Applied Ocean Research 56 (2016) 132–142

Contents lists available at ScienceDirect

Applied Ocean Research

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

Information structuring and risk-based inspection for the marine oil pipelines

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ARTICLE INFO

Article history:
Received 21 October 2015
Received in revised form 22 January 2016
Accepted 24 January 2016
Available online 26 February 2016

Keywords:
Experience
Knowledge
Inspection
Maintenance
Risk assessment
Equipment failure
Intelligent pigging
Safety
Environment
Offshore production

ABSTRACT

The proposed work is incorporated into the research theme concerning the maintenance and inspection of sensitive facilities in production systems. It is essential to promote the methodological deployment of inspection techniques to ensure the good functioning of services provided by complex production systems as well as their different components. We use a risk-based inspection methodology offering an organized analysis with knowledge sharing for collaborative possibilities in a multidisciplinary context and it consists of the following steps: data acquisition and information collection, failure analysis (probability and consequences), risk assessment, inspection plan, mitigation and revaluation. The application of this methodology can improve the maintenance management strategies of industrial companies. The inspection department is able to forecast its potential failure, root causes and impacts on the safe operation of the considered production system, based on a reliable inventory of existing situations and review options for continuous improvement in maintenance management. In particular, we addressed the application of a Risk-Based Inspection (RBI) methodology in the French petroleum company with operations on the west coast of central and southern Africa. The incorporation of expert knowledge into risk assessment is helping to find the best preventive plan for pipeline inspection in the case study.

1. Introduction

The current management frameworks of industrial enterprises must integrate engineering standards and recommended practices to reflect the increasing complexity of production systems. In addition, the legislation requires that enterprises comply with applicable normative rules by using industrial practices that are environmentally and logistically sustainable. In certain circumstances, the law obliges companies to make risk information (threat cryptograms and the associated risk and safety descriptions) available on the industrial sites. The increasing complexity of oil and gas installations and operations, along with growing public awareness to ensure higher levels of safety, has put great pressure on the designers and operators to find innovative solutions to ensure safe as well as economically viable operation [1]. Reliability and Maintenance with tools such as RCM (Reliability Centred Maintenance) and RBI (Risk-Based Inspection) contribute to collaboratively working towards seeking reasonable and practical solutions in the industrial settings [2]. In scientific literature, there are different categories of risk analysis and risk-assessment methods and techniques (qualitative, quantitative and hybrid approaches) [3]. A varied range of methodologies presently in use for risk-based inspection includes marketable and internal software packages particular to explicit plants [4]. In the complex production systems, the work package of maintenance engineering is important to ensure continuity of services, optimize production capacity, improve safety and reduce the environmental impact. Risk Based Inspection (RBI) is an interesting maintenance perspective with an incremental stepwise procedure used to examine sensitive equipment such as pressure vessels, heat exchangers and piping in complex industrial plants [5]. RBI provides a modelling process for organizations to control its reliability, safety and health aspects, ensure maintenance compliance and to iteratively improve the technical performance

Abbreviations: Ath, Allowed minimum THickness; CMIMS, Computerized Maintenance and Inspection Management System; Cof, Consequence of the failure; CL, Corrosion Likelihood; CR, Corrosion Rate; EFF, Effectiveness; ESD, Electrical Schematic Diagram; FPSO, Floating Production, Storage and Offloading; HSE, Health, Safety and Environment; HV, High-Voltage; HMI, Human–machine interface; LAY, Lay-out; Lof, Likelihood of failure; LV, Low-Voltage; MAOP, Maximum Allowable Operating Pressure; MOP, Maximum Operating Pressure; MOGA, Multi-Objective Genetic Algorithm; NCL, Natural Corrosion Likelihood; P&ID, Piping and Instrumentation Diagram; PCS, Process Control System; PFD, Process Flow Diagram; PSS, Process Safety System; PLC, Programmable Logic Controller; RBI, Risk-Based Inspection; RCM, Reliability Centred Maintenance; SLD, Single-Line Diagram; ST, State; SLD/C, Structural design or construction failure Likehood; SLthird, Structural failure third party Likehood; SLmec, Structural mechanical failure Likehood; SLnat, Structural natural failure Likehood; SL, Structure Likelihood; SAP, Systems, Applications & Products in Data Processing; UFD, Utility Flow Diagram.

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http://dx.doi.org/10.1016/j.apor.2016.01.009
0141-1187/

and cost of projects [6]. However, the implementation of the RBI requires structured and coherent information management in order to maximize its integration in the target computerized management information system for maintenance and inspection. The aim of this work is to propose a conceptual approach providing structured information for semantic modelling of the hierarchical organization of components that characterize all the sensitive areas of a complex system that must be inspected or verified by the RBI method. This semantic modelling will formalize the taxonomic organization of equipment and instruments of the considered system. These components are classified according to their nature through the study of essential documents and information provided by vendors and the manufacturer of the system. The obtained structured information can be transferred to the Computerized Maintenance and Inspection Management System (CMIMS) for the management issues (analysis and diagnosis) or engineering issues (task lists).

The paper is structured as followed. Section 2 exposes a background of the risk based inspection management. Section 3 presents the industrial challenge of the risk based inspection management. Section 4 presents the suggested methodology. Section 5.1 describes an illustrative case study for petroleum pipelines. Section 5.2 delivers an analysis of this study. Sections 6 and 7 presents the results and discussion based on research findings. Finally, Section 8 gives the conclusion and underlines both the related works and the challenges that lay ahead.

2. Background

2.1. Practices of risk-based inspection

Risk-based Inspection (RBI) offers practical ways for the implementation of an inspection process that provides to maintenance actors a method of assessing the probability and effect of failure, evaluating risk level and generating the kinds of relevant actions that can lead to development of required risk management policies [7]. There are different illustrations of RBI practices which increase cost effective actions and can be considered as promising developments to shift from a reactive to a proactive maintenance management in various domains. We mention as examples the implementation of risk assessment in civil engineering applications [8]. In the petrochemical and chemical industries, the deployment of online and offline inspection procedures to equipment such as pipelines has led to substantial improvements in operational reliability and the prevention of incidents (e.g. Management of Corrosion) [9,10]. In nuclear engineering and design, there are current practices and trends in the risk-based inspection and maintenance for safety evaluation [11]. The RBI method was used to assess the risk of large-scale crude oil tanks in order to determine the acceptable risk and internal inspection interval of tanks [12]. There are some examples of the application of risk-based methods in industrial coal-fired boilers with some interesting results [13]. RBI programmes are also established for reliability analysis purposes in heavy water plants with the assessment of failure pressure and estimation of the frontier state functional analysis [14]. The RBI methods are also adopted and useful in the offshore wind energy industry for the organization of maintenance logistics with significant influences on important cost parameters of energy production [15–17].

In general, the majority of industrial applications of RBI methodologies are used in the refinery systems and petrochemical sectors [18]. RBI addresses clearly the threats (personnel death and injury, damage to the environment and financial loss) to the integrity of the asset and it is performed for piping and vessels, including heat exchangers, tanks, pressure vessels, and filters [19]. Pipeline system inspections can be done either internally or externally as continuous inspections over the complete pipeline length or as local inspections for particular sections or local zones in order [20]:

- *In-Line inspections* (*ILI*) of pipelines are generally accomplished using a pig. The pig moves through the pipeline guided by the flow or fluid or may be pulled by a vehicle or a cable. It gathers data as it turns through the pipeline. The technical resources may be automatic or self-contained or may be activated from outside the pipeline via a data and power connexion. Diverse technical resources can be combined in a pig train. The internal inspection techniques comprises Magnetic Flux Leakage, Ultrasound Technology (UT), Laser-optical inspection tool, Geopig and Calliper.
- *External inspections* are generally accomplished using a remotely operated transporter equipped with diverse inspection techniques and resources. This can for instance be techniques for visual inspections (video recording) and physical measurements (steel electrochemical voltage measurements). External inspection can also be accomplished by a diving team. The external inspection techniques comprises Visual/Video/photo, sidescan sonar (SOund NAvigation Ranging), Multibeam Echosounder (MBE), Cross profiler, Pipetracker, Sub bottom profiler, Stabbing, Eddy Current and External UT (Ultrasonic Testing).

The scope of these inspections methods encompasses all pressure systems in the industrial site, and they can be used to inspect pipes/other static equipment and take the geometric measurements (diameter, wall thickness, metal loss, crack and other defects). The selection of inspection method is based on optimizing a number of features that symbolize each technique: (i) Confidence in identifying the estimated damage state, (ii) Cost of technique/method, including human and technical resources, and (iii) Magnitude of maintenance support necessary to perform the work (scaffolding, process shutdown, opening of equipment).

2.2. Principles for risk evaluation

The RBI evaluation is used to engender an inspection plan at desired detail level of the considered system with adequate time allowing to not exceeded the risk limit, to keep track of degradation processes with the potential selection of the appropriate mitigation action. Risk acceptance limits for inspection plan ning resulting from main targets related to availability, profit and safety can imply pure maintenance engineering acceptance criteria such as acceptable wall thickness (requirement for pressure retaining purposes). The risk evaluation is based on consequences and probabilities of failures that are evaluated in a distinct way, under the following assumptions [21]:

- The consequences of system faults, loss of main functions and sub-functions, are independent of the equipment carrying out the functions.
- The actual equipment and the operational conditions affect the probability of failure.

The outcome of the RBI process is determination of [22]:

- location and extent of inspections and condition monitoring,
- inspection methods,
- inspection intervals.

The consequences of main function failures are evaluated according to the effect on the enterprise, activity sector, industrial site and system level regarding the production loss and direct cost measured in interruption and economic terms, while consequences of impairment of health and environmental degradation are