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Environmental risk source management system for the petrochemical industry

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ABSTRACT

We identify environmental risk sources within the petrochemical industry with a bow-tie analysis, evaluate environmental risk sources with an integrated environmental risk assessment index, and classify environmental risk sources considering both environmental consequences and management costs. Furthermore, we develop a routine management system for environmental risk sources based on browser/server model and web-GIS technology. The system has four main functions: petrochemical enterprise registration and declaration, environmental risk source information correction and confirmation, environmental risk source evaluation and classification, and environmental risk source management. The system runs with the following sequential steps. (1) Petrochemical enterprises register and declare their environmental risk source information. (2) The registered environmental risk source information is checked, corrected and confirmed by local environmental officials. (3) The probability and intensity of environmental risk are calculated for all registered petrochemical factories. (4) All environmental risk sources are classified into high, medium and low risk sections based on their potential regional environmental and ecological impacts. (5) The system provides recommendations on the routine risk management based on empirical expert opinions. The software provides an effective tool for safety production of petrochemical enterprises and can be applied by local governments for environmental risk source management.

Keywords: Petrochemical industry; Bow-tie analysis; Environmental risk source; Environmental risk assessment; Environmental risk management

1. Introduction

The petrochemical industry is one of the most important economic forces on a global or local scale, and it provides materials for many industries, such as automotive, agriculture and medicine. However, the petrochemical industry encompasses highly diverse processes of transport, storage, and use of hazardous materials, which makes it one of the riskiest industries. Accidents within the petrochemical industry are usually caused by transport spills, pipe leaks of toxic materials, explosions and fires (Yang et al., 2010). As a result, large amounts of pollutants can be abruptly released into the environment (water, air, and soil), which can have negative impacts on the quality of the local environmental and human health. The degree of damage is determined by the amount and type of the released materials and the vulnerability of the risk receptors (the ecology and lives) (Huang et al., 2012). To mitigate environmental risk accidents, it is critical to identify potential risk sources, evaluate their probability and intensity, and manage them effectively (Benn et al., 2009).

Previous research focused on the methods to identify and evaluate environmental risk to reduce the impact on the environment and human health. The bow-tie method (Delvosalle et al., 2006) and fault tree analysis (Lindhe et al., 2009) are regarded as common methods and are widely used in environmental risk identification. In addition to the aforementioned methods, the analytic hierarchy process was frequently used to identify inherent risk factors lead to an incident in a petrochemical plant where a pollutant was released (Helland, 2009). The environmental risk assessment index is a preferred approach that has been used to communicate the level of environmental risk, because it is inexpensive and provides

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simple results that are easily understood by decision-makers (James, 2009). The environmental hazard index is also one of the few environmental risk assessment indices that are concerned not only with the quantities of chemicals but also the process routes and potential "weak links" in the transport and manufacturing chain (Cave and Edwards, 1997). An atmospheric hazard index was developed to estimate atmospheric impacts from environmental accidents/releases (Gunasekera and Edwards, 2003). The expert system is based on the experiences of experts and is not usually effective at providing suggestions on environmental risk management (Bone et al., 2011). It is necessary to acquire enough information such as hazardous materials, danger production process and geospatial data before an accurate environmental risk assessment can be generated. Geospatial data are widely used in the field of environmental risk assessment and receptor analysis (Nataliia et al., 2011). With continued research in this field, technologies for data collection and analysis, and spatial information analysis have been introduced. For example, Web-GIS is a useful software tool used for the qualitative assessment of desertification risk (Monia et al., 2010).

Though the methods of environmental risk identification and assessment develop quickly, questions remain regarding their effectiveness. First, the method of major hazard installations identification is focused on a specific piece of equipment or process in a plant, such as storage tanks containing hazardous materials but did not consider the whole plant and cumulative conditions that might magnify environmental risk. Second, the vulnerability of the risk receptor, environmental and safety management of the organization, and the accident emergency level were not given adequate attention. However, the vulnerability of the risk receptor is closely related to the intensity of potential environmental impacts. Finally, the results of environmental risk assessment were highly relied upon for the information collected; therefore, inaccurate input data may have led to a higher level of uncertainty. Highly inaccurate data completely invalidate the risk assessment conclusions.

To improve the efficiency and effectiveness of environmental risk management, several models and software have been developed (Dokas et al., 2009; Environmental Protection Agency, 2011). For example, the federal emergency management information system (FEMIS), developed at the Pacific Northwest National Laboratory, is an automated decision support system that integrates all phases of emergency management. FEMIS was specifically designed to support operations in response to an accidental chemical agent release and has been expanded to include capabilities for use with other hazards (Darbra et al., 2010). RiskWare is designed to support the implementation of risk management regulations, and it contains the functions of risk assessment, risk management and technical training. Based on the hazardous installations databases on safety reports, hazardous substances and environmental GIS, RiskWare can simulate and evaluate accident scenarios (Environmental Software and Services, 2011). The petrochemical industry emergency treatment system (PETS) is used for environmental emergency treatment, with known information about the types and quantities of flammable, explosive and toxic materials (Yang et al., 2010). If an emergency does occur, such as an explosion or toxicant spilling, the PETS system sends an alarm signal to the emergency response center and at the same time provides appropriate suggestions (based on input data) about emergency treatment. However, this system does not address environmental risk source identification, environmental risk assessment, and routine management of environmental risk sources.

This study identified environmental risk sources within the petrochemical industry using the bow-tie analysis method and evaluated the probability and the intensity with the environmental risk assessment index. Furthermore, we classified environmental risk sources based on the empirical opinions of experts and have developed software called *petrochemical industry environmental risk source management system* (PIERSMS), which is based on the Brower/Server model and web geographical information systems (Web-GIS). This software can be used to collect, confirm and correct environmental risk information, classify environmental risk sources, and provide recommendations on safety production for petrochemical enterprises. Furthermore, the software has been applied as a basic tool for environmental risk source management by the Center for Environmental Emergency Response and Accident Investigation in the Jiangsu Province, which is a division of the Jiangsu Environmental Protection Agency.

2. Methods

2.1. *Environmental risk analysis*

Environmental risk analysis consists of a series of processes: (1) definition of the scope; (2) identification of environmental risk sources, such as materials, processes and actions contributing to risks; (3) estimation of risk probability and consequences; (4) potential environmental risk receptor analysis; (5) risk evaluation; and (6) proposal for risk reduction and control. Identification of the environmental risk source is one of the most important processes in environmental risk analysis, and bow-tie analysis is regarded as an effective tool for environmental risk source identification because the diagrams clearly display the links between the potential causes, preventative and mitigative controls and consequences of a major accident (R4Risk Pty Ltd., 2012). The left side of the bow-tie diagram consists of a simplified fault tree and the right side of a bow-tie diagram resembles an event Tree (CGE, 2012). The tool uses fault tree and event tree analysis to determine the causes and consequences as well as the safety barriers of the basic event.

Fire and explosion are two highly probable accidents in the petrochemical industry, and they usually lead to and exacerbate the release of materials into the environment. With the bow-tie method, it is possible to ascertain the causes, consequences and safety barriers of each kind of accident, as shown in Fig. 1.

The primary factors that contribute to a fire include explosive/flammable materials and a source of ignition. An accidental fire may cause damage to the plant and nearby facilities, injury to human health, environmental pollution and ecological pollution. As the fire proceeds, safety barriers such as equipment quality certification, maintenance of equipment, alarm systems and emergency devices play an important role in ascertaining the amount of damage that will be caused by the accident.

With bow-tie analysis, the influence factors of an environmental risk within the petrochemical industry are acquired and divided into two groups: risk-source-associated factors and risk-receptor-associated factors. The first group of factors includes the quantity of hazardous materials on site, the