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Risk assessment along the gas pipelines and its application in urban planning

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ABSTRACT

With the rapid development of industry in China, the number of gas pipelines that are proposed or under construction is increasing year by year. Accidents such as fire, explosion, and toxic diffusion inevitably happen, which often cause a large number of casualties and property losses. It is increasingly important to analyze the risk along the gas pipelines realistically and to suitably plan, and utilize the surrounding land based on the risk analysis results, thereby reducing the hazards. A theoretical system for risk assessment along the gas pipelines is proposed in this paper. Risks of various major accidents are considered together, superposition effect is analyzed. After the individual risk distribution is obtained, risk zones are divided according to corresponding individual risk value of HSE, and land-use planning suggestions are proposed. Finally, a natural gas pipeline in China is used as an example to illustrate the risk assessment process and its application in urban land-use planning. The proposed method has a certain theoretical and practical significance in establishing and improving risk analysis along the gas pipeline and urban land-use planning.

Introduction

The European Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances (the “SEVESO II” Directive) aims at the prevention of major accidents and the limitation of their consequences for man and the environment, with a view to ensuring high levels of protection throughout the Community in a consistent and effective manner. Article 12 of the Seveso II Directive required that the objectives of preventing major accidents and limiting their consequences be taken into account by the Member States in their land-use policies and/or other relevant policies. This requirement recognized that planning policies could be directed toward the need, in the long term, for appropriate distances between establishments covered by the Directive and residential areas, areas of public use and areas of particular natural sensitivity or interest.

With the rapid development of the economy, the number of gas pipelines involving inflammable, explosive, toxic, and hazardous goods has increased annually. Due to human, equipment, production management, or environmental factors, the gas pipelines may lead to accidents such as leakage, and then fire, explosion, toxic proliferation, and so on (Jiang, 1999). Once an accident occurs, it often spreads to the surrounding population and environment, causing adverse effects and leading to heavy casualties and property losses. A growing community concern and an important issue to be resolved are how to plan gas pipelines and construction projects reasonably, prevent and control potential major accidents, reduce the impacts and losses of accidents, ensure the safe operation of gas pipelines or construction projects, and safeguard the surrounding environment.

Risk analysis is the foundation and scientific basis of the safety planning for urban land use. Therefore, it is necessary, based on risk analysis, to plan the gas pipelines, the location of construction projects and the surrounding land uses of the gas pipelines, taking into consideration which areas are designated for residential use, which areas for business, and which areas should be restricted on population density. Reasonably safe distances should also be established between the gas pipelines and the sensitive targets, so as to balance the land effectiveness and risks, not only to ensure that the land is maximally used but also to minimize significant risk for urban public safety.

Since the promulgation of the Seveso II Directive, European countries have introduced risk analysis into the safety planning of land use (Christou and Marina, 2000). Scholars have carried out multi-direction studies from different perspectives and levels.

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During the survey of land-use safety planning in the Netherlands and the United Kingdom, the supporting role of risk maps was analyzed (Claudia et al., 2007). The safety planning standards of the land use were applied to control the major accidents, the risk-mitigation measures were accordingly proposed based on the analysis of risks and consequences (Valerio et al., 2006). GIS was also used as a decision-making tool to analyze the reasonableness of the location for geothermal power plants (Hossein and Sachio, 2007). The multi-standard of space was used to analyze the best location of the industrial park, combined with Integrated Land and Water Information System (ILWIS) tools (Zucca et al., 2008).

These studies provide a theoretical guide for the risk analysis of regional hazards and land-use planning, but there have not been a systematic theoretical method for assessing the gas pipelines or a practical application for the corresponding land-use planning. In this paper, the individual risk value is selected as the risk index and the risk of gas pipelines is quantitatively analyzed, so that the distribution of individual risk can be obtained and land-use planning analyzed accordingly.

The remainder of the paper was organized as follows. Section "*Theory*" defined the basic theory for "risk based" approaches. Section "*Methods*" presented the core method of the land-use safety planning based on individual risk. In section "*Case study*", a natural gas pipeline in China is selected as an example to have a case study. Section "*Discussions*" made a conclusion and pointed out the potential usage in industrial area.

Theory

In the recent years, different methods and tolerability thresholds have been developed in European countries, fulfilling the SEVESO II requirements regarding LUP. In general, two risk assessment methodologies are applied to risk-informed land-use planning: a consequence-based and a risk-based approach. A number of other methods have also been developed, which are mainly a combination or a derivative of these two main methodologies.

LUP criteria are based on specific acceptability with respect to the calculated risk. Generally a risk-based approach consists of five parts:

(1) identification of hazards;
(2) calculation of the probability of occurrence of the potential accidents;
(3) estimation of the extent of consequences of the accidents and their probability;
(4) integration into overall risk indices/models that may include both individual and societal risk;
(5) comparison of the calculated risk with acceptance criteria.

This approach is followed in the United Kingdom and in the Netherlands and has been applied in specific case studies in Greece.

Individual risk (IR) is the likelihood of death due to accidents for people at a permanent, fixed location with no protection. The individual risk represents only the risk level of a position and does not consider whether or not the individual is actually present (Jonkman et al., 2003).

The following method was usually used to quantify the individual risks:

$$\mathrm{IR} = P_f \cdot P_{d/f} \tag{1}$$

where P_f is the probability of accident and $P_{d/f}$ is an individual death probability due to the occurrence of accidents. Individual risk is a probability value.

Table 1
Human vulnerability model.

Vulnerability factors	Mathematical model of probability	Dose
Toxic gas leakage	$Y = a + b \ln D$	$D = C^n t_e$
Thermal radiation	$Y = -37.23 + 2.56 \ln D$	$D = I^{1.33} t_e$
Shock wave overpressure	$Y = 5.13 + 1.37 \ln D$	$D = P_s$

D is the lethal dose; C is the toxicant concentration, ppm; I is the radiation intensity, W/m^2; P_s is the peak value of the static overpressure, Pa; t_e is the exposure time, s; a, b and n are constants depending on the types of chemicals.

Determination of accident probability

The accident occurrence probabilities of gas pipelines were obtained from statistical data gathered in Europe over a multiyear period. Thus in this work, the accident probability values given in the FRED (Failure Rate and Event Data) database of the United Kingdom HSE (Health and Safety Executive Committee) were selected as the accident probabilities in the risk analysis (Ale, 2002).

Noting that the industrial revolution is originated from UK. UK has accumulated systematically the industrial accident probabilities for a multiyear period, but China cannot do this. As a newly emerging industrial country, development processes in China and Europe are similar, so the accident statistics can be transplanted into China. Also, the State Administration of Work Safety in China also launched the establishment of industrial accident data bank in resent years. But it is immature and unrepresentative until now.

Calculation of accident consequences

The accident consequences of the risk factors were calculated using ALOHA (Areal Locations of Hazardous Atmospheres) recommended by the U.S. EPA. ALOHA was developed by the U.S. EPA and the National Oceanic and Atmospheric Administration (NOAA) (U.S. EPA and NOAA, 2007). The mathematical models used in ALOHA are: Gaussian model, heavy gas dispersion model, vapor cloud explosion model, BLEVE fireball, and other mature consequences calculation models.

The calculation progress of the accident consequences for the dangerous equipment within the city using ALOHA is shown in Fig. 1.

Calculation of individual death probabilities

After calculating the toxic gas concentration, the thermal radiation, and the shock wave overpressure at the location (x,y) under a certain accident scene, the individual death probability $d_i(x,y)$ can be obtained based on the probability function (Keun, 2002; Daniel et al., 1997; Judy and Gary, 2002). The relationship between the probability variable Y and the probability (or percentage) d_i can be expressed as:

$$d_i = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Y-5} \exp\left(-\frac{u^2}{2}\right) du \tag{2}$$

where Y is the probability variable and u is an integral variable. The probability variable Y obeys the normal distribution, and its average is 5; standard deviation is 1. For spreadsheet computations, a more useful expression for performing the conversion from probits to percentage is given by(3)$P = 50\left[1 + \frac{Y-5}{|Y-5|} erf\left(\frac{|Y-5|}{\sqrt{2}}\right)\right]$

where *erf* is the error function.

Y can be calculated with the human vulnerability model (Daniel and Joseph, 2001). The specific mathematical models can be seen in the table below (Table 1).