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The probability prediction method of domino effect triggered by lightning in chemical tank farm

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ABSTRACT

A lightning strike is the main cause of fire accidents in chemical storage tanks, and the thermal radiation produced by a large storage tank fire may lead to a domino effect. A prediction method aiming to evaluate the probability of a domino effect at different levels triggered by lightning in the chemical tank farm is proposed. The developed method takes into account both the probability calculation model of fire triggered by lightning and the assessment method of the subsequent domino effect probability. Firstly, the accident scenarios and causes of fire triggered by lightning are analyzed by the event tree method, and a probability calculation model of fire accident triggered by lightning is developed. Secondly, the graph of chains of accidents is built considering synergistic effects and multi-level domino effects, and the Bayesian network is applied to calculate the probability of each accident chain. The most dangerous primary equipment is identified by comparison with the probabilities of the domino effect at different levels. By setting up the failure states of different tanks, the probabilities of events are updated under a given situation, and the most susceptible target equipment with respect to the domino effect are identified. Finally, the method is illustrated with two case studies in a chemical industry park. The results will be helpful for the prevention of domino effects based on the theory of chain-cutting disaster mitigation.

1. Introduction

Natural disasters have the potential to trigger accidents in chemical plants that result in the release of hazardous materials, fires, and/or explosions. These events are commonly defined as Natech accidents (Cozzani et al., 2010). As shown by historical accident analysis (Krausmann et al., 2011), Natech events often led to severe consequences. Statistical data shows that lightning strikes on equipment in storage and processing activities are the main cause of accidents triggered by natural disasters (Rasmussen, 1995), and 33% of storage tank accidents is caused by lightning (Chang and Lin, 2006). Several accidents involving flammable substances were triggered by lightning in the past decades. For instance, lightning struck an oil tank in Egypt in 1994 and eight tanks were ignited, resulting in more than four hundred people killed (Ash, 2010). In another example, lightning struck an external floating roof oil tank in China in 1989, resulting in fires and explosions in four tanks with 19 people losing their lives (Liu, 2008).

In order to reduce storage cost, chemical storage tank technology gradually develops in the direction of large-scale tanks, and chemical tank farms are normally characterized by large inventories of hazardous materials (Zhang et al., 2017). When an accident, triggered by lightning, occurs in a chemical storage tank, its physical effects often damage surrounding tanks. Once a domino effect takes place, hazardous materials spilled from equipment will lead to a more serious accident scenario (Cozzani et al., 2005). Therefore, in order to prevent such accidents, it is important to study domino effects triggered by lightning in a chemical tank farm.

The recent research on Natech events triggered by lightning are mainly focused on three aspects: (i) accident scenarios triggered by lightning strikes (Kostogorova-Beller and Lu, 2013; Renni et al., 2010; Necci et al., 2014c); (ii) risk assessment of accidents triggered by lightning (Borghetti et al., 2010; Necci et al., 2016; Wu and Chen, 2016); (iii) risk mitigation measures to avoid accidents caused by lightning (Necci et al., 2013; Necci et al., 2014b; Zhang et al., 2014). These studies only consider the fire and explosion accidents triggered by lightning and seldom involve its subsequent, possible domino effect. The research on domino effects are mainly focused on three key issues (Necci et al., 2015): (i) historical accident analysis; (ii) vulnerability models for equipment damage (Bernechea et al., 2013; Mukhim et al., 2017); (iii) quantitative risk assessment and safety management of domino effect scenarios. However, most

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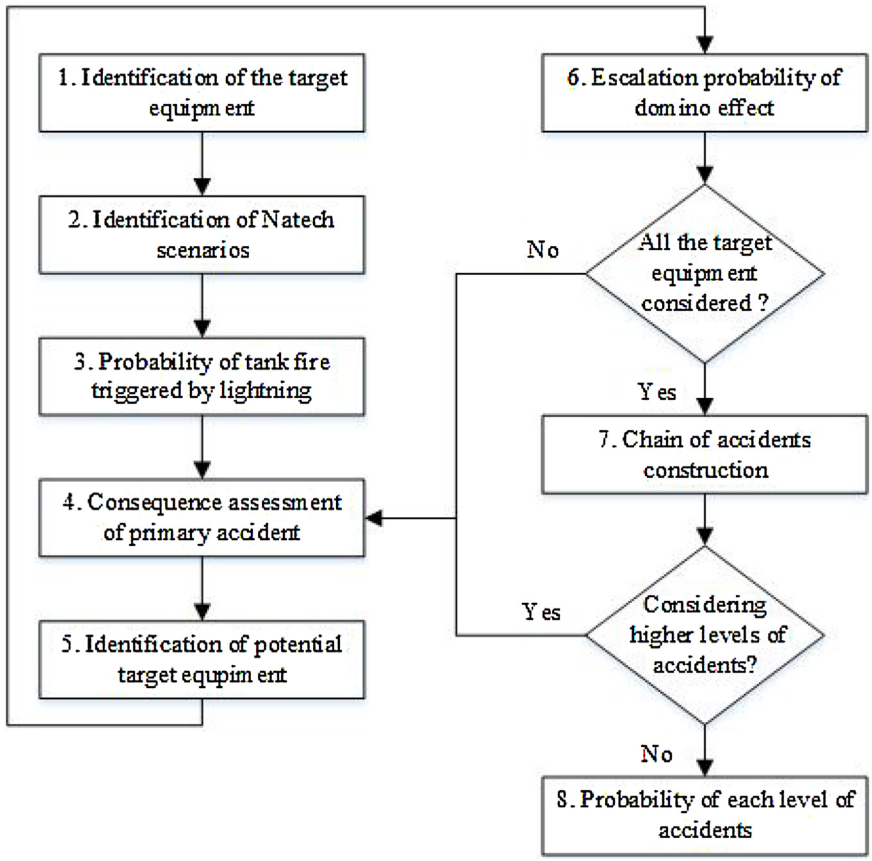

Fig. 1. Flow chart for probability prediction of domino effect triggered by lightning.

Table 1
The value of the location factor of the tank (C_D) (IEC, 2010).

Relative location	C_D
Structure surrounded by higher objects	0.25
Structure surrounded by objects of the same height or smaller	0.5
Isolated structure: no other objects in the vicinity	1
Isolated structure on a hilltop or a knoll	2

of the previous research have neither recognized nor included the higher levels of domino effects, but only the first level of accidents where primary and secondary events are taking place.

The Bayesian network is a probabilistic graphical method in uncertainty reasoning (Ahmed, 2007), which has recently served as a promising substitute for other well-established methods in the domino effect analysis and hazard identification. For example, Khakzad et al. (2013, 2017) applied the ordinary Bayesian network to identify the most probable path of accidents and assess the probability of domino effects at different levels, and applied the dynamic Bayesian network to assess the performance of fire protection systems during domino effects. Yuan et al. (2016) applied Bayesian networks to analyze the domino effect of dust explosions. Xin et al. (2017) introduced the Bayesian network in real time hazard identification and obtained the probability ranking for hazards. Nevertheless, the application of the Bayesian network to assess the probability of domino effects triggered by lightning and identify the most dangerous primary equipment struck by a lightning strike has been lacking. The present study aims to develop a methodology using the Bayesian network for assessing the probability of domino effects triggered by lightning and identifying the most susceptible primary equipment and target equipment. Furthermore, the method is further validated using the closeness centrality of graph theory.

2. General methodology

Based on the characteristics of industrial accidents caused by lightning and the propagation of the domino effect, the procedure for probability prediction of a domino effect triggered by lightning can be derived, as shown in Fig. 1. Industrial accidents caused by lightning usually result in pool fires or full surface fires (Necci et al., 2014c) as the oil tanks in chemical tank farms are mostly large floating roof tanks with tens of thousands of cubic meters of flammable material (Liu et al., 2013). Once a fire occurs, a domino effect could be triggered. Therefore, the procedure for the probability prediction of domino effects triggered by lightning can be divided into two parts: the probability calculation of a tank fire induced by lightning (steps 1–3) and the probability calculation of the subsequent domino effect (steps 4–8).

2.1. Probability model for tank fire induced by lightning

There are two possible accident scenarios when lightning strikes a tank: a pool fire caused by the ignition of a flammable liquid spilled from the tank damaged by lightning; a full surface fire caused by the failure of the fixed fire extinguishing system (Necci et al., 2014c). The event tree of a tank fire triggered by lightning is shown in Fig. 2. In order to obtain the probability of the tank fire by lightning, firstly the probability of target tank captured by lightning should be calculated, and then the occurring probability of target tank fire.