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Evaluating Multidimensional NaTech Risks Considering Flood Events In Natural Gas Pipelines

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The recent COP 28 has presented future climate change scenarios, drawing attention to the urgent need for innovative approaches to manage potential accidents in industrial systems. As a result, climate change is increasingly recognized as a growing threat to human welfare, the environment, and property assets. Within this context, the assessment of NaTech (Natural Hazard Triggering Technological) accidents presents a substantial concern for risk management due to the insufficient preparedness that companies have to handle the impacts of such type of accident. NaTech events encompass a wide range of industrial impacts induced by natural events, spanning earthquakes, tsunamis, landslides, and floods. Notably, incidents triggered by floods has posed significant danger to industrial systems (Cozzani et al., 2010). The influence of hydrological events, especially flash floods, on gas pipelines have shown the increase of failure frequency (EGIG, 2011) through the years, indicating the vulnerability of pipes to flood and the potentiality to trigger severe consequences. As the conditions of global climate change evolve, the frequency of hydrological events could increase exponentially, necessitating adjustments in the way natural gas companies and authorities formulate risk assessment. In this manner, companies should use flood hazardous scenarios for the infrastructure by using specific vulnerability models to estimate probabilities and consequences. As an alternative to estimate flood-induced accidents, practitioners have considered intensity measures of flooding, such as speed and depth of precipitation to estimate risks.

Khakzad and Van Gelder (2018) explore a Bayesian network to assess the vulnerability of chemical installations to flood based on the definition of failure modes such as flotation, buckling, and sliding. (Rossi et al. 2022) propose a vulnerability model to access failure probabilities of process pipelines affected by flood. (Antonioni et al. 2015) also developed a vulnerability framework to estimate NaTech-induced release frequencies for atmospheric and pressurized equipment. Zeng et al. (2021) address a quantitative NaTech-risk assessment with domino effects for storage tanks of hazardous products considering floods. These models incorporate different partial and complete information on flooding-trigger damages in probabilistic models and calculate scenarios of impacts for industrial facilities. However, they all investigate one dimension of consequence, limiting the existence of multiple impacts or NaTech accidents. Girgin and Krausmann (2018) conducted a historical analysis of incidents where natural hazards compromised hazardous liquid pipelines. The outcomes of these accidents are multiple, encompassing environmental damage, financial losses, and adverse effects on human health, justifying the proposition of this study. In respect to the assessment of risks, different approaches exist to aid the decision-making process of prioritize actions to pipelines considering NaTech-flood scenarios. Embracing the assumption that NaTech accidents may cause multiple losses, the utilization of Multicriteria Decision Making/Aid (MCDM/A) is a valuable tool for addressing challenges covering multiple dimensions of risks, as deeply discussed by De Almeida et al. (2015). Also, it is worthy nothing that natural disasters also may incorporate multiple and simultaneous accidents as a matter of assessing the potentiality of profound societal impacts, including power outages, infrastructure devastation, and explosions. From this perspective, Brito, de Almeida, and Mota (2010) advocate a multidimensional risk model for categorizing risks in natural gas pipelines. Similarly, Viana et al. (2021) employ a sensitivity analysis to develop a multidimensional risk model that scrutinizes uncertainties associated with pipeline controlling parameters. Da Silva et al. (2020) and Da Silva, Alencar, and De Almeida (2022) explore a multidimensional decision model focused on prioritizing flood risks in urban regions, integrating physical, topographic, and hydrological parameters within a probabilistic framework to evaluate vulnerability.

Particularly concerning this contribution, this study put forward a decision-making approach that uses quantitative risk assessment concerning different flooding scenarios. The multidimensional risk evaluation is applied to take in consideration that flood induces different and multiple independent consequences, and that is possible to insert preferences information of managers into the decision model and choose the best strategy to prioritize the reduction and elimination of risks. Also, under the presumption that decision-makers present different behaviors regarding risks, decisions involving NaTech -flood risks are so better defined. The multidimensional approach incorporates a probabilistic assessment of multiple dimensions of loss, denoted as $\boldsymbol{p}$. According to decision analysis theory (Berger, 1985), risk is calculated as the expected loss for dimension p under conditions of uncertainty θ. This process results in risk r_p being calculated as shown in (1):

$$r_p = \sum_{\theta \in \Theta} \pi_i(\theta).L(\theta). \tag{1}$$

Here, the loss function $L(\theta)$ represents the probabilistic payoff under a given scenario of uncertainty θ and $\pi_i(.)$ the probability of this scenario. This approach enables the creation of a comprehensive risk assessment framework that incorporates scenarios of flood hazards affecting natural gas pipelines. This provides a basis for managing risks associated with NaTech flood scenarios in natural gas pipeline systems. In this sense, this paper contributes to risk analysis of NaTech-flood events by investigating the i) consequences of flooding estimates; and (ii) how decisions should be made to avoid losses in pipeline system's operations inherent to the pipeline supply.

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