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# Hybrid models for handling variability and uncertainty in probabilistic and possibilistic failure analysis of corroded pipes

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ABSTRACT

The pipes carrying oil and gas are inspected for any damage that can lead to leakages and ruptures. Unfortunately, the data collected from these inspections is always inflicted with a number of imperfections, like variability, uncertainty and imprecision. These imperfections can be handled using the traditional probabilistic approach or the possibilistic approach. Both of these approaches have their own advantages and disadvantages. The probabilistic approach tends to give very low probability for events resulting from the low probability input values. This can often give a false sense of security, especially when the "weakest" link may cause a major accident. On the other hand the possibilistic approach is rather imprecise and may give over conservative and uneconomical recommendations. The recent advances in the field of fuzzy-probabilistic modelling offer an improvement in the way the calculations have been traditionally carried out by using the strengths of both techniques. This paper presents two different hybrid approaches for calculating the likelihood of failure of corroded pipes under internal pressure.

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## 1. Introduction

In an effective maintenance programme that is required to tackle the effect of corrosion on oil and gas pipes, inspection of the pipes plays an important role. The inspection provides knowledge about the condition of the pipes and provides directions for the future maintenance work. The data collected from inspection is used to calculate the integrity of the pipes using models like those presented in the ASME B31G.

For the calculation of the maximum safe working pressure the ASME B31G standard requires information about (a) diameter of the pipe; (b) wall thickness; (c) length of corrosion pits; and (d) depth of corrosion pits [1]. A number of intrusive and non-intrusive methods have been developed to inspect the condition of pipes and take the necessary measurements. Unfortunately, the collected data is always inflicted with imperfections. These imperfections may be due to many reasons, including the random nature of the variables, the imperfect nature of the instrument and the complexities of the operating conditions.

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The inspection results have two major types of imperfections – variability and uncertainty. In this paper variability refers to the extent to which the measured values in a distribution differ from their mean. It arises because a pipe has varying actual diameter and wall thickness; and different corrosion pits have different lengths and depths.

On the other hand, the uncertainty of a variable is the quantification of the doubt about the measured result [2]. It can arise due to a number of reasons like the inherent characteristic of the measuring instrument, operating condition and operator's skill. Since all the measurements have some degree of uncertainty it is essential to state the accompanying uncertainty. Thus:

$$\text{Measurement} = \text{Best Estimate} \pm \text{Uncertainty} \tag{1}$$

The evaluation of the uncertainties can be done in various ways. These evaluation methods can be grouped into two types [2–4]:

- Type A evaluation – uncertainties estimation based on statistics. The uncertainty is represented by standard deviation.
- Type B evaluation – uncertainties estimation based on any other means or information like the manufacturer's specifications, past experience, expert opinion or subjective feel. The uncertainty is represented by an approximate standard deviation of an assumed probability distribution based on the available information.

Since a measurement is always accompanied by the uncertainty it is important to mention it along with the measurement. Unfortunately, the uncertainty of a measurement depends upon a number of factors and it is often difficult to quantify it under all measuring conditions. Hence, in this paper the Type A uncertainties have not been dealt with because the same corrosion pit has not been inspected and measured multiple times to enable the statistical evaluation of the uncertainties. Thus, only the Type B evaluation of the uncertainty has been carried out.

Traditionally, the structural reliability analysis based on the probabilistic framework has been used for handling the imperfections that are random in nature. In this technique the scope of the deterministic ASME B31G model is extended by considering the input values with probability density functions instead of fixed values. This technique works well for handling the variability of data [5–8].

An alternative framework, based on fuzzy logic, can be employed for handling vague and imprecise data. The possibilistic approach gives possibility and necessity measures of failure. Since the possibility of failure is always higher than the probability, the fuzzy modelling offers a safer methodology. On the other hand the necessity of failure is less conservative than the probability of failure thus it is useful for analyzing the non-critical sections of pipes that can be used until failure. This technique works well for Type B evaluation of the uncertainty of data [8].

These methodologies work well when there is only one form of imperfection – randomness or imprecision; but run into problems when the data is characterised by both types of imperfections. To some extent these methodologies can be extended to handle both – variability and uncertainty. The Monte Carlo simulation technique for handling variation can be extended to the Two-Dimensional Monte Carlo simulation [9]. As shown in the previously published paper, the 2D Monte Carlo simulation has disadvantages such as:

- The probabilistic analysis requires statistical data to develop probability density functions. In the absence or paucity of this data, expert judgment is required to develop the density functions. Such exercise can lead to vagueness, imprecision or personal bias. At times these shortcomings of the results may not be obvious [10].
- The 2D Monte Carlo requires a large number of calculations. While this is not such a big problem with the advent of modern computers, the output data requires post-processing which is not easy to handle [9].

Extension of the possibilistic approach for handling both – variability and uncertainty – has a different set of limitations. These include:

- Loss of information while converting the inspection data to the possibility membership functions [11].
- Propagation of possibility distribution functions by arithmetic operations can result in violation of consistency [11].

A hybrid approach, which can combine the probabilistic and possibilistic approaches, would be better than either of the two above mentioned approaches. The output of such a hybrid approach would be a fuzzy-probability distribution function. Such a technique would use all the available information in the probabilistic framework. When the explicit information is not available for the probabilistic framework it will retain the conservative nature of the possibilistic framework [10].

The probabilistic and possibilistic approaches can be combined in a number of ways. This paper examines two different ways of combining them for evaluating the integrity of corroded pipes. The application of these two methodologies is illustrated by a case study of an actual pipeline located in the Norwegian continental shelf.

## 2. Calculation of reliability

In the structural reliability analysis, the limit state function ($z$) is calculated using [12]:

$$z = P_S - P_A \tag{2}$$

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