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Dynamic accident modeling for high-sulfur natural gas gathering station

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ABSTRACT

Dynamic accident modeling for a gas gathering station is implemented to prevent high-sulfur natural gas leakage and develop equipment inspection strategy. The progress of abnormal event occurring in the gas gathering station is modeled by the combination of fault tree and event sequence diagram, based on accident causal chain theory, i.e. the progress is depicted as sequential failure of safety barriers, then, the occurrence probability of the consequence of abnormal event is predicted. Consequences of abnormal events are divided into accidents and accident precursors which include incidents, near misses and so on. The Bayesian theory updates failure probability of safety barrier when a new observation (i.e. accident precursors or accidents data) arrives. Bayesian network then correspondingly updates failure probabilities of basic events of the safety barriers with the ability of abductive reasoning. Consequence occurrence probability is also updated. The results show that occurrence probability trend of different consequences and failure probability trend of safety barriers and basic events of the safety barriers can be obtained using this method. In addition, the critical basic events which play an important role in accidents occurrence are also identified. All of these provide useful information for the maintenance and inspection of the gas gathering station.

Keywords: Fault tree; Event sequence diagram; Accident causal chain theory; Bayesian theory; Bayesian network; Dynamic risk

1. Introduction

High-sulfur natural gas gathering station is an extremely complicated system containing lots of flammable or toxic substances such as high-sulfur natural gas, fuel gas and methanol. The ever-increasing complexity of system element such as operators, procedure, equipments, the operating environment and their interactions may lead to potentially disastrous accidents.

Process accident is usually a result of sequential failure of the events arising from malfunction or failure of one or more components and the deviation of process parameter, which is not caused by a single failure or an error. These events are usually referred to as abnormal events. The accident models are theoretical frameworks which illustrate the relationship between causes and consequences and describe why and how accidents take place. The effective use of accident models provides the basis for investigating and analyzing accidents, preventing accidents and assessing risk. Most of traditional accident models such as domino theory, energy accidental release theory and orbit intersecting theory were mainly focused on the factors of human, organization and management. They are mainly descriptive models without predictive ability (Jin and Yang, 2010). Information about near misses, mishaps and incidents which frequently occur in process operations is often termed as accident precursor data (Meel and Seider, 2006). Moreover, the above-mentioned models are used to simulate severe accident, rather than accident precursors (Heinrich, 1941; Kjellen, 2000; Rathnayaka et al., 2011a; Safety and Environmental Protection Department of China National Petroleum Corporation, 2009). Therefore, the above mentioned conventional accident models can't make use of the accident precursor data to develop prevention strategies, evaluate risk and reduce uncertainty in process industry.

Kujath et al. (2010) proposed a process accident model for offshore oil and gas processing environments to prioritize

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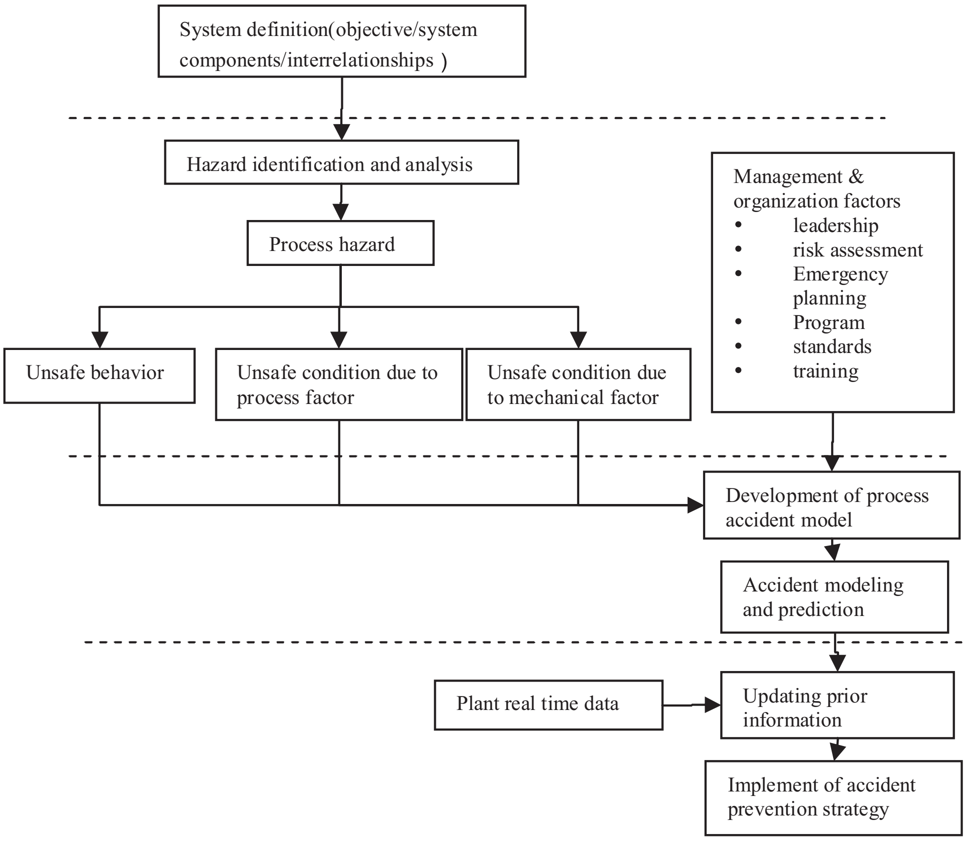

Fig. 1 – System hazard identification, prediction, and prevention (SHIPP) method.

the prevention of process accidents. In this model, natural gas release accidents were modeled using the safety barrier concept. Rathnayaka et al. (2011a) and Rathnayaka et al. (2011b) further developed Kujath's model which had created a holistic view of the accident process and quantification mechanism with updating capability to reduce uncertainty of the probabilistic assessment by using accident precursor data. The improved model is enhanced by integrating fault tree and event tree analysis to represent the cause-consequence relationship graphically, referred to as SHIPP (System hazard identification, prediction and prevention) method. Subsequently, SHIPP method has been validated for safety assessment in an LNG processing facility (Rathnayaka et al., 2012). However, this method has certain limitations in dynamically updating failure probability of accident prevention measures, namely, basic events of the safety barriers. As a result, accident prevention measure which will be a failure can't be focused on, in inspection and maintenance. In addition, it's unreasonable that this method always assumes safety barriers are independent.

The objective of this work is to propose an improved SHIPP method based on Kujath and Rathnayaka's work. Due to acute toxicity of the high-sulfur natural gas, poison prevention barrier and emergency evacuation barrier are added in the proposed method. This method can dynamically estimate risk of accident occurrence taking the dependency of safety barriers into account. Further, for critical basic events playing an important role in accidents occurrence, this improved method can identify them and dynamically estimate their failure probabilities by use of plant real time data. Finally, this method is applied to perform dynamic risk assessment for the high-sulfur natural gas gathering station.

2. Process accident model

The accident process usually follows three steps: initiation, propagation and termination (Crowl and Louvar, 2002), and the hazardous event may evolve in each step. Identification and analysis of the accident process are to determine what type of safety barrier is needed to prevent or mitigate this process. In gas processing, typical accident sequence steps of release accident scenarios consist of material release followed by dispersion of material, ignition of flammable material, escalation of fire or explosion and exposure to property, humans and the environment. Relevant barriers are designed to prevent, mitigate and/or control each step of the accident sequence process.

SHIPP method is used to model accident process (Kujath et al., 2010). The objective of the SHIPP method is to identify hazards, assess them, predict and prevent their occurrences, and continuously monitor, especially for process hazards. The SHIPP method is made up of four phases: (1) system definition, (2) hazard identification and analysis, (3) accident modeling and prediction, and (4) updating and implementation of accident prevention strategy, as shown in Fig. 1. The advantage of the SHIPP method is that it can be used to assess the risk of the failure of the entire system, as well as subsystems, and that it can also identify hidden interactions of the subsystems by modeling the accident process with accident analysis techniques.

The accident model characterizes the accident process in terms of safety barriers. Taking the acute toxicity of high-sulfur natural gas into account, the model developed by Rathnayaka (Rathnayaka et al., 2011a) is modified. The logical relationship of the barriers is modeled as shown in Fig. 2.