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On how to understand and present the uncertainties in production assurance analyses, with a case study related to a subsea production system

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ABSTRACT

Production assurance analyses of production systems are in practice typically carried out using flow network modelling and Monte Carlo simulations. Based on the network and probability distribution assumptions for equipment lifetime and restoration time, the simulation tool produces predictions/estimates and uncertainty distributions of the production availability, which is defined as the ratio of production to planned production, or any other reference level, over a specified period of time. To adequately communicate the results from the analyses, it is essential that there is in place a framework which clarifies how to understand the concepts introduced, including the uncertainty distributions produced. Some key elements of such a conceptual framework are well established in the industry, for example the use of probability models to represent the stochastic variation related to lifetimes and restoration times. However an overall framework linking this variation, as well as "model uncertainties", to the epistemic uncertainty distribution for the output production availability, has been lacking. The purpose of the present paper is to present such a framework, and in this way provide new insights to and guidelines on how to understand and present the uncertainties in practical production assurance analyses. An example related to a subsea production system is used to illustrate the framework and the guidelines.

1. Introduction

Production assurance analyses have been performed for production systems in the oil and gas sector for about 30 years. The oil and gas business involves large capital investment costs as well as operational expenditures, and the profitability of this industry is very much dependent upon the reliability, availability and maintainability (RAM) of the systems. This has motivated the development of RAM-specific methods and tools for supporting the decision making for choice of arrangements and measures, and an industry standard for how to carry out the analyses has been established (ISO 20815 [1]).

A production system may be a subsea installation consisting of wells, x-mas trees, control systems, manifolds and flowlines. It may also be a processing system consisting of separators, compressors, pumps and valves, or a pipeline system comprising of pipelines and valves. A production system may be a part or the whole of the system from the well where the fluid enters the system, through the processing system on the installation and through the transportation system bringing the gas/oil from the installation to shore.

Production assurance analyses of production systems are in practice typically carried out using flow network modelling and Monte Carlo simulations (e.g. [2,3]). Based on the network and probability distribution assumptions for equipment lifetime and restoration time, the simulation tool produces predictions/estimates and uncertainty distributions of the production availability, which is defined as the ratio of production to planned production, or any other reference level, over a specified period of time.

The industry standard ISO 20815 [1] provides recommendations and guidelines for how to conduct production assurance analyses. In many respects, this standard gives the industry the clarity and precision required to be able to carry out high quality analyses. Key concepts such as "production assurance" and the representation of the stochastic variation related to lifetimes and restoration times using probability distributions, are well defined. A number of textbooks on reliability analysis provide the theory in line with this set-up (e.g. [4,5]). However, the present authors' practical experience from a number of real-life analyses in recent years has demonstrated that there is still confusion concerning

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how to represent and treat uncertainties in relation to the production assurance analyses. The problems relate, for example, to the link between uncertainties associated with parameter values and the presentation of uncertainties of the overall production assurance figures. Another difficulty concerns the concept of "model uncertainty": how should this type of uncertainty be understood and dealt with in a production assurance context? The purpose of the present paper is to contribute to a clarification on these issues. We present and discuss an overall framework which clarifies how to understand the concepts introduced, including the uncertainty distributions produced. A main aim has been to link the stochastic variation, as well as the "model uncertainties", to the epistemic uncertainty distribution for the output production availability. An uncertainty factor analysis is presented showing the importance of the uncertainties linked to key assumptions made. A case study related to a subsea production system is used to illustrate the framework and the discussion.

The paper is organized as follows. In Section 2, we present the framework. The case studied is introduced in Section 3 and we show how the framework works for this case. Section 4 discusses the framework and Section 5 provides some conclusions.

2. Proposed framework

Let Y be the output quantity of interest, for example the production during a specific period of time in the future. In practice there could be several quantities of interest, but for the purpose of the present study it is sufficient to consider one. The aim of the production assurance analysis is to predict this quantity and assess the associated uncertainties, as well as identifying main contributors to the production loss. To this end, a model g of the production system is developed, linking Y and some underlying quantities $X=(X_1, X_2, \ldots)$ on a more detailed system level, typically representing the lifetimes (uptimes) and restoration times (downtimes) of specific components of the system. Using the model g, the production loss Y is computed by $g(X)$. We write:

$$Y_g = g(X)$$

where Y_g is the production when derived from the model g. The model error is defined by $Y - Y_g$ and uncertainty about this error is referred to as model uncertainty [6].

At the time of the analysis, X and Y are uncertain and the analysts use probabilities to describe the uncertainties. These probabilities are judgemental or knowledge-based probabilities, expressing the analysts' degree of belief concerning the true values of the quantities X and Y. A reference uncertainty standard, for example an urn, is used to interpret the probabilities. If for example a probability of 0.1 is assigned, the uncertainty (degree of belief) of the event occurring is the same as drawing one particular ball out of an urn comprising 10 balls. Let H_X be the assigned probability distribution of X. Then using the model g and the law of total probability, we establish the probability distribution of Y_g by conditioning on $X=x$;

$$P(Y_g \le y) = \int P(g(X) \le y | X = x) dHX(x) = \int P(g(x) \le y) dHX(x) = \int_{\{X: g(X) \le y\}} dHX(x). \quad (2.1)$$

In practice this distribution is obtained by Monte Carlo simulation, drawing values x of X and computing the fractions of simulations that have production $g(x)$ not exceeding y.

The framework allows for two different implementation schemes of the analysis on a more detailed level. We illustrate these by a simple example where the system is a one-unit system modelled as a process of uptime, downtime, uptime, downtime, etc., where the uptimes have a distribution F_U and the downtimes have a distribution F_D:

I. The probability distributions F_U and F_D are based on strong background knowledge (data, expert knowledge), and the observations of the previous uptimes/downtimes would not lead the analysts to change the probability distributions for the coming uptimes/downtimes. This means that we can treat the process as an alternating renewal process [7]. We may for example have a situation where F_U is an exponential distribution with failure rate 1 and F_D is a uniform distribution over a specified interval.

II. The probability distributions F_U and F_D are specified by introducing probability models $F(\lambda)$, where λ is an unknown parameter (could be a vector), for example an up time distribution which is exponential with an unknown failure rate, and a down time distribution which is lognormal with unknown parameters. In this case a distribution H_λ needs to be assigned for λ, expressing the analysts uncertainty about the "true" value of λ. The production loss is generated by drawing λ values from H_λ and then repeating the analysis in I using the $F(\lambda)$ distributions for the uptimes and downtimes. The theoretical formula justifying this procedure is

$$P(Y_g \le y) = \int P(Y_g \le y | \lambda.) dH_\lambda(\lambda),$$

and then using (2.1) for computing $P(Y_g \le y | \lambda)$ with the $F(\lambda)$ distributions in place of F_U and F_D.

To establish metrics for production loss contributions, various measures can be used, for example the improvement potential [7]. The idea here is to measure the changes in probabilities and related expected values when assuming that a subsystem/component is in a perfect state all the time.

To apply the model it must be found acceptable for its purpose. This means that the model error must be judged as sufficiently small. Also other assumptions introduced in the analysis must be judged as acceptable. A way of performing such judgements is presented in the coming section, in which a case study related to a subsea production system is used to illustrate the framework and the discussion.

3. Case study

The purpose of this section is to illustrate the framework presented in Section 2, using a case study related to a subsea production system.

3.1. Description of the case

A subsea gas production system is being designed, and to support the decision making on which arrangements and measures to choose, the owner of this system would like to conduct an analysis providing predictions of the production availability. As was mentioned in Section 1, the production availability refers to the ratio of production to planned production, over a specified period of time. The purpose of the subsea gas production system is to transport the well flow from the production wells below the sea bed to a platform above sea level for processing the gas. The well flow goes through the well, x-mas tree, manifold and umbilical before the topside processing on the platform. This subsea system consists of two manifolds and respectively four and three production wells are connected to each of them. The manifolds collect the well flow from several x-mas trees and transport the flow through