantage in the future. The act of planning is performed to direct their resources' allocation and anticipate the future situation.

A similar process was defined by Aven (2008) as risk (C, C*, U, P, K), as shown in Figure 1. According to this definition, risk is the consequences (C) of the activity (including the initiating event A), which is affected by uncertainties (U) that are associated with whether or not A will occur and which values C will take. C* is the prediction of C, and P is the probabilities of how likely various events and outcomes are, and they are based on prior knowledge (K) (Aven, 2008).

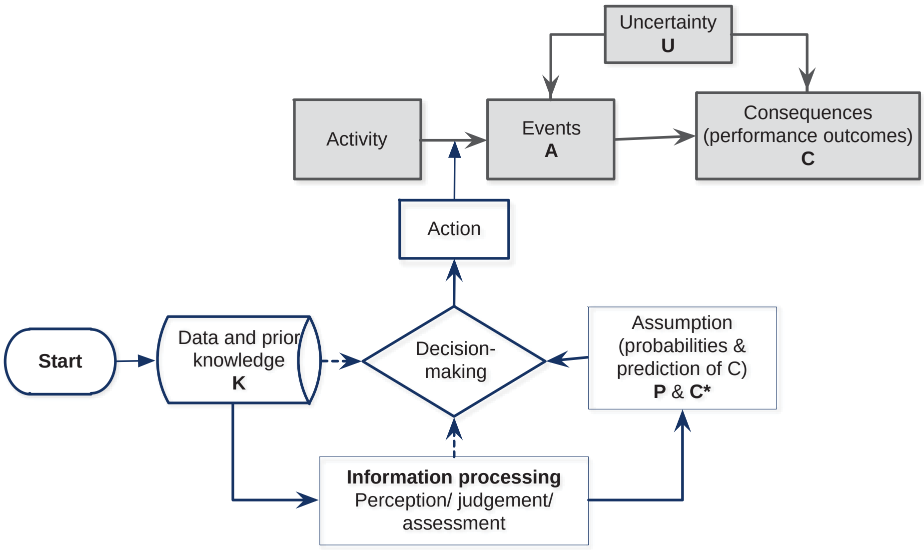


Figure 1. Decision making process based on risk description (C, C*, U, P, K) (Aven, 2008)

In this definition, risks are both opportunities and threats, including all possible consequences that might arise, which in AIM would include business and technical terms. This definition will delineate the term 'risks' throughout this thesis.

Overall, an SP process is essentially a decision-making process to manage foreseeable risks, and it may be linked to strategic decision-making (Grant, 2003). Additionally, Capon et al. (1987) emphasize the continuous process loop in SP to tackle the volatile business environment. Thus, for the purpose of this study, strategic planning is defined as "*a systematic and continuous process of risks identification that uses probabilities and other knowledge as a basis to forecast consequences to undertake anticipatory decision-making of resource allocations to achieve the organization´s objectives*" (Steiner, 1979; Capon et al., 1987; Aven, 2008).

Recent development of strategic AIM planning

Since the 1990s, the strategic planning practices in the petroleum industry have evolved into a more informal and decentralized process to adapt to the turbulent and unpredictable volatile business environments (Grant, 2003). This creates a semi-structured process, where the bottom-up decentralization allows more freedom for business units to formulate their own strategy, without losing certain control from the organization (Brown and Eisenhardt, 1997). Larger organizations would normally establish a set of performance standards or key performance indicators (KPI), for their offshore units, but nowadays it is a more common practice for divisional business units, such as operation and maintenance, to have more influence on their department's strategy.

The volatile environment also generate more responsive strategic decision-making, which creates a shorter term for strategic planning and is more focused on performance-management and goals (Grant and Cibin, 1996). This term stretches the definition of strategic planning (previously viewed as long-term planning) into a process, which is more adaptive to the strategic decision-making. This change provides a strong background for a petroleum installation's quarterly appraisals and its business units, which are updating their plans yearly.

Mankins and Steele (2006) stressed that the difference between strategic decision-making and strategic planning is that the strategic planning is about documenting choices that have already been made rather than about making decisions. This is in accordance with Mintzberg (1994), who distinguished between deliberate strategy and emergent strategy. The first was based on original intention, and the latter is a result of the organization's responses to a variety of unanticipated events. The delineation between the two brings forward the continuous improvement characteristic in the SP process, which enables incidental decision-making to be incorporated into the plan. As observed by Brown and Eisenhardt (1997), successful organizations have figured out a way to integrate these two processes, such that the organization's consideration of the present and future (plans) gives a direction for change.

Due to the long life span of oil production facilities, long-term AIM strategic planning is established at the design phase and reflected in the life cycle plan with a span of around 25-30 years, while the shorter-term strategic planning is normally reflected in five-year and yearly plans and monitored in a timely manner through performance measurements or performance management systems (Grant and Cibin, 1996; Tsang, 1998; Grant, 2003; Parida and Kumar, 2009). In accordance with bottom-up decentralization, divisional strategic planning is assigned to related business units (e.g. to the operations and maintenance department) that drive the development of strategic planning in this area (see for example Horner et al., 1997; Tsang, 1998; Murthy et al., 2002; Al-Turki, 2011).

Moreover, the establishment of asset management was buoyed up by the publication of PAS 55 in 2004 and the ISO 55000 series in 2014 (Standardization, 2014). AIM has been known in the petroleum industry as an integrated management of the petroleum installation to achieve the desired integrity. Besides method and research developments in AIM (for example Baby, 2008; Ratnayake, 2012; Bharadwaj et al., 2012), there have also been developments in software that are promoting ‘integrated’ access to strategic areas of AIM (Quinn et al., 2007; Kusumawardhani and Markeset, 2015). Therefore, since the focus has shifted to AIM, it will be beneficial to study the strategic planning process in this area.

1.3 Research questions

Based on the discussion in the previous sections and interaction with industry practitioners, the following research questions were posed:

1. What are the current research, theory and practices of AIM in petroleum organizations, and what are the knowledge gaps?
2. What are the factors affecting the success of AIM in petroleum organizations?
3. What are the best practices for implementing AIM in petroleum organizations and how can they be improved?

1.4 Research objectives

The main objective of this thesis is to study the current theory and practices of AIM to acquire knowledge that would be useful for improvements and continually develop AIM practices in organizations.

This is done through looking at the role of technologies, organizational processes, collaborations, and how organizations advance through overcoming challenges.

Sub-objectives include:

1. To identify and map the current research, theory and practices of AIM in petroleum organizations and identify the gaps.
2. To contribute to better understanding of AIM roles in a fluctuating market.
3. To identify the success factors of AIM practices in petroleum organizations.
4. To develop a method to plan, establish and implement AIM for a petroleum asset.

1.5 Research delimitations

This study does not take into account other than Petroleum industry. The study and the findings are based on research work and surveys that are conducted in Norway, Houston (Texas) and Singapore.

This study does not take into account organizational administrative functions related to AIM (e.g. human resources, insurance, contracts, etc.). The focus lies in obtaining knowledge of AIM practices in terms of technical and organizational functions.

2 Research approach

The research approach in this study follows pragmatic beliefs that uses diverse methods, which could provide the best way to obtain knowledge to solve the problem and are often associated with mixed methods research (Tashakkori and Teddlie, 1998). The study follows a research process illustrated in Figure 2 and utilizes the conceptual building blocks for AIM research (BBAR) (Kusumawardhani et al., 2016).

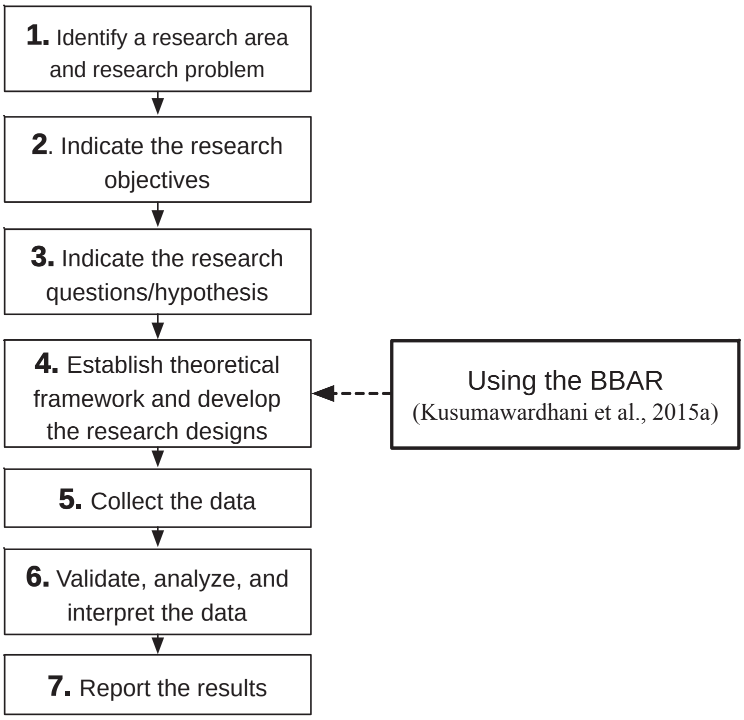


Figure 2. The scientific method for AIM research used in this study (adapted from Edmonds and Kennedy, 2013)

Since a pragmatic approach allows multi-methods, as illustrated in Figure 2, this study adapts inductive reasoning to take a broad view of AIM practices and retroductive reasoning to discover underlying AIM mechanisms in organizations.

The study is divided into three phases as illustrated in Figure 3. The first phase aims to study the current research in AIM and asset management (AM) in general. The purpose is to identify and map the current AM studies. The second phase involves a preliminary research of AIM practices with the goal of identifying the gap between theory and practices, and mapping the challenges of AIM practices. The third phase constitutes a subsequent study, based on the findings in the second phase.

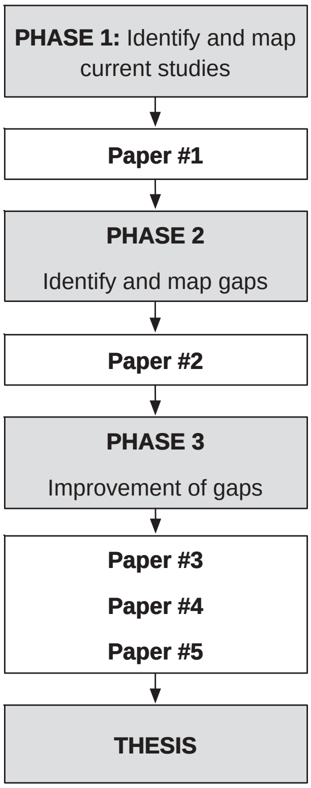


Figure 3. Research phases in this study

This study attempts to proactively involve industry practitioners. The purpose is to discover and reduce the gap between AIM theory and petroleum industry practices. Thus, the role of the participants is essential in the research process. To obtain a better understanding of the organization's processes, respondents mostly held senior management positions. However, subsidiary data were also collected whenever possible and taken into consideration for validation and triangulation purposes (e.g. organization´s procedures, standards, meetings, etc.).

In general, studies that involve industry practitioners consist of two methods, namely interviews and a questionnaire. The interview method was chosen primarily to observe the phenomenon from the respondent's point of view through a structured approach, while the questionnaire aimed to observe the trends amongst the respondents (see also Creswell, 2003).

In total, 20 respondents participated in the study. There were difficulties in convincing industry practitioners to participate. Some of the main reasons for this were their organization's policy, which restrains knowledge sharing, patented processes, recent incidents in their company and other constraints related to the low oil prices during the research period.

2.1 Phase 1: Identify and map current studies

The objective of Phase 1 of the study was to explore research approaches in AM publications and map them based on groups of research approaches. Samples of publications were obtained using computerized search engines. The search criteria are publications with asset management topics within the petroleum industry (e.g. production installations, drilling installations, well, refinery, storage, equipment, machinery, components, etc.). Then, the result was refined by manual filtering, according to the predetermined criteria as illustrated in Figure 4.

Tronvoll et al. (2011) applied similar methods, and it was admitted that this sampling method is not randomized and does not cover the entire population. However, to study the research methods used over the years, this method is sufficient to generalize a sample of publications from a particular topic.

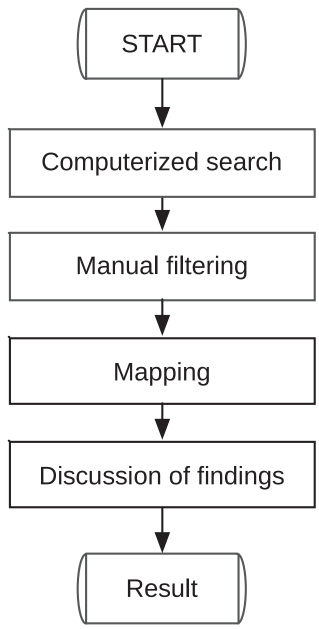


Figure 4. Data gathering and analysis method for Phase 1

Publications that met the assigned criteria were filtered from each database, resulting in 14 publications in total. The publications were then grouped based on evaluation of problem definition, the identified fundamental beliefs, reasoning, control process, analysis and validation.

2.2 Phase 2: The preliminary study

The objective of the preliminary study was to discover the gap between the theory and practices of AIM in petroleum organizations. The study consisted of two parts. The first part was a semi-structured face-to-face guided interview with industry practitioners located in Houston, Texas, USA and Singapore. In the second part, respondents located in Houston, Texas, USA and Singapore and Norway were asked to complete a questionnaire. Figure 5 illustrates the study process in Phase 2.

The questions for the interview were developed to map AIM practices, concerns and other implementation variables within the organizations through a literature study, as well as with the collaboration of senior researchers. Some of the questions for the questionnaire were added later to incorporate suggestions from industry practitioners and to map the significance of the interview results. Several respondents also provided access to company documents that allowed the researcher to learn about their practices and work processes.

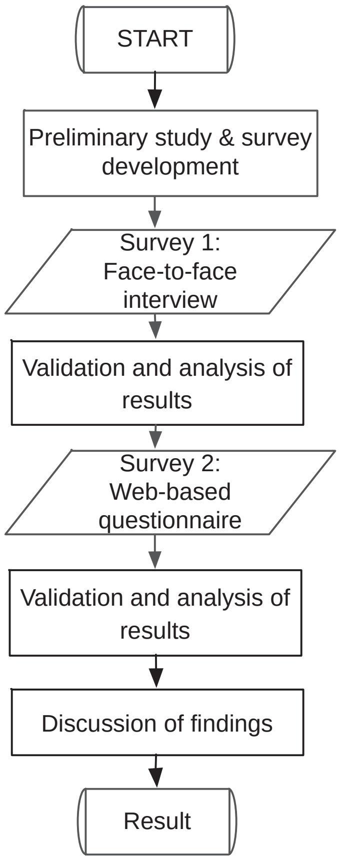


Figure 5. Data gathering and analysis process for Phase 2

Data processing and analysis method

Respondents were individually asked about their challenges with regard to AIM through a guided interview and a questionnaire. In the guided interview, respondents communicated their experience, practices, challenges and improvement suggestions regarding AIM. The interview provided in-depth information about the challenge facing the petroleum industry, while the questionnaire provided quantitative information.

In the questionnaire, respondents were asked to rank the significance of several AIM challenges identified in the interviews. The significance of AIM challenges was ranked on a scale of 1 to 5, with 1 signifying the least significant, and 5 the most significant. The average value (Avg.) was calculated as follows: $Avg = (5 * n_5 + 4 * n_4 + 3 * n_3 + 2 * n_2 + 1 * n_1) / (n_5 + n_4 + n_3 + n_2 + n_1)$, where n_x is the number of respondents giving the rating x.

2.3 Phase 3: The follow-up study

A follow-up study was conducted to understand the practices and progression of AIM establishment, implementation and planning in petroleum organizations. The study consisted of a semi-structured guided interview and a questionnaire. The semi-structured guided interview was mostly performed face-to-face when possible, while, in the second part, respondents were asked to fill in a questionnaire.

Both methods were performed with the cooperation of six industry practitioners located in Norway and Houston, Texas, USA. Face-to-face interviews were conducted with the four respondents located in Stavanger and Oslo, Norway, and one respondent in Houston was contacted through e-mail. All of the respondents have 10-33 years of experience in the petroleum industry and all hold managerial positions at a corporate level. Figure 6 illustrates the study process for Phase 3.

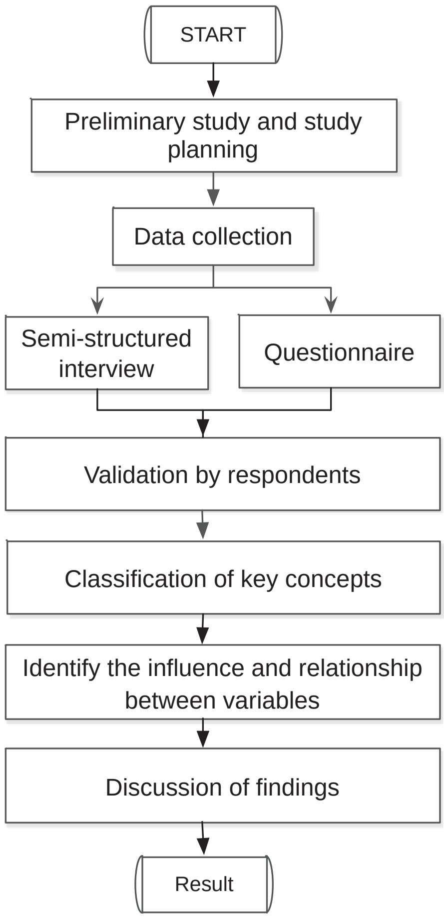


Figure 6. Data gathering and analysis process for Phase 3

Data processing and analysis method

The questions were developed through a literature study and from observations, as well as with the collaboration of senior researchers. The results from the questionnaire were analyzed for trends, and some variables were ranked according to the responses. The notes that were taken during face-to-face semi-structured interviews were summarized immediately after each interview and sent back to the respondents for validation of content. Additionally, some of the respondents also provided access to company documents to support the interview data. The interview results and the supporting data from each organization were analyzed to distinguish some of the key variables that were later collectively analyzed with the results from other organizations.

2.4 Validation of results

The survey summary was sent to each of the respondents for validation. Triangulation was also implemented by verification with findings from the organization´s documents, as well as with findings in the questionnaire. Other sources, such as voluntary provision of data and external data on the subject, were also collected in order to maximize the reliability and validity of the study.

3 Research results: discussions and conclusions

This section summarizes five papers that encapsulate the research study. The papers are presented as such to demonstrate a holistic view of the research work.

3.1 Paper 1: Mapping of asset management research approaches in the petroleum industry

Paper 1 aims to study and map the current research approaches in asset management in general. This will pave the way for a suitable research approach for the AIM study discussed in this thesis. This paper explores research methods in AM publications and classifies them according to the appropriate research approach.

Samples of publications were obtained from online databases. There were 14 publications that were classified based on evaluation of problem definition, the identified fundamental beliefs (e.g. ontology, epistemology, methodology and values), reasoning (inferences), control process, analysis and validation. Ontology is related to the nature of reality, epistemology is related to the understanding, creation and dissemination of knowledge, while methodology addresses more specifically how knowledge is assimilated or understood (Steup, 2014). Meanwhile, values are criteria that can help scientists to evaluate models and theories, and can tell them what are considered to be relevant problems.

Even though the sampling technique did not aim to represent the entire population of AM publications, the research approaches found are believed to be the most commonly used (Tronvoll et al., 2011). These research approaches are: constructivist/hermeneutic/interpretivist, pragmatic, critical theory/dialogic, and positivist (see Reeves, 1997; Creswell, 2003; Mackenzie and Knipe, 2006; Bryman and Bell, 2011; Tronvoll et al., 2011).

AM publications that were classified in the constructivist/ hermeneutic/I nterpretivist group are those that assume that knowledge is gained from the understanding and interpretation of phenomena through individual and collective construct reality and our knowledge of reality (Tronvoll et al., 2011). This research approach is related to abductive reasoning (Fischer, 2001).

Publications included in the pragmatic group focus on solving the research problem and normally use diverse methods that could provide the best way to obtain knowledge to solve the problem (Tashakkori and Teddlie, 1998). This approach is often associated with mixed methods research and accepts all four types of reasoning (Peirce, 2009).

The critical theory/dialogic approach shapes knowledge collectively through social inquiries between participants (within an organization) over a period of time (Bohman, 2015). This approach is associated with inductive reasoning (Denzin and Lincoln, 1994).

In the positivist approach, representative population samples and testing of hypotheses are of fundamental importance (Swaak and de Jong, 1996). Positivists believe that a theory, and thereby a hypothesis, is not acceptable until it has been empirically validated through value-free research, which corresponds to deductive reasoning (Bryman and Bell, 2011).

AM research design

From the classifications, some unique characteristics from each research approach were mapped and were developed into the building block of AM research (BBAR) illustrated in Figure 7. The BBAR is a mapping tool and should only be used after the research questions are identified. An example of an applicable scientific method was previously illustrated in Section 2 under Figure 2 (adapted from Edmonds and Kennedy, 2013).

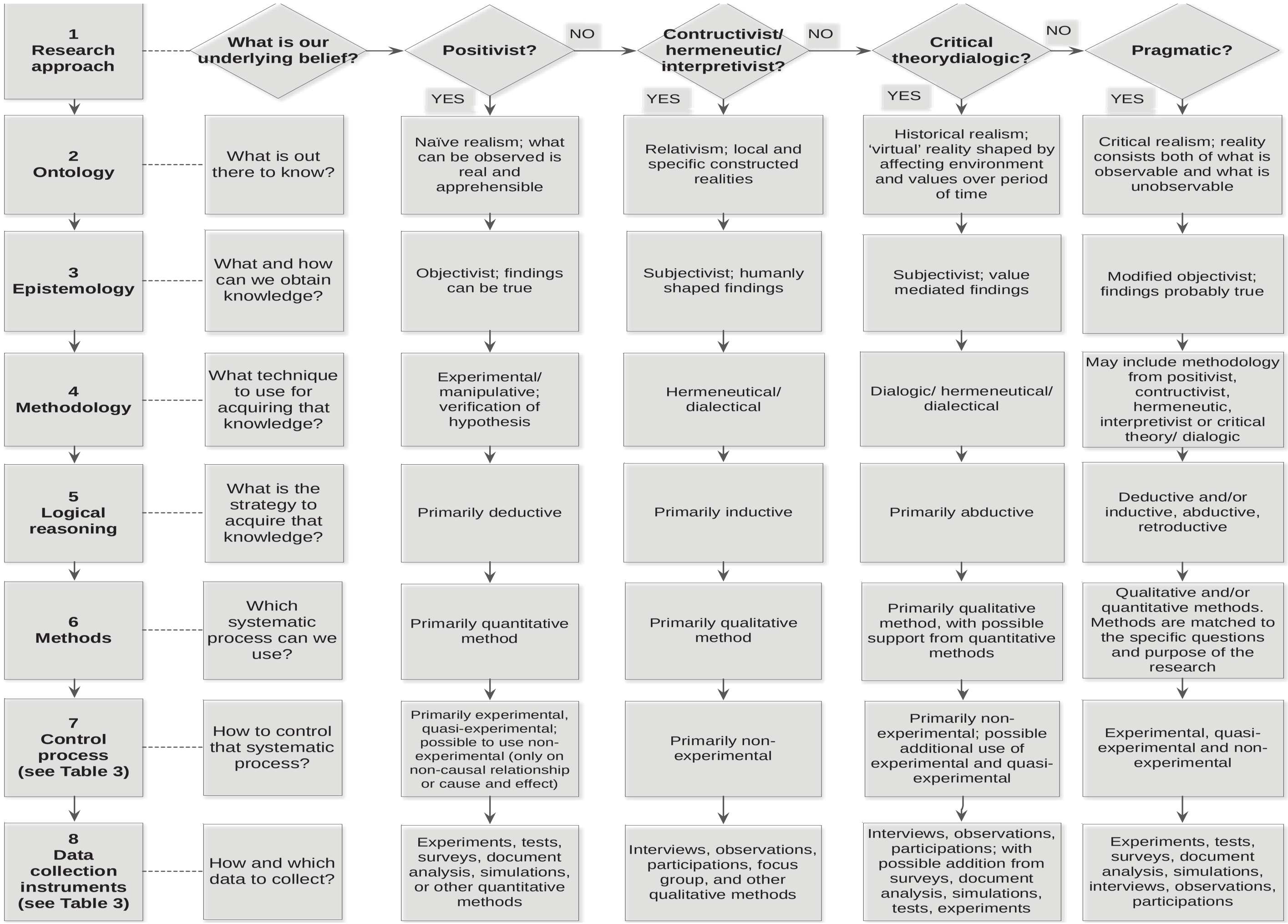


Figure 7. The conceptual building blocks of AM research (BBAR) (Blaikie, 2007; Denzin and Lincoln, 1994; Mackenzie and Knipe, 2006; Hay, 2002

The BBAR concept was adapted from Hay (2002) (as cited in: Grix, 2002) and carries additional concepts from Denzin and Lincoln (1994), Blaikie (2007) and Mackenzie and Knipe (2006). The concept of reasoning (in research by Blaikie, 2007), was added as the fifth building block, since the idea provides the researcher with more detailed guidance in knowing where to start and what to achieve in a research. In addition, the paper also presented the associated research instruments (i.e. quasi-experimental, non-experimental quantitative, non-experimental qualitative with cross-sectional quantitative, non-experimental quantitative and non-experimental qualitative).

The BBAR blocks are self-explanatory and relatively easy to follow. The BBAR illustrates a simplified form of what a research approach can provide as a guideline in developing a research design. Together with the scientific method, BBAR could provide AM researchers with clear guidelines in designing a research.

3.2 Paper 2: Asset integrity management: offshore installations challenges

Paper 2 lays the foundation for the remainder of the study by identifying and studying AIM practices in the industry, identifying the gap between existing theory and practices and mapping the existing challenges. The mapped challenges provide room for improvements, which will be the topic for the following papers.

In the study, the respondents expressed several asset integrity management challenges. These challenges were subsequently added to the questionnaire, and respondents were asked to rank the significance of the challenges.

During the guided interviews, the discussions on the management of assets were often intertwined with the discussion on profit. The prime motivation for organizations to manage their assets is to maximize profit, but there are organizations that avoid AIM due to the fear of AIM costs. From the study, it was revealed that only 58% of the total interviewed respondents have established an AIM strategy, or similar, in their organizations. Both opinion groups provided clear and reasonable arguments for their choices, and from the interview it was apparent that an organization's preference on AIM strategy depended on their short-term and long-term strategies. All of the respondents were aware of the cost of establishing AIM, but, on the other hand, they also considered the expected trade-off benefits from establishing AIM. Nonetheless, all respondents expressed some encounters with challenges related to asset integrity. These challenges were listed and grouped as illustrated in Figure 8.

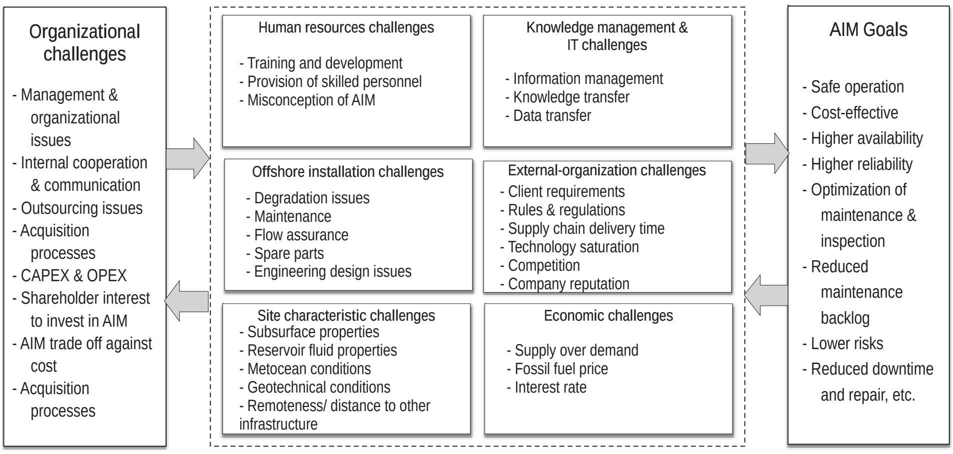


Figure 8. Influence of AIM challenges in organizations with offshore petroleum production asset to reach AIM goals

To further study these AIM challenges, respondents were asked to rank the significance of each of them through a questionnaire. The result shows that the most significant challenges were the organizational challenges, followed by human resources challenges, knowledge management and IT challenges, offshore installation challenges, external-organization challenges, site characteristic challenges and, lastly, by economic challenges.

Apparently, other corresponding studies have stated similar results in addressing organizational issues in asset integrity (see for example Amadi-Echendu et al., 2010; KP3, 2007; Ratnayake, 2012). Moreover, the results were interestingly similar, despite the different geographical locations. The differences lay in the significance the respondents placed on the factors shown in Figure 8. For example, respondents from Houston stressed their challenges regarding provision of skilled resources, while, in Singapore, the managerial issues were particularly stressed. In Norway, the first place was earned by human resources challenges, followed by knowledge management and IT, as most of the organizations' work processes have been digitalized.

3.3 Paper 3: Asset integrity knowledge management: A case study from the petroleum industry

According to Paper 2, knowledge management (KM) is one of the main challenges in AIM practices. Paper 3 discusses this topic in detail and offers several potential solutions. The scope of knowledge management in AIM is first discussed, followed by the proposition of a KM definition that suits the context of the study. The paper defines KM as *"an organized planning, coordination and control of organizational activities and resources to effectively capture, distribute, and use knowledge."* The information system (IS), however, is a part of KM and is defined as *"any organized combinations of information and communication technology (ICT) and human activities that utilizes the ICT to ensure handling of data in order to serve its objectives in an organization".*

In the study, respondents were asked about their organization´s practice and concerns in KM with regard to the asset integrity of offshore installations. The result showed that respondents expressed the following concerns in relation to KM:

- Knowledge transfer
- Information management
- Data transfer between onshore and offshore
- Information technology (IT) processes and security
- Quality of data
- Integrated system
- Introducing and adapting to new technology

Industrial service as possible solution

The paper proposed industrial service as a potential solution to KM challenges. Industrial service was defined as "*processes and resources* *provided by a service company to a customer to produce performance that is meant to create output to provide solutions to the customer´s needs"*.

The paper reasoned that, since industrial service is available throughout the installation´s life cycle, as illustrated in Figure 9, it could potentially offer a practical solution to KM challenges in the form of the outsourcing of KM activities to service providers. Additionally, the engagement of service providers could bring other benefits such as increased work efficiency, cost saving, distribution of risk, ability to be competitive, more focus on core competences, technology innovation and adaptation, custom-made solutions, business transformation or expansion, and increased safety, availability, reliability and responsiveness (Jain and Natarajan, 2011; Sanjay and Ravi, 2007). Particularly for KM, globalization has increased the availability and cost saving; for example, many advanced countries outsource their IT services to cheaper service providers in developing countries.

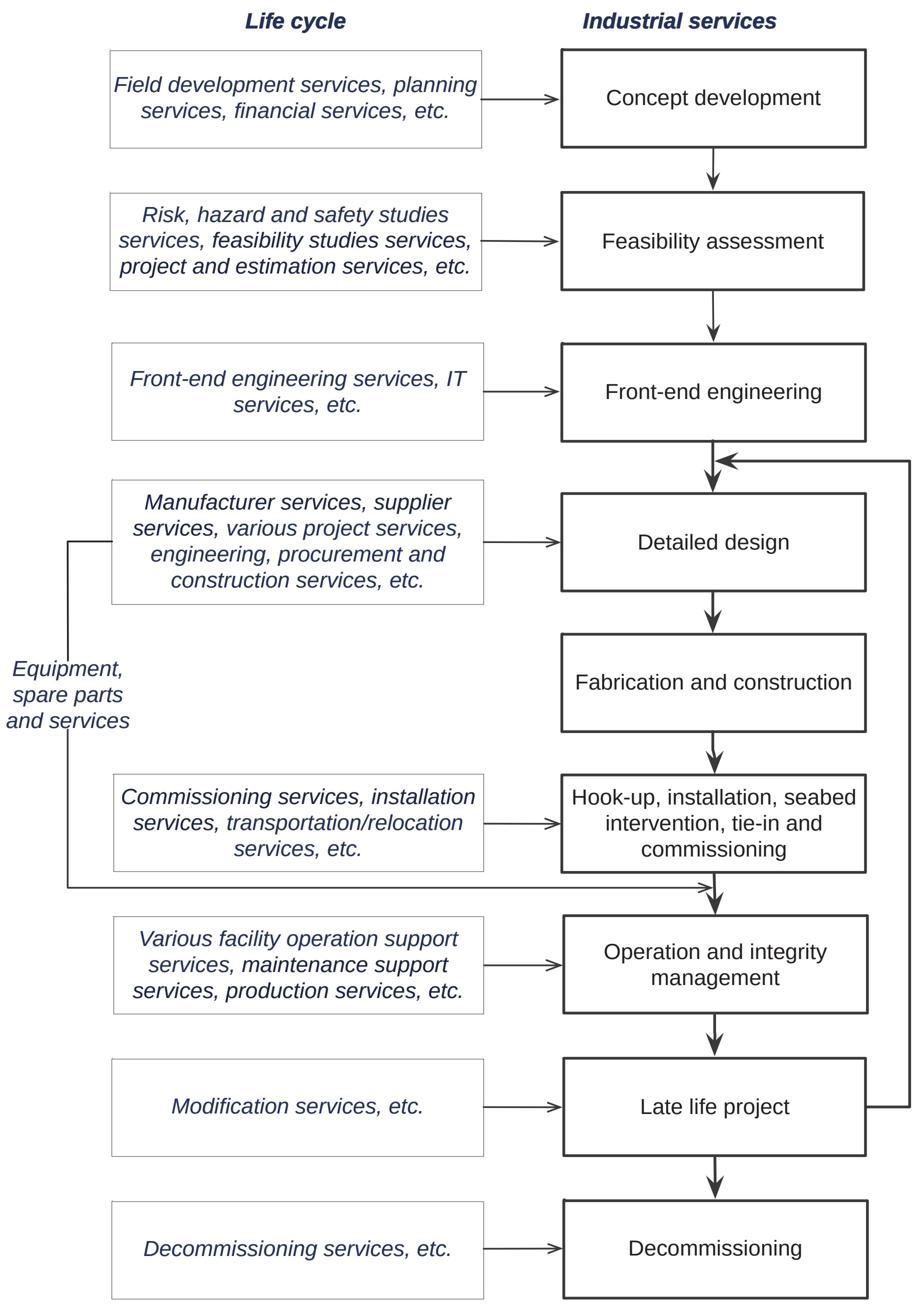


Figure 9. Industrial services in the life cycle of a petroleum installation (Kusumawardhani and Markeset, 2015)

However, the engagement of service providers is not without its own challenges. Organizations could also be faced with several difficulties, starting from the selection of service providers, managing the interface, quality issues, performance issues, even contractual issues (see for example Salonen, 2004; Arpan Kumar, 2014). Nevertheless, these challenges can be coped with through the organization's supplier management. There are several literature references that discuss risk, quality and performance issues (Vilko and Ritala, 2014), contractual issues (Stremersch et al., 2001) and supplier selection issues (McIvor, 2008).

3.4 Paper 4: Establishing operational readiness and assurance for petroleum projects

This paper is related to the overall technical and organizational challenges discussed in Paper 2. It responds to one of the challenges related to the poor condition inherited from the prior life cycle phase (see for example Baker, 2011; Lind, 2013). For example, in some cases where the operation team is not involved in the early life cycle phase, the inherited technical condition is often unsatisfactory (Al-bidaiwi et al., 2012). Thus, the importance of integrating asset integrity prior to the operation phase is suggested in several studies (Songhurst and Kingsley, 1993; Baby, 2008; Lind, 2013). This paper proposed an operational readiness and assurance (ORA) structure to pave the way for successful AIM implementation. In this study, some industry practitioners were also requested to review the suitability of the proposed ORA structure.

The paper starts with a discussion of ORA practices in petroleum projects. The current ORA practices focus on the involvement of operation knowledge in the project phases and the assurance of the asset's readiness. The ORA process is normally integrated into the project, but ORA can also be a partial establishment (Smith et al., 2002; Nossair et al., 2012). The ORA process should begin as early as possible in the project phase as an integral part of the project. The process shall cover operational readiness knowledge areas (Nossair et al., 2012; Powell, 2012; Verre, 2008) and shall be integrated into the project plan, as illustrated in Figure 10.

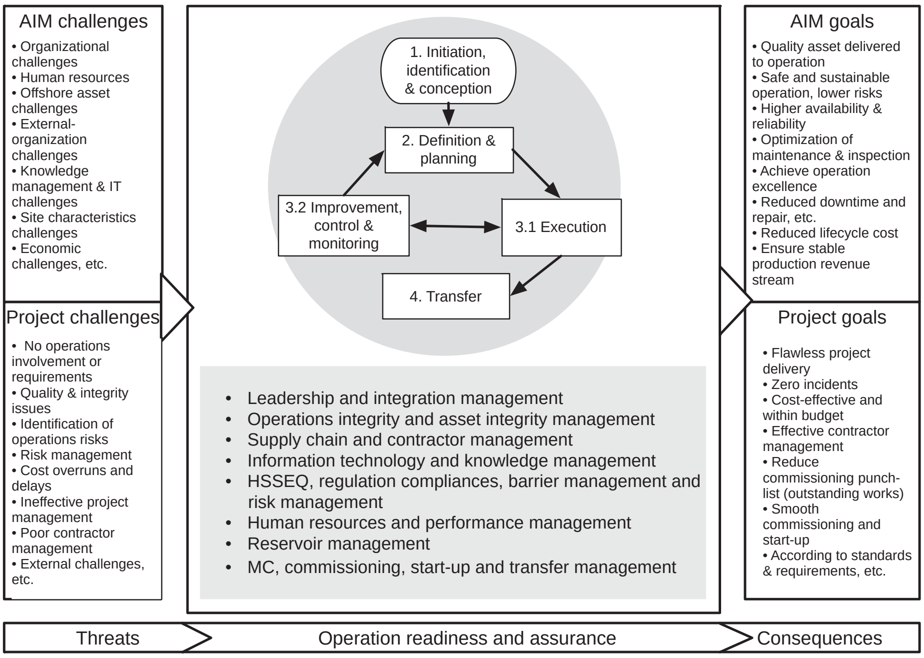


Figure 10. Example of ORA process and knowledge areas (adapted from Kusumawardhani et al., 2015; Powell, 2012)

ORA governance structure

In the initiation phase of a project, an appointed preliminary ORA team, together with a project team, should initiate the ORA process. In synergy with the project team, the ORA team will proactively identify and evaluate the need for ORA processes, as well as incorporating operational knowledge into the project. The team should establish ORA governance and the required knowledge areas. Since the governance structure in a project plays an important role in the alignment of project outputs (Hallgrim et al., 2014), the ORA governance structure needs to be in line with the project and corporate governance and may vary, depending on the chosen methods. An example of an ORA governance structure is illustrated in Figure 11.

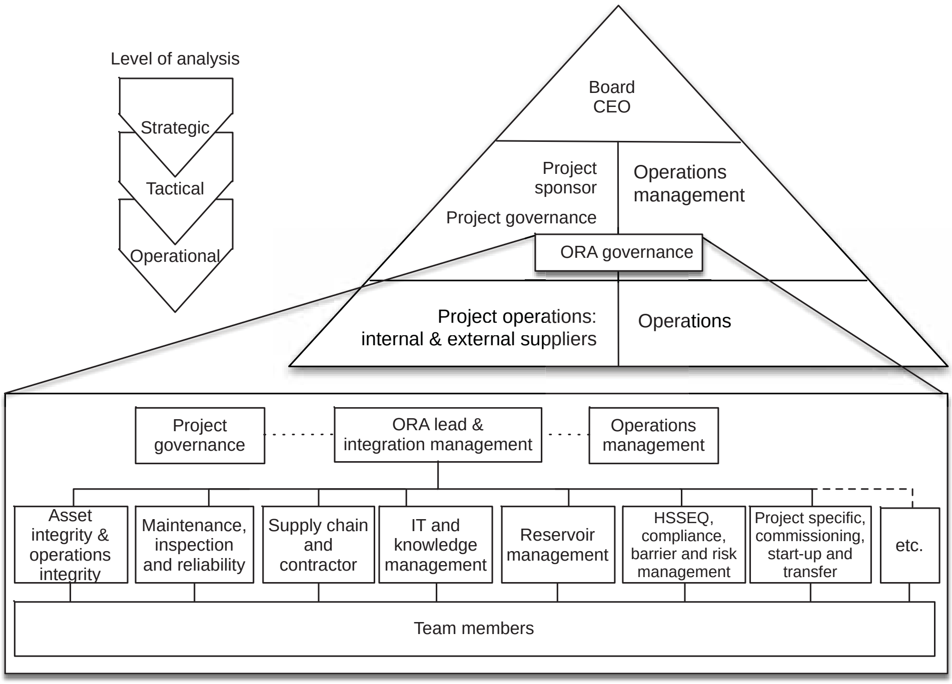


Figure 11. Example of ORA governance structure in a petroleum project (adapted from Hallgrim et al., 2014)

The distribution and breakdown of work

The paper shows an ORA work breakdown as an example. The work breakdown is constructed and distributed according to the knowledge areas. The knowledge areas can be arranged or grouped into disciplines (and sub-disciplines), according to the project´s needs and preference. Thereafter, the WBS (work breakdown structure) is listed under each of the disciplines (and sub-disciplines), consisting of various control means such as tasks, activities/actions, documents or deliverables that act as tools to ensure assurance values. A member of the personnel or a team will be assigned the responsibility of various works. An example of the breakdown of ORA work is illustrated in Figure 12.

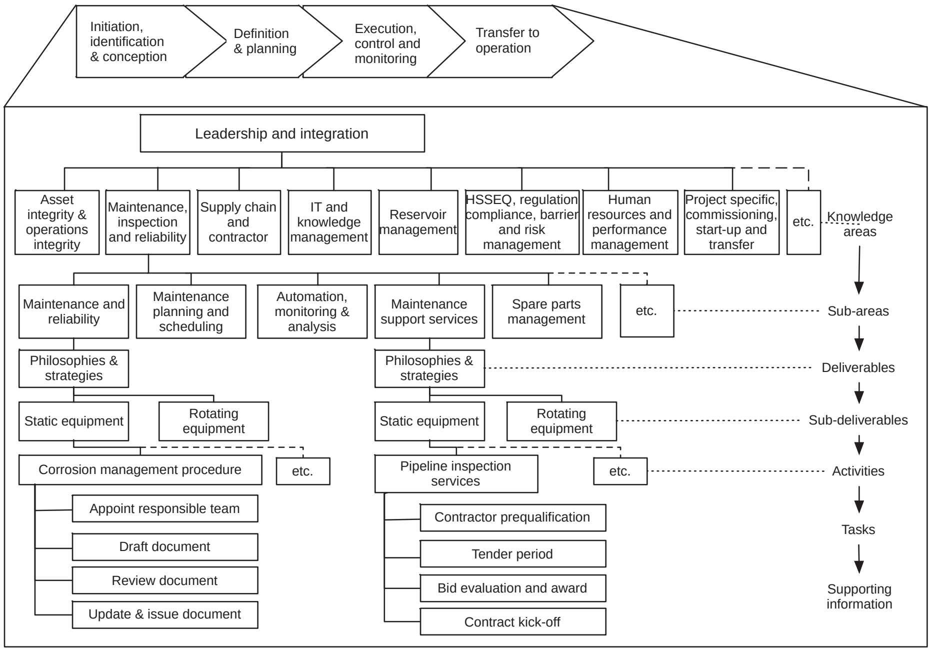


Figure 12. Example of ORA work breakdown structure

3.5 Paper 5: Development of strategic asset management planning in the petroleum industry

The final paper aims to addresses one of the challenges identified in Paper 2, related to organizational context, and is a continuation of Paper 4. Paper 5 tries to view the AIM challenges on a grander scale and proposes strategic planning as an aid for AIM implementations.

AIM planning is necessary since the scope covers a large area across business and technical disciplines in the internal and external organization, a fact which increases its vulnerability (Janele et al., 1998). However, AIM strategies often fail due to the lack of both integration and a unified effort from different groups in the organization (Ciaraldi, 2012; Parida et al., 2015). Thus, different groups in the organization need to be led towards the same goals and, to align different groups, the organization needs to develop a strategy and a plan to implement this (Steiner, 1979). For this to happen, there is a need for AIM strategic planning, where AIM activities are directed to achieve the organizational strategy (El-Akruti and Dwight, 2013; Woodhouse, 2003).

To address this, a survey consisting of interviews and a questionnaire was conducted to study the practices and progression of AIM strategic planning in petroleum organizations. Since most of the respondents' organizations chose to withhold their strategy planning documents, the interviews took place so that the respondents could explain the process verbally and compare their practices against an AIM strategic planning structure. From their responses, all of the respondents agree that the model is applicable and that their organizations have similar processes in practice. The smaller organizations, however, are limited in terms of the allocation of resources and budget, thus seeing AIM strategic planning as mid-term or long-term planning. Instead, they adjusted their budgeting every one to two years and their tactical objectives when necessary.

The biggest change that was suggested was to clearly distinguish between the corporation's and the business unit's processes. Corporations also tend to have static objectives (static targets) in their guidelines, thus the business unit needs to further specify its objectives and performance indicators. Another suggestion is to change the term 'annual plan' into 'tactical plan', since the period could vary for different organizations. These changes were incorporated into a new structure, as shown in Figure 13.

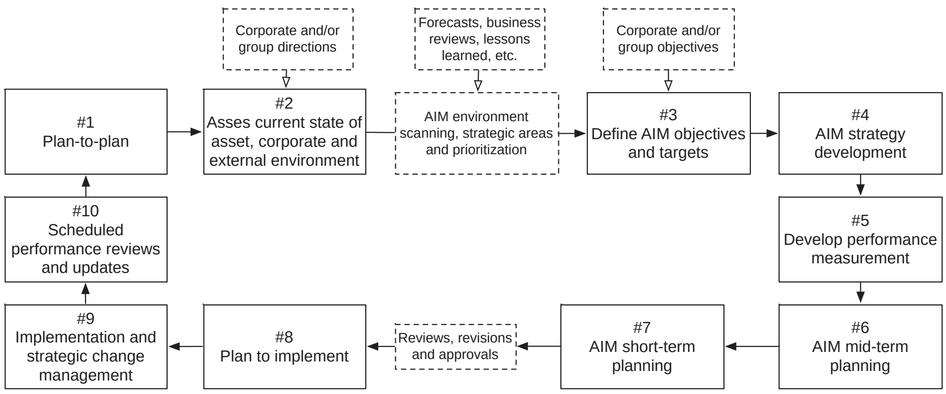


Figure 13. Revised AIM strategic planning model

The ‘environment scanning’ is a fundamental step in initiating the AIM planning process, although it may be known by different terms in other organizations (e.g. strategic analysis, SWOT, benchmarking, portfolio analysis, etc.). Environment scanning is an assessment of the asset’s business environments, which consist of the organization’s internal and external environments. This is because AIM possesses unique potential and traits due to its multi-disciplinary nature and its position between corporate business and direct connection to the asset. Prioritization is also a part of environment scanning, which gives significance to the more imperative subjects for resource allocation.

It was also noted that the larger organizations were restructuring their AIM processes; this was one of their recent strategic planning objectives. Efficiency is especially promoted in the corporate strategic plan. This was mainly due to the fluctuating oil price since 2014. Despite the fluctuating oil price, all of the respondents agreed that the integrity of the asset would not be compromised.

From the study it was observed that, as a multi-disciplinary subject, AIM strategic planning involves several business units in the organizations, and all elements are significant for reaching objectives. This statement is in opposition to Visser (1998), who views maintenance, which is a part of AIM, as the heart of enterprise and, hence, should have its own strategic plan. Instead, the findings suggested integration between business units in the organization to reach AIM objectives. This includes integration between, for example, operations, maintenance, production, engineering, supply chain, support, etc. Consequently, AIM has multiple focus areas, which, according to the respondents, are mostly significant and reliant on one another. These focus areas are analyzed and given priority in the planning, due to the limited allocation of resources and budget.

4 Research contributions

This study contributes to the asset integrity management (AIM) body of knowledge in general. This study focuses on AIM practices in the petroleum industry and contributes to gaining a better understanding AIM practices and to acquiring knowledge that would be useful for further improvements.

The study has mapped existing research methods in AM publications and classified them according to the appropriate research approach. This could provide researchers with clear guidelines for designing research for AIM studies. In addition, the study also presented associated research instruments that would be beneficial in planning data collection.

This study also identifies the gap between the existing AIM theory and practices. From the identified gaps, the study mapped the existing challenges faced by the respondents. The mapped challenges provided room for improvements that could be a topic for future research.

Furthermore, the survey and the interaction with industry practitioners have provided better understanding of the underlying mechanism of AIM practices. The survey has also studied important factors that affect the success of AIM in petroleum organizations, especially in the fluctuating market situation. It is important information for organizations wishing to sustain the business aspect of the asset without compromising its integrity.

The study also addressed some of the main challenges of AIM practices related to knowledge management and organizational context. Some solutions were proposed for the challenges found in knowledge management as well as in organizational context. The work suggested a structure for establishing AIM during the pre-operational phase, as well as a strategic planning structure for AIM. Both of the structures could aid the planning, establishment and implementation of AIM in organizations.

From the study it was observed that AIM strategic planning practices vary between different organizations. The larger the organization, the more available are the resources and budget to be allocated to strategic planning.

The findings also suggested integration between business units in the organization in order to reach AIM objectives.

5 Suggestions for further research

AIM is part of physical asset management and will continue to develop alongside the awareness of safety, efficiency and sustainability in the petroleum industry. The increased life cycle cost will require high efficiency and innovation. Thus, further studies will be required to continue developing the current research and practices.

The study has identified research approaches in AIM based on research principles, but the topic of research validation has not been extensively discussed. Thus, it will be advantageous to study the research validation methods for AIM research.

It was also observed that offshore installations represent a complex and dynamic sociotechnical environment that needs to be managed as a whole, both in technical and organizational terms. Many of the issues are interrelated, and seeing the issues as a system might provide a better path to a potential solution. Thus, for future study, it will be beneficial to further identify the sociotechnical structure of offshore installations and to study how to establish a holistic AIM and operation integrity solution that will satisfy both technical and organizational terms.

This paper has also summarized the findings in a study of AIM strategic planning in the petroleum industry in a simplified structure. In the structure, environment scanning or other forms of business assessment for the asset are considered as an important initiation step in the strategy-making process. It was also observed that environment scanning for AIM is a process that is unique, due to the AIM business and technical traits. Thus, for future study, it will be advantageous to study the process of AIM environment scanning.

This study also pointed to the integration of different disciplines in AIM strategic planning; however, the limited study time did not allow further research into the integration mechanism. A further study on the integration and coordination mechanism in AIM would be of benefit, considering that this is one of the main reasons that AIM practices are unsuccessful.

6 References

Al-bidaiwi, M.S., Beg, M.S. and Sivakumar, K. (2012), "Deal with Start-Up and Commissioning Threats and Challenges at an Early Stage of the Project for a Successful Handover and Project Completion", paper presented at *SPE International Production and Operations Conference and Exhibition*, 14-16 May 2012, Doha, Qatar.

Al-Turki, U. (2011), "A framework for strategic planning in maintenance", *Journal of Quality in Maintenance Engineering,* Vol. 17 No. 2, pp. 150-62.

Amadi-Echendu, J.E., Willett, R., Brown, K., Hope, T., Lee, J., Mathew, J., Vyas, N. and Yang, B.-S. (2010), "What Is Engineering Asset Management?", in Amadi-Echendu, J.E., Brown, K., Willett, R. and Mathew, J. (Eds.), *Definitions, concepts and scope of engineering asset management*, Springer London, pp. 3-16.

Arpan Kumar, K. (2014), "Revisiting the supplier selection problem: An integrated approach for group decision support", *Expert Systems with Applications,* Vol. 41 No. 6, pp. 2762-71.

Aven, T. (2008), *Risk analysis assessing uncertainties beyond expected values and probabilities,* Wiley, Chichester, England; Hoboken, NJ.

Baby, R. (2008), "Integrity Management during Design Stage", paper presented at *Abu Dhabi International Petroleum Exhibition and Conference*, 3-5 November 2008, Abu Dhabi, UAE.

Baker, J. (2011), "Integrating reliability, obsolescence and integrity management into life cycle management of subsea facilities", *Underwater Technology: International Journal of the Society for Underwater,* Vol. 30 No. 1, pp. 35-41.

Bharadwaj, U.R., Silberschmidt, V.V. and Wintle, J.B. (2012), "A risk based approach to asset integrity management", *Journal of Quality in Maintenance Engineering,* Vol. 18 No. 4, pp. 417-31.

Blaikie, N. (2007), *Approaches to social enquiry: advancing knowledge,* Polity, Cambridge.

Bohman, J. (2015), "Critical Theory", available at: http://plato.stanford.edu/archives/spr2015/entries/critical-theory/ (accessed 06/07/2015).

Brown, S.L. and Eisenhardt, K.M. (1997), "The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations", *Administrative Science Quarterly*, pp. 1-34.

Bryman, A. and Bell, E. (2011), *Business research methods,* Oxford University Press, Oxford.

Capon, N., Farley, J.U. and Hulbert, J.M. (1987), *Corporate strategic planning,* Columbia University Press, New York.

Carr, A.S. and Smeltzer, L.R. (1997), "An empirically based operational definition of strategic purchasing", *European Journal of Purchasing & Supply Management,* Vol. 3 No. 4, pp. 199-207.

Ciaraldi, S.W. (2012), "Why asset integrity implementation often fails", *Journal of Petroleum Technology*, No. July 2012, pp. 64-65.

Creswell, J.W. (2003), *Research design: qualitative, quantitative, and mixed methods approaches,* Sage Publ., Thousand Oaks, California.

Denzin, N.K. and Lincoln, Y.S. (1994), "Competing paradigms in qualitative research", in Denzin, N.K. and Lincoln, Y.S. (Eds.), *Handbook of qualitative research*, Sage Publications, Thousand Oaks, pp. 105-17.

Edmonds, W.A. and Kennedy, T.D. (2013), *An applied reference guide to research designs: quantitative, qualitative, and mixed methods,* SAGE Publications, Thousand Oaks.

El-Akruti, K. and Dwight, R. (2013), "A framework for the engineering asset management system", *Journal of Quality in Maintenance Engineering,* Vol. 19 No. 4, pp. 398-412.

Fischer, H.R. (2001), "Abductive reasoning as a way of worldmaking", *Foundations of Science,* Vol. 6 No. 4, pp. 361-83.

Grant, R.M. (2003), "Strategic planning in a turbulent environment: Evidence from the oil majors", *Strategic Management Journal*, No. 24, pp. 491-517.

Grant, R.M. and Cibin, R. (1996), "Strategy, structure and market turbulence: the international oil majors, 1970–1991", *Scandinavian Journal of Management,* Vol. 12 No. 2, pp. 165-88.

Grix, J. (2002), "Introducing students to the generic terminology of social research", *Politics,* Vol. 22 No. 3, p. 175.

Hallgrim, H., Ola, L. and Jardar, L. (2014), "The need for a project governance body", *International Journal of Managing Projects in Business,* Vol. 7 No. 4, pp. 661-77.

Hay, C. (2002), *Political analysis: a critical introduction,* Palgrave, Basingstoke.

Horner, R.M.W., El-Haram, M.A. and Munns, A.K. (1997), "Building maintenance strategy: a new management approach", *Journal of Quality in Maintenance Engineering,* Vol. 3 No. 4, pp. 273-80.

ISO. (2014), "ISO 55000:2014", in *Asset management — Overview, principles and terminology*, International Organization for Standardization, Geneva, Switzerland, https://www.iso.org/obp/ui/ -iso:std:iso:55000:ed-1:v2:en.

Jain, R.K. and Natarajan, R. (2011), "Factors influencing the outsourcing decisions: a study of the banking sector in India", *Strategic Outsourcing: An International Journal,* Vol. 4 No. 3, pp. 294-322.

Janele, P.T., Galvin, T.J. and Kisucky, M.J. (1998), "Integrated Asset Management: Work Process and Data Flow Models", paper presented at *SPE Asia Pacific Conference on Integrated Modeling for Asset Management*, 23-24 March 1998, Kuala Lumpur, Malaysia.

KP3. (2007), "'Key programme 3: asset integrity programme', A report by the Offshore Division of HSE's Hazardous Installations Directorate", in, UK, p. 74.

Kumar, R., Panesar, S.S. and Markeset, T. (2009), "Development of technical integrity management services – a concept", *Journal of Quality in Maintenance Engineering,* Vol. 15 No. 3, pp. 271-84.

Kusumawardhani, M., Gundersen, S. and Markeset, T. (2016), "Mapping of research approaches in petroleum industry", Accepted for publication in *Journal of Quality in Maintenance Engineering*.

Kusumawardhani, M., Kumar, R. and Markeset, T. (2016), " Asset integrity management: offshore installations challenges", Accepted for publication in *Journal of Quality in Maintenance Engineering*.

Kusumawardhani, M. and Markeset, T. (2015), "Asset integrity knowledge management: A case study from the petroleum industry", *Operations and Supply Chain Management,* Vol. 8 No. 3, pp. 146-53.

Lind, A.O. (2013), "Pipeline Integrity Management – From Design to Operation", in *The Twenty-third International Offshore and Polar Engineering Conference*, Anchorage, Alaska, 30 June-5 July, International Society of Offshore and Polar Engineers.

Mackenzie, N. and Knipe, S. (2006), "Research dilemmas: paradigms, methods and methodology", *Issues in Educational Research,* Vol. 16 No. 2, pp. 193-205.

Mankins, M.C. and Steele, R. (2006), "Stop Making Plans; Start Making Decisions", in *Harvard business review*, Harvard Business Publishing, Boston, MA.

McIvor, R. (2008), "What is the right outsourcing strategy for your process?", *European Management Journal,* Vol. 26 No. 1, pp. 24-34.

Miller, C.C. and Cardinal, L.B. (1994), "Strategic planning and firm performance: a synthesis of more than two decades of research", *Academy of Management Journal,* Vol. 37 No. 6, pp. 1649-65.

Mintzberg, H. (1994), "The fall and rise of strategic planning", *Harvard Business Review,* Vol. 72 No. 1, pp. 107-14.

Murray, J.A.H.B.R.W. (2013), "The Oxford English dictionary", in *The Oxford English dictionary*, Clarendon Press, Oxford.

Murthy, D.N.P., Atrens, A. and Eccleston, J.A. (2002), "Strategic maintenance management", *Journal of Quality in Maintenance Engineering,* Vol. 8 No. 4, pp. 287-305.

Nag, R., Hambrick, D.C. and Chen, M.-J. (2007), "What is strategic management, really? Inductive derivation of a consensus definition of the field", *Strategic Management Journal,* Vol. 28 No. 9, pp. 935-55.

Nastasie, D.L., Koronios, A. and Haider, A. (2010), "Integration Through Standards – An Overview of Internal Information Standards for Engineering Asset", in Amadi-Echendu, J.E., Brown, K., Willett, R. and Mathew, J. (Eds.), *Definitions, concepts and scope of engineering asset management*, Springer London, pp. 239-58.

NITO. (2016), "Sikkerhet må være prioritet nr. 1", in, NITO.

Nossair, A., Al-Tamimi, A., Al Amri, A., Al-Katheeri, K., Hann, T.O.M. and Finigan, T. (2012), "Mega Projects Integrated Readiness Assurance Process", paper presented at *Abu Dhabi International Petroleum Exhibition*, 11-14 November 2012, Abu Dhabi, UAE.

Parida, A. and Kumar, U. (2009), "Maintenance productivity and performance measurement", in *Handbook of maintenance management and engineering*, Springer, London, pp. 17-41.

Parida, A., Kumar, U., Galar, D. and Stenström, C. (2015), "Performance measurement and management for maintenance: a literature review", *Journal of Quality in Maintenance Engineering,* Vol. 21 No. 1, pp. 2-33.

Peirce, C.S. (2009), *The collected papers of Charles Sanders Peirce,* InteLex Corp., Charlottesville, Va.

Powell, D. (2012), *Operations readiness & assurance,* Lulu Com, [S.l.].

Quinn, R., Kavanagh, K., Power, J. and Thompson, H. (2007), "Integrated Approach to Subsea Integrity Management: Benefits of Early Field Integrity Management Planning for Chevron's Tahiti Field", paper presented at *Offshore Technology Conference*, 2007/1/1/, Houston, Texas, U.S.A.

Rahim, Y., Refsdal, I. and Kenett, R.S. (2010), "The 5C model: A new approach to asset integrity management", *International Journal of Pressure Vessels and Piping,* Vol. 87 No. 2, pp. 88-93.

Ratnayake, R.C. (2012), "Modelling of asset integrity management process: a case study for computing operational integrity preference weights", *International Journal of Computational Systems Engineering,* Vol. 1 No. 1, pp. 3-12.

Reeves, T.C. (1997), "Established and Emerging Evaluation Paradigms for Instructional Design", in Dills, C.R.R.A.J. (Ed.) *Instructional development paradigms*, Educational Technology Publications, Englewood Cliffs, N.J., pp. 163-78.

Salonen, A. (2004), "Managing outsourced support services: observations from case study", *Facilities,* Vol. 22 No. 11/12, pp. 317-22.

Sanjay, J. and Ravi, S. (2007), "Selection of logistics service provider: An analytic network process (ANP) approach", *Omega,* Vol. 35 No. 3, pp. 274-89.

Schuman, C.A. and Brent, A.C. (2005), "Asset life cycle management: towards improving physical asset performance in the process industry", *International Journal of Operations & Production Management,* Vol. 25 No. 6, pp. 566-79.

Smith, C., Wintermute, R., Duran, J., Broussard, K. and Spillman, F. (2002), "Brutus Operational Readiness: Building on Past Projects", paper presented at *Offshore Technology Conference*, 6-9 May 2002, Houston, Texas.

Songhurst, B.W. and Kingsley, M. (1993), "Life-Cycle Cost Reduction through Designing for Maintenance", paper presented at *Offshore Technology Conference 1993*, 3-6 May 1993, Houston, Texas.

Steiner, G.A. (1979), *Strategic planning: what every manager must know,* Simon and Schuster, New York.

Steup, M. (2014), "Epistemology", available at: http://plato.stanford.edu/archives/spr2014/entries/epistemology/ (accessed 06/07/2015).

Stremersch, S., Wuyts, S. and Frambach, R. (2001), "The purchasing of full-service contracts: an exploratory study within the industrial maintenance market", *Industrial Marketing Management,* Vol. 30, pp. 1-12.

Swaak, J. and de Jong, T. (1996), "Measuring intuitive knowledge in science: The development of the what-if test", *Studies in Educational Evaluation,* Vol. 22 No. 4, pp. 341-62.

Tashakkori, A. and Teddlie, C. (1998), *Mixed methodology: combining qualitative and quantitative approaches,* SAGE Publications, Thousand Oaks, Calif.

Tennyson, R.C., Don, W. and Cherpillod, T. (2005), "Monitoring Pipeline Integrity using Fiber Optic Sensors", paper presented at *CORROSION 2005*, 3-7 April, Houston, Texas.

Tronvoll, B., Brown, S.W., Gremler, D.D. and Edvardsson, B. (2011), "Paradigms in service research", *Journal of Service Management,* Vol. 22 No. 5, pp. 560-85.

Tsang, A.H.C. (1998), "A strategic approach to managing maintenance performance", *Journal of Quality in Maintenance Engineering,* Vol. 4 No. 2, pp. 87-94.

Tsang, A.H.C. (2002), "Strategic dimensions of maintenance management", *Journal of Quality in Maintenance Engineering,* Vol. 8 No. 1, pp. 7-39.

Verre, F. (2008), "Be Ready, Cost-Effective for Project Operations in Complex Environments", in *The Way Forward*, Society of Petroleum Engineers, Richardson, Texas.

Vilko, J. and Ritala, P. (2014), "Service supply chain risk management", *Operations and Supply Chain Management,* Vol. 7 No. 3, pp. 114-20.

Visser, J. (1998), "Modelling Maintenance Performance: A Practical Approach", in *IMA Conference, Edinburgh*, pp. 1-13.

Woodhouse, J. (2003), "Asset management: A science emerging", *International Journal of COMADEM,* Vol. 6 No. 3, pp. 4-10.

Woodhouse, J. (2007), "Asset Management: Joining up the jigsaw puzzle – PAS 55 standards for the integrated management of assets", in, Sep/Oct 2007 ed., Maintenance Online, UK.

PART II

PAPERS

Paper 1 - Mapping the research approach of asset management studies in the petroleum industry

Kusumawardhani, M., Gundersen, S. and Markeset, T. (2015), " Mapping the research approach of asset management studies in the petroleum industry", *Accepted for publication in Journal of Quality in Maintenance Engineering*.

Paper 2- Asset integrity management: offshore installations challenges

Kusumawardhani, M., Kumar, R. and Markeset, T. (2016), " Asset integrity management: offshore installations challenges ", *Accepted for publication in Journal of Quality in Maintenance Engineering*.

Asset integrity management: offshore installations challenges

Abstract

Purpose – The purpose of this paper is to identify the challenges facing asset integrity management (AIM) practices in the oil and gas industry, in order to continually develop AIM practices in organizations. The focus is to investigate various challenges in fluctuating oil and gas market conditions, and how organizations can continuously ensure the safety and integrity of their offshore facilities.

Design/methodology/approach – AIM challenges were identified by analysing data from literature study, guided interviews and web-based questionnaire with industrial experts in regions in North America, Southeast Asia and Norway. The results are validated through triangulation method with both quantitative and qualitative technique, as well as comparison with other studies.

Findings – The paper identifies, analyses and validates the challenges and factors that may impact the management of asset integrity on offshore installations. The challenges were discussed to develop understanding of the root cause and thus aim to resolve underlying issues.

Research limitations/implications – The paper focuses on offshore production installations with experts from organizations that have experience in Gulf of Mexico, Brazil, South Asia, Southeast Asia and Norway fields. The sample of respondents may not represent the entire population; however, the same approach and result can be used in similar topics and conditions.

Originality/value – The identified challenges can be used by organizations to resolve underlying AIM challenges, improve their AIM strategy and obtain insights into current AIM practices in the petroleum industry.

Keywords Asset integrity management**,** Asset integrity, Asset management, Offshore installation, Petroleum, Oil industry

Paper type Research paper

Introduction

Asset integrity management is one of the drivers for operating installations safely (Ritchie, 2011). Most of the serious accidents that have taken place were due to lack/ignorance of asset integrity (AI) and resulted in catastrophic events such as Piper Alpha or the Macondo blowout (Ratnayake, 2012). However, AI is often misunderstood by organizations as a mere financial burden (Tsang, 2002). This misconception might relate to the old school of thought on maintenance cost, which is linked to AI. This phenomenon is one of the factors that affect the asset integrity management (AIM) practices in the petroleum industry, especially on offshore installations that have a higher breakeven value than their onshore counterparts.

Therefore it will be advantageous to clearly define and document AIM potentials in a strategic plan such as in AIM strategy (Ciaraldi, 2012). The AIM strategy should focus on the integrity of the installation and maintaining a safe working environment, as well as maximizing the return on investment (ROI). In troubled times, some organizations may choose to rearrange the priorities of several AIM activities to some degree; however, questions are raised as to whether these decisions would compromise the HSEQ (health, safety, environment and quality) and integrity of the installation. Nevertheless, most offshore petroleum installations are still operated regardless of price fluctuations, which demonstrates that the installation's integrity needs to be continuously maintained at all times. Even in situations such as a low oil price, proper AIM will prove to be advantageous. For example, AIM documents such as criticality analysis and risk register would aid the management decision-making in rearranging priorities while still preserving the asset integrity.

Besides the organizational challenges in AI, there are other challenges such as lack of resources, suppliers and training support (Luxhøj et al., 1997); technical challenges such as aging equipment, corrosion, degradation and cracking (Al-Sulaiman et al., 2013); human error challenges (Skalle et al., 2014), as well as challenges in engineering design (Ghani et al., 2014). However, while previous studies are mainly focused on maintenance rather than asset integrity as a holistic approach (see for example Karim et al., 2009; Tsang, 2002; Markeset, 2013), AIM requires organizations to manage their asset holistically (Kumar et al., 2009). Thus, in order to acquire a broader perspective on AIM practices in organizations, it was necessary to perform a study through direct research with the practitioners.

Therefore, a study was conducted to map current challenges faced by AIM in offshore installations. A preliminary literature study was carried out and thereafter research data were gathered from face-to-face guided interviews and questionnaire with industrial experts who have experience from the Gulf of Mexico (GoM), Brazil, South Asia, Southeast Asia and Norway. Identified potential challenges will be discussed to suggest improvements in prevention and mitigation practices to maintain the asset integrity.

This study is part of a larger research project that resides in the area of AIM practises and developments. The paper will first outline a definition of AIM and discuss its interrelated components. Thereafter, study method and the results will be presented, followed by a discussion and the classification of results.

Asset integrity management for offshore installations

The petroleum industry started to adapt asset management (AM) to manage their physical assets in the late 1980s. Later on, terms like AIM and EAM (engineering asset management) were established to address specific functions of AM and to distinguish the term from other disciplines.

AIM definition

Since AIM is focusing more on managing physical assets, for the purpose of this paper, 'asset' is defined as a physical item or entity that has potential or actual value for an organization (ISO 55000:2014, ISO, 2014).

Kusumawardhani et al. (2016) discussed the disposition of AIM and for the purpose of this study proposed to define AIM as: "*the development, implementation and execution of a coordinated plan together with managerial control and organizational activities, to ensure that the physical asset is performing its intended function in a safe, effective and efficient manner over its entire lifecycle, in order to achieve the organizational objectives*". Here the 'asset' is defined as an offshore petroleum production installation including the machinery, equipment, structures, control systems, software, etc., that placed on the installation to perform a function. The 'integrity' of an asset is associated with 'technical integrity' or the ability of the installation to perform its required function in a safe, effective and efficient manner. More specifically, for petroleum installations, integrity is particularly associated with the ability to safely contain various substances related to hydrocarbon production.

AIM in petroleum industry

The term asset management (AM) was first come to light in the mid-to late-1960s (Builta, 1994). However, the AM trend was only started to surfaced in 1990s, mainly in managing public infrastructures, utility system, property, transport systems and public health system (Vanier, 2001; Schuman and Brent, 2005; Jolicoeur and Barrett, 2005; Brown and Humphrey, 2005). Later on, the petroleum sector has grasped this concept for implementation in the integrity of their assets, later known as asset integrity management (AIM).

In the petroleum industry, the emergence of AIM studies has been encouraged by the demand of a safer and more sustainable workplace (Kusumawardhani et al., 2016). Organizations have shifted their attention from isolated approach into holistic approach of the asset, where different disciplines are working together towards the same goal (Ciaraldi, 2012). As a holistic approach, AIM touches the entire aspects of the organizations, which made AIM a multi-discipline field. Besides technical and business aspects (see for example Lind, 2013; Tennyson et al., 2005), AIM also engages social and organizational aspects (see for example Liyanage and Kumar, 2003; Tsang, 2002).

Following the emerging trend in asset integrity management, there are various standards published to regulate mutual view and quality within asset management. For example, in the year 2000, ASTM formed ASTM Committee E53 that focusing on asset management (ASTM, 2013), and the presence of AIM was strengthened by the publication of the ISO 55000 series that standardized guidelines in managing assets (ISO, 2014).

The study method

A research study was conducted to discover the gap between theory and practices of AIM in organizations' offshore production installations. The study consisted of two parts, the first part is a semi-structured face-to-face guided interview that was held with industry practitioners located in Houston, Texas, USA, Singapore and Norway. In the second part, respondents were asked to fill a set of questionnaire.

The questions for the interview were developed to map AIM practices, concerns and other implementation variables within the organizations through literature study, as well as with the collaboration with senior researchers. While some of the questions for the questionnaire were added later to incorporate suggestions from industry practitioners and to map the significance of the interview results. Some of the respondents also provided access to company literature that allowed the researcher to learn about their practices and work processes.

For the survey, in total there were 20 respondents that were divided between two categories. The categories selection was intended to represent both perspectives of users and suppliers of petroleum services. One category consisted of 9 respondents who were working at operator or installation owner organizations (OP), and the second group consisted of 11 respondents who were working at service providers or manufacturing companies (SP). Geographically, eight respondents were located in Houston, seven in Singapore and another ten respondents were located in Oslo and Stavanger, Norway. The respondents have had experience from petroleum offshore installations in the GoM, Brazil, South Asia, Southeast Asia and North Sea.

For the initial interview, there were eight respondents located in Houston (7 SP and 1 OP) and seven respondents were located in Singapore (1 SP and 6 OP). For the second part of the survey (i.e. questionnaire) there were 15 respondents that have completed the questionnaire, which are five from Norway (3 SP and 2 OP), five from Houston (4 SP and 1 OP), and five from Singapore (1 SP and 4 OP).

In order to attain a better understanding of the organization's strategy, respondents mostly held senior management positions. However, views from other non-management employees were also collected whenever possible and taken into consideration to represent both perspectives and triangulation of data.

The respondents validated data gathered from interviews by sending the summary back for verification as shown in Figure 1. Triangulation technique was also implemented by verification with findings from the organization literature study, as well as with the questionnaire. Other sources, such as voluntary provision of data and external data on the subject, were also collected in order to maximize the reliability and validity of the study.

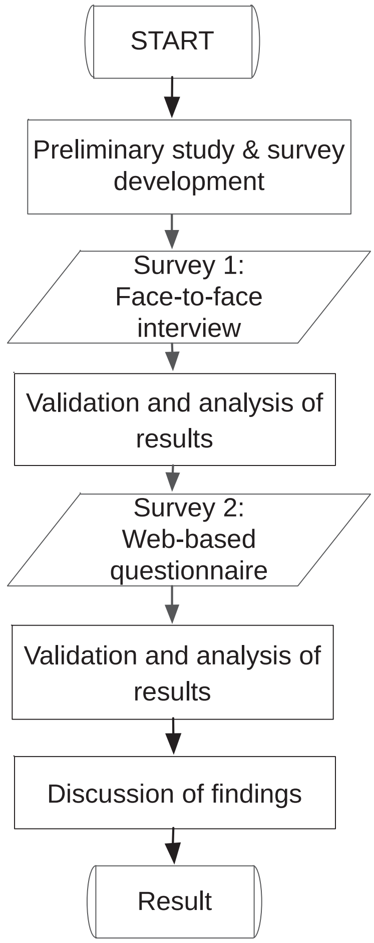


Figure 1. Data gathering and analysis process

Data processing and analysis method

Respondents were individually asked about their challenges with regard to the asset integrity management of offshore installations through a guided-interview and a questionnaire. In the guided-interview, respondents communicated their experience, practices, challenges and improvement suggestions on AIM.

From the interview, the respondents expressed several challenges to the integrity management of offshore assets. These AIM challenges were subsequently added to the set of questionnaire and respondents were asked to rank the significance of several challenges to the integrity management of offshore assets as listed on Table 1. The interview has provided an in-depth study regarding the challenges faced by the petroleum industry, while the questionnaire provided a quantitative means to the survey.

The significance of AIM challenges were ranked with a scale of 1 to 5, with 1 as the least significant to the 5 as the most significant. The average value (Avg.) in Table 1 was calculated as follows: $Avg = (5 * n_5 + 4 * n_4 + 3 * n_3 + 2 * n_2 + 1 * n_1) / (n_5 + n_4 + n_3 + n_2 + n_1)$, where n_x is the number of respondent giving the rating x. Additionally, the percentage high scores (%HS) is the percentage of $(n_4 + n_5)$ over the total respondents, while the percentage low scores (%LS) is the percentage of $(n_1 + n_2)$ over the total respondents.

Findings

During the guided-interviews, the discussions on managing assets were often intertwined with the topic of profit. The prime motivation for organizations to manage their assets is to maximise profit, but on the contrary there are organizations that avoid AIM due to the fear of AIM costs. From the study, it was revealed that only 58% of the total interviewed respondents have established an AIM strategy or similar in their organizations. Both opinion groups provided clear and reasonable arguments for their choices, and from the interview it was apparent that an organization’s preference on AIM strategy depended on their short-term and long-term strategies. All of the respondents were aware of the cost of establishing an AIM strategy, but, on the other hand, they also considered the expected trade-off benefits from establishing AIM.

Nonetheless, all respondents expressed some degree of challenges related to asset integrity. These challenges were listed and grouped as illustrated in Figure 2.

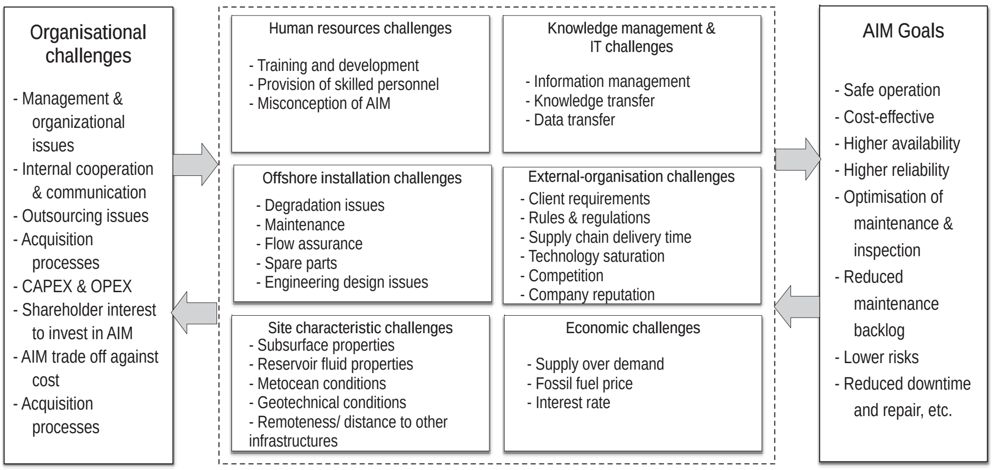


Figure 2. Influence of AIM challenges in organizations with offshore petroleum production asset to reach AIM goals

Figure 2 shows the seven groups of AIM challenges that influencing each other, whether directly or indirectly, in the pursuance of the same objective of achieving AIM goals. From the analysis, it was discovered that technical challenges were outnumbered by organizational related challenges.

To further study these challenges, respondents were asked to rank the significance of these challenges on AIM through a questionnaire as seen on Table 1. Similar to the interview results, according to the respondents, the most significance challenges were the organizational challenges, followed by human resources challenges, knowledge management and IT, offshore installation challenges, external-organization challenges, site characteristic challenges and lastly by economic challenges.

Table 1. The significance of AIM challenges

AIM Challenges	Ratings					AVG	%HS	%LS
	5	4	3	2	1			
Organizational challenges (Avg.)						*4,18*		
Internal cooperation	10	2	3	0	0	4,47	80%	0%
CAPEX and OPEX	9	4	2	0	0	4,47	85%	0%
Management and organizational	10	2	2	1	0	4,40	80%	5%

AIM Challenges	Ratings					AVG	%HS	%LS
	5	4	3	2	1			
issues								
Internal communication	9	3	3	0	0	4,40	80%	0%
AIM trade-off against cost	7	6	2	0	0	4,33	85%	0%
Shareholder interest to invest in AIM	6	5	3	1	0	4,07	75%	5%
Acquisition processes	4	4	6	1	0	3,73	60%	5%
Outsourcing issues	4	5	3	1	2	3,53	65%	15%
Human resources challenges (Avg.)						*4,02*		
Misconception of AIM	7	4	2	2	0	4,07	70%	10%
Provision of skilled personnel	7	3	4	1	0	4,07	65%	5%
Training and competence development	7	2	4	2	0	3,93	60%	10%
Knowledge management & IT (Avg.)						3,97		
Knowledge transfer	7	5	2	1	0	4,20	85%	5%
Data transfer between onshore and offshore	6	5	4	0	0	4,13	80%	0%
Information management	5	4	3	3	0	3,73	70%	15%
Offshore installation challenges (Avg.)						*3,89*		
Degradation issues	7	4	2	2	0	4,07	80%	10%
Spare part availability	7	2	5	1	0	4,00	70%	5%
Maintenance strategy and implication	6	3	5	1	0	3,93	70%	5%
Engineering design issues	5	5	3	2	0	3,87	75%	10%
Flow assurance	2	7	4	2	0	3,60	70%	10%
External-organization challenges (Avg.)						*3,83*		
Rules and regulations	7	5	2	1	0	4,20	75%	10%
Supply chain delivery time	5	7	2	1	0	4,07	75%	10%
Client requirements	9	1	0	4	1	3,87	85%	10%
Company reputation	5	5	2	3	0	3,80	65%	20%
Competition	3	7	2	3	0	3,67	65%	20%
Technology saturation	1	5	10	1	0	3,35	55%	10%
Site characteristic challenges (Avg.)						*3,49*		
Subsurface properties (e.g. depth, seabed)	4	5	6	0	0	3,87	55%	0%
Remoteness/ distance to other	2	7	4	2	0	3,60	55%	10%

AIM Challenges	Ratings					AVG	%HS	%LS
	5	4	3	2	1			
infrastructures								
Reservoir fluid properties	2	3	10	0	0	3,47	35%	0%
Meteorology & oceanography conditions	4	3	4	2	2	3,33	45%	20%
Geotechnical conditions	2	3	8	0	2	3,20	35%	10%
Economic concerns (Avg.)						*3,47*		
Fossil fuel price	9	2	1	3	0	4,13	55%	30%
Over-supply of production	3	4	1	7	0	3,20	35%	50%
Interest rate	3	2	3	7	0	3,07	25%	50%

Apparently, other corresponding studies have also stated similar results in addressing organizational issues in asset integrity (see for example Amadi-Echendu et al., 2010; KP3, 2007; Ratnayake, 2012). Moreover, the results were interestingly similar, despite the different geographical locations. The differences lay in the significance the respondents place on the factors shown in Figure 2. For example, respondents from Houston stressed their challenges on provision of skilled resources, while in Singapore the managerial issues were particularly stressed. In Norway the first place was earned by human resources challenges and followed by knowledge management and IT, as most of the organizations' work processes has been digitalized. Most of the respondents in Norway have eagerly shared their organization's efforts and success in managing knowledge and technology for their fleets.

The top four groups and their relations with other groups are discussed below, ranked from the more significance to the least.

- **Organizational-related challenges**

The accumulated managerial concerns range from managerial actions, decision-making, perspective towards AIM, corporate communication and also knowledge management, which are all interrelated and need to be managed simultaneously. Besides a good plan, mature organizations also uses lesson learned as continuous improvement tool. For example, in one interviewed company, some of its offshore installations manage to save downtime by referring to lesson learn register from other installations. In this case, management enforced record and documentation procedures over the entire lifecycle through strategic management plan. This strategy is similar with Haines (2000) idea on organizational plan. Figure 4 shows an adaptation of the concept on an AIM strategic management plan.

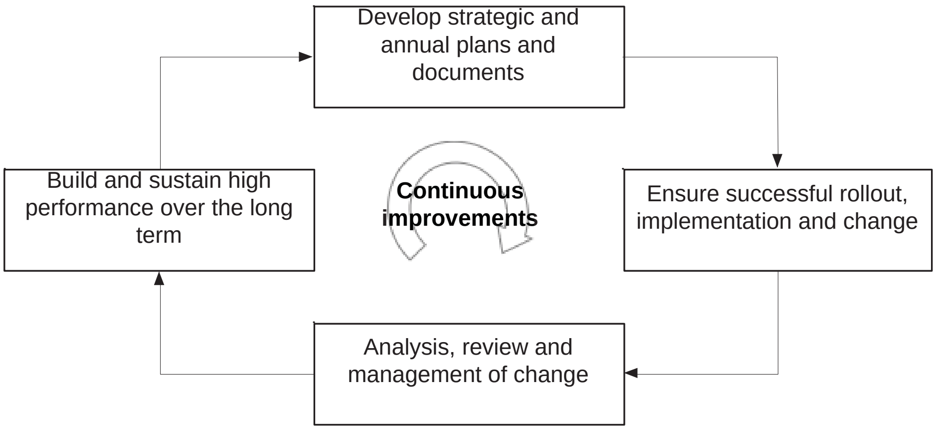


Figure 4. AIM strategic management model (adapted from: Haines, 2000)

The four boxes illustrate a continuous work processes, while the inside arrow represent continuous improvements initiatives outside the prescribed process that need to be taken to improve the process itself. Related to documentations, the organizations that reported concerns in information management are organizations that did not establish AIM strategy or similar procedures. This shows that both factors might be related.

In addition, some organizations prescribed management of change in their strategy. In dynamic environments such as offshore installations, it is important to plan a fail-safe mechanism such as change management and knowledge transfer, in order to adapt quickly to changes, including the change of key people who usually hold vital knowledge about the organization. Additionally, management does not have to be associated with an individual or group; thus, once a suitable strategy is established, every step needs to be properly documented to ensure proper knowledge transfer.

A few respondents expressed their concerns regarding the organization´s decision to use cheaper and less reliable equipment to reduce capital cost (CAPEX). They explained that equipment with lower reliability would typically require extra maintenance or repair in the future, which will add up to a higher operational cost (OPEX). Moreover, the fluctuating oil and gas price has increased the sensitivity towards investment and expenditure in offshore installations, weighing into the cost issues and the willingness to invest in AIM. This challenge is related to the perception of CAPEX as a trade off against OPEX for maximum ROI. Additionally, since the scope of AIM includes the entire life cycle of an offshore installation, the organization will be dealing with AIM early in the life cycle phase. Through this argument, it is understandable why operators can be hesitant about new technology, since it can be technically or commercially prohibitive for operators to introduce new technologies both at an early development phase and later during the operation phase.

Most respondents agreed that proven technologies are preferable over new and untested technologies. The uncertainties carried by the lack of track records might convert to additional costs. Thus, it can be difficult to make an argument for investment. One of the respondents suggested the service contracts as a channel to distribute the risk of investing in new technology. For example, the respective respondent´s company has agreed to engage an unproven technology and shared any loss that was caused by the technology implementation. Additionally, the contract should include amendment clause that will come in handy during oil price fluctuations.

- **Human resources**

Management plays an important role in managing human resources as well as other resources, and conversely, management also consists of humans. Some of the respondents expressed that quite often, the management decisions depend on one individual without adequate knowledge background, and thus inhibiting informed decision-making. This issue also related to the knowledge transfer in the organization that extends not only to the management, but also to the whole organization, especially to offshore personnel.

Another example for this case was shown when several interviewed respondents complained that individuals sitting in 'the management' often block operation efforts in maintaining asset integrity. One respondent even revealed that it took a major offshore catastrophe to shift the management's perspective regarding AIM and the advantage of operating strategically versus operating tactically.

Learning from previous offshore-related accidents, most companies are aware that human error has a big impact on asset integrity; thus, the quality of personnel is vital. The study revealed that the oil and gas industry is struggling with the provision of skilled personnel as well as their training and development. In several regions, the respondents even needed to run intensive campaigns in order to shift personnel's traditional perception regarding asset integrity and encourage a new AI culture.

The study observed respondents' perspectives from before and after the oil price fell in 2014. It was discovered that even though there are more available human resources since the oil price has fallen, they do not necessarily have the right skills for the task. Since personnel also need to interact with technologies, there is a potential that unfamiliarity with the technology will cause errors. Therefore companies would need to provide training prior to job assignment.

Human error is a wide topic, especially in a complex environment such as in offshore installations. A more complex system is formed when the operator engages one or more service provider(s) in AIM activities, which is a common practice these days. Work processes are shared between internal and external organizations, and also between the onshore and offshore environment, creating a complex system. As an impact from the diversity, personnel need to deal with not only the relationships amongst the personnel themselves, but also between different technical and organizational environments. Additionally, personnel are also interacting with technologies; thus, respondents were concerned whether unfamiliarity with technology would cause an error. This is similar to Bridger (2003) idea of the human machine model. In the current implementation, personnel are exposed to multi-environments (onshore and offshore) and thus are consequently required to interact with a variety of equipment as illustrated in Figure 6. According to

Bridger (2003), in this situation there is a potential gap input when transferring information from one piece of equipment to another.

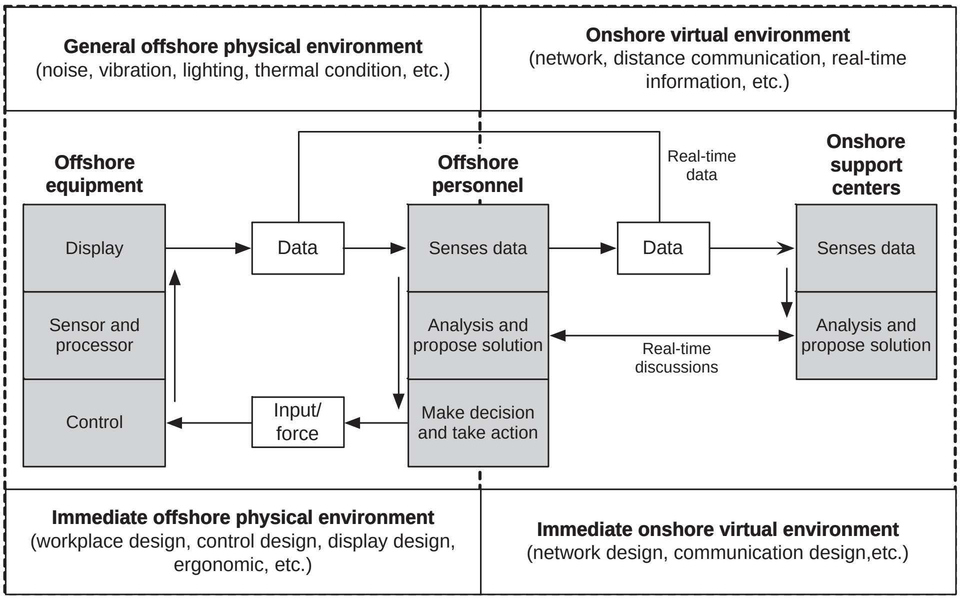


Figure 6. Human–machine model of offshore personnel (adapted from Bridger, 2003)

Latent conditions could also emerge from the interaction with other information users. Since the onshore team relies greatly on the information made offshore, analysis that is carried out based on an unreliable set of information would have less value or even lead to incorrect decision making. For example, from experience, it was revealed that onshore inspection planners are relying on historical data as a foundation for future inspection plans. Thus, if corrosion is undetected, and hence there are no plans for a repair, it could potentially lead to leakage or severe corrosion.

In such a complex sociotechnical environment, management needs to be involved and proactive in managing the complexity. It was not surprising that some of the respondents expressed their concerns on social interactions rather than on technical and organizational interactions. The respondents were struggling to understand the decreased offshore productivity, despite the high salaries and advanced technology, when apparently it was discovered that lack of cooperation between departments was the main cause.

Some respondents suggested that barriers to human errors could be implemented in several areas such as improving the human-machine interface design, equipment calibration, qualification and training of personnel, etc. Aside from that, other respondents suggested that involving personnel in the creation of system processes has created a sense of ownership of the asset and a sense of responsibility for their task.

- **Knowledge management (KM) and information technology (IT)**

Although information technology has a major influence in the advancement of the petroleum industry, the adaptation of these new technologies is not without its challenges. In the interviews, respondents expressed various challenges related to the knowledge transfer, information management and data transfer between onshore and offshore. Geographically, KM is more stressed in Norway, partially due to the petroleum industry standardization. For example, Norsok has standardized the technical information management in Norsok Z-003 (NTS, 1998).

In some countries where the government or the clients do not regulate KM practices, some of the respondents experienced challenges related to documentation and records, either historically or from the present operational activities. Establishing management of knowledge early in the facility’s life cycle could prevent this. For a more comprehensive discussion on this topic please refer to Kusumawardhani and Markeset (2015).

- **The offshore installation**

Operators are all too familiar with degradation issues, especially with corrosion. One of the respondents admitted that one of their vessels burst during operation, and the degradation issues mainly caused it. There was also another respondent that reported degradation issues on their hulls, and not long after the study was completed the respondent’s installations experienced a major incident causing downtime and fatality.

Corrosion is just one of many degradation-caused issues. Offshore installations are prone to defects that are caused by operating conditions as well as external conditions. Defects can also be inherited from the construction or commissioning phases (pre-service), but are usually less considered than the defects that occur during the operation phase (in-service). The defects that occur before operation can generally be removed or detected prior to operation. However, attention to pre-service defects might increase when the respective installation undergoes a modification or life extension, since other anomalies may occur during the process. Other considerations are the success rate of the design phase, the result of construction and commissioning, as well as an outstanding punch list inherited by the operation, which overall will affect the installation's reliability.

Even if it is assumed that there are no inherited defects, from the case study it was found that there were reported defects during operation that may occur from various sources such as from environmental conditions, design and operating conditions or from physical activities, as illustrated in Figure 5.

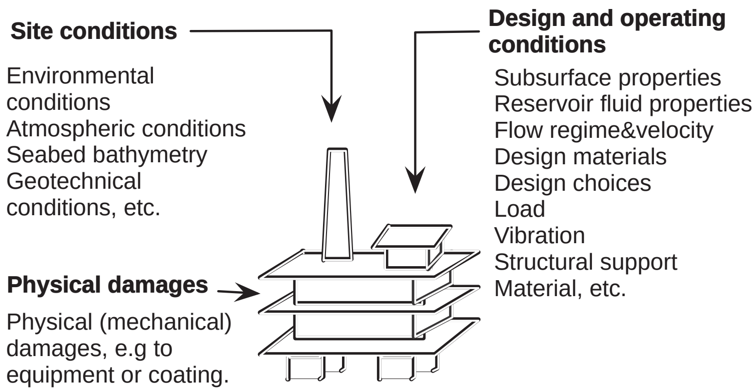


Figure 5. Factors affecting the degradation of an offshore installation

In the AIM concept, an organization needs to establish a strategy to maintain the entire installation integrity that at least covers its entire lifetime. The lifetime of an asset is determined early in the initial design stage as a guideline for the life-cycle plan and design requirement. The failure rate of an asset will continuously increase in time, but the increasing rate of failure can be altered through proper preventive measures such as good design choices and materials, condition-based maintenance, preventive maintenance, reliability based maintenance, etc.

However, in the late-life phase of an asset, these preventive measures would become more frequent in order to maintain the integrity. At this stage, some of the installation's equipment may have been replaced or modified to prolong the life of the asset. Nevertheless, the rest of the equipment that is not being renewed would require a proactive approach to inspection and maintenance management. In some cases, respondents have reported that the history of equipment could not be found due to traditional log systems and changes in the system or personnel. Several respondents also reported a lack of documentation and records from the previous asset owner, thus making it difficult to state the integrity level and failure rate of the equipment. These factors are essential in AIM, similar to the thoughts of Wintle et al. (2006), which indicated that a good documentation and technical information is a necessity in preserving an aging asset.

Concluding remarks

Even after several offshore catastrophes as wake-up calls, some organizations still have a traditional perception regarding AIM. Organizations have expressed their challenges in implementing AIM and the major concerns were regarding managerial decisions, human resources, knowledge management and IT, cost and degradation. As mentioned at the beginning of this paper, several researchers have addressed these challenges individually and suggested multiple solutions for these specific challenges (see for example Al-Sulaiman et al., 2013; Skalle et al., 2014; Ghani et al., 2014). However, a holistic solution for the organization is needed for successful AIM, since AIM consists of various processes that need to be coordinated simultaneously. Moreover, it is necessary for the organization to raise awareness of the importance of AIM and to cultivate a culture of preserving asset integrity.

Most of the challenges are recurring and similar, despite the geographical location. If the issue is not properly treated from the root-cause, it will keep reoccurring; thus, an organization needs to investigate the root cause, and its relation with other components, and document the findings as a lesson learned record.

It was also observed that offshore installations represent a complex and dynamic sociotechnical environment that needs to be managed as a whole, both in technical and organizational terms. Many of the issues are interrelated, and seeing the issues as a system might provide a better path to a potential solution. Moreover, some of the challenges are related to operation integrity, such as work procedures, record keeping, safety culture, training and competency, etc. This shows that AIM is closely related to operation integrity and need to be managed hand-in-hand.

Thus, for future study, it will be advantageous to further identify the sociotechnical structure of offshore installations and to study how to establish a holistic AIM and operation integrity solution that will satisfy both technical and organizational terms.

Acknowledgement

We would like to thank all the participating respondents and acknowledge Professor Matthew A. Franchek, University of Houston, for the support he provided during our long research visit with his research group in Houston, Texas. Without his support, this study would not be possible.

References

Al-bidaiwi, M.S., Beg, M.S. and Sivakumar, K. (2012), "Deal With Start-Up and Commissioning Threats and Challeges at an Early Stage of the Project for a Sucessful Handover and Project Completion", paper presented at *SPE International Production and Operations Conference and Exhibition*, 14-16 May 2012, Doha, Qatar.

Al- Turki, U. (2011), "A framework for strategic planning in maintenance", *Journal of Quality in Maintenance Engineering,* Vol. 17 No. 2, pp. 150-62.

Amadi-Echendu, J.E., Willett, R., Brown, K., Hope, T., Lee, J., Mathew, J., Vyas, N. and Yang, B.-S. (2010), "What Is Engineering Asset Management?", in Amadi-Echendu, J.E., Brown, K., Willett, R. and Mathew, J. (Eds.), *Definitions, Concepts and Scope of Engineering Asset Management*, Springer London, pp. 3-16.

Arpan Kumar, K. (2014), "Revisiting the supplier selection problem: An integrated approach for group decision support", *Expert Systems with Applications,* Vol. 41 No. 6, pp. 2762 - 71.

Aven, T. (2008), *Risk analysis assessing uncertainties beyond expected values and probabilities,* Wiley, Chichester, England; Hoboken, NJ.

Baby, R. (2008), "Integrity Management During Design Stage", paper presented at *Abu Dhabi International Petroleum Exhibition and Conference*, 3-5 November 2008, Abu Dhabi, UAE.

Baker, J. (2011), "Integrating reliability, obsolescence and integrity management into life cycle management of subsea facilities", *Underwater Technology: International Journal of the Society for Underwater,* Vol. 30 No. 1, pp. 35-41.

Bharadwaj, U.R., Silberschmidt, V.V. and Wintle, J.B. (2012), "A risk based approach to asset integrity management", *Journal of Quality in Maintenance Engineering,* Vol. 18 No. 4, pp. 417-31.

Blaikie, N. (2007), *Approaches to social enquiry: advancing knowledge,* Polity, Cambridge.

Bohman, J. (2015), "Critical Theory", available at: http://plato.stanford.edu/archives/spr2015/entries/critical-theory/ (accessed 06/07/2015 2015).

Brown, S.L. and Eisenhardt, K.M. (1997), "The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations", *Administrative science quarterly*, pp. 1-34.

Bryman, A. and Bell, E. (2011), *Business research methods,* Oxford University Press, Oxford.

Capon, N., Farley, J.U. and Hulbert, J.M. (1987), *Corporate strategic planning,* Columbia University Press, New York.

Carr, A.S. and Smeltzer, L.R. (1997), "An empirically based operational definition of strategic purchasing", *European Journal of Purchasing & Supply Management,* Vol. 3 No. 4, pp. 199-207.

Ciaraldi, S.W. (2012), "Why Asset Integrity Implementation Often Fails", *Journal of Petroleum Technology,* No. July 2012, pp. 64-65.

Creswell, J.W. (2003), *Research design : qualitative, quantitative, and mixed methods approaches,* Sage Publ., Thousand Oaks, California.

Denzin, N.K. and Lincoln, Y.S. (1994), "Competing paradigms in qualitative research", in Denzin, N.K. and Lincoln, Y.S. (Eds.), *Handbook of qualitative research*, Sage Publications, Thousand Oaks, pp. 105-17.

Duggan, M. and Blayden, R. (2001), "Venture maintainability: a path to project success Why are some projects less successful than others and what can we do to improve?", *Journal of Quality in Maintenance Engineering,* Vol. 7 No. 4, pp. 241-51.

Edmonds, W.A. and Kennedy, T.D. (2013), *An applied reference guide to research designs : quantitative, qualitative, and mixed methods,* SAGE Publications, Thousand Oaks.

El-Akruti, K. and Dwight, R. (2013), "A framework for the engineering asset management system", *Journal of Quality in Maintenance Engineering,* Vol. 19 No. 4, pp. 398-412.

Fischer, H.R. (2001), "Abductive Reasoning as a Way of Worldmaking", *Foundations of Science,* Vol. 6 No. 4, pp. 361-83.

Grant, R.M. (2003), "Strategic planning in a turbulent environment: Evidence from the oil majors", *Strategic Management Journal,* No. 24, pp. 491-517.

Grant, R.M. and Cibin, R. (1996), "Strategy, structure and market turbulence: the international oil majors, 1970–1991", *Scandinavian Journal of Management,* Vol. 12 No. 2, pp. 165-88.

Grix, J. (2002), "Introducing Students to the Generic Terminology of Social Research", *Politics,* Vol. 22 No. 3, pp. 175.

Hallgrim, H., Ola, L. and Jardar, L. (2014), "The need for a project governance body", *International Journal of Managing Projects in Business,* Vol. 7 No. 4, pp. 661-77.

Hay, C. (2002), *Political analysis : a critical introduction,* Palgrave, Basingstoke.

Horner, R.M.W., El- Haram, M.A. and Munns, A.K. (1997), "Building maintenance strategy: a new management approachnull", *Journal of Quality in Maintenance Engineering,* Vol. 3 No. 4, pp. 273-80.

ISO. (2014), "ISO 55000:2014", in *Asset management — Overview, principles and terminology*, International Organization for Standardization, Geneva, Switzerland, pp. https://www.iso.org/obp/ui/ - iso:std:iso:55000:ed-1:v2:en.

Jain, R.K. and Natarajan, R. (2011), "Factors influencing the outsourcing decisions: a study of the banking sector in India", *Strategic Outsourcing: An International Journal,* Vol. 4 No. 3, pp. 294-322.

Janele, P.T., Galvin, T.J. and Kisucky, M.J. (1998), "Integrated Asset Management: Work Process and Data Flow Models", paper presented at *SPE Asia Pacific Conference on Integrated Modeling for Asset Management*, 23-24 March 1998, Kuala Lumpur, Malaysia.

Judd, M., McArthur, S., McDonald, J. and Farish, O. (2002), "Intelligent condition monitoring and asset management. Partial discharge monitoring for power transformers", *Power Engineering Journal,* Vol. 16 No. 6, pp. 297-304.

KP3. (2007), "'Key programme 3: asset integrity programme', A report by the Offshore Division of HSE's Hazardous Installations Directorate", in, UK, pp. 74.

Kumar, R., Panesar, S.S. and Markeset, T. (2009), "Development of technical integrity management services – a concept", *Journal of Quality in Maintenance Engineering,* Vol. 15 No. 3, pp. 271-84.

Kusumawardhani, M., Gundersen, S. and Markeset, T. (2016), "Mapping of research approaches in petroleum industry", *Accepted for publication in Journal of Quality in Maintenance Engineering*.

Kusumawardhani, M. and Markeset, T. (2015), "Asset Integrity Knowledge Management: A Case Study from the Petroleum Industry", *Operations and supply chain management,* Vol. 8 No. 3, pp. 146 – 53.

Lind, A.O. (2013), "Pipeline Integrity Management – From Design to Operation", in *The Twenty-third International Offshore and Polar Engineering Conference*, Anchorage, Alaska, 30 June-5 July, International Society of Offshore and Polar Engineers.

Liyanage, J.P. and Kumar, U. (2003), "Towards a value-based view on operations and maintenance performance management", *Journal of Quality in Maintenance Engineering,* Vol. 9 No. 4, pp. 333-50.

Mackenzie, N. and Knipe, S. (2006), "Research dilemmas : paradigms, methods and methodology", *Issues in Educational Research,* Vol. 16 No. 2, pp. 193-205.

Mankins, M.C. and Steele, R. (2006), "Stop Making Plans; Start Making Decisions", in *Harvard Business Review*, Harvard Business Publishing, Boston, MA.

McIvor, R. (2008), "What is the right outsourcing strategy for your process?", *European Management Journal,* Vol. 26 No. 1, pp. 24-34.

Miller, C.C. and Cardinal, L.B. (1994), "Strategic planning and firm performance: a synthesis of more than two decades of research", *Academy of Management Journal,* Vol. 37 No. 6, pp. 1649-65.

Mintzberg, H. (1994), "The fall and rise of strategic planning", *Harvard Business Review,* Vol. 72 No. 1, pp. 107-14.

Murray, J.A.H.B.R.W. (2013), "The Oxford English dictionary", in *The Oxford English dictionary*, Clarendon Press, Oxford.

Murthy, D.N.P., Atrens, A. and Eccleston, J.A. (2002), "Strategic maintenance management", *Journal of Quality in Maintenance Engineering,* Vol. 8 No. 4, pp. 287-305.

Nag, R., Hambrick, D.C. and Chen, M.-J. (2007), "What is strategic management, really? Inductive derivation of a consensus definition of the field", *Strategic Management Journal,* Vol. 28 No. 9, pp. 935-55.

Nastasie, D.L., Koronios, A. and Haider, A. (2010), "Integration Through Standards – An Overview of Internal Information Standards for Engineering Asset", in Amadi-Echendu, J.E., Brown, K., Willett, R.

and Mathew, J. (Eds.), *Definitions, Concepts and Scope of Engineering Asset Management*, Springer London, pp. 239-58.

NITO. (2016), "Sikkerhet må være prioritet nr. 1", in, NITO.

Nossair, A., Al-Tamimi, A., Al Amri, A., Al-Katheeri, K., Hann, T.O.M. and Finigan, T. (2012), "Mega Projects Integrated Readiness Assurance Process", paper presented at *Abu Dhabi International Petroleum Exhibition*, 11-14 November 2012, Abu Dhabi, UAE.

Panesar, S.S. and Markeset, T. (2008a), "Development of a framework for industrial service innovation management and coordination", *Journal of Quality in Maintenance Engineering,* Vol. 14 No. 2, pp. 177-93.

Panesar, S.S. and Markeset, T. (2008b), "Industrial service innovation through improved contractual relationship: A case study in maintenance", *Journal of Quality in Maintenance Engineering,* Vol. 14 No. 3, pp. 290-305.

Parida, A. and Kumar, U. (2009), "Maintenance productivity and performance measurement", in *Handbook of maintenance management and engineering*, Springer, London, pp. 17-41.

Parida, A., Kumar, U., Galar, D. and Stenström, C. (2015), "Performance measurement and management for maintenance: a literature review", *Journal of Quality in Maintenance Engineering,* Vol. 21 No. 1, pp. 2-33.

Peirce, C.S. (2009), *The collected papers of Charles Sanders Peirce,* InteLex Corp., Charlottesville, Va.

Powell, D. (2012), *Operations readiness & assurance,* Lulu Com, [S.l.].

Prajapati, A., Bechtel, J. and Ganesan, S. (2012), "Condition based maintenance: a survey", *Journal of Quality in Maintenance Engineering,* Vol. 18 No. 4, pp. 384-400.

Quinn, R., Kavanagh, K., Power, J. and Thompson, H. (2007), "Integrated Approach to Subsea Integrity Management: Benefits of Early Field Integrity Management Planning for Chevron's Tahiti Field", paper presented at *Offshore Technology Conference*, 2007/1/1/, Houston, Texas, U.S.A.

Rahim, Y., Refsdal, I. and Kenett, R.S. (2010), "The 5C model: A new approach to asset integrity management", *International Journal of Pressure Vessels and Piping,* Vol. 87 No. 2, pp. 88-93.

Rahmawati, S.D., Whitson, C.H., Foss, B. and Kuntadi, A. (2012), "Integrated field operation and optimization", *Journal of Petroleum Science and Engineering,* Vol. 81 No. 0, pp. 161-70.

Ratnayake, R.C. (2012), "Modelling of asset integrity management process: a case study for computing operational integrity preference weights", *International Journal of Computational Systems Engineering,* Vol. 1 No. 1, pp. 3-12.

Ratnayake, R.M.C. and Markeset, T. (2010), "Technical integrity management: measuring HSE awareness using AHP in selecting a maintenance strategy", *Journal of Quality in Maintenance Engineering,* Vol. 16 No. 1, pp. 44-63.

Raza, J. and Liyanage, J.P. (2009), "Application of intelligent technique to identify hidden abnormalities in a system", *Journal of Quality in Maintenance Engineering,* Vol. 15 No. 2, pp. 221-35.

Raza, J., Liyanage, J.P., Atat, H.A. and Lee, J. (2010), "A comparative study of maintenance data classification based on neural networks, logistic regression and support vector machines", *Journal of Quality in Maintenance Engineering,* Vol. 16 No. 3, pp. 303-18.

Reeves, T.C. (1997), "Established and Emerging Evaluation Paradigms for Instructional Design", in Dills, C.R.R.A.J. (Ed.) *Instructional development paradigms*, Educational Technology Publications, Englewood Cliffs, N.J., pp. 163-78.

Salonen, A. (2004), "Managing outsourced support services: observations from case study", *Facilities,* Vol. 22 No. 11/12, pp. 317-22.

Sanjay, J. and Ravi, S. (2007), "Selection of logistics service provider: An analytic network process (ANP) approach", *Omega,* Vol. 35 No. 3, pp. 274 - 89.

Schuman, C.A. and Brent, A.C. (2005), "Asset life cycle management: towards improving physical asset performance in the process industry", *International Journal of Operations & Production Management,* Vol. 25 No. 6, pp. 566-79.

Smith, C., Wintermute, R., Duran, J., Broussard, K. and Spillman, F. (2002), "Brutus Operational Readiness: Building on Past Projects", paper presented at *Offshore Technology Conference*, 6-9 May 2002, Houston, Texas.

Songhurst, B.W. and Kingsley, M. (1993), "Life-Cycle Cost Reduction Through Designing For Maintenance", paper presented at *Offshore Technology Conference 1993*, 3-6 May 1993, Houston, Texas.

Steiner, G.A. (1979), *Strategic planning : what every manager must know,* Simon and Schuster, New York.

Steup, M. (2014), "Epistemology", available at: http://plato.stanford.edu/archives/spr2014/entries/epistemology/ (accessed 06/07/2015 2015).

Stremersch, S., Wuyts, S. and Frambach, R. (2001), "The purchasing of full-service contracts: an exploratory study within the industrial maintenance market", *Industrial Marketing Management,* Vol. 30, pp. 1-12.

Swaak, J. and de Jong, T. (1996), "Measuring intuitive knowledge in science: The development of the what-if test", *Studies in Educational Evaluation,* Vol. 22 No. 4, pp. 341-62.

Tashakkori, A. and Teddlie, C. (1998), *Mixed methodology : combining qualitative and quantitative approaches,* SAGE Publications, Thousand Oaks, Calif.

Tennyson, R.C., Don, W. and Cherpillod, T. (2005), "Monitoring Pipeline Integrity Using Fiber Optic Sensors", paper presented at *CORROSION 2005*, 3-7 April, Houston, Texas

Thorstensen, T.A. and Rasmussen, M. (1999), "A cost model for condition based overhaul/replacement", *Journal of Quality in Maintenance Engineering,* Vol. 5 No. 2, pp. 102-14.

Tronvoll, B., Brown, S.W., Gremler, D.D. and Edvardsson, B. (2011), "Paradigms in service research", *Journal of Service Management,* Vol. 22 No. 5, pp. 560-85.

Tsang, A.H.C. (1995), "Condition- based maintenance: tools and decision making", *Journal of Quality in Maintenance Engineering,* Vol. 1 No. 3, pp. 3-17.

Tsang, A.H.C. (1998), "A strategic approach to managing maintenance performance", *Journal of Quality in Maintenance Engineering,* Vol. 4 No. 2, pp. 87-94.

Tsang, A.H.C. (2002), "Strategic dimensions of maintenance management", *Journal of Quality in Maintenance Engineering,* Vol. 8 No. 1, pp. 7-39.

Veldman, J., Wortmann, H. and Klingenberg, W. (2011), "Typology of condition based maintenance", *Journal of Quality in Maintenance Engineering,* Vol. 17 No. 2, pp. 183-202.

Verre, F. (2008), "Be Ready, Cost-Effective for Project Operations in Complex Environments", in *The Way Forward*, Society of Petroleum Engineers, Richardson, Texas.

Vilko, J. and Ritala, P. (2014), "Service Supply Chain Risk Management", *Operations and supply chain management,* Vol. 7 No. 3, pp. 114 - 20.

Visser, J. (1998), "Modelling maintenance performance: a practical approach", in *IMA conference, Edinburgh*, pp. 1-13.

Woodhouse, J. (2003), "Asset Management: A Science Emerging", *International Journal of COMADEM,* Vol. 6 No. 3, pp. 4-10.

Woodhouse, J. (2007), "Asset Management: Joining up the jigsaw puzzle – PAS 55 standards for the integrated management of assets", in, Sep/Oct 2007 ed., Maintenance Online, UK.

Paper 3 - Asset integrity knowledge management: a case study from the petroleum industry

Kusumawardhani, M. and Markeset, T. (2015), "Asset integrity knowledge management: a case study from the petroleum industry", *Operations and supply chain management*, Vol. 8 No. 3, pp. 146 – 53.

Asset integrity knowledge management: a case study from the petroleum industry

Abstract
The practice of knowledge management in the petroleum industry is motivated by the HSE, technical and business requirements. Aligned with the development of knowledge management, various advancements in information systems are used to maintain the asset integrity of petroleum installations. However, the advancement also poses its own risks. With the increasing use of advanced technology in the petroleum installations, there are potential threats that can affect the installation´s integrity. This paper aims to identify knowledge management and information system practices and challenges in maintaining the asset integrity of petroleum installations. This study is part of a larger-scale case study that analyzes current asset integrity management (AIM) practices in the petroleum industry. The study is based on a literature study and face-to-face interviews with industry practitioners in Houston, Texas, and Singapore. The main findings revealed seven groups of AIM challenges; knowledge management and information technology are part of these.

Keywords: Information technology, information system, industrial services, operation management, asset integrity, asset management.

Introduction

The applications of information system (IS) in organization´s knowledge management (KM) have been expanding alongside advancements in information and communication technology (ICT), such as digital technology (Brynjolfsson, 2012). Digital technology processes data in order to deliver necessary information to the intended recipient. The management of knowledge enables appropriate information to be obtainable whenever it is required in order to support decision-making. Various advancements in IS technologies are also applied in asset integrity management (AIM) of petroleum installations. Moreover, KM and IS are present in the entire life cycle of a petroleum installation. For example, facility operators have utilized data to support asset integrity applications, such as in decision-making tools, performance monitoring and improvement tools in various life cycle phases (see for example Brule, 2013, Gang et al., 2010, Karim et al., 2009).

However, with the increasing use of digital technology and advances in IS, there are potential threats that can affect the installation´s integrity (Brynjolfsson, 2012, Ringstad and Andersen, 2006, Torstensen and Skramstad, 2008). Although information technology has brought petroleum activities into a new horizon, the adaptation of new technologies is not without its challenges. For example, companies are not able to avoid the development of technology in order to compete and adhere with government regulatory. Besides that, challenges also arise from other aspects of KM that are related to the characteristics of the installation itself, such as environment and geographical aspects. These potential issues can be identified in a systematic manner, by associating the related components in KM and IS with the installation's integrity factors. Once these challenges are identified, the organization will be able to establish the necessary prevention and mitigation procedures in managing the asset integrity.

Definitions

Knowledge management typically involves the handling of data, which is backed-up by the information system (IS). IS is a system that accepts data resources as input and processes them into information products as output. The handling of data includes various activities necessary to process data into information and then to manage the information until it reaches the end-users. Data handling consists of data-related activities such as data input, data processing, output, storage, feedback and control. Related KM activities are enabled by the use of technology, especially ICT; however, the involvement of the human factor is also a necessity. The advancement in technology allows increasing functions of KM such as operations support, management support, and decision-making support. With the growing demand for KM functions, components of KM are expanding from data, humans, procedures, simpler technology such as software and hardware to include more developed technology such as telecommunication and network (Marakas and O'brien, 2013). These elements interact and integrate to form a collective entity (i.e. system) in order to serve its function as illustrated in Figure 1. The feedback loop and control is inevitably present to adjust system performance to fulfill its function output.

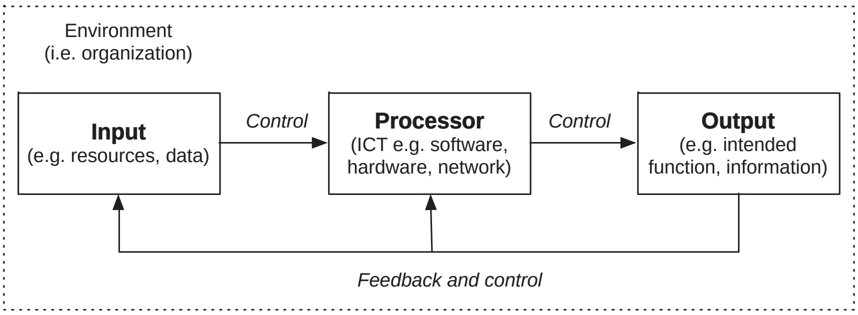


Figure 1. Basic information system process

From the discussion above, we can form a definition of KM that fits with the context of this paper: "knowledge management is an organized planning, coordination and control of organizational activities and resources to effectively capture, distribute, and use knowledge." IS, however, is a part of KM that is defined as "any organized combinations of information and communication technology (ICT) and human's activities that utilizes the ICT to ensure handling of data in order to serve its objectives in an organization".

Knowledge management for Asset Integrity Management

Besides the previously discussed fundamental components, the application of KM in a petroleum installation involves more complex processes and dynamic socio-technical environments. For an offshore installation, the socio-technical environment includes onshore and offshore working environments as illustrated in Figure 2.

Figure 2 illustrates a simple KM process in the operation phase of a petroleum installation. As well as in the operation phase, KM is also present in the entire lifecycle. These systems are interdependent on one another, since they carry the facility´s data. Prior to the operation phase of a facility, several types of data need to be made available, such as provision of technical system evaluation, equipment identification and specifications, equipment classification and other required information. The data gathered from this process is integrated into the database system intended for maintaining asset integrity.

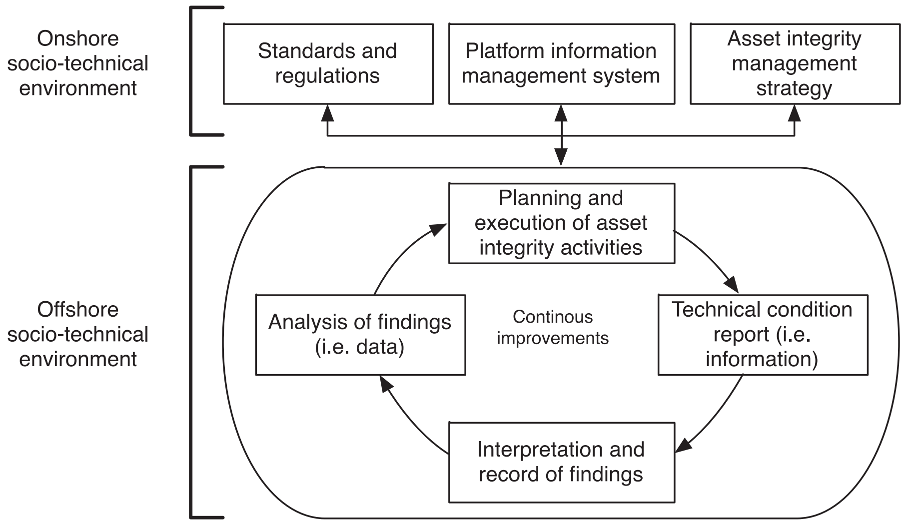


Figure 2. Example of asset integrity KM for an offshore installation

The data gathered then integrates with real-time data taken from sensors installed in the equipment or system in the operation phase. In the operation phase, the data is being used for maintenance analysis. Nowadays, the maintenance operating system has become proactive and capable of analysis functions, such as prognostic maintenance, diagnostic maintenance and forensic maintenance. The analysis system is able to monitor and diagnose the current system performance from the real-time data. The operating system also acquires forensic data from prior failures in order to give a prognosis of the health of the equipment, and it can predict future system performance. Besides basic functionality maintenance, the provision of adequate information on the equipment can be used as decision support and to improve equipment performance. Table 1 summarizes the maintenance analysis enabled by utilizing equipment data.

Table 1. Maintenance analysis from equipment data

Criteria	Analysis types		
	Diagnostic	Prognostic	Forensic
Occurrences	Real-time diagnostic	Prior to failure/prognosis	Posterior to failure
Performance analysis	Current performance monitoring: to monitor the performance and the health of the system using real-time information	Future performance prognosis: to estimate the degradation rate and predict future performance	Fault investigation: to investigate situations after the fact, and to establish what occurred based on collected evidence
Failure analysis	Failure detection: to indicate whether something is going wrong in the current monitored system	Failure prediction: to determine whether a fault is impending and estimate how soon and how likely a fault will occur	Fault identification: to identify the nature of the fault when it is detected

Today, the significance of real-time data and informed decision-making is highly regarded. Therefore, technological development focuses on delivering seamless information from plant facility to the intended users and vice versa. The real-time data is produced by various instruments mounted on equipment, while other sources of data might come from industrial experience, manufacturer's data, historical data, etc.

The term 'smart technology' relates to the ability of a system to process real-time data. The real-time data is analyzed in order to observe, predict and proactively interact with the monitored system. Furthermore, the data can also be utilized and integrated with other sets of information to be developed using analytical systems and other data processing to help transform data into a meaningful presentation to support decision-making. For example, in the case of equipment performance monitoring, correct information has helped the organization to make better maintenance decisions on equipment before it fails (Fidler, 2009).

Knowledge management challenges

A research study was conducted to analyze the practices and challenges of AIM in offshore installations. A part of the study analyzes the role that knowledge management plays in maintaining the asset integrity. The data for the case study were gathered from multiple data collection methods and sources, mainly from interviews and information provided by respondents. Industrial practitioners located in Houston, Texas, USA, and Singapore participated in semi-structured face-to-face guided interviews. The KM related questions were constructed to investigate KM practices in managing asset integrity, concerns and other implementation variables within the organizations.

The Case Study

Respondents were divided into two groups: one group consisting of respondents from operator or installation owner (OP) organizations and the second group consisting of respondents from service providers or manufacturing companies (SP), as illustrated in Figure 3. In total, there were 15 respondents, eight located in Houston and seven in Singapore. The data gathered from interviews (data set A) were analyzed together with findings from the case study and literature study (data set B).

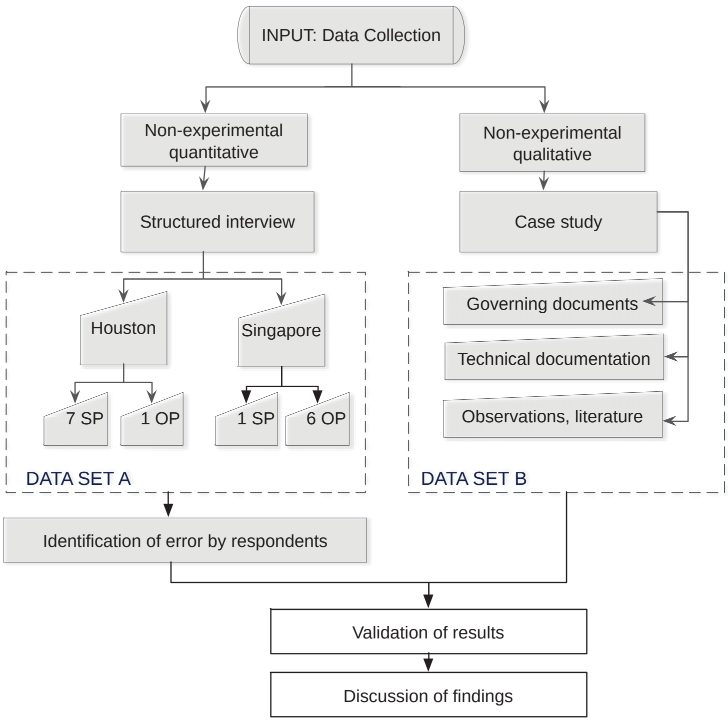


Figure 3. Data gathering and analysis process

Findings and Discussions

In the interviews, respondents were asked about their organization´s practice and concerns in KM with regard to the asset integrity of offshore installations. From data set A, respondents expressed the following concerns in relation to KM:

- Knowledge transfer
- Information management
- Data transfer between onshore and offshore

Other concerns that were gathered from data set B are:

- Information technology (IT) processes and security
- Quality of data
- Integrated system
- Introducing and adapting to new technology

From data set A, it was apparent that respondents' preferences towards KM depended on their short-term and long-term strategies. Respondents were aware of the cost of establishing KM, but they also considered the trade off between short-term and long-term benefits. The findings from both data sets are discussed below.

- **Knowledge transfer**

Some of the respondents reported experiencing challenges in acquiring documentation and records, either from the previous owner/operator or from the present operation and maintenance (O&M) activities. Management of knowledge is crucial and needs to be established early in the facility's life cycle; however, engaging sophisticated software is not the final answer. Most of the respondents are utilising state-of–the-art document management systems and CMMS, but the tools are only as good as the input.

Some of the challenges were an easy fix; for example, if an organization does not have guidelines for document management, then the organization needs to establish suitable procedures. This is also related to the tag management of the asset, where it was discovered that some organizations do not develop a pipeline list or a proper equipment register. These registers are highly vital, mainly related to safety uses such as to identify risks in the facility. The respondents argued that costs are kept to the minimum to increase the margin, especially in the case where respondents are not the asset owners. And vice versa, organizations that rent out their asset, without operating it themselves, are concerned about integrity of their asset.

- **Information management**

The integration of operating systems that are employed in the operation and maintenance phases presents another challenge. Respondents expressed their concerns regarding operating systems that are not interconnected with one another; thus, much information is missing and systems may not support each other (Kusumawardhani and Markeset, 2014). To avoid this problem, it is necessary to integrate the information systems and construct a solid structure that overlays the connection between operating systems. In such a case, a reliable database and information system would provide a great support to integrity management.

- **Data transfer between onshore and offshore**

Offshore installations are often located far from shore and lack the surrounding infrastructure. This causes difficulties in maintaining a communication line. One of the respondents suggested a solution through the installation of fiber optics (Forster and Dria, 2013). For long-distance offshore installations, fiber optics are an ideal technical solution since they have low line losses. Moreover, fiber optics are non-electrical, which makes them immune to electromagnetic interference (Tennyson et al., 2005). However, the cost of using fiber optics may be prohibitive over other traditional cables.

- **Information technology (IT) processes and security**

Smart technology is enabled by the combination of several advanced technologies (Khan et al., 2012, Torstensen and Skramstad, 2008). The basic model involves the input of data, analysis or processing of data that produces the outcome in a form of beneficial information, and lastly the distribution of information to the intended user, as illustrated in Figure 4.

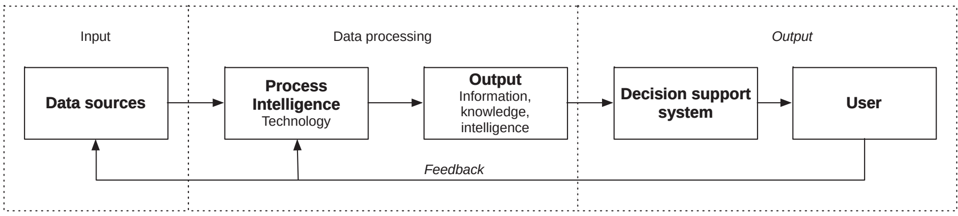


Figure 4. Basic model for data utilization

The methods for processing data vary according to the facility requirements and their capabilities. Various information technology suppliers offer different custom-made solutions in the form of software and hardware or even system architecture, which allows the customer to tweak between business needs as well as the cost (see for example: Edison, 2011, Edwards et al., 2010).

Besides IT processes, the petroleum industry also frequently faces security threats to the company's information system and data, particularly within smart technology that utilizes networks as data transfer throughout the company and with external users. Aarset and Mo (2008) suggested a set of actions including planning and establishing a secure plant network, as well as implementing remote services. The separation of data that can be accessed by external users such as service suppliers is also crucial. Several technologies, such as fiber optic networks or data architecture, are able to mitigate this challenge (Forster and Dria, 2013, Tennyson et al., 2005).

- **Quality of data**

The availability of good quality and reliable data is one of the major issues in the petroleum industry (Griffiths, 2012, Ouertani et al., 2008). Despite being advantageous, previous experience has also revealed that data quality could be potentially beneficial or misleading (Radhay, 2008). The issues arise mainly because the quality of analysis depends greatly on the reliability and robustness of the initial data input, as illustrated in Figure 3.

Above all, in this automation era, the role of data is highly regarded due to the use of data as an input process. Besides data, other technology features, such as reliable sensors and other instruments are important for data quality, particularly in an environment with challenging operating conditions (Saunders, 2008). In addition to this, other factors such as governing documents, human factors, equipment and tools could also affect the quality of data (Kusumawardhani, 2013).

- **Integrated system**

Data integration and collaboration between involved parties has also become one of the challenges in delivering seamless information. Data integration involves the interaction around man, technology and organizations. Ringstad and Andersen (2006) have discussed similar challenges from the safety point of view. Sätra et al. (2011) have also suggested that collaboration needs to be further developed between organizations. One of the possible solutions is to manage the installation holistically, i.e. as a total system rather than as a set of isolated parts, during the entire lifecycle.

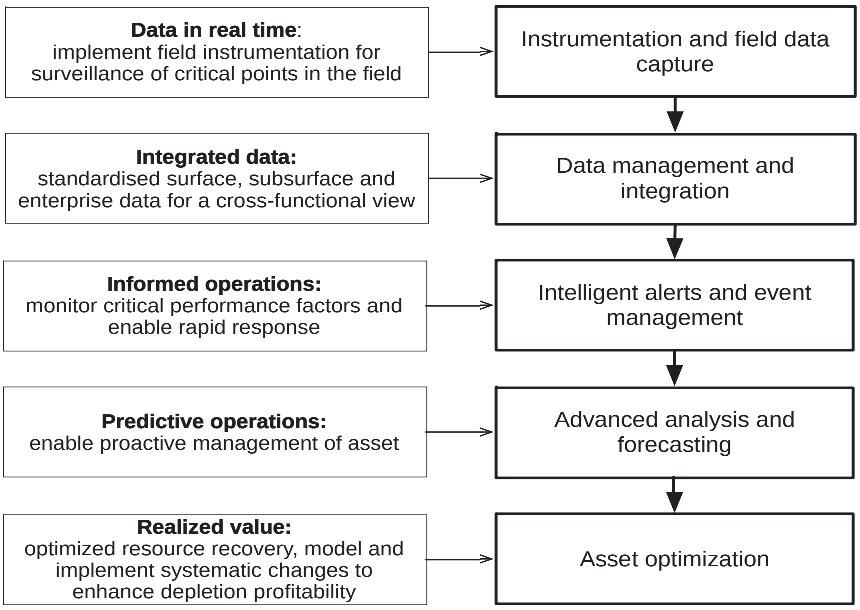


Figure 5. Towards smarter oil and gas fields (Edwards et al., 2010)

In order to achieve this, the organization needs to have a control system integrated with different departments and decision-makers to have the coordination to support the overall organization objective (El-Akruti and Dwight, 2013). Some service providers are already offering a holistic solution that focuses on the management and distribution of data, as illustrated in Figure 5. Therefore the data management for operation and maintenance is also part of holistic data management and should be built in such a way that it is integrated with the overall facility data management.

Industrial services as a possible solution

Industrial services emerged as one possible solution following the increasing service market in the petroleum industry. The trend of outsourcing maintenance support services, alongside other segments such as subsea services and engineering services, has been increasingly popular in the last couple of decades. In maintenance services, inspection and maintenance alone has tripled its market value in the last two decades (Rystad-Energy, 2013).

To date, there is no commonly agreed definition of industrial service. However, for the purpose of this paper, industrial service will be defined as "processes and resources provided by a service company to a customer to produce performance that is meant to create output to provide solutions to the customer´s needs" (Kusumawardhani and Markeset, 2014).

Industrial Services for Petroleum Installations

Following the fast-growing industrial development in the oil and gas industry, various service offerings exist in today's market. The main contributors to the development of service offerings are technology and knowledge. Both are present throughout the installation´s lifecycle, as illustrated in Figure 6. The services are present in three different forms: customer service, service as value-added service, and service as the product (Bitner et al., 2000).

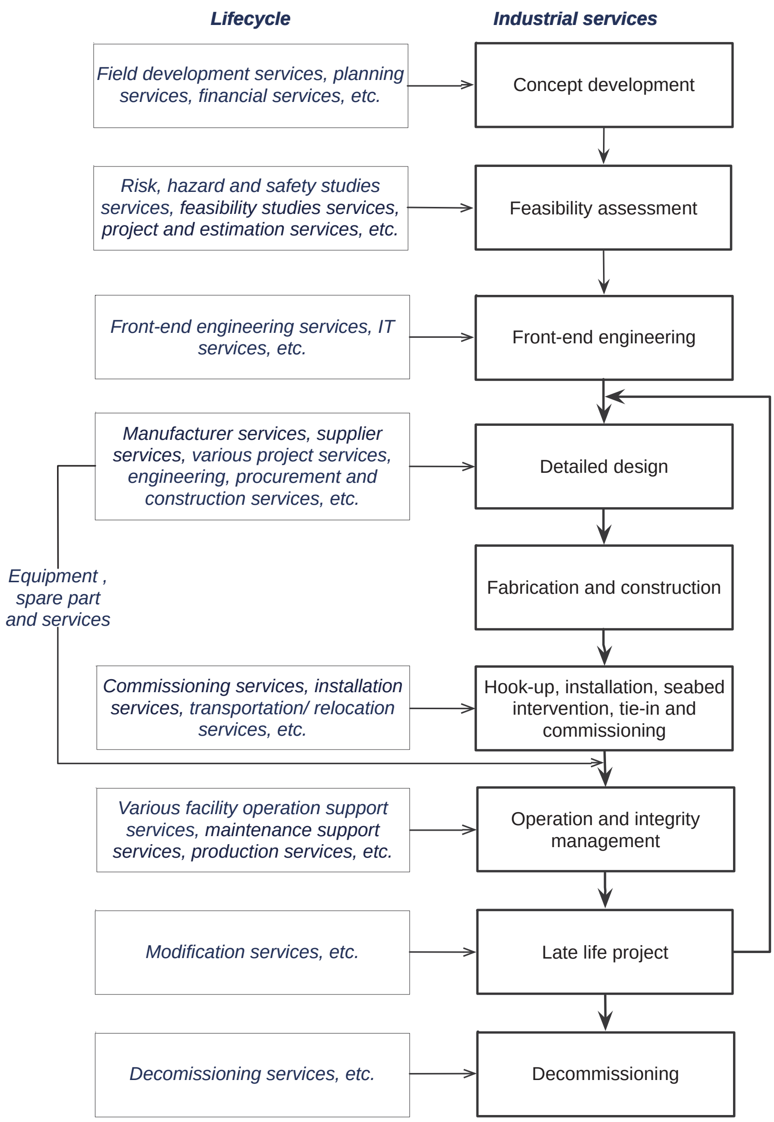


Figure 6. Industrial services in the lifecycle of a petroleum installation

The developments of technology and knowledge have both affected the way a company sells its service and physical products. In particular, companies have more advanced alternatives to merely offering conventional products, such as functional-product (Markeset and Kumar, 2005) or integrated product-service offerings (Park et al., 2012).

Technology has also been a big stimulator for the growth of service business. Technology exists as an enabler, mediator, and facilitator for the provision of physical products, service products or the integration of both. From the standpoint of service, technology has been seen as the instrument to provide new forms of business such as customization of service, new processes or new types of service encounters (Bitner et al., 2000). Services that exist because of technology are categorized as technology-enabled services. Meanwhile, from the standpoint of the product, technology is mainly seen as an instrument for new product development or to enhance existing ones (Ulrich, 2012).

The second contributor, knowledge, implies the filtering and interpretation of information to enable the user to act more effectively (Davis and Botkin, 1994). In practice, knowledge-based service involves the extraction of particular information from the source of knowledge that is relevant for the user, allowing the user to apply informed decision-making. Examples of knowledge-based services are financial consulting, engineering services, information technology (IT) services, etc.

Industrial Service for KM Challenges

Operators who have experienced the benefit of outsourcing have fostered a co-dependent relationship with service providers over the years. This is because, besides providing a solution, the engagement of service providers could give other benefits such as work efficiency, cost saving, distribution of risk, ability to be competitive, focus on core competences, technology innovation and adaptation, custom-made solutions, business transformation or expansion, and increased safety, availability, reliability and responsiveness (Jain and Natarajan, 2011, Sanjay and Ravi, 2007).

Particularly for KM, globalization has increased the availability and cost saving; for example, many advanced countries outsource their IT services to cheaper service providers in developing countries. Some of the benefits and potential solutions from engaging service providers for the challenges discussed in Section 2 are summarized in Table 2.

Table 2. Industrial service possible solutions for KM challenges

KM challenges	Possible solutions	Industrial service providers	Potential benefits
Knowledge transfer	Establish procedure for knowledge transfer, establish a shared network to exchange information, establish lessons learned registers.	Data architecture services, network services, etc.	Custom-made solutions, increased mobility, increased reliability, etc.
Information management	Integration between operating systems, software and various geographical locations.	Data architecture services, software services, etc.	Integrated solutions, increased availability, increased reliability, etc.
Data transfer between onshore and offshore	Establish tailor-made technology and network solutions.	Data architecture services, fiber optic services, etc.	Custom-made solutions, increased security, increased reliability, etc.
Information technology (IT) processes and security	Application of custom-made information technology, network and architecture according to requirements and regulations.	Data architecture services, fiber optic services, IT security services, etc.	Custom-made solutions, increased security, increased reliability, core competences focus, etc.
Quality of data	Ensure reliable data for input and processing into information from the beginning of field development through decommissioning.	Engineering services, information system services, operation readiness services, asset management services, etc.	Cost saving, competitive abilities, increased reliability, etc.
Integrated system	Establish a control system integrated with different departments and decision-makers to have coordination to support the overall organization objective.	Asset management services, IT services, engineering services, etc.	Increased safety, custom-made solutions, increased responsiveness, technology adaptation, etc.

KM challenges	Possible solutions	Industrial service providers	Potential benefits
Introducing and adapting to new technology	Organization may opt to outsource new technology requirement to service providers; that way risk is distributed and organization is avoiding high initial investment.	Engineering services, equipment manufacturer and services, field services, etc.	Cost saving, competitive abilities, technology adaptation, etc.

Conversely, the engagement of service providers is not without its challenges. Organizations are often faced with several difficulties starting from the selection of service providers, managing the interface, quality issues, performance issues, even contractual issues (see for example Salonen, 2004, Arpan Kumar, 2014). Nevertheless, these challenges can be coped with through the organization's supplier management. There are several literature references that discuss risk, quality and performance issues (see for example Vilko and Ritala, 2014, Zakaria et al., 2010), contractual issues (see for example Stremersch et al., 2001, Panesar and Markeset, 2008) and supplier selection issues (see for example: Keramydas, 2011, McIvor, 2008).

Concluding remarks

The extensive discussion of KM in the integrity of petroleum installations has revealed the challenges that are present as well as the known benefits. The engagement of industrial services could be of potential benefit to customers, mainly in outsourcing activities and saving the initial investment cost on technologies.

One of the challenges presented was the utilization of data and the integration of technology, to which some industrial service providers are offering solutions. However, integration does not stop at the level of technology; integration at organizational level is also one of the highlighted issues. Organizations need to actively participate in strategic technological collaborations amongst concerned parties for economic and security reasons. This having being said, the involvement of the customer in the outsourcing process and integration of activities is crucial for the overall integrity of petroleum installations.

From the interviews it was also revealed that government regulations are often altered in favor of new technological advances. Customers who outsource to industrial services benefit from this situation, since it is the service provider who needs to deliver services that comply with the new regulations. By outsourcing to industrial services, the customer will be able to compete with the fast-growing technology and their competitors without having to invest in buying new technologies.

Future research is needed to study the methods for KM integration across organizations involved in the lifecycle of offshore installation, i.e. operator and vendors, in addition to integration between the onshore and offshore locations of petroleum installations. In addition, research on the supplier selection process, specifically for the asset management of a petroleum installation, would be beneficial.

References

Aarset, M. F. & Mo, O. 2008. IT Security and Architecture for Integrated Operations: Examples from Deliveries to Ormen Lange and Draugen. Intelligent Energy Conference and Exhibition. Amsterdam, The Netherlands: Society of Petroleum Engineers.

Arpan Kumar, K. 2014. Revisiting the Supplier Selection Problem: An Integrated Approach for Group Decision Support. Expert Systems with Applications, 41, 2762 - 2771.

Bitner, M., Brown, S. & Meuter, M. 2000. Technology Infusion in Service Encounters. Journal of the Academy of Marketing Science, 28, 138-149.

Brule, M. 2013. Big Data in Exploration and Production: Real-Time Adaptive Analytics and Data-Flow Architecture. 2013 SPE Digital Energy Conference and Exhibition. The Woodlands, TX, USA: Society of Petroleum Engineers.

Brynjolfsson, E. M. A. 2012. Race against the Machine : How the Digital Revolution Is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy, Lexington, Mass., Digital Frontier Press.

Davis, S. & Botkin, J. 1994. The Coming of Knowledge-Based Business. Harvard Business Review, 72, 165-170.

Edison, L. S. 2011. The Value of Smarter Oil and Gas Fields. In: Insights, I. C. F. A. (ed.) http://www.ibm.com/. New York, USA: IBM.

Edwards, S., Ishaq, O. & Johnsen, Ø. 2010. Oil and Gas 2030: Meeting the Growing Demands for Energy in the Coming Decades. In: Services, I. G. (ed.) http://www.ibm.com/. New York, USA: IBM.

El-Akruti, K. & Dwight, R. 2013. A Framework for the Engineering Asset Management System. Journal of Quality in Maintenance Engineering, 19, 398-412.

Fidler, E. S. 2009. Asset Performance Management Helps Oil and Gas Companies Increase Asset Availability, Improve Uptime and Empower More Intelligent Decision Making. 2009 Offshore Technology Conference : Proceedings; 4 - 7 May, Reliant Park, Houston, Texas, U.S.A. Richardson, Tex.: Offshore Technology Conference.

Forster, L. & Dria, D. E. 2013. Real-Time Subsea Fiber-Optic Monitoring. Offshore Technology Conference.

Gang, N., Bo-Suk, Y. & Michael, P. 2010. Development of an Optimized Condition-Based Maintenance System by Data Fusion and Reliability-Centered Maintenance. Reliability Engineering & System Safety, 95, 786 - 796.

Griffiths, P. 2012. Information Audit: Towards Common Standards and Methodology. Business Information Review, 29, 39-51.

Jain, R. K. & Natarajan, R. 2011. Factors Influencing the Outsourcing Decisions: A Study of the Banking Sector in India. Strategic Outsourcing: An International Journal, 4, 294-322.

Karim, R., Söderholm, P. & Candell, O. 2009. Development of Ict-Based Maintenance Support Services. Journal of Quality in Maintenance Engineering, 15, 127-150.

Khan, F., Testard, B., Boero-Rollo, J.-G. & Verbrugge, E. 2012. Managing Operation Events in Real-Time: From Smart to Smarter. SPE Intelligent Energy International. Utrecht, The Netherlands: Society of Petroleum Engineers.

Keramydas, C., Xanthopoulos, A. & Aidonis, D. 2011. A Decision-Making Framework for the Optimal Selection of Suppliers. Operations and Supply Chain Management: An International Journal, 4, 68 - 77.

Kusumawardhani, M. 2013. Reliability Analysis of Non-Destructive Testing of Topside Flowline Pipe System on Aging Platform: Plant, Human and Technology. Master of Science Case Study, University of Stavanger.

Kusumawardhani, M. & Markeset, T. 2014. Research Design for Industrial Service Studies. 6th International Conference on Operations and Supply Chain Management (OSCM). Bali, Indonesia.

Kusumawardhani, M. & Markeset, T. 2014. Asset Integrity of Deepwater Petroleum Production Facilities. In: Ieee, ed. IEEE International

Conference on Industrial Engineering and Engineering Management (IEEM2014), December 09-12th 2014 Kuala Lumpur, Malaysia.

Marakas, G. M. & O'brien, J. A. 2013. Introduction to Information Systems, New York, NY, McGraw-Hill/Irwin.

Markeset, T. & Kumar, U. 2005. Product Support Strategy: Conventional Versus Functional Products. Journal of Quality in Maintenance Engineering, 11, 53-67.

Mcivor, R. 2008. What Is the Right Outsourcing Strategy for Your Process? European Management Journal, 26, 24-34.

Ouertani, M.-Z., Parlikad, A. K. & Mcfarlane, D. Asset Information Management: Research Challenges. Research Challenges in Information Science, 2008. RCIS 2008. Second International Conference on, 2008. IEEE, 361-370.

Panesar, S. S. & Markeset, T. 2008. Industrial Service Innovation through Improved Contractual Relationship: A Case Study in Maintenance. Journal of Quality in Maintenance Engineering, 14, 290-305.

Park, Y., Geum, Y. & Lee, H. 2012. Toward Integration of Products and Services: Taxonomy and Typology. Journal of Engineering and Technology Management, 29, 528-545.

Radhay, R. 2008. Facilitating Data Quality Improvement in the Oil and Gas Sector. SPE Asia Pacific Oil and Gas Conference and Exhibition. Perth, Australia: Society of Petroleum Engineers.

Ringstad, A. J. & Andersen, K. 2006. Integrated Operations and Hse - Major Issues and Strategies. SPE International Health, Safety & Environment Conference. Abu Dhabi, UAE: Society of Petroleum Engineers.

Rystad-Energy 2013. Introduction to Rystad Energy's Offshore Market Report Norway. 2013 ed. Oslo, Norway: Rystad Energy.

Salonen, A. 2004. Managing Outsourced Support Services: Observations from Case Study. Facilities, 22, 317-322.

Sanjay, J. & Ravi, S. 2007. Selection of Logistics Service Provider: An Analytic Network Process (Anp) Approach. Omega, 35, 274 - 289.

Sätra, U. S. A., Christensen, R., Tanase, A., Koppervik, I. & Rokke, E. 2011. Proactive Maintenance in the Context of Integrated Operations Generation 2. SPE Economics & Management, 3, 102-108.

Saunders, C. 2008. Thrulife – Integrity Management of Deepwater Subsea Systems [Online]. Woodgroup. Available: http://www.woodgroup.com/SiteCollectionDocuments/news-tech-articles/2008-11_ThrulifeIM-Offshore_MCS.pdf [Accessed 05 December 2013].

Stremersch, S., Wuyts, S. & Frambach, R. 2001. The Purchasing of Full-Service Contracts: An Exploratory Study within the Industrial Maintenance Market. Industrial marketing management, 30, 1-12.

Tennyson, R. C., Don, W. & Cherpillod, T. 2005. Monitoring Pipeline Integrity Using Fiber Optic Sensors. NACE International.

Torstensen, A. & Skramstad, T. 2008. Reliable It for Integrated Operations. Intelligent Energy Conference and Exhibition. Amsterdam, The Netherlands: Society of Petroleum Engineers.

Ulrich, K. T. E. S. D. 2012. Product Design and Development, New York, McGraw-Hill/Irwin.

Vilko, J. & Ritala, P. 2014. Service Supply Chain Risk Management. Operations and Supply Chain Management, 7, 114 - 120.

Zakaria, H., Zailani, S. & Fernando, Y. 2010. Moderating Role of Logistics Information Technology on the Logistics Relationships and Logistics Service Quality. Operations and Supply Chain Management: An International Journal, 3, 134 - 147.

Mayang Kusumawardhani is a Research Fellow in the Department of Mechanical and Structural Engineering and Materials Science at the University of Stavanger, Norway. She holds a BEng degree in Mechanical Engineering and an MSc degree in Offshore Technology from the University of Stavanger. With nearly 10 years' experience in working in the petroleum industry within operation and maintenance engineering, she is currently pursuing a PhD degree in Offshore Technology, specializing in industrial asset management at the University of Stavanger.

Professor Tore Markeset is the Head of Department of Industrial Economics, Risk Management and Planning and Professor of Mechanical Engineering (Operations and Maintenance) at the University of Stavanger (UiS). He is Adjunct Professor at the University of Tromsø, Norway. He was awarded a BSc degree in Petroleum Engineering from the University of Stavanger in 1985, BSc (1989) and MSc (1991) degrees in Mechanical Engineering from the University of Minnesota, USA, and a Dr. Ing. degree in Offshore Technology – Operations and Maintenance, at the UiS, in 2003, after working in the industry for a number of years. He has supervised 11 PhD, 90 MSc and three BSc theses, as well as having published more than 130 papers. His research interests are in operation and maintenance engineering and management as well as industrial services.

Paper 4 - Establishing operational readiness and assurance for petroleum projects

Kusumawardhani, M., Kumar, R. and Markeset, T. (2016), "Establishing operational readiness and assurance for petroleum projects", Submitted for publication in International Journal.

Paper 5 - Development of strategic asset management planning in the petroleum industry

Kusumawardhani, M., Kumar, R. and Markeset, T. (2016), "Development of strategic asset management planning in the petroleum industry ", *Accepted for publication in Journal of Quality in Maintenance Engineering.*

PART III

APPENDICES

Appendix 1 - Preliminary survey

Introduction

This work is part of an ongoing research study at the University of Stavanger (www.uis.no) is funded by the Royal Norwegian Ministry of Education and Research (Norsk: *Kunnskapsdepartementet*).
The goal of this study is to have better understanding of how asset integrity management (AIM) programs in the oil and gas industry are established and how they can be continually improved.

This survey will particularly develop and propose a model for AIM practice, focusing on "how it can become better than today". Therefore, it requires to map and understand the current practices within the oil & gas (O&G) industry. It will help to identify the factors and potential of each factor and its influences on managing asset integrity in a manner which is safe and beneficial.

Methods

We would to gather information from oil and gas firms and relevant service firms through face-to-face guided interviews.

Contacts

The study is conducted by:

1. Mayang Kusumawardhani, research fellow at the University of Stavanger.
   Contact: mayang.kusumawardhani@uis.no, +47 518 32 151/ +47 40455251

2. Tore Markeset, PhD, Professor of Mechanical Engineering
   Contact: tore.markeset@uis.no +47 997 06 378

3. Rajesh Kumar, PhD, University of Stavanger
   Contact: rajesh.kumar@uis.no

Definitions

Asset	A physical item or entity that has potential or actual value to an organization; i.e., in the current context, an offshore petroleum production facility.
Integrity	is associated with the ability of the facility to perform its required function in a safe, effective and efficient manner; the ability of the facility to safely contain various substances related to hydrocarbon production.
Asset integrity management (AIM)	Asset integrity management is “the development, implementation and execution of a coordinated plan together with managerial control and organizational activities, to ensure that the physical asset is performing its intended function in a safe, effective and efficient manner over its entire lifecycle, in order to achieve the organizational objectives”.
Availability	The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided.
Maintenance	A combination of all technical, administrative and managerial actions, during the life cycle of an item, intended to retain it in, or restore it to, a state in which it can perform the required function.
ORA	Operation readiness and assurance can be defined as “the development and execution of a coordinated plan together with managerial control and organizational activities, to ensure that the physical asset and its supporting organizations are ready to operate and perform its intended function in a safe, effective and efficient manner.

Preliminary information

Place: ______________________

Date: ______________________

Respondent information

Name:

____

E-mail:

____

Position:

____

Brief job description:

____

____

Working in current position since: ______________________

Total working experience: ______________________

Can we mention company name in the report ☐ **Yes** ☐ **No**

Guided interview questions

Asset integrity	
1.	Please describe the asset integrity department in your organization
2.	Please describe the asset integrity strategy in your organization
3.	Please describe what are the tools you are utilizing for asset integrity
4.	Please describe how does your organization assess technology and innovation for asset integrity?
5.	Please describe the major challenges that you encounter in asset integrity.
Business impact	
6.	Please describe how has your organization developed as over the years?
7.	How would you rate the current market development in different continents?
8.	How does your company respond to current market trends?
9.	Please describe the major challenges that you encounter for your business in general.
Organizational collaboration and decision making	
10.	Please describe how does your department conduct organizational collaboration/interaction?
11.	Please describe how does your organization conduct interaction with your clients/ service provider?
Technology and innovation	
12.	Please describe the process of innovation in your organization
13.	Please describe the influence of innovation and technology in your organization.
14.	Please describe how does your organization identify innovation for new product/service?
15.	Please describe how you develop your existing product-line/services.

Sourcing strategy
16. Please describe how does resources requirement is fulfilled in your organization?
17. Please describe how does your organization engage external service providers?
18. Please describe how does your organization monitor/control the external service providers?
19. Please describe how does your organization evaluates the deliveries from the service providers.

Appendix 2 - Questionnaire

Introduction

This work is part of an ongoing research study at the University of Stavanger (www.uis.no) is funded by the Royal Norwegian Ministry of Education and Research (Norsk: *Kunnskapsdepartementet*).
The goal of this study is to have better understanding of how asset integrity management (AIM) programs in the oil and gas industry are established and how they can be continually improved.

This survey will particularly develop and propose a model for AIM practice, focusing on "how it can become better than today". Therefore, it requires to map and understand the current practices within the oil & gas (O&G) industry. It will help to identify the factors and potential of each factor and its influences on managing asset integrity in a manner which is safe and beneficial.

Methods

We would to gather information from oil and gas firms and relevant service firms through face-to-face guided interviews.

Contacts

The study is conducted by:

1. Mayang Kusumawardhani, research fellow at the University of Stavanger. Contact: mayang.kusumawardhani@uis.no, +47 518 32 151/ +47 40455251
2. Tore Markeset, PhD, Professor of Mechanical Engineering Contact: tore.markeset@uis.no +47 997 06 378
3. Rajesh Kumar, PhD, University of Stavanger Contact: rajesh.kumar@uis.no

Definitions

Asset	A physical item or entity that has potential or actual value to an organization; i.e., in the current context, an offshore petroleum production facility.
Integrity	is associated with the ability of the facility to perform its required function in a safe, effective and efficient manner; the ability of the facility to safely contain various substances related to hydrocarbon production.
Asset integrity management (AIM)	Asset integrity management is “the development, implementation and execution of a coordinated plan together with managerial control and organizational activities, to ensure that the physical asset is performing its intended function in a safe, effective and efficient manner over its entire lifecycle, in order to achieve the organizational objectives”.
Availability	The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided.
Maintenance	A combination of all technical, administrative and managerial actions, during the life cycle of an item, intended to retain it in, or restore it to, a state in which it can perform the required function.
ORA	Operation readiness and assurance can be defined as “the development and execution of a coordinated plan together with managerial control and organizational activities, to ensure that the physical asset and its supporting organizations are ready to operate and perform its intended function in a safe, effective and efficient manner.

Preliminary information

Place: ____________________

Date: ____________________

Respondent information

Name:

____

E-mail:

____

Position:

____

Brief job description:

____

____

Working in current position since: ____________________

Total working experience: ____________________

Can we mention company name in the report ☐ **Yes** ☐ **No**

Questionnaire

1. Please indicate if your Company have written an asset integrity management (AIM) / operation readiness and assurance (ORA) strategy / similar strategy.

	YES	NO
AIM Strategy		
AIM Plan		
ORA Strategy		

Others? ____

Please indicate when an AIM strategy or similar programme should ideally be incorporated over a lifecycle of an offshore platform.

	YES	NO
Very early at concept development phase		
Engineering phase		
Construction phase		
Commissioning phase		
Operations phase		

Others? ____

2. Please indicate some of the main concerns related to asset integrity management in your organization (scale: 5 = most important; 1 = least important).

	5	4	3	2	1
Site concerns (e.g. Subsurface properties, reservoir fluid properties, meteorology & oceanography conditions, geotechnical conditions, remoteness/ distance to other infrastructures)					
Offshore installation challenges (e.g. Degradation issues, flow assurance, maintenance strategy and implication, spare part availability, engineering design issues)					
Knowledge management & information tech. (e.g. Knowledge transfer, information management, data transfer between onshore and offshore)					
Economic concerns (e.g. Fossil fuel price, over-supply of production, interest rate)					
Human resources concerns (e.g. Provision of skilled personnel, misconception of AIM, training and competence development)					
External-organization concerns (e.g. Client requirements, rules and regulations, supply chain delivery time, technology saturation, competition, company reputation)					

	5	4	3	2	1
Organizational concerns (e.g. Management and organizational issues, internal cooperation, internal communication, outsourcing strategy, shareholder willingness to invest in AIM, AIM trade-off against cost, CAPEX and OPEX, acquisition processes)					

Others? ____

3. Please indicate the <u>strategic areas</u> to be included in an AIM strategy and/or plan
   (scale: 5 = most important; 1 = least important).

	5	**4**	**3**	**2**	**1**
Leadership and integration management OR&A organization Integrated planning and management Assurance management Budgets, Pre-ops and OPEX Management of change Stakeholder management					

	5	4	3	2	1
Asset and operations integrity management Production management Flow assurance Chemical management plan Subsea management Drilling and reservoir Integrated operations Philosophies, strategies and procedures Process safety Storage, exports and manifolds Associated infrastructures and brownfields Shutdown planning and scheduling Inventory, logistic and material management					
Maintenance, inspection and reliability management Maintenance management Reliability availability maintainability (RAM) management Inspection management Automation, control, equipment monitoring and analysis Major maintenance planning and scheduling					
Procurement and contractor management Service delivery options Maintenance & inspection support services Operations support services Contractor evaluation and selection plan Spare parts management Contracts and legal					

	5	4	3	2	1
Information technology and knowledge management Information technology (IT) and information system (IS) Information management Document and data management					
Reservoir management Production surveillance and management Efficiency studies Enhanced oil recovery (EOR) management					
HSSEQ, compliance and risk management Incident investigation and analysis Emergency preparedness HSE management Waste and emission management Risk management Quality management Security management Compliance management Community awareness and outreach					
Resources and performance management AIM organizations Operations organizations Training and competency					
Project specific, commissioning, start-up and transfer management Mechanical completion (MC) and commissioning management Start-up management Asset transfer and acceptance					

Others? ____

4. Please suggest some Key performance indicators (KPI) for AIM strategy.

____

5. Please indicate the best sources for AIM budget adjustment (scale: 5 = most important; 1 = least important).

	5	4	3	2	1
Human resources					
Training and competence development					
Consultants					
Service providers					
Modifications & upgrades					
Major maintenance activities					
Minor maintenance activities					
Operational budget					
Research and development					
Information technology					
New projects & investments					
Travel cost					
New technology					

Others? ____

6. Please suggest other necessary improvements related to asset integrity management.

Appendix 3 - Follow-up survey: guided interview

Introduction

This work is part of an ongoing research study at the University of Stavanger (www.uis.no) is funded by the Royal Norwegian Ministry of Education and Research (Norsk: *Kunnskapsdepartementet*).
The goal of this study is to have better understanding of how asset integrity management (AIM) programs in the oil and gas industry are established and how they can be continually improved.

This survey will particularly develop and propose a model for AIM practice, focusing on "how it can become better than today". Therefore it requires to map and understand the current practices within the oil & gas (O&G) industry. It will help to identify the factors and potential of each factor and its influences on managing asset integrity in a manner which is safe and beneficial.

Methods

We would to gather information from oil and gas firms and relevant service firms through face-to-face guided interviews.

Contacts

The study is conducted by:

1. Mayang Kusumawardhani, research fellow at the University of Stavanger. Contact: mayang.kusumawardhani@uis.no, +47 518 32 151/ +47 40455251
2. Tore Markeset, PhD, Professor of Mechanical Engineering
   Contact: tore.markeset@uis.no +47 997 06 378
3. Rajesh Kumar, PhD, University of Stavanger
   Contact: rajesh.kumar@uis.no

Definitions

Asset	A physical item or entity that has potential or actual value to an organization; i.e., in the current context, an offshore petroleum production facility.
Integrity	is associated with the ability of the facility to perform its required function in a safe, effective and efficient manner; the ability of the facility to safely contain various substances related to hydrocarbon production.
Asset integrity management (AIM)	Asset integrity management is "the development, implementation and execution of a coordinated plan together with managerial control and organizational activities, to ensure that the physical asset is performing its intended function in a safe, effective and efficient manner over its entire lifecycle, in order to achieve the organizational objectives".
Availability	The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided.
Maintenance	A combination of all technical, administrative and managerial actions, during the life cycle of an item, intended to retain it in, or restore it to, a state in which it can perform the required function.
ORA	Operation readiness and assurance can be defined as "the development and execution of a coordinated plan together with managerial control and organizational activities, to ensure that the physical asset and its supporting organizations are ready to operate and perform its intended function in a safe, effective and efficient manner.

Preliminary information

Place: ____________________

Date: ____________________

Respondent information

Name:

____

E-mail:

____

Position:

____

Brief job description:

____

____

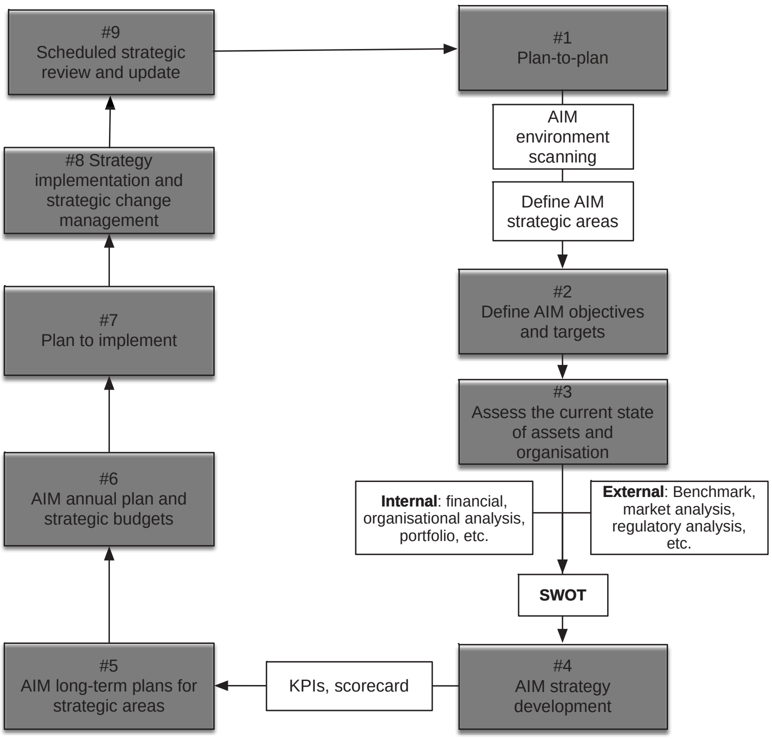
Working in current position since: ____________________

Total working experience: ____________________

Can we mention company name in the report ☐ **Yes** ☐ **No**

Section 1: Asset integrity management (AIM) strategy

1. Please describe AIM practices in your organization related to an offshore asset. Please describe how you develop the AIM strategy or similar programme.
2. Please describe how you measure the performance of the AIM strategy or similar strategy.
3. Please share your opinion of the AIM strategy framework below: Is it applicable to your company?



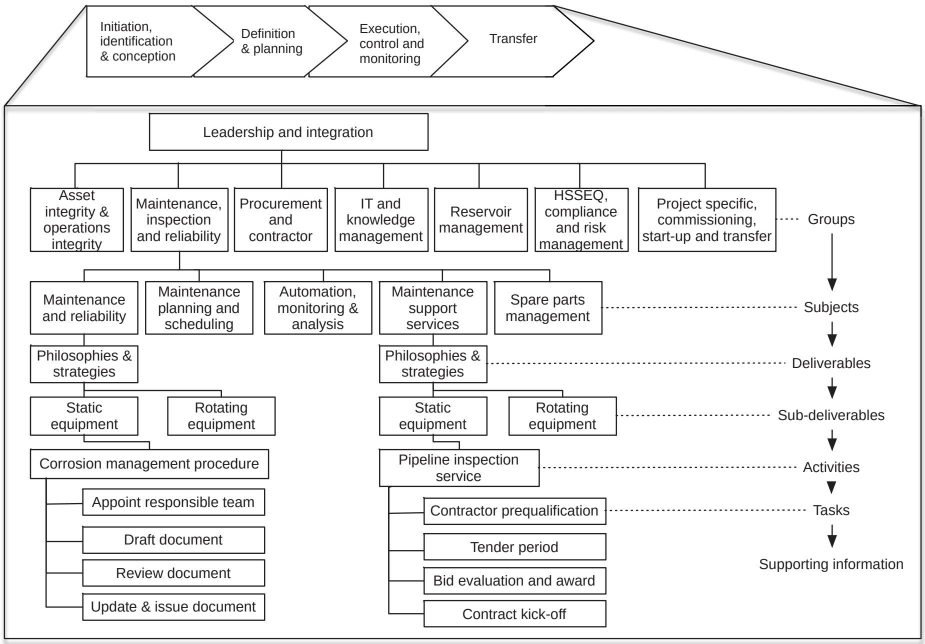
Section 2: Asset integrity practices

4. Please describe how you measure the integrity of an offshore asset.
   a. What are the most important factors influencing the integrity of your offshore asset?
   b. What tools and methods are you using?
   c. What are your main concerns?

5. Please mention some of the key elements with respect to maintaining the integrity of an asset.

Section 3: Operation readiness and assurance (ORA)

6. Please describe ORA practices in your organization related to an offshore asset.
7. Please describe how you develop the ORA plan or similar programme and measure the performance of the programme.
8. Please share your opinion of the ORA work breakdown structure below. Will it be applicable in your company?



Section 4: Organization challenges and achievements

9. Please explain the impact of fluctuating oil price on asset integrity and how your organization would manage the situation.
10. Please share some of your success stories in managing asset integrity.