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Condition assessment, remaining useful life prediction and life extension decision making for offshore oil and gas assets

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ABSTRACT

Offshore oil and gas assets are highly complex structures comprising of several components, designed to have a lifecycle of about 20 to 30 years of working under harsh operational and environmental conditions. These assets, during their operational lifetime, are subjected to various degradation mechanisms such as corrosion, erosion, wear, creep and fatigue cracks. In order to improve economic viability and increase profitability, many operators are looking at extending the lifespan of their assets beyond the original design life, thereby making life extension (LE) an increasingly critical and highly-discussed topic in the offshore oil and gas industry. In order to manage asset aging and meet the LE requirements, offshore oil and gas operators have adopted various approaches such as following maintenance procedures as advised by the original equipment manufacturer (OEM), or using the experience and expertise of engineers and inspectors. However, performing these activities often provides very limited value addition to operators during the LE period of operation. This paper aims to propose a systematic framework to help operators meet LE requirements while optimizing their cost structure. This framework establishes an integration between three individual life assessment modules, namely: condition assessment, remaining useful life (RUL) prediction and LE decision-making. The benefits of the proposed framework are illustrated through a case study involving a three-phase separator system on a platform which was constructed in the mid-1970s in West Africa. The results of this study affirm the effectiveness of this framework in minimizing catastrophic failures during the LE phase of operations, whilst ensuring compliance to regulatory requirements.

1. Introduction

Rejuvenating existing fields through life extension (LE) is regarded as one of the most lucrative strategies for end-of-life management within the offshore oil and gas industry. This has led to an increase in initiatives aiming at extending the service lifespan of existing installations operating within these fields. Over half of the installed structures in both the North Sea and Gulf of Mexico regions have gone past their original design lives of 20–30 years (Ersdal and Selnes, 2010; Ersdal, 2005; Stacey et al., 2008). The operational lives of these assets not only are dependent on environmental loading conditions but also are related to the age of oil field. Hence, for conducting LE analysis, it is imperative to understand the operational life of an asset tied to a field's life.

A typical operational timeline for an offshore oil and gas asset linked to the corresponding field life is illustrated in Fig. 1. The asset life begins at time $t = 0$, which indicates the time of commissioning of the field and commencement of operation of the asset. The asset operates until the point $t = l_o$, where l_o denotes the end of original field life and marks the beginning of the life extension phase of operation, owing to the remaining reserves. However, in order to be granted a license until an extended operational period l_e ($>l_o$), companies are obligated to meet some regulatory requirements. To meet these requirements while simultaneously ensuring profits from the extended period of operations, the asset managers need to address the following fundamental questions:

1) How operators can make sure whether their existing assets will be satisfactorily operating after end-of-life or they must be discarded at time $t = l_o$?
2) How long will be allowed to extend the life of assets for?

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3) What type of integrity management programme needs to be put into place to support asset operations over the life extension period?

In order to provide appropriate answers to above questions, Vaidya and Rausand (2011), Animah et al. (2016) and Shafiee et al. (2016) suggested, in their respective studies, that it is vital for LE decision makers to estimate the remaining useful life (RUL) of their candidate equipment, as it will enable stakeholders to achieve accurate conclusions during the LE decision-making process. Also, Liao et al. (2006) suggested that when ageing degradation is detected, it is important to re-estimate the RUL in order to expedite urgent maintenance decisions and avert possible failures. This is because the preliminary RUL estimated for offshore oil and gas equipment at the design stage is often conservative, since in practice, the actual operational and environmental conditions can be different than those considered during design. Hence, during the LE decision-making process, an enhanced computation process is imperative to determine the actual remaining service life of critical systems, subsystems and components, which may be shorter or longer than the lifetime estimated during design.

The concept of RUL is popular in operational research, reliability and statistics literature, and has real life applications in industries such as material science, biostatistics and econometrics (Si et al., 2011). However, very little research efforts have been carried out towards analysing how RUL prediction can support LE decision making in the offshore oil and gas industry. As a step in that direction, this study proposes a framework that establishes an integration between asset condition assessment, RUL estimation and the LE decision making process. Hence to reiterate, the proposed framework is broken down into three modules, namely: i) condition assessment module, which evaluates the current technical health status of subsystem and components; ii) RUL prediction module, which estimates the maximum duration of time a subsystem or component can operate beyond its original design life; and (iii) LE management module, which establishes the LE management program for the candidate equipment based on RUL results. The framework facilitates assets managers to provide appropriate answers to above-mentioned questions, which help minimize the occurrence of undesirable consequences such as frequent unplanned shutdowns, production losses and environmental damages attributed to unsuspected failures. The benefits of this integrated approach are illustrated through a case study involving a three-phase separator system on an oil platform.

The rest of this paper is structured as follows. Section 2 provides an overview of the state-of-the-art of RUL and its applications within the offshore oil and gas sector. Subsequently, Section 3 highlights the factors that influence RUL prediction for offshore oil and gas assets. Section 4 proposes the integrated condition assessment, RUL prediction and life extension decision making framework. Thereafter, Section 5 presents a case study to demonstrate, test and validate the proposed framework and further discusses the findings. Finally, the conclusions as well as future work directions are presented in Section 6.

2. State-of-the-art of remaining useful life (RUL) in the oil and gas industry

According to Banjevic and Jardine (2006) and Galar et al. (2012), the time left before a system fails to operate at acceptable levels is referred to as ‘remaining useful life’ (RUL). The purpose of RUL is to predict failure time before it occurs, based on current and past conditions of a system (Jardine et al., 2006). RUL is one of the key factors which should be considered when implementing condition monitoring (CM) and prognostic health management (PHM) (Cui et al., 2004; Lee et al., 2006). Wang and Zhang (2008) suggested that precise and proper estimation of equipment RUL is imperative for cost-effective operations as well as prompt maintenance responses. Over the past few years, RUL has emerged as a plausible technical health assessment and decision-making tool for equipment in the offshore oil and gas industry, while keeping life cycle costs low and helping operators meet regulatory requirements.

Literature on RUL estimation to support decision-making in the offshore oil and gas industry encompasses both deterministic and probabilistic methods. RUL approaches are classified either as physics-based approach, data-driven approach, or fusion approach which is a hybrid of the physics and data driven approaches (Varde et al., 2014), while Ahmadzadeh and Lundberg (2013) also added the experiment-based approach as the fourth classification. A brief discussion and application of each of these approaches is presented below.

2.1. Physics-based approach

The fundamental principle behind the physics-based approach is the formulation of theoretical mathematical models to interpret equipment degradation and damage modelling over time. These models involve the evaluation of failure modes such as crack propagation, wear and corrosion degradation rate of equipment (Galar et al., 2012). In situations where the accuracy of prediction is crucial and access to data is limited, these physics-based models are suitable and they also take various environmental conditions into account. These models are often expressed in terms of differential equations or partial differential equations and can be solved analytically or numerically due to their level of complexity.

Several studies have so far utilized the physics-based approach for estimating RUL to support the decision making process in the offshore oil and gas industry. Dowdy et al. (1988) developed a methodology for predicting the RUL of an in-service mooring chain. Divine et al. (1993) employed both qualitative and quantitative approaches for determining the RUL of submersible pumps which were used in the upstream sector of the oil and gas industry. Ammtatmula and Ohl (1997) investigated the corrosion-related, life-limiting conditions of a double-shell tank, and thereafter developed a model to estimate its RUL for an extended service life. Vaidya (2010) reviewed the technical health factors that influence RUL decision making process. The paper suggested Bayesian Belief Network (BBN) as a useful technique for RUL estimation. Vaidya and Rausand (2011) proposed a LE decision making model based on RUL prediction by combining heterogeneous requirements such as

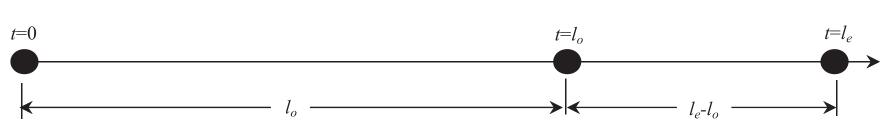

Fig. 1. The original design life and the extended life of an asset.