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Methods and models in process safety and risk management: Past, present and future

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ABSTRACT

The paper reviews past progress in the development of methods and models for process safety and risk management and highlights the present research trends; also it outlines the opinions of the authors regarding the future research direction in the field. Based on the open literature published in the leading journals in the field of safety, risk and reliability, the review covers the evolution of the methods and models developed for process safety and risk management. The methods and models are categorized as qualitative, semi-quantitative, quantitative and hybrid. The progress in the last few decades is discussed in the context of the past. Developments in the current decade formulate the basis of the present trends; future directions for research in these fields are also outlined. The aim of the article is to provide a historical development in this field with respect to the driving forces behind the development. It is expected that it will help researchers and industrial practitioners to gain a better understanding of the existing concepts. At the same time the aim is to provide direction to bridge the existing gaps through research and developments.

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1. Introduction

Continuing technological and social development of the world creates enormous demand for energy, chemicals, commodities, and food. This leads to an increase in the size and complexity of processing plants. This has inevitably created new hazards and increased risk that must not be compromised with mere economic benefits; instead they are required to be prevented and mitigated. Unfortunately this is not the case as accidents keep occurring with different levels of severity. Khan and Abbasi (1999a) conducted a comprehensive study on major process accidents that occurred during 1926–1977 and recommended the need for accident forecasting, consequence assessment, and development of emergency management plans. The report of Marsh Energy Practices listed 100 largest property damage losses that have occurred in hydrocarbon processing industries from 1970 to 2011 (Marsh, 2012). There are a number of databases maintaining the record of accidents which occurred in process industries and their respective consequences. Among them, the Major Hazard Incident Data Service (MHIDAS), Major Accident Reporting System (MARS), Process Safety Incident Database (PSIC), Failure and Accident Technical Information System (FACTS) and World Offshore Accident Database (WOAD) are the most recognized and widely used databases. Pondicherry University Process-industry Accident Database (PUPAD) is a comprehensive open-source database to assist past accident analysis (Tauseef et al., 2011). In the present work, authors performed a brief analysis of notable past process accidents that occurred during the last two decades using the accident information available in open literature including from the United States Chemical Safety Board (Marsh, 2012; Khan and Abbasi, 1999a). This will help to develop an overall view of accident trends and their consequences (property and production loss). Fig. 1 is the plot developed using the information available in the above mentioned resources. It is observed that the accident trend has not followed a uniform pattern. Both accident occurrences and their consequences show a non-uniform fluctuation. This non-uniform trend confirms the uncertain and unpredictable behavior of accidents and their consequence and reinforces the need of efficient and effective process safety and risk management to implement preventive and mitigating safety measures to reduce both the likelihood and severity of industrial accidents.

Process safety is the common global language used to communicate the strategies of hazard identification and analysis, risk assessment and evaluation, safety measures, and safe critical decision making. Process safety is identified as an integral part of process development and manufacturing rather than considering it as an “add-on” to the process (Gibson, 1999). Process safety differs from occupational safety as it solely focuses on preventing and mitigating major process accidents such as fires, explosions, and toxic releases, whereas occupational safety focuses on workplace hazards such as trips, slips, and falls. Process safety assessment/management includes several essential steps (Bahr, 1997). Though every step is equally important, hazard identification, risk assessment and management can be considered as the key steps of process safety management. Hazard identification, known as safety brainstorming for “what can go wrong”, identifies as many process hazards as are possible. “Risk” can be considered as the measurement of process safety and defined as the combination of “how bad an accident would be?” and “how often could it happen?”. It can be quantitatively expressed as a function of probability or frequency and their consequences (CCPS, 2000, 2007). During the risk analysis, understanding about the systems’ risk is portrayed in terms of qualitative and quantitative elements. Risk/safety management combines efforts to manage risk through risk estimation, risk evaluation, and risk-based decision making and design improvement.

There are a number of review articles published focusing on different area of process safety and risk management such as hazard identification, risk assessment and management, accident modeling, and inherent safety. Khan and Abbasi (1998a) briefly discussed existing risk assessment techniques and methods and their advantages and disadvantages. A different perspective of risk was discussed by Aven and Kristensen (2005). They discussed risk analysis in terms of some prevailing perspectives such as engineering, economics, social science, anthropology, and unifying approaches. The existing risk assessment and analysis techniques published in scientific literature were discussed by Marhavilas et al. (2011). Their analysis was limited to a discussion of only the key risk assessment methods and also was focused only on articles published during 2000–2009. Accident modeling is used to formulate an accident scenario prior to risk analysis and generate an overall picture of system safety. Lehto and Salvendy (1991) performed a systematic evaluation of the strength and limitation of accident causation models developed before the