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Societal risk acceptance criteria for pressure pipelines in China

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ABSTRACT

When a pressure pipeline accident occurs in the vicinity of people, it may cause a large number of injuries and deaths. Risk management has become one of the most effective means of preventing pressure pipeline accidents. However, there are no clearly proposed pipeline risk acceptance criteria in China. To improve the level of safety supervision and strengthen the decision-making ability of enterprises and governments at all levels, this paper attempted to establish societal risk acceptance criteria for pressure pipelines in China. FN-curves were used as the indicator of societal risk. A large amount of historical accident data was analyzed via linear regression. Then, the role of interval estimation derived from the regression equation was utilized in combination with the ALARP principle to form the acceptable criteria for societal risk. Graphical results were disclosed and showed that the upper limits of tolerable risk and broadly acceptable risk respectively started from about $10^{-4.6}$/a and $10^{-5.3}$/a and declined with a slope of 1.47. The approach was reasonable in that it accurately reflected the characteristics and rules of pressure pipeline accidents in China. Simultaneously, to ensure stability and continuous improvement, the use and applicability of societal risk acceptance criteria were discussed from both dynamic and regional factors based on the Chinese environment for making related suggestions.

1. Introduction

Classified as "special equipment" in China—i.e., equipment that poses a substantial risk to human safety (SCC, 2009)—pressure pipelines contact and affect many people at all stages of the life cycle. Pressure pipelines pose not only individual and local risk but also (and more importantly) regional and societal risk (Duan et al., 2014; Zeng et al., 2014). Therefore, risk management has played an important role in managing the safety of pressure pipelines. Reasonable risk acceptance criteria are one of the key issues in risk management studies (Wu et al., 2001), are a vital basis for quantitative risk assessment (Li, 2010), and are the main method for solving the problem of "How safe is safe enough?" (Starr, 1969). As valid bases for risk control (Fig. 1), such criteria have a positive effect on judgments about the output of risk analysis and decision-making (Evans and Verlander, 1997), and they play a guiding role in the subsequent safety management of enterprises and governments at all levels.

Risk acceptance criteria are of great significance for improving the scientificity and applicability of quantitative risk assessment, the accuracy of which is directly related to the rationality and effectiveness of risk management (Li, 2010). The first study of risk acceptance criteria was carried out by Starr (1969), who proposed the famous question of "How safe is safe enough?" Starr obtained the acceptability of different risks through the revealed preference method. Subsequently, Lowrance (1976) argued that something might be safe only when its risk is low enough to accept. According to Fischhoff et al. (1981), risk is acceptable only when the benefits obtained can compensate for the expected loss, and the risk acceptance problem is actually a matter of decision-making. A great deal of work was also performed by the Health and Safety Executive (HSE) in early studies that provided a clear definition of tolerable risk based on a continuous investigation of nuclear power stations and suggested typical individual risk acceptance criteria for major industrial hazards at a value of 10^{-6}–10^{-5} per year (HSE, 1992). However, the HSE initially mentioned only individual risk, and it was not until 1999 that societal risk was added (HSE, 1999). In 1995, the HSE continued to define acceptable risk (HSE, 1995). Later, the HSE emphasized the difference between tolerable risk and acceptable risk and established a framework that conformed to the ALARP principle to describe the relationship among acceptable risk, tolerable risk and unacceptable risk (HSE, 2001).

Based on early pioneering studies, many scholars have discussed the methods and applicability of risk acceptance criteria (Aven, 2007; Aven and Vinnem, 2005; Hokstad et al., 2004; Jongejan et al., 2011; Jonkman et al., 2003; Lind, 2002; Travis and Hattemer-Frey, 1988), which have promoted the development of research on the risk acceptance problem. In contrast to studies in other countries with more

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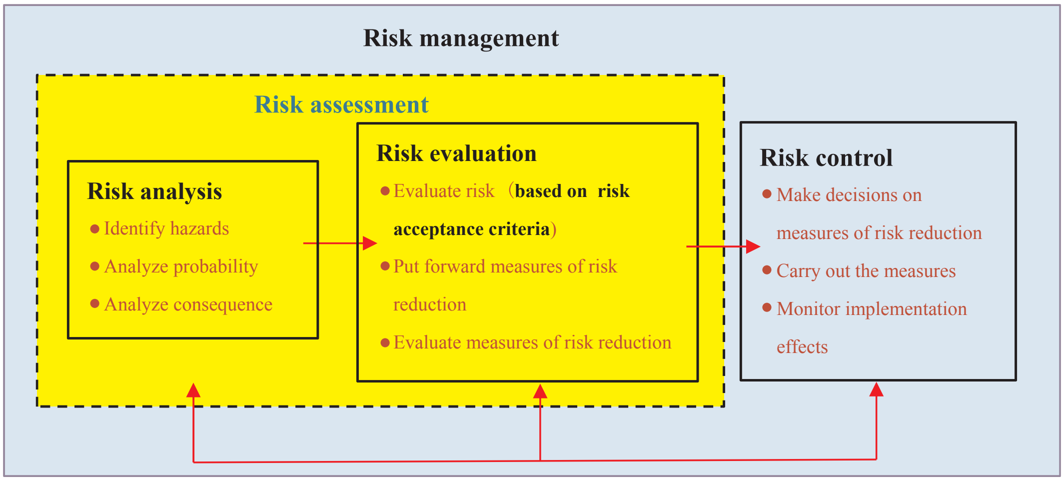

Fig. 1. Risk management flowchart and location of risk acceptance criteria (IEC, 1995).

mature systems for risk acceptance criteria (Ale, 2005; AGS, 2007; ANCOLD 2003; Bottelberghs, 2000; HSE, 2001; USBR, 2003; Yelokhin et al., 2004), China's studies (Li et al., 2007; Zhang and Wu, 2012; Zhang et al., 2015; Zhu and Du, 2010) still are primarily based on foreign research ideas, and they attempt to determine risk acceptance criteria directly from foreign methods based on current safety production (Zhou et al., 2015). Because of China's late start, the country's studies on risk acceptance criteria are focused mainly on bridges (Gan, 2013), dams (Li et al., 2015; Peng et al., 2014; Zhu and Du, 2010), coal mines (Zhang et al., 2015) and transportation (Chen et al., 2016). The few results pertaining to pressure pipelines are simple quantitative risk analyses and reviews of principles and methods from foreign studies (Liang et al., 2009; Liu et al., 2011; Liu et al., 2012; Zhao et al., 2008). Additionally, interim regulations in China (CSAWS, 2015) address only the individual and societal risk acceptance criteria for hazardous chemicals; there is a lack of criteria based on national conditions for pressure pipelines and other high-risk installations that are highly relevant for human safety.

Because pressure pipelines come into contact with people at all stages of their life cycle, they can cause many injuries and deaths in the event of an accident. Life risk is an important indicator for evaluating the safety of hazards, whereas societal risk can sufficiently reflect the comprehensive, dynamic and realistic risk level of pressure pipelines (Duan et al., 2014). Thus, societal risk is the object of the present study, which intends to provide data and theoretical guidance for enterprise and government safety regulators to grasp the overall risk level, to make accurate decisions and to develop reasonable goals and control measures by determining the societal risk acceptance criteria of pressure pipelines. Additionally, the findings obtained are likely to provide advice and methodology for formulating national standards.

Societal risk was originally defined by the Institution of Chemical Engineers (Jones, 1985) as the relationship between the probability and the number of people in a given population who suffer from a specified level of harm caused by the realization of specified hazards. China's State Administration of Work Safety (CSAWS, 2015) further defined it as the probability of an accident with N (the number of people) or more deaths to describe the overall risk level of specified hazards within a certain period (usually for a year) and area. Significantly different from individual risk, whose size depends upon a particular point or geographical place, societal risk is completely dependent upon actual population densities (Stallen et al., 1996). Many indicators measure societal risk; these include *AWR* (Piers, 1998), $E(N)$ (Laheij et al., 2000), *SRI* (Carter, 1995), *RI* (Carter and Hirst, 2000), FN-curves (Farmer, 1967), and *PLL* (Ale et al., 1996), among others. Here, we choose FN-curves—which are the most commonly used measurement in many countries, including China (CSAWS, 2015)—to characterize the societal risk of pressure pipelines. The paper is organized as follows. We briefly review the concepts and principles of FN-curves in Section 2. Then, based on a large amount of historical accident data, we determine the criterion FN-line by the hierarchical clustering method and linear regression analysis in Section 3. In Section 4, we combine the ALARP principle with related statistical theory to determine the negligible line and the intolerable line, which together constitute the ultimate societal risk acceptance criteria. In Section 5, we focus on discussing the use and applicability of the criteria. Section 6 concludes.

2. FN-curves

FN-curves are a type of descriptive risk indicator that draws the variables F and N in the same plane coordinate system to express the relationship between them. The horizontal axis variable N indicates the consequence of an accident, that is, the number of deaths caused by the accident. Corresponding to N, as CSAWS (CSAWS, 2015) defined, the vertical axis variable F indicates the probability of an accident with N or more deaths However, because it is difficult to determine, it is often replaced by frequency. In view of the large variation range in F and N, FN-curves are usually shown in the double logarithmic coordinate system (Jonkman et al., 2003), and the theoretical expression (Evans and Verlander, 1997) is as follows:

$$F(n) = P(N \geqslant n) = \sum_{i=n}^{N_{max}} f(i) \tag{1}$$

where n is an integer constant; $F(n)$ is the frequency of accidents involving n and more deaths per year (Skjong and Eknes, 2001); P is the frequency of accidents; N_{max} is the maximum possible number of deaths caused by an accident; and $f(i)$ is the frequency of accidents involving exactly i deaths per year.

An FN-curve shows the probabilistic risk of a hazard in different accident scenarios. It has at least three functions:

- Present the history of accidents (Rausand, 2011) and the probability distribution of all types of fatalities.
- Describe societal risk (CSAWS, 2015), expressed by the probability of an accident with N or more deaths per year (F).
- Draw a criterion FN-line of societal risk and then determine risk acceptance criteria.

The criterion FN-line can judge whether the output (societal risk described by FN-curves) of risk estimation has reached an acceptable level. Briefly, if an FN-curve of societal risk falls below the criterion FN-line, the risk is acceptable. In contrast, if any part of the FN-curve is