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The negative binomial distribution as a model for external corrosion defect counts in buried pipelines

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ABSTRACT

The spatial distribution of external corrosion defects in buried pipelines is usually described as a Poisson process, which leads to corrosion defects being randomly distributed along the pipeline. However, in real operating conditions, the spatial distribution of defects considerably departs from Poisson statistics due to the aggregation of defects in groups or clusters. In this work, the statistical analysis of real corrosion data from underground pipelines operating in southern Mexico leads to conclude that the negative binomial distribution provides a better description for defect counts. The origin of this distribution from several processes is discussed. The analysed processes are: mixed Gamma-Poisson, compound Poisson and Roger's processes. The physical reasons behind them are discussed for the specific case of soil corrosion.

1. Introduction

The spatial distribution and density of external corrosion defects[1], taken as the number of defects per ditch, unit length, or unit area in underground pipelines, are parameters of paramount importance in corrosion science and engineering since reliability analyses and predictions strongly depend on these two aspects [1–4]. The knowledge of the spatial distribution of corrosion-caused metal losses provides valuable information on the corrosion conditions along the pipeline.

Usually, the reliability assessment of an operating pipeline is carried out for a series system because in a pipeline with multiple corrosion defects; a failure at any of its sections entails the failure of the whole system. It is also recognized that failures at individual defects are likely correlated events [5]. Such correlation has its source, among other things, in the spatial correlation between corrosion defects.

Although a pipeline can fail as a consequence of different types of degradation mechanisms, it has been statistically proven that corrosion remains one of the most significant mechanisms of failures [6,7]. Specifically, in the southern region of Mexico, external corrosion constitutes the cause of about 60% of the registered pipeline failures [8].

Despite the importance of the knowledge about the spatial distribution of corrosion defects in a pipeline, as far as the authors are aware, there have been very few studies on this subject. Some authors [5,9] have noted the importance of considering various correlation degrees between corrosion depths for defects located in adjacent pipeline segments when performing calculations of the pipeline failure probability, but without delving into the nature of the spatial distribution of these defects.

In this paper several definitions are handled, which are worth clarifying. The spatial distribution, or spatial pattern, of the corrosion defects refers to the way the defects are spatially distributed along the pipeline. Meanwhile, the defect count or defect density is the random variable, independent and identically distributed, that takes into account the number of defects per unit area or length of the analyzed pipeline. On the other hand, the distribution function of the defect count is the probability distribution function to which the defect count data can be fitted. In this context, the stochastic model or process refers to the underlying chance mechanism

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[1] Corrosion defects considered here, also named pits, are corrosion-caused metal losses of the pipe wall present in the external surface of the pipeline which are known to reduce the pipeline's pressure-carrying capacity.

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Fig. 1. Photographs of two excavated pipelines where corrosion defects are found (a) mainly as isolated features in an excavation ditch in a 24-in diameter pipeline, and (b) grouped in a cluster in a section of a 6-in diameter pipe.

that leads to the aforementioned distribution function, and which is responsible for the observed defect spatial pattern.

According to their observed spatial pattern, the spatial distributions of corrosion defects can be classified as regular, random, and clustered [10]. In a regular distribution, corrosion defects are deployed at regular distances, so that they develop a spatial pattern that resembles a lattice. In the random case, any defect is equally likely to occur at any location and the position of any other point is not affected by the position of the other ones. This type of pattern can be modelled as a Poisson process [10]. Finally, in clustered patterns defects aggregate at separate sites where many defects are concentrated, while large areas between clusters contain very few, if any, defects. An example of the latter case can be found in Fig. 1(b), where a cluster of external corrosion defects in a pipeline is observed.

Generally, a random spatial pattern is considered in corrosion literature, notably for pipeline corrosion [10–14]. However, in previous works, the interaction between corrosion defects and the presence of defect clusters in corroding pipelines has been widely recognized [15–17]. This is in clear contradiction with the use of a Poisson process to describe the spatial distribution of corrosion defects. While the spatial variability of corrosion defects in pipelines has been insufficiently explored, in other areas of structural reliability, such as the reliability of reinforce concrete structures, it has been investigated and taken into account in different ways [18,19].

A relevant precedent for this research is provided by the work of Kuniewski and van Noortwijk [20]. These authors modelled the deterioration process of steel structures suffering from localized corrosion and found that the probability of having a number N of defects at certain time t has a negative binomial (NB) distribution. They arrived to this conclusion considering several Poisson processes in the studied system with parameters randomly distributed following a Gamma distribution. This approach is actually equivalent to assume a Gamma-Poisson mixture [21] model as the one that will be described and used in the present paper. However, the authors never get to relate their Poisson processes to specific areas of the analysed corroding structure, and throughout their paper they assumed that the studied system suffered from defects uniformly distributed in space. This contradicts the essence of the NB distribution, which, as will be shown later, involves the aggregation of defect counts.

The results of an extensive external corrosion field survey carried out by sampling inspection in non-piggable buried upstream pipelines in South Mexico [22,23] revealed that the NB distribution fits the counts of external corrosion defects per excavation ditch in these pipelines. This indicates that interaction and clustering play a significant role in the spatial distribution of defects so that the Poisson model is inadequate to describe this pattern. The statistical support to this finding was significant enough to postulate that some physical reasons, related to the corrosion process in these pipelines, are responsible for the fact that corrosion defects tend to interact and cluster rather than to distribute uniformly along underground pipelines.

The foregoing discussion drives the present study, where the suitability of NB distribution for describing the defect density in oil and gas underground pipelines is proven through a thorough statistical analysis of the observed corrosion defects in the set of pipelines surveyed in [22]. This goal is achieved using a Bayesian algorithm recently developed by the authors and described in Ref. [23]. Also, the reasons for obtaining the NB as the distribution for defect counts are related to three possible processes: the Gamma-Poisson mixture, the compound Poisson process, and the Roger's process. The suitability of these models as underlying processes leading to NB-distributed spatial pattern of external corrosion defects in underground pipelines is illustrated using the data obtained from an in-line inspection of an oil pipeline operating in the same region.

2. Spatial point process: theoretical background

Spatial point processes are finite and countable processes X with realizations x. The term spatial point process is mostly reserved