Automation in Construction 45 (2014) 50–65

Contents lists available at ScienceDirect

Automation in Construction

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

Artificial neural network models for predicting condition of offshore oil and gas pipelines

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ARTICLE INFO

Article history:
Received 10 August 2013
Revised 17 March 2014
Accepted 3 May 2014
Available online 22 May 2014

Keywords:
Offshore oil and gas pipelines
Condition prediction
Artificial neural network

ABSTRACT

Pipelines daily transport and distribute huge amounts of oil and gas across the world. They are considered the safest method of transporting oil and gas because of their limited number of failures. However, pipelines are subject to deterioration and degradation. It is therefore important that pipelines be effectively monitored to optimize their operation and to reduce their failures to an acceptable safety limit. Numerous models have been developed recently to predict pipeline conditions. Nevertheless, most of these models have used corrosion features alone to assess the condition of pipelines. Hence, this paper presents the development of models that evaluate and predict the condition of offshore oil and gas pipelines based on several factors besides corrosion. The models were developed using artificial neural network (ANN) technique based on historical inspection data collected from three existing offshore oil and gas pipelines in Qatar. The models were able to successfully predict pipeline conditions with an average percent validity above 97% when applied to the validation data set. The models are expected to help pipeline operators to assess and predict the condition of existing oil and gas pipelines and hence prioritize the planning of their inspection and rehabilitation.

1. Introduction

Pipelines remain a reliable means of transporting products vital to the sustenance of national economies in the world such as water, oil, and gas [11]. The first oil pipeline, which was built in 1879 in Pennsylvania, was 109 miles long and 6 in. in diameter [21]. Nowadays more than 60 countries have pipeline networks exceeding 2000 km in length. The United States has the longest pipeline network followed by Russia [17].

Gas and oil pipelines are subject to deterioration and degradation. Pipeline accidents can cause catastrophic environmental damage due to oil spillage as well as economic losses due to production interruption [12]. Several types of accidents of oil and gas pipelines have been recorded in the CONCAWE (CONservation of Clean Air and Water in Europe) report [9]. They are most frequently classified in five cause categories: 1) third party, which represents a damage caused by operations carried out by others in the pipeline vicinity and not related to its management; 2) corrosion, which consists of an inside corrosion related to the product being transported and an outside corrosion related to the pipeline coating and cathodic protection; 3) mechanical, which consists of fractures or cracks occurring when efforts go beyond the efforts of the system permits; 4) operational error, which is caused by excessive pressure or system malfunction; and 5) natural events such as landslides, floods, erosion in general, subsidence, earthquakes, frost or lightning. It is therefore important that the condition of pipelines is effectively monitored to optimize their operation and reduce their failures to an acceptable safety limit.

Most of the developed condition assessment models are either subjective (i.e., depending only on expert opinion considering no historical data), or not comprehensive (i.e., dealing with only one failure cause). Therefore, the objective of this research is to develop a more comprehensive condition assessment model that allows pipeline operators to take the necessary actions to prevent future catastrophic failures.

2. Research objectives

The main objectives of the present study are to design a condition assessment and prediction models and develop expected deterioration curves for offshore oil and gas pipelines.

3. Background

Various attempts have been carried out in the last two decades for oil and gas pipelines' leakage, defect type, corrosion rate, failure type, and failure probability predictions. Ren et al. [30] applied back propagation neural network to predict the corrosion rate of natural gas pipelines. Particle swarm optimization (PSO) technique was employed by Liao et al. [23] to develop a model that predicts internal corrosion rate for

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http://dx.doi.org/10.1016/j.autcon.2014.05.003
0926-5805/

wet gas gathering pipelines. The model was also developed using genetic algorithm (GA) and ANN techniques which outperformed the PSO. Dawotola et al. [10] developed a rupture risk management model for crude oil pipelines using a methodology that incorporates structured expert judgment and analytic hierarchy process (AHP). Noor et al. [27] used semi-probabilistic and deterministic methodologies to predict the remaining strength of submarine pipelines subjected to internal corrosion. Bersani et al. [4] developed a risk assessment model using historical data from the United States Department of Transportation (DOT) to predict the failure caused by third party activity. Historical failure data was also used to develop a tool to predict the class of each spillage in oil pipelines using statistical analysis classification and regression tree [5]. Li et al. [22] presented a method to predict the corrosion and the remaining life of underground pipelines using a mechanically-based probabilistic model that considers the effect of randomness in pipeline corrosion using Monte Carlo simulation technique. Singh and Markeset [33] presented a proposed methodology, based on fuzzy logic framework, for the establishment of a risk-based inspection program for pipelines according to the estimation of its corrosion rate. Peng et al. [28] developed a fuzzy neural network model, which is based on failure tree and fuzzy computing, to predict the rate of failure for oil and gas pipelines. Dawotola (2009) [41] proposed a combined AHP and Fault Tree Analysis to support the design, the construction, and the inspection and maintenance of oil and gas pipelines by proposing an optimal selection strategy based on the probability and consequence of failure. Jinhai et al. [19] proposed a leak fault-detection method based on the combination of Rough Set (RS) and ANN, called hybrid fault-detection method based on RS and ANN (HFDMRSNN). Carvalho et al. [7] used the ANN technique for pattern recognition of magnetic flux leakage (MFL) signals in weld joints of pipelines obtained by intelligent pig to distinguish the presence of defects and their type. AHP was used by Dey [12] to develop a model to help decision makers select a suitable type of inspection or monitoring technique for pipelines. Hallen et al. [18] presented a probabilistic analysis framework to evaluate the condition of a corroding pipeline and the evolution of its probability of failure with time. Sinha and Pandey [34] developed a simulation-based probabilistic fuzzy neural network model to estimate the failure probability of aging oil and gas pipelines due to corrosion. Ahammed [1] presented a methodology to assess the remaining service life of a pressurized pipeline containing active corrosion defects. Belsito et al. [3] developed a leakage detection system for liquefied gas pipelines using ANN for leak sizing and location.

Most of the previously-mentioned models were either subjective [10,12] or did not cover all the failure causes of oil and gas pipelines [1,4,18,22,23,26,27,30,33,34]. In other words, they lack the objectivity in predicting the different failure types of pipelines. As a result, Senouci et al. [31] developed a regression and artificial neural network (ANN) models to predict possible failure types for oil and gas pipelines. The model took into consideration the prediction of failure types beside corrosion, such as mechanical, third party, natural hazard, and operational failures. The model was built based on a historical data collected from a report that was prepared by CONCAWE [9]. Later, [32] developed another model for the same purpose using fuzzy logic technique and compared the results with those obtained using the regression and ANN models developed by Senouci et al. [31]. The results comparison showed that the developed fuzzy-based model outperformed the regression and ANN models with respect to model validity.

Despite the attempts made to predict the failure type of oil pipelines considering causes other than corrosion, still none of the previously-mentioned models can be used to assess the condition of pipelines. Actually, such models were intended to either predict the corrosion rate, pipe leakage, or failure/defect type focusing mostly on corrosion related factors. In addition to that, the important issues of "interdependency" between different factors' relations and "uncertainty" of factors' severity weights were not addressed simultaneously. Furthermore, none of the previous studies developed models that can forecast the deterioration rate of oil and gas pipelines and hence can build up their respective deterioration curve. Consequently, El-Abbasy et al. [14] developed a model that assesses the condition of oil and gas pipelines based on several factors including corrosion using both Analytic Network Process (ANP) and Monte-Carlo simulation. The model considered factors' interdependency (using ANP), made decisions under uncertainty (using simulation), and handled decisions involving large number of variables (using integrated simulation/ANP). It was successfully tested on an existing offshore gas pipeline in Qatar by comparing the results obtained using the model with the actual pipeline condition.

The simulation model built by El-Abbasy et al. [14] is considered as a first phase to evaluate or assess the condition of offshore oil and gas pipelines. Two major limitations were found in the study conducted by El-Abbasy et al. [14]. First, the factors that were used to predict the pipeline condition were not sufficient due to the lack of collected data. The factors related to the pipeline structural condition were also not considered. Second, the model was developed and tested using inspection data for a single 12-inch gas pipeline. The limited historical inspection data did not allow the examination of the effect of changing the pipe diameter or the type of the transported product on the developed model. Moreover, the limited inspection data did not allow the development of sound deterioration curves for oil and gas pipelines. To overcome the above limitations, an extensive data collection was performed in a study conducted by El-Abbasy et al. [15] where seven historical inspection data seta were collected for three different pipelines with several sizes (i.e. diameters), materials, and types of the carried product. Four factors were considered in addition to those presented in the previous study [14]. The additional factors included the "anode wastage" and three factors related to the pipeline structural condition namely, "support condition", "joint condition", and "free spans". The regression analysis technique was used to correlate between all these factors using the gathered data. The developed models were validated yielding an average validity percentage above 96%. In addition, the study proposed a standard condition assessment scale or rating system for oil and gas pipelines. This rating system can be used as a guideline to decide and plan the maintenance of pipelines (i.e., lining, cathodic protection, replacement, etc.) and to prioritize rehabilitation/upgrading projects within the approved budget.

Although the study conducted by El-Abbasy et al. [15] provided sound results, the use of the regression analysis technique as a machine learning algorithm has still some limitations. Several other machine learning algorithms can be used to predict pipeline condition including ANN, Support Vector Machine (SVM), Naïve Bayes (NB), Decision Trees (DT), Random Forest (RF), and K-Nearest Neighbor (K-NN). Although ANN is considered one of the oldest methods, it is still found to be a competitive algorithm among the new ones. For instance, Tahyudin et al. [36] compared the performance of SVM, DT, ANN, NB, and Logistic Regression (LR) to predict the graduation students on time. The results showed that ANN and SVM were the best predictors with an accuracy rate almost 100%. Caruana and Niculescu-Mizil [6] carried out a comparison between ten supervised learning algorithms being applied on eleven binary classification problems using eight performance metrics. It was found that the ANN was among the top five best algorithms. Other studies showed the outperformance of the ANN technique. Mohana and Thangaraj [24] showed that ANN is better than SVM for modelling resource state prediction. Prabhakar [29] also showed the better performance of ANN over SVM in predicting software effort. Mollazade et al. [25] compared four different learning algorithms, namely, ANN, SVM, DT, and Bayesian Network (BN) for grading raisins based on visual features. Results of validation stage showed ANN had the highest classification accuracy, 96.33%. After ANN, SVM with polynomial kernel function (95.67%), DT with J48 algorithm (94.67%) and BN with simulated annealing learning (94.33%) had higher accuracy, respectively. On the contrary, Folorunsho [16] used medical dataset to predict the diabetes probability of any patient using ANN and DT. It was found that DT outperformed ANN with a lower error metrics and