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DISCUSSION

Discussion on "Data-driven Methods to Predict the Burst Strength of Corroded Line Pipelines Subjected to Internal Pressure https://doi.org/10.1007/s11804-022-00263-0"

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The authors (Cai et al., 2022) claim that their proposed machine learning (ML) models, which are based on three typical ML algorithms and are trained to predict the burst capacity of pitting corroded pipelines, perform better than the existing semi-empirical formulas recommended by the international engineering code developers, DNV and ASME. The authors'assessments of the semi-empirical burst capacity formulas in Figure 10(a) and Table 8 (Cai et al., 2022) incorrectly indicate that DNVGL-RP-F101, ASME B31G, and modified ASME B31G are dangerously unsafe due to significantly overestimating burst pressures in several cases. In contrast to the results and conclusions in Cai et al. (2022), these semi-empirical formulas have been consistently found to be conservative (Benjamin et al., 2000; Benjamin et al., 2002; Chena et al., 2015; Cronin and Pick, 2000; Kiefner and Vieth, 1989; Mokhtari and Melchers, 2016; 2018; 2019; Netto et al., 2005; Teixeira et al., 2008; Yeom et al., 2015; Zhou and Huang, 2012), and have been safely implemented in the oil/gas industry for many years. The main cause of the contradiction between the authors' claims and well-established practical applications and results lies in the data upon which the study (Cai et al., 2022) is based, along with the authors' misinterpretation of the semi-empirical formulas. These points are elaborated below.

To train their ML models, the authors (Cai et al., 2022) collected pipe and burst pressure data from a series of experimental studies reported in the literature, the same data that were used to assess the performance of the semi-empirical burst capacity formulas recommended by the DNV and ASME codes. However, some of the collected data presented in Cai et al. (2022) do not appear to match those in the reference/source studies. Other data appear to be misinterpreted. Two examples that caused the significantly unsafe predictions (i.e. overestimations) by the semi-empirical burst capacity formulas are given below.

Table 8 (Cai et al., 2022) shows that DNVGL-RP-F101 overestimates the burst pressure by 26.31% for S. N. 61. This drastic overestimation is because the authors incorrectly substituted the 'true' ultimate tensile strength (UTS) instead of the 'engineering' UTS for σ_u in Eq. (13) (Cai et al., 2022). In DNVGL (2017a), σ_u is the 'engineering' UTS, which is often replaced by the specified minimum tensile strength (SMTS) because, in practice, only the material grade is available which provides SMTS and not the UTS (Abdelghani et al., 2018; Callister, 1997; DNVGL, 2017a; DNVGL, 2017b; Gao et al., 2019; Mondal and Dhar, 2019; Mustaffa and van Gelder, 2010). The 'engineering' UTS for S.N. 61 is about 570 MPa in the reference study by Choi et al. (2003), while the 675 MPa listed in Table 1 (Cai et al., 2022) for S.N. 61 is the 'true' UTS of the pipe material. Note that the authors (Cai et al., 2022) have given the wrong reference, Freire et al. (2006), for S.N. 61, which was actually taken from (Choi et al., 2003).

S.N. 33 is another case for which all the semi-empirical burst capacity models, DNVGL-RP-F101, ASME B31G, and modified ASME B31G, are shown in the author's Table 8 (Cai et al., 2022) to markedly overestimate the burst pressure. These overestimations are the direct result of the authors using an incorrect defect length in the semi-empirical formulas. The circumferential defects in Mok et al. (1991), from which the S. N. 33 data in Cai et al. (2022) were taken, are ring grooves and run around the entire circumference of the pipe. In Mok et al. (1991), the extent of metal loss along the axial direction of the pipe caused by the ring grooves is 100.235 mm for two of the four burst tests with circumferential defects and 203.2 mm

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for the other two. However, the authors (Cai et al., 2022) have substituted a very short length of 10 mm for these circumferential defects (e.g., S.N. 33 in Table 1 (Cai et al., 2022)). This error has caused the DNVGL-RP-F101, ASME B31G, and modified ASME B31G equations to overestimate the burst pressure of S.N. 33 by 35%, 21%, and 21%, respectively. Much larger false overestimations (e.g., around 70% for DNVGL-RP-F101) can be observed for S.N. 34 in Figure 10 of Cai et al. (2022) due to substituting 10 mm for the defect length that is actually 203.2 mm.

To conclude, the DNV and ASME burst capacity models are misjudged in Cai et al. (2022) due to using poor quality data, as showcased by the examples given above. In turn, this invalidates the ML models since they have been trained with erroneous data. While there are many accurate semi-empirical models in the engineering standards and literature (e.g. PCORRC (Leis and Stephens, 1997; Stephens and Leis, 1997; Stephens et al., 2000) and CSA model (CSA, 2007)), the authors (Cai et al., 2022) chose instead to employ an outdated model, ASME B31G (ASME, 1984; 1991). The B31G model (ASME, 1984; 1991) has long been known to produce excessively conservative results and consequently, it was modified to a less conservative model, the modified B31G (Kiefner and Vieth, 1989; 1990), more than three decades ago. It is therefore difficult to understand why the authors chose to use the overly conservative B31G model in their comparative study instead of other more accurate models. This comparative study, which includes only three semi-empirical models from two engineering standards (i.e. ASME B31G and DNVGL-RP-F101), cannot justify their universal conclusion that their proposed data-driven models perform better than the semi-empirical models in the existing engineering standards.

Regardless of the errors in the study (Cai et al., 2022), the concept of estimating the burst pressure of pitting corroded pipelines using ML models is not meaningful in the light of recently developed and powerful automated finite element analysis (FEA) tools, employed in finite element based digital twins. Further, despite the authors' statement that FEA is too time-consuming (Cai et al., 2022), the recent automation of FEA tools has led to the rapid, accurate physics-based prediction of burst pressures (see Cabral et al. (2007), Motta et al. (2010), Silva et al. (2008)) for initial versions of such tools with rectangular defects and Pimentel et al. (2020) for a more recent academic version with complex-shaped defects). In the latest versions of fully automated FEA tools with cloud computing options, developed and implemented in consulting firms, there is almost no human intervention in the pre- and post-processing as the input data are automatically read from a text file and the required results are produced in a report file. The input data and the finite element models are automatically updated based on the field data collected by sensors. Then, the models are solved automatically with negligible computational cost due to the combination of cloud computing and efficient finite element models. Finally, the computed results/data such as the burst pressure are fed back to the operator to close the loop. These tools do not have the ML models' generalization issue as they can automatically develop multiple internal and/or external defects with different shapes (not only rectangular) and can account for the operational/environmental loads, effects of temperature on material properties, different boundary conditions, etc. In contrast to these modern powerful tools, the ML models in Cai et al. (2022) are trained only for pipes subject to a single, external rectangular pit (not common in practice) and internal pressure. Even for such a simple case, the authors encountered a data shortage in the literature during data collection and trained their models with a small dataset. In addition, they made (human) errors in interpreting and applying the available data.

If the data used to train an ML model is significantly erroneous such as that in Cai et al. (2022), there is always the possibility of producing highly inaccurate predictions. However, this is not an issue in the automated FEA tools because the finite element models are physics-based and validated against many experimental tests during their development phase. Even one overprediction of the burst pressure could be catastrophic given that steel pipelines transfer hazardous and flammable fluids under high pressure. Ultimately, it seems entirely unreasonable to undergo the immensely labour-intensive, time-consuming and expensive process of data collection/preparation to develop an ML model free of human errors that could account for various corrosion defect types/shapes/numbers and operational and boundary conditions when, at best, such an effort can only reach the same capability as that already available in the rapidly improving FEA tools used in digital twins.

It should be noted that the above argument refers to ML model development efforts that focus on the specific topic studied in Cai et al. (2022), which is "time-independent burst capacity prediction of corroded pipelines based on experimental data". Otherwise, there are many challenges in the pipeline industry that could benefit from ML methods (e.g., see Chen et al. (2022)) and more practical ways to obtain sample data. For example, sample data could be efficiently generated by validated and automated finite element models with negligible errors to save a tremendous amount of time and effort, avoid misinterpretation of data, and eliminate the generalization issue of the ML models.

Competing interest The authors have no competing interests to declare that are relevant to the content of this article.

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