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Intelligent systems for HAZOP analysis of complex process plants

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Abstract

Process safety, occupational health and environmental issues are ever increasing in importance in response to heightening public concerns and the resultant tightening of regulations. The process industries are addressing these concerns with a systematic and thorough process hazards analysis (PHA) of their new, as well as existing facilities. Given the enormous amounts of time, effort and money involved in performing the PHA reviews, there exists considerable incentive for automating the process hazards analysis of chemical process plants. In this paper, we review the progress in this area over the past few years. We also discuss the progress that has been made in our laboratory on the industrial application of intelligent systems for operating procedure synthesis and HAZOP analysis. Recent advances in this area have promising implications for process hazards analysis, inherently safer design, operator training and real-time fault diagnosis.

Keywords: Process safety; Environment issues; Occupational health; HAZOP analysis

1. Introduction

Complex modern chemical plants pose major challenges for the systematic analysis and assessment of the various process hazards inherent in such plants. This, of course, raises serious environmental, occupational safety and health related concerns. Further, the plants are often operated at extremes of pressure and temperature to achieve optimal performance, making them more vulnerable to equipment failures. Despite advances in computer-based control of chemical plants, the fact that two of the worst ever chemical plant accidents, namely, Union Carbide's Bhopal, India, accident and Occidental Petroleum's Piper Alpha accident (Lees, 1996), happened in recent times is a troubling development. Also, industrial statistics show that even though major catastrophes and disasters from chemical plant failures may be infrequent, minor accidents are very common, occurring on a day to day basis, resulting in many occupational injuries, illnesses, and costing the society billions of dollars every year (McGraw-Hill Economics, 1985; Bureau of Labor Statistics, 1998; National Safety Council, 1999).

All these concerns have led the federal agencies in the US to create safety, health and environmental regulations. The Occupational Safety and Health Administration (OSHA) passed its PSM standard Title 29 CFR 1910.119, which requires all major chemical plant sites to perform process hazards analysis (PHA) (OSHA, 1992). In addition, EPA instituted the Risk Management Program (RMP) in 1995 (EPA, 1995). All these require the systematic identification of process hazards, their assessment and mitigation. To analyze process hazards, plant personnel systematically ask questions such as, 'What can go wrong?', 'How likely is it to happen?', 'What is the range of consequences?', 'How could they be averted or mitigated?', 'How safe is safe enough?' and so on in order to evaluate and improve the safety of the plant. The answers to these and other related questions are sought in what is known as Process Hazards Analysis (PHA) of a chemical plant. Process Hazards Analysis is the systematic identification, evaluation and mitigation of potential process hazards which could endanger the health and safety of humans and cause serious economic losses.

A wide range of methods such as Checklist, What-If Analysis, Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA) and Hazard and Operability (HAZOP) Analysis are available for performing PHA (CCPS, 1985). Whatever method is chosen, the PHA, typically performed by a team of experts, is a laborious, time-consuming and expensive activity which requires specialized knowledge and expertise. For PHAs to be

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thorough and complete, the team can not afford to overlook even routine causes and consequences which will commonly occur in many plants. The importance of performing a comprehensive PHA is illustrated by Kletz (1986, 1988, 1991) with examples of industrial accidents that could have been prevented if only a thorough PHA had been performed earlier on that plant. Of the various available methods, HAZOP is the most widely used PHA methodology and hence it is the approach we have chosen to discuss in this paper.

A typical HAZOP analysis can take 1–8 weeks to complete, costing over $ 13 000–25 000 per week. By an OSHA estimate, approximately 25 000 plant sites in the United States require a PHA (Freeman, Lee & McNamara, 1992). An estimated $ 5 billion is spent annually by the chemical process industries (CPI) to perform PHAs and related activities. The estimated cost of process hazards reviews in the CPI is about 1% of sales or about 10% of profits.

Given the enormous amounts of time, effort and money involved in performing PHA reviews, there exists considerable incentive to develop intelligent systems for automating the process hazards analysis of chemical process plants. An intelligent system can reduce the time, effort and expense involved in a PHA review, make the review more thorough, detailed, and consistent, minimize human errors, and free the team to concentrate on the more complex aspects of the analysis which are unique and difficult to automate. Also, an intelligent PHA system can be integrated with CAD systems and used during early stages of design, to identify and decrease the potential for hazardous configurations in later design phases where making changes could be economically prohibitive. It would facilitate automatic documentation of the results of the analysis for regulatory compliance. Also these PHA results can be made available online to assist plant operators during diagnosis of abnormal situations as well as to train novice operators.

Despite the obvious importance of this area, there has only been limited work on developing intelligent systems for automating PHA of process plants. In this paper, we will review the past approaches towards the automation of PHA from the perspective of intelligent systems. This paper is written as a brief survey of the literature in this area with an emphasis on the overview of the results of the Purdue investigations on intelligent systems for PHA over the past 12 years. Of the various methods, HAZOP analysis is the most widely used and recognized as a preferred PHA approach by the chemical process industries. Hence, the main focus of this paper will be on HAZOP analysis which primarily addresses the hazard identification aspect of PHA. This is a practical first step towards automating PHA because the nominal information required for HAZOP, including piping and instrumentation diagrams and operating procedures, is more readily available for every process. The quantitative information required for hazard evaluation and mitigation, such as mean time between failures and failure rates and fundamental mathematical process models, however, are not.

2. Intelligent systems for automating HAZOP analysis

HAZOP analysis was developed in the late 1960s at ICI in the UK. The basic principle of HAZOP analysis is that hazards arise in a plant due to deviations from normal behavior. A group of experts systematically identify every conceivable deviation from design intent in a plant, find all the possible abnormal causes, and the adverse hazardous consequences of that deviation. The experts in the study team are chosen to provide the knowledge and experience in different disciplines for all aspects of the study to be covered comprehensively. The procedure involves examining the process P&ID systematically, line by line or section by section (depending on the level of detail required), by generating deviations of the process variables from their normal state. The possible causes and consequences of each deviation so generated are then considered, and potential problems are identified. In order to cover all possible malfunctions in the plant, the process deviations to be considered are generated systematically by applying a set of guide words, namely, NONE, MORE OF, LESS OF, PART OF, REVERSE, AS WELL AS and OTHER THAN, which correspond to qualitative deviations of process variables.

In addition to identifying the hazards in a process plant, the HAZOP study also identifies operability problems which prevent efficient operation of the plant. Detailed descriptions of the HAZOP analysis procedure with illustrative examples are given in CCPS (1985), Knowlton (1989), Kletz (1986).

Variants on this basic structure of HAZOP analysis have been developed to make the approach more thorough. For example, ICI has adopted a six stage Hazard Study methodology which not only embraces HAZOP within its Hazard Study 3, but also the appropriate elements of the other PHA techniques (Preston & Turney, 1991). Hazard Study 1 is the key SHE (Safety, Health and Environment) study during process conception, including inherent Safety and Environmental Impact. Hazard Study 2 is carried out on the process flow diagrams to identify top events and the need for further quantification, including QRA (frequency/consequence) design modification and hazard elimination/minimization. Hazard Study 3 relates to the engineering phase as the classic line by line critical examination of the Engineering Line Diagram (ELD) or P&ID prompted by guide words. Hazard Studies 4 and 5 relate to construction and commissioning and Hazard Study 6 is a final audit after the plant is in beneficial operation.