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Production availability analysis of Floating Production Storage and Offloading (FPSO) systems

Huixing Meng[a,*], Leïla Kloul[b], Antoine Rauzy[c]

[a] *Laboratory of Computer Science, École Polytechnique, Paris, France*
[b] *DAVID, Université de Versailles St-Quentin-en-Yvelines, Versailles, France*
[c] *Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Trondheim, Norway*

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ABSTRACT

Floating Production Storage and Offloading (FPSO) systems are currently the popular scheme in offshore oil and gas industry. The profitability of these systems is extremely dependent on their production availabilities. In this article, we report the lessons learned from the assessment of the production availability of a FPSO system. Regarding this study, we used stochastic simulation as the assessment tool because it is naturally suitable for performance evaluation of the production systems. To obtain relevant results, it requires a strong modeling discipline as well as rigorous experimental protocols. By adopting modeling patterns in the production availability analysis, we can model the target systems in a modular way. We propose here to build models by assembling modeling patterns dedicated to production availability studies. We discuss the performed experiments with a special focus on sensitivity analyses. The results by changing the failure rates are validated with those altering the repair rates.

1. Introduction

Floating Production Storage and Offloading (FPSO) units are currently the popular scheme in offshore oil and gas industry [1,2]. They are employed to process and to store temporarily the crude oil/gas coming from the production platforms or directly from the subsea wells. The oil stored in FPSO is transferred periodically to shuttle tankers. FPSO have the capacity to work in both shallow and deep waters, as well as in rich and poor (marginal) oil reserves and gas fields. They can be shifted from one offshore field to another conveniently and economically. FPSO are however complex systems. Their operations may face lots of hazards and failures. Many incidents and accidents of FPSO have been reported and studied (see e.g. [3–10]). In recent years, an explosion on board of the FPSO *Cidade de São Mateus* left nine fatalities and several injured [11]. Besides such accidents (low probabilities and high consequences) that must be avoided at all costs, long outages can decrease seriously the performance of these systems and have strong economic effects [12]. This is the reason why the profitability of these systems is extremely dependent on their reliability, availability and maintainability (RAM) [13]. It is therefore of importance to assess these characteristics by means of the calculation of suitable performance indicators obtained from dedicated models.

Production availability is such an indicator, which measures how a system is capable to meet the demand for deliveries or performance [14]. It is defined as the ratio of the actual production to the planned production, or field capacity, over a specified period of time [15–17]. It combines thus both RAM indicators and production expectation. Production assurance, or production regularity have similar meaning [17–19].

FPSO have several specific characteristics that influence strongly the way production availability can be assessed [20]. Stochastic simulation is a candidate assessment tool because it is naturally suitable for performance evaluation in general [16,21]. Stochastic Petri nets (SPN, see e.g. [22,23]) are a candidate modeling formalism to support stochastic simulation. They can deal with arbitrary probabilistic distributions and describe both static and dynamic characteristics with a high algorithmic efficiency. They have been already applied for various types of offshore studies (see e.g. [24–27]). For our study, we use an extension of SPN, so-called Stochastic Petri nets with assertions and predicates (SPN-AP), as it is implemented in the GRIF modeling and simulation environment [28]. SPN and SPN-AP models are however far from easy to design and even more difficult to maintain and to share with stakeholders [28].

The pattern can be utilized for reusing capitalized knowledge, which was initially proposed in civil engineering [29]. The con-

* Corresponding author.
E-mail addresses: Huixing.Meng@hotmail.com (H. Meng), Leila.Kloul@uvsq.fr (L. Kloul), Antoine.Rauzy@ntnu.no (A. Rauzy).

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cept was adopted in software engineering subsequently as design patterns [30]. These patterns are descriptions of communicating objects and classes that are customized to solve a general design problem in a particular context [30]. A design pattern promotes design reuse, conforms to a literary style, and defines a vocabulary for discussing design [31]. Modeling patterns are therefore generalizations of frequently occurring system (functional and physical) behaviors which can be applied to solve a generic modeling problem in a specific context.

We propose here a set of modeling patterns dedicated to production availability studies. We formulate these patterns in terms of a simplified version of Guarded Transition Systems (GTS) [32]. GTS both generalize and simplify the mathematical framework of SPN-AP. This generalization is obtained at no computational cost. We show how the model of the particular FPSO we studied is obtained by composing these modeling patterns. Subsequently, based on this model, we discuss the experimental protocol we apply to determine the sensitive parameters and critical components of the FPSO, with respect to production availability.

The remainder of this article is organized as follows. Section 2 discusses some related works. In Section 3, we describe the architecture of a FPSO system. Section 4 recalls basics about guarded transition systems and investigates some modeling patterns used for this study. Section 5 presents the experimental results. Eventually, Section 6 concludes the article.

2. Related works

ISO 20815 [16] and NORSOK Z-016 [15] standards provide a general framework to perform production availability studies. Two categories of methods have used so far: analytical methods and simulation based methods (see [33] for a review).

Most of the analytical methods rely on formulas describing the system failures, typically a fault tree, a block diagram or a Markov chain [18,19,34–36]. These methods are interesting, but limited in terms of size and complexity of the systems.

In general, simulation based studies are performed using discrete events Monte-Carlo simulation, where events such as failures, repairs and reconfigurations are associated with stochastic delays [37–41]. Although nowadays computers are powerful and efficient softwares have been developed, the computational cost remains quite high.

Stochastic Petri Nets (SPN) is the dominant modeling formalism to assess production availability via simulation based methods [22,42]. An international standard (IEC 62551) [43] has been released for SPN which are also among the recommended methods by ISO 20815 standard.

Stochastic Petri Nets with predicates and assertions (SPN-AP), as implemented in the GRIF Workshop modeling and simulation environment[1] have been used by different authors to assess production availability of offshore systems. Ref. [44] studies the European SAFERELNET test case. Ref. [27] studies the subsea part of the FPSO system, which directly obtains the oil and gas from the subsea wellheads and manifolds.

As pointed out in the introduction, there is a strong need for methods to structure simulation/analytical models in order to improve their design and their maintenance. An interesting attempt in this direction is the work by Signoret et al. in [28]. Their approach is related to the use of high-level modeling languages such as AltaRica [45].

[1] http://grif-workshop.com/.

3. The FPSO system

Our case study is a FPSO system serving in an offshore oil field. This FPSO includes the crude oil processing system, a single point mooring system, a crude oil storage and ballast system, a fire protection and lifesaving system, a power and instrumental system [46,47]. In this paper, we focus on the production availability of the crude oil processing system which we refer to as the FPSO system, for the sake of simplicity. Failures of the rest offshore assets can also influence the FPSO production performance. For example, a fire (or an explosion) occurred in the facility, therefore after the failure of the fire protection system, can lead to the suspension of the entire system. The investigation of the leakage points and ignition sources is out of this research scope. In this work, we focus on studying the system reliability issue rather than the safety aspect.

3.1. System overview

The FPSO system consists of four sub-systems: platforms A, B, C and the FPSO subsystem, as shown in Fig. 1. Platform A transfers the oil to a buffer tank in platform B. Together with the output oil of platforms B and C, the overall oil is transported to the heat exchangers of the FPSO subsystem. In Fig. 1, solid arrows represent the crude oil flow, while dashed arrows represent the separated gas or waste water. These three platforms are relatively independent. The unavailability of either platforms A, B, or C cannot lead to the output unavailability of platforms. The unavailability of platforms B and C can result in the output unavailability of platforms. The unavailability of platform B can trigger the closure of platform A.

3.1.1. The platforms

Platform A is in charge of the pre-fractionation and transportation of the oil from well head A (WEA). WEA stands for dozens of production wells under the fixed production platform. There are two main components on platform A: the primary separator A (PSA) and the efflux pump A (EPA). PSA separates the crude oil into three parts: the gas is transported to vent A (VA), the water is delivered to water processing system A (WPSA), and the purified crude oil flow is sent to EPA. The provisional destination of the crude oil from platform A is the crude oil buffer tank (COBT) on platform B.

Platform B purifies preliminarily the crude oil and transports it from Well head B (WEB). Platform B is made of the primary separator B (PSB), COBT, the efflux pumps B1 (EPB1) and B2 (EPB2). PSB separates the crude oil into three parts: the separated gas flows to vent B (VB), the exporting crude oil is carried to EPB1, and the remaining water is delivered to water processing system B (WPSB). The oil temporarily stored in COBT is transferred to platform C through EPB2. The exported oil from EPB1 and EPB2 are integrated into a unique flow to platform C.

Platform C purifies the initial oil flow and transports it from the Well head C (WEC). Like Platform A, Platform C includes two main components: the primary separator C (PSC) and the efflux pump C (EPC). PSC separates the initial crude oil into three parts: the gas is transferred to vent C (VC), the water is delivered to water processing system C (WPSC), and the treated crude oil is transferred to EPC. The oil from EPC joins the flows from EPB1 and EPB2 to the FPSO subsystem.

3.1.2. The FPSO subsystem

The FPSO subsystem processes and stores the crude oil. It consists of two parallel heat exchangers (HEs), a sea water cooler (SWC), three parallel booster pumps (BPs), two parallel pre-heaters (PHs), as well as three processors (TCP, EDHP, EDSP).

The main function of the FPSO subsystem is to process the primarily separated oil so to make it at the standard quality. The overall oil flowing from platforms is initially delivered to HEs to increase