



Applying data mining techniques to analyze the causes of major occupational accidents in the petrochemical industry



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ABSTRACT

Accidents that occur in the petrochemical industry frequently result in serious social issues. Behind every occupational accident, there are safety management problems requiring investigation. This study collected 349 cases of major occupational accidents in the petrochemical industry between 2000 and 2010 in Taiwan for analysis. Using descriptive statistics, we elucidated the factor distribution of these major occupational accidents. The data mining classification and regression tree (CART) was used to examine the distribution and rules governing the factors of the disasters. This study found that for equipment such as pipelines and control valves, devising high-quality safety and protective devices/maintenance/renewal plans and pipeline setups/design plans can effectively prevent accidents such as fires, explosions, and poisoning caused by material leakage, as well as employees being caught in/rolled up in machinery. Furthermore, implementing safety management measures, such as worker safety educational training, and enforcing standards for inspections, operations, and risk assessments personnel, has become an important factor in accident prevention. This study suggests the use of the following measures: for abnormal conditions such as pipeline cracking/damage or rusting, high-temperatures caused by material leakage into the inner protective layer of pipelines should be prevented. Considering overlapping pipelines, rusting issues caused by pipelines touching each other should be avoided, and maintenance and repair should be performed to ensure the safety of work environments. These measures can eliminate the risk of work injuries and resulting social issues.

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1. Introduction

1.1. Background

Accidents have been a regular occurrence in the petrochemical industry over the last decade. Serious injuries and deaths resulting from major industrial accidents caused by fires, explosions, or material leakage have been reported worldwide (Freitas, 1996; Khan & Abbasi, 1999; Lewis, 1993; Mahoney, 1990; Wisner, 1993), demonstrating the high-risk nature of petroleum industry jobs. The lessons learned from these industrial accidents can lead to better measures for preventing future accidents, and investigating them is crucial for the purpose of safety management (Heinrich, 1959). Academic research on accident investigation worldwide has generally focused on major accidents (Balasubramanian & Louvar, 2002; Drogaris, 1993; Le Coze, 2008) and on gaining experience

and feedback through the use of various methods and technologies (Dien, Llory, & Montmayeul, 2004; Johnson, 2002; Johnson & Holloway, 2003; Katsakiori, Sakellaropoulos, & Manatakis, 2009; Khan & Abbasi, 1999; Kjellen, 2000; Sklet, 2004).

Of all the petrochemical industry accidents in Taiwan since 2000, fires and explosions have caused the most significant damage to the industry because of the resulting social concerns and economic losses. From 2000 to 2010 major industrial accidents in the petrochemical industry, such as fires, explosions, and contact with harmful substances, caused 29 deaths and 221 personal injuries. The seven incidents of fires and explosions at Mialiao's Liucing Industrial Park (Taiwan) in 2012, though thankfully resulting in no human casualties, generated a high level of public and media concern. According to a report from the Research, Development, and Evaluation Commission (RDEC) of the Executive Yuan, government compensation in the form of labor insurance for occupational injuries that are caused by industrial accidents exceeds six billion NT dollars per year. According to the International Labor Organization's (ILO) estimation model (GDP 0.4–4%), economic losses caused by occupational injuries totaled no less than 50 billion NT dollars.

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Furthermore, according to the statistical results from the 2010 annual report of labor inspection issued by the Council of Labor Affairs, the number of people suffering injuries as a result of being caught in or rolled up in machinery, cut, or bruised were highest in the petrochemical industry (Kao, Chen, & Shu, 2011). These results highlight the serious deficiencies in safety and protective devices for machines and equipment in the petrochemical industry, which ultimately results in high injury compensation for laborers. In 2010 alone, the statistics include: injuries or sickness following being caught in/rolled up in machinery, 8731; permanent disability, 1509; death, 39.

One solution to these problems is to use modern information technology to identify key associations between relevant factors among the mass of complicated data on occupational accidents (Cheng, Lin, & Leu, 2010; Liao & Perng, 2008; Tsay & Chiang, 2005). Against this background, the present study undertook a detailed analysis of a large number ($N = 349$) of occupational accident and fatality reports in Taiwan for the period 2000–2010. The raw data were then subjected to the classification and regression tree (CART) method of data mining analysis to explore potential cause-and-effect relationships and accident occurrence rules in occupational accidents. The results of these analyses can provide management with evidence of probable cause-and-effect relationships, thus facilitating the establishment of a safer working environment in the petrochemical industry.

1.2. Factors contributing to occupational accidents

In the petrochemical industry, because of the variety of equipment involved in operations and because most chemicals that are used during the manufacturing process are toxic, flammable, and pyrophoric, the slightest mistake can result in chemical leakage that can trigger accidents such as explosions or fires (Chen, Wang, Chen, Dai, & Shu, 2010; Kao & Hu, 2002). These issues endanger the safety of the factory and employees (Carson & Mumford, 1988; Davenport, 1988; Guo, Gao, Yang, & Kang, 2009; Khan & Abbasi, 1999). Many accidents are caused by the repetition of the same mistakes (Kletz, 1991).

Reviews of the causes of industrial disasters in the petrochemical industry are typically divided into two types. First, researchers explore the causes of general chemical disasters in factories, including human factors, equipment factors, and environmental factors. Chemical equipment, including boilers/heaters, reactors, tanks, pressure vessels, mixing machineries, pipelines and ancillary equipment, pumps and compressors, and tower tanks, accounts for the highest proportion of incidents caused by equipment (Chang & Lin, 2006; Darbra, Palacios, & Casal, 2010; Kang, 1999; Oggero, Darbra, Muñoz, Planas, & Casal, 2006; Zhang & Zheng, 2012). Second, researchers examine the causes of chemical disasters triggered by operational failures during the manufacturing process including (i) unfamiliarity with the chemical reactions that occur during the manufacturing process; (ii) improper engineering designs; (iii) improper control systems; and (iv) improper operational procedures and training (Abdolhamidzadeh, Abbasi, Rashtchian, & Abbasi, 2011; Kao et al., 2011; Kwon, 2006).

In 1998, the American Petroleum Institute (API) studied 100 major industrial accidents in the petroleum industry over the past 30 years and investigated their causes, finding that mechanical failure accounted for 44% of these accidents and that human errors accounted for 22%. Khan and Abbasi (1999) demonstrated that vapor cloud explosion (VCE) poses the greatest risk of damage in process industries. Yang et al. (2010) gathered and compiled analyses of 322 cases of highway accidents that occurred while transporting hazardous materials in China between 2000 and 2008, showing that driver negligence was the primary cause of these

accidents, followed by machinery problems, equipment failure, and management oversight. Darbra et al. (2010) collected data on 225 chemical disasters from 1961 to 2007 and found that mechanical failure (i.e., overheating and overpressure), collisions, and human factors (i.e., procedural oversight and design errors) were the major causes of chemical disasters. Chang and Lin (2006) studied 242 tank tower accidents from 1960 to 2003 and showed that lightning was the primary factor contributing to tank tower accidents (33%), followed by human error (30%). Oggero et al. (2006) selected 1932 cases of hazardous material transportation accidents from the major hazard incident data service (MHIDAS) that were recorded by the UK Health and Safety Executive for further analysis. Their study found that collisions were the major cause of accidents, followed by mechanical failure, external events, and human error. Nivolianitou, Konstantinidou, and Michalis (2006) gathered the data of 85 major petrochemical industry accidents between 1985 and 2002 from the major accident reporting system (MARS) for analysis. Their study showed that design and procedural oversights were the major cause of occupational accidents. Kang (1999) analyzed 93 cases of major industrial accidents in South Korea from 1988 to 1997, finding that operational error (including unfamiliarity with operations and other human errors) was the primary cause of accidents, followed by other causes such as equipment failure. In these studies the causes of accidents included human, equipment, and environmental factors, as well as additional factors such as operational failures, chemical storage, and equipment maintenance. The results are compiled and shown in Table 1.

1.3. Classification and regression tree (CART)

Data mining, which involves the retrieval and analysis of large amounts of data from a data warehouse, has been successfully used to uncover hidden patterns (or rules) among data in a variety of fields. In the present study, the CART approach to data mining was used (Breiman, Friedman, Olshen, & Stone, 1984; Chang & Chen, 2005; Ripley, 1996). CART is a recursive partitioning method that can be used for both regression and classification by building classification and regression trees for prediction of continuous dependent variables (regression) and categorical predictor variables (classification) (Breiman et al., 1984). CART works by recursively splitting the feature space into a set of non-overlapping regions, and then predicting the most likely value of the dependent variable within each region. Because the database in the present study primarily contained categorical data, CART analysis was chosen as the research methodology from among the many classification tree models. CART is constructed by splitting subsets of the data set using all predictor variables to create two child nodes repeatedly, beginning with the entire data set. The goodness-of-fit measure is chosen using a variety of impurity or diversity measures (Ture, Tokatli, & Kurt, 2009). This study used the measure of Gini impurity for categorical target variables. Examples of the successful application of various data mining techniques include market basket analysis (Agrawal & Srikant, 1994; Lee & Olafsson, 2006), product recommendation (Berry & Linoff, 1997), business administration (Hui & Jha, 2000), web page pre-fetch (Liu, Grossman, & Yanhong, 2004), medical records analysis (Ture et al., 2009), industry, and engineering (Bevilacqua, Braglia, & Montanari, 2003; Cheng, Lin, et al., 2010).

1.4. Study objectives

The selection of analysis methods depends on the study objective and data classification. Fuzzy logic deals with uncertainty and imprecision for solving problems where knowledge uncertainty may occur (Li, Chen, Dai, & Li, 2010; Markowski,

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