Ocean Engineering 158 (2018) 171–185

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Assessment of safety barriers for the prevention of cascading events in oil and gas offshore installations operating in harsh environment

Marta Bucelli [a,b,c], Gabriele Landucci [d,e], Stein Haugen [f], Nicola Paltrinieri [b], Valerio Cozzani [a,*]

[a] Department of Civil, Chemical, Environmental and Material Engineering, Alma Mater Studiorum – University of Bologna, Via Terracini 28, 40131, Bologna, Italy
[b] Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology NTNU, S.P. Andersens Veg 5, 7031, Trondheim, Norway
[c] Safetec, Klæbuveien 194, 7037, Trondheim, Norway
[d] Department of Civil and Industrial Engineering, University of Pisa, Largo Lucio Lazzarino 2, 56126, Pisa, Italy
[e] Institute of Security and Global Affairs, Faculty of Governance and Global Affairs, Leiden University, Wijnhaven, Turfmarkt 99, 2511 DP, Den Haag, The Netherlands
[f] Department of Marine Technology, Norwegian University of Science and Technology NTNU, Otto Nielsen Veg 10, 7031, Trondheim, Norway

ARTICLE INFO

Keywords:
Harsh environment
Major accident hazard
Offshore
Oil&gas installations
Safety barriers
Cascading events

ABSTRACT

Fire in the topside production area of offshore Oil and Gas (O&G) platforms has the potential to trigger cascading events and may lead to catastrophic consequences for operators, environment and asset. Safety barriers, such as hardware systems and emergency response, are critical elements aimed at preventing the propagation of this type of scenarios. Harsh environmental conditions may strongly affect the integrity of protective equipment and significantly hinder an effective and timely emergency response, with a consequent increase in the risk level. The present study is aimed at developing a structured methodology to the quantitative performance assessment of safety barriers, specifically addressing the analysis of offshore facilities operating in harsh and sensitive environment. An expert judgment elicitation procedure is adopted to score external factors associated with harsh environmental conditions. Simplified relationships are established for availability and effectiveness evaluation of safety barriers in offshore O&G platforms. A dedicated framework is developed for the analysis of emergency response. The approach is tested through the application to a case study, aimed at the assessment of the influence of harsh environmental conditions on the risk due to cascading events in a reference offshore installation.

1. Introduction

In the last decades, energy request has been increasing due to a continuous economic and social progress. Although renewable resources are increasingly developed, according to the International Energy Agency, the primary energy resource is still fossil fuels and their demand is expected to grow by more than 35% in the period 2010 to 2040 (IEA - International Energy Agency, 2017).

The raising energy demand drives oil & gas (O&G) exploration companies to search for novel reservoirs. Therefore, exploration activities are moving towards Arctic and sub-Arctic regions, along the Norwegian, American and Russian continental shelfs. According to the United States Geological Survey, 22% of world hydrocarbon reserves are contained in these areas (www.usgs.gov). The exploration of these areas started in the early 1960s (National Petroleum Council, 2015). However, their harsh climate conditions entail undertakings and risks for drilling operations (Paltrinieri et al., 2017a,b). The oil production in these areas encounters different challenges due to cold, harsh climate, wind, snowfall, darkness and sensitive environment with respect to pollution. The weather may delay operations as well as maintenance activities and the remoteness of the installations may lead to logistic and emergency response problems. Besides, severe legislative frameworks are in force for environmental protection (Norwegian Environment Agency, 2011).

Poor experience in design and operations of Arctic O&G facilities within harsh environment and difficulties in emergency response and management may represent critical issues to overcome. As Bercha et al. (2003) and Gao et al. (2010) affirm, technical and operational performance of safety barriers are critical aspects to be addressed in these specific conditions. The effect of the environment and external factors on systems reliability have been investigated in the past and several models are available in the literature, such as the proportional hazard model (PHM) (Cox, 1972) or the accelerated failure time model (Kalbfleisch and Prentice, 2002). On the other hand, innovative techniques for operational support may be applied to such scenarios (Landucci and Paltrinieri,

* Corresponding author.
E-mail address: valerio.cozzani@unibo.it (V. Cozzani).

https://doi.org/10.1016/j.oceaneng.2018.02.046
Received 28 December 2017; Received in revised form 16 February 2018; Accepted 21 February 2018

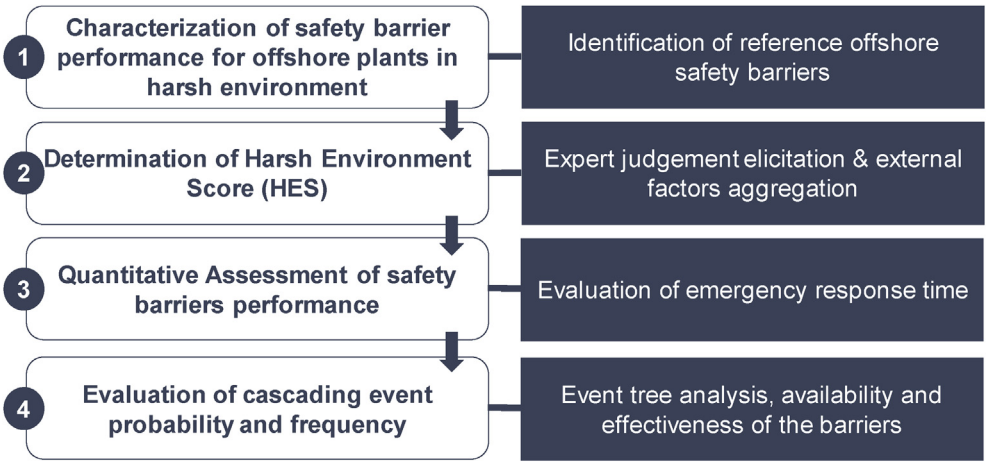

Fig. 1. Flowchart of the method developed in the present study to assess the probability and frequency assessment of cascading events triggered by fire in offshore O&G installations. The method accounts for the effect of harsh environmental conditions on the protection performance of safety barriers.

2016; Paltrinieri et al., 2017a,b; Paltrinieri and Khan, 2016).

Systems maintainability is also affected by external environment. Maintenance relies on resources, such as operators, tools, and equipment, accessibility and testing. In Arctic conditions, operators may delay or may be unable to perform maintenance activities, remoteness may hinder the deployment of tools and equipment needed and these may result in overdue or inappropriate maintenance. These issues were specifically addressed in the work by Gao et al. (2010). Despite that risk-based design enhancing safety of operations in harsh environment was discussed by several authors (Gao et al., 2010; Paik et al., 2011; Vinnem, 2014), a comprehensive and systematic safety assessment is still lacking for accident scenarios associated with offshore O&G facilities in harsh environment.

Among the most critical accident scenarios which may affect O&G extraction and production facilities, fires and explosions may directly cause severe damage to human health and environment, but also affect the structural integrity of the facility and asset. In this latter case, accidents may propagate among different equipment processing or storing hydrocarbons, eventually leading to the amplification of consequences (Khakzad and Reniers, 2015; Necci et al., 2015). Those scenarios are indicated as cascading or domino events (Cozzani and Reniers, 2013), and severely affected offshore O&G installations (e.g. Piper Alpha disaster, July 1988 (Lord Cullen, 1990) and Macondo blowout, April 2010 (BP, 2010)) and, more in general, the process industry (Cozzani and Reniers, 2013).

In the last decades, the hazards posed by cascading events inspired the development of different approaches aimed at accounting this event in risk analysis and management (Bagster and Pitblado, 1991; Cozzani et al., 2005; Gledhill and Lines, 1998). More recent approaches proposed for cascading events triggered by fire assessment included Monte Carlo simulations (Abdolhamidzadeh et al., 2010), simplified risk indexes (Cozzani et al., 2009; Zhang and Chen, 2011) and tools based on Bayesian networks (Khakzad et al., 2013), eventually accounting for analysis of safety barrier performance (Khakzad et al., 2017). However, none of the mentioned approaches addresses the influence of harsh environmental conditions on risk evaluation and possible prevention or mitigation associated with the performance of safety barriers.

A preliminary attempt to analyse cascading events triggered by fire in harsh environmental conditions was developed by Landucci et al. (2017). The authors improved a methodology for the quantitative assessment of safety barriers based on event tree analysis (Landucci et al., 2016, 2015) introducing the analysis of environmental effect on the performance of safety barriers, accounting for external factors such as cold weather, extreme snow, wind or other meteorological conditions. However, the approach was primarily focused on the assessment of cascading event risk for onshore facilities, without specific and detailed analysis to the peculiar aspects of emergency rescue and response in O&G offshore installations.

Therefore, the present work addresses the need for a systematic framework for risk analysis of cascading events assessment and emergency response. The focus is on the performance of safety barrier mitigating fired domino scenarios in offshore platforms and facilities. The effects of harsh environmental conditions are included in the investigation in order to develop a comprehensive framework able to analyse how domino frequency (or probability) may vary due to external severe weather conditions.

The paper is structured as follows. In Section 2, a detailed overview of the developed methodology is provided. A description of the case study installation and the meteorological characterization of the area where it operates are provided in Section 3. Results are presented in Section 4 while Section 5 discusses the overall findings. Conclusions are provided in Section 6.

2. Methodology

2.1. Overview

The present work is based on a methodology aimed at evaluating the performance of safety barriers in O&G facilities operating in offshore harsh environment. Fig. 1 reports the flowchart of the methodology, detailing the specific features.

The preliminary step of the methodology (step 1 in Fig. 1) is aimed at the identification of safety barriers that are installed on offshore O&G installations in order to prevent and/or mitigate the occurrence of cascading events. Barriers are identified according to specific standards and guidelines (American Petroleum Institute, 2007a; HSE Health and Safety Executive, 1992; ISO-International standardization organization, 1999; PSA, 2013). Each safety barrier is characterized by protection performance parameters in order to support further steps for the quantitative characterization. In step 2 (see Fig. 1), a harsh environmental score, namely HES, is determined, based on a weighted combination of penalties associated with external climate and environmental factors (e.g., cold temperatures, wind, waves, snowfall, etc.). In this step, a specific elicitation process and a novel aggregation procedure is adopted to reduce the uncertainties in the methodology.

The so evaluated HES is applied in step 3 (see Fig. 1) in order to determine the quantitative parameters related to the performance of the safety barriers in harsh environment. The safety barriers performance is expressed in terms of i) availability, i.e. the capability of the barrier to respond on demand and ii) effectiveness, i.e. the capability of the barrier