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An approach for prediction of petroleum production facility performance considering Arctic influence factors

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ABSTRACT

As the oil and gas (O&G) industry is increasing the focus on petroleum exploration and development in the Arctic region, it is becoming increasingly important to design exploration and production facilities to suit the local operating conditions. The cold and harsh climate, the long distance from customer and suppliers' markets, and the sensitive environment may have considerable influence on the choice of design solutions and production performance characteristics such as throughput capacity, reliability, availability, maintainability, and supportability (RAMS) as well as operational and maintenance activities. Due to this, data and information collected for similar systems used in a normal climate may not be suitable. Hence, it is important to study and develop methods for prediction of the production performance characteristics during the design and operation phases.

The aim of this paper is to present an approach for prediction of the production performance for oil and gas production facilities considering influencing factors in Arctic conditions. The proportional repair model (PRM) is developed in order to predict repair rate in Arctic conditions. The model is based on the proportional hazard model (PHM). A simple case study is used to demonstrate how the proposed approach can be applied.

1. Introduction

It is important for a petroleum production company to assure oil and gas (O&G) delivery in order to obtain and sustain good reputation in the market, to reach profitability goals of the stakeholders, as well as to comply with regulatory requirements and standards. The design and operation of offshore O&G production facilities require large investment of capital as well as large operational and maintenance expenditure. During the production plant design phase, a procedure should be applied to guide the development of a production plant reference design in order to meet goals and performance criteria [1]. The starting point of this procedure is the selection of the reference design (see Fig. 1). If the deterministic criteria can be achieved, production performance analyses and risk analyses are used to predict and assess deliverability and safety-related measures. The results of these analyses constitute a basis for decision making about modification and improvement of production plant design.

In this methodology, prediction of throughput capacity is important for decision making and is useful and necessary in both engineering design and operation phases to, for example:

- compare different design and improvement alternatives with respect to production availability;
- identify relevant cost parameters;
- predict production levels for financial planning, cost/benefit evaluations and sales contract negotiations;
- identify critical items requiring spare part attention and special requirements, and form input to spare part planning;
- evaluate maintenance and operating strategies to see their effects on field performance;
- identify system bottlenecks, vulnerabilities and components with unnecessary over-capacity;
- evaluate the availability effects of system modifications, e.g. equipment redundancy and capacity modifications.

However, as the Norwegian O&G industry is increasing the focus on petroleum reserve exploration and development in the harsh, remote, and sensitive environment of the Barents Sea, a significant increase is expected in investment costs during the design phase and in expenditure during the operational and maintenance phase of a production facility. In this region, environmental conditions such as cold and harsh climate, long

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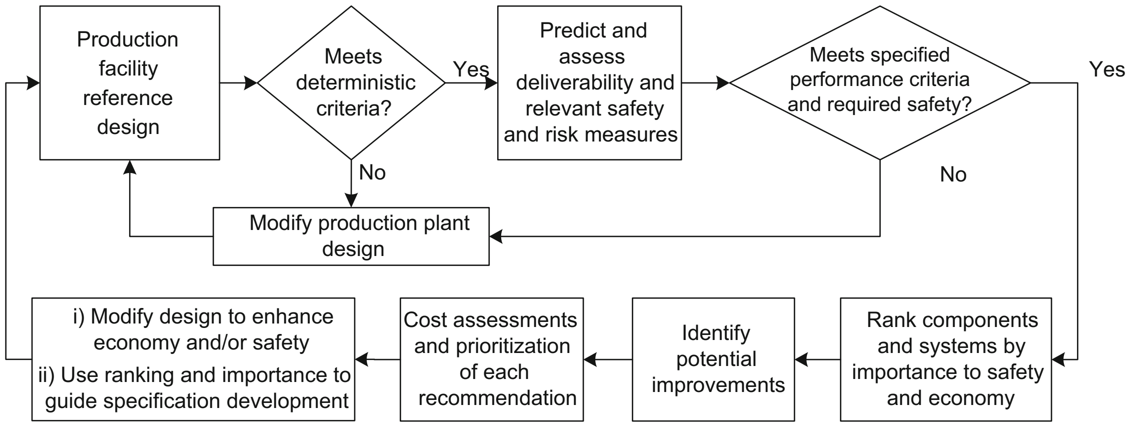

Fig. 1. Design for production performance [1].

distance from customer and suppliers' markets, and sensitive environment with respect to pollution may have considerable influence on the choice of design solutions, on equipment reliability, maintainability, and supportability as well as on maintenance and operational activities of the production facility, etc. There is little experience on the design and operation of O&G production facilities in Arctic conditions and locations [2–7]. Historical performance data and experience on the operation of equipment/systems installed on O&G production facilities on the Norwegian continental shelf (NCS) have been accumulated in the Offshore Reliability Data (OREDA) database over the last 40 years [8]. However, the data collected on the NCS cannot be used directly for performance prediction of a production facility to be used in Arctic conditions. Hence, the risk may increase and it may become more challenging to assure that the production performance objectives are achieved. It is a challenge to consider the use of available data and experience for prediction of production performance and to assess the magnitude of effects of covariates (e.g. operating environment, operating condition, or the type of design or material) on production performance characteristics (e.g. reliability and maintainability) during design.

With respect to reliability, there are available methods (e.g. the proportional hazards model (PHM), proportional covariate model (PCM), and the acceleration model) that can be used for predicting the effect of environment on system reliability [9–16]. The proportional hazards model was introduced in 1972 by Cox [9]. Since the last decades, the PHM is widely used in reliability engineering field in order to estimate effects of different covariates influencing the time to failure (TTF) or time between failures (TBF) of a system [12–20]. Dale [21] illustrated the application of the PHM as an alternative to the accelerated failure time model in estimating the hazard rate of motorettes operating at various temperatures.

System maintainability can be very easily influenced by the operational environment and other factors. Maintainability largely depends on, for example, resources (e.g. human, material, tools) available for maintenance, on correct installation of the equipment/system, on logistic support and accessibility, etc. In a harsh environment, maintenance activities may be more difficult to perform (e.g. cold climate will seriously affect work force's productivity) and frequency of maintenance intervals may be different as well. Low temperatures, in combination with wind, snowfall, and darkness, may reduce operational effectiveness drastically. Furthermore, the remote location may affect the effectiveness and efficiency of logistics of required maintenance support services and delivery of supplies. However, to our knowledge there is no available model for accurate estimation and prediction of maintainability considering external influencing factors. Hence, the aim of this paper is to introduce an approach for the prediction of production performance for an offshore production facility in the northern part of Norway in the design phase considering influencing factors. The paper also introduces the concept of the proportional repair model (PRM) – which is a development of the PHM – in order to predict the component's repair rate considering Arctic influence factors.

The rest of this paper is organized as follows. Section 2 briefly reviews the concept of PHM and discusses different factors influencing the failure rate/reliability of an offshore installation in Arctic conditions. In Section 3, the PRM approach is introduced in order to assess repair rate/maintainability considering environmental conditions. Various factors influencing the repair rate/maintainability of an offshore installation in Arctic conditions is discussed as well. A process for production performance analysis considering influence factors is described in Section 4. Section 5 demonstrates the application of this model using a case study from the offshore industry and Section 6 concludes the paper.

2. Proportional hazards model for reliability estimation in Arctic conditions

Reliability characteristics of equipment in Arctic conditions can be influenced by environmental conditions such as temperature, snow, wind, etc. [2,4–7,22,23] and these influences therefore need to be seriously considered in the prediction of reliability in the design phase. A valuable statistical procedure to estimate the reliability/failure rate of equipment subjected to its operating environment and conditions is the PHM. Other relevant regression models, such as the PCM, are used for situations where symptoms of a system are monitored. However, the PHM is more suitable for situations where environmental conditions are monitored.

The PHM was initially applied in medical analysis [24]. Thereafter, it has been widely applied in reliability engineering, as mentioned in Kumar and Klefsjö [19]. Some extension of the PHM has been developed for the use in the field of aeronautics, O&G, and mining [14,18,25–27]. In PHM, the hazard function for an item is a product of the baseline hazard function of the item and an exponential term incorporating the effect of a number of explanatory variables. The generalized form of PHM that is most commonly used is written as [9]

$$h(t,z) = h_0(t)\varphi(z\alpha), \tag{1}$$

where $h(t,z)$ denotes the resultant hazard, $h_0(t)$ is the baseline hazard rate, and $\varphi(z\alpha)$ represents the influence function. To estimate the effect of environmental conditions on system