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Multi-attribute risk assessment for risk ranking of natural gas pipelines

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Abstract

The paper presents a decision model for risk assessment and for risk ranking of sections of natural gas pipelines based on multi-attribute utility theory. Pipeline hazard scenarios are surveyed and the reasons for a risk assessment model based on a multi-attribute approach are presented. Three dimensions of impact and the need to translate decision-makers' preferences into risk management decisions are highlighted. The model approaches these factors by using a multi-attribute utility function, in order to produce multi-dimensional risk measurements. By using decision analysis concepts, this model quantitatively incorporates the decision-maker's preferences and behavior regarding risk within clear and consistent risk measurements. In order to support the prioritizing of critical sections of pipeline in natural gas companies, this multi-attribute model also allows sections of pipeline to be ranked into a risk hierarchy. A numerical application based on a real case study was undertaken so that the effectiveness of the decision model could be verified.

Keywords: Natural gas pipelines; Pipeline hazard scenarios; Risk assessment; Multi-attribute utility theory; Decision analysis

1. Introduction

Pipelines are seen as one of the most practical and economically effective modes for transporting dangerous and flammable substances, such as natural gas, for which road or rail transportation is often impractical [1]. In most countries, the more that pipeline systems are expanded and natural gas consumption increases, the more their economies become dependent on the stable, continuous and safe operation of these facilities [2].

According to international historical data [3–5], accidents involving natural gas pipelines do happen, even though the frequency of such occurrences is generally low when compared to road or rail accidents. Moreover, pipeline accidents often result in consequences which have impacts of different dimensions. This implies that measures need to be adopted in order to adequately quantify and thereby to mitigate the risks.

Several approaches have been applied in order to identify and estimate risks to pipelines [6–10]; safety distances from pipeline facilities [3,11,12] and other studies have been conducted on pipeline accidents [5,13]. However, a limitation can be observed regarding several widely used methods for risk analysis and risk assessment. This concerns consideration being given to the multiple dimensions that the impacts of accidents arising from natural gas releases from pipelines can assume. As accidents recorded around the world have shown, an approach of risk dimensions, if it only considers the human or financial aspects, is incomplete and inadequate due to the complexity of the issues involved. Nowadays, what is clear is the need to reconcile the concerns of society, the State and the gas companies in relation to the operation and safety of pipelines.

Another point rarely explored in traditional methods of risk assessment for operating pipelines is to incorporate the preferences and value judgments of decision-makers who are responsible for the management of pipelines. It is important to take into consideration their behavior regarding risk in decision processes which involve planning, prevention, supervision and maintenance activities to reduce risks.

As Cagno et al. [9] have pointed out, the effectiveness of many techniques still used for safety management in pipelines is low. This often causes inefficiency as to

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prioritizing those pipeline segments that must receive investments and supplementary maintenance. Papadakis [14] emphasizes that, in order to overcome traditional deterministic techniques, probabilistic approaches such as risk ranking, which combines probabilities of an event with its resulting consequences, have proved to be more adequate for priority level problems, such as in setting replacement policies.

Therefore, in order to help decision-makers tackle this problem, this paper presents a multi-attribute decision model for risk assessment in pipelines and for ranking sections of gas pipelines into a risk hierarchy. This model takes into account the possible human, environmental and financial impacts that an accident in a given pipeline section can bring about. Multi-attribute utility theory (MAUT) [15] is used in order to aggregate several dimensions of consequences and to incorporate the decision-maker's preferences and behavior in cases of uncertainty within a clear and mathematically based risk measurement.

2. Causes of pipeline failure and hazard scenarios

Pipelines are usually laid underground, and supposedly free from the influence of external factors on the surface. However, they can be damaged by various activities, which can result, though not necessarily immediately, in serious accidents. These activities are described as the principal causes that can start an accidental event in pipelines, and they are classified into five main categories: external interference; erosion; mechanical failures and construction defects; earth movements and natural disasters; and unknown causes [1,3,4,16].

The presence of pipelines transporting natural gas brings intrinsic risk of damage. As Yuhua and Datao [10] assert, accidents due to natural gas releases from ruptures or punctures in pipelines can cause fatalities, large economic losses and environmental damage. According to Montiel et al. [13], the severity of the consequences of a potential natural gas leakage is accentuated by the existence of hundreds of kilometer-long pipelines which are buried under areas with intense human activity, cross urban centers and farming properties, and sometimes run parallel to highways. However, the risks related to the possible hazards of having pipelines laid in a certain area are usually accepted by society when it is not higher than a standard accepted failure probability, such as 10^{-6} or 10^{-5} [3,17]. The laying of the pipeline is then accepted and its presence is tolerated because of the benefits and comforts that these facilities provide.

As Papadakis [14] affirms, the choice of using pipelines as a mode of natural gas transportation, as well as for other dangerous substances, is due to the fact that pipelines are recognized as one of the safest and most economical means of conveying these substances. The transportation of gas by pipeline presents lower frequencies of accident than those associated with road or rail haulage. However, failures in pipelines do happen and sometimes they lead to catastrophic consequences.

Due to the combustible, explosive and diffusible nature of natural gas (and of other substances such as petroleum), damage to pipelines that cause the release of natural gas due to puncturing of the pipe creates a dangerous situation that may provoke explosions and fire. Fig. 1 shows an event tree and a set of accident scenarios resulting from a release of gas [3,11].

Fig. 1 displays the main factors responsible for the evolution of an accident arising from a natural gas leakage, namely: the pipeline failure mode, the time gap between the leakage and a possible ignition of the resulting

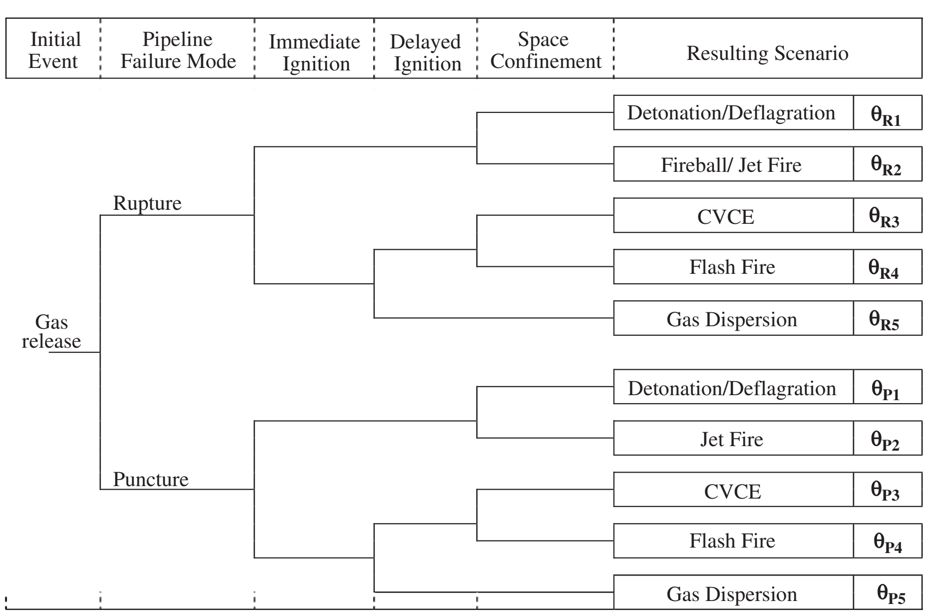

Fig. 1. Event tree for accidental release of natural gas from pipelines.