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Review

Towards dynamic risk analysis: A review of the risk assessment approach and its limitations in the chemical process industry

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ABSTRACT

The objective of this review is to analyse the progress of Risk Assessment during the last decades and to offer an overview on its recent advancements and possible future direction for chemical and process industries. Despite the general approach of Quantitative Risk Assessment (QRA) is unchanged since its origin in the early 1980s, QRA has continuously evolved in different forms and its fields of application have enlarged significantly beyond process safety, where it has always been traditionally developed and used for chemical process industries. Now risk assessment techniques play a fundamental role in process design, implementation of safety systems, inspection and maintenance planning as well as operation management. Eventually risk assessment has become an essential tool for the development, continued operation and expansion of process installations. On the other hand, QRA limitations, such as its inability to update the risk picture, led to the development of several recent dynamic risk assessment approaches, whose methodological and applicative contributions are presented in this paper. This demonstrates that risk assessment is in continuous development; nevertheless, it still shows many challenges to face: the way forward is improving its preciseness and its capability to be dynamically updated, that it will be useful to support real-time decision-making.

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1. Introduction

During the last three decades, risk assessment has emerged as an essential and systematic tool that plays a relevant role in the overall management of many aspects of our life.

In particular, risk assessment has shown dramatically its importance in technical domains dealing with hazardous materials. Pasman affirms that events involving hazardous materials represent the most dreadful risk (Pasman, 2015). Such substances may range in nature and effect and a high-level definition may be provided by the CBRNE (Chemical, Biological, Radiological, Nuclear and Explosive) acronym, on which the Council of the European Union has recently focused its attention. In fact, a CBRNE agenda was defined to develop strategic and overarching approach to CBRNE policy fields involving internal and external safety and security aspects (Council of the European Union, 2012).

Loss of control of such substances has the potential to cause high consequence low probability accidents (Pasman, 2015) and specific safety measures are designed to mitigate such risk. For this reason, accurately evaluating risk of a system represents the foundation for effective prevention.

The chemical and nuclear sectors commonly store large amounts of CBRNE substances – mostly chemical and explosive the former and radiological and nuclear the latter. Presumably due to the high social impact of nuclear accidents (e.g. on the 30th anniversary of the Chernobyl disaster, access within the 30-km exclusion zone is still restricted (Fountain, 2016)), risk assessment has its roots in the nuclear sector and only later spread to the chemical process industry (Pasman, 2015).

Despite the obvious differences between the two sectors, continuous exchange of knowledge and methods from one to the other has led to huge improvements in the chemical process industry (Charvet et al., 2011) and helped to cope with increasing issues of social acceptability (Marshall, 1997).

Nuclear power risk analysts have a long tradition of quantitative approaches: the United States Nuclear Regulatory Commission developed its first nuclear power plant Probabilistic Risk Assessment in the 1970s (US Nuclear Regulatory Commission, 2016). However, Quantitative Risk Analysis (QRA) reached the chemical process industry only at a later stage. For instance, before 2003 quantitative probability assessment was used to assess risk in the French chemical industry (Charvet et al., 2011). Similarly, the accident occurred in Buncefield (United Kingdom) in 2005 called into question the semi-qualitative risk analysis approach used for flammable substances in the British chemical industry, whereas the other hazardous substances were subject to QRA since the 1980s (Buncefield Major Investigation Board, 2008).

While the disadvantage of QRA was mainly represented by the computational effort needed to perform it, its advantage is that it deals with some of the criticisms made to qualitative analysis (Buncefield Major Investigation Board, 2008):

- vagueness in terminology, for example "a very high degree of protection", "worthwhile (sometimes almost total) protection", "unlikely but foreseeable";
- arbitrariness and lack of transparency in selection of the worst-case event, and through this, potential inconsistency in treatment between installations;
- challenges at comparing the degree of protection achieved with that for other everyday risks.

With the progressive increase in computation power, QRA is nowadays a tool widely applied to provide quantitative information on risk caused by conventional accidents in chemical process plants.

Despite the obvious fact that QRA is not an exact description of reality, it may represent the best available, analytic predictive tool data to assess the risks of complex process and storage facilities. QRA consists of a set of methodologies for estimating the risk posed by a given system in terms of human loss or, in some cases, economic loss (CCPS - Center for Chemical Process Safety, 2000; Mannan, 2005). Recently, risk assessment methodologies and applications have rapidly evolved toward a dynamic direction, in order to address risk issues in a continuously evolving environment, support operations and overcome limitations of conventional techniques. Moreover, this allows for continuous integration with more accurate information and refinement of the risk picture (Paltrinieri and Khan, 2016). The Living Probabilistic Safety Analysis (LPSA), theorized for the nuclear sector in 1999 (IAEA, 1999), might have inspired such evolution.

In the past, several reviews dealt with risk assessment under different perspectives. Due to the difference in the review scopes, different techniques have been considered by these studies. However, they all address the fundamental phases of risk assessment and may provide useful insight.

Khan and Abbasi have presented a relevant state-of-art review on the techniques and methodologies available up to 1998 for risk assessment in the chemical process industry, but some steps forward have been made in the meantime (Khan and Abbasi, 1998). Tixier et al. have listed 62 risk analysis methodologies, both qualitative and quantitative ones, for generic industrial plants (Tixier et al., 2002). Marhavilas et al. have published a review of risk analysis and assessment, but generically referred to different work sites (Marhavilas et al., 2011). More recently, Reniers and Cozzani (2013) and Necci et al. (2015) presented reviews on quantitative risk assessment for the chemical process industry, but specifically concerning domino accidents.

The present work aims to provide a comprehensive and up-to-date picture of risk assessment methodologies and relevant applications for the chemical process industry, which may be missing by reading the mentioned past reviews. This sector is addressed because of its high criticality in terms of safety. Progresses and drawbacks are identified in order to propose an overview on recent advancements and future directions. This allows understanding what is the state of the art of QRA in chemical process industry and why specific approaches are used today. Achievements and limitations suggest how risk assessment approaches may (or may not) be applied for different purposes. Moreover, limitations pave the way for future research and development of the current techniques.

The literature review proposed starts in Section 2 with a description of the implications of risk definition, whose concept provides sound foundation for risk assessment. Fundamentals of Quantitative Risk Assessment are reported in Section 3, in order to make clear what has been nowadays accomplished as current industrial practice in risk assessment and what are eventually the criticalities. Section 4 intends to consider, with a novel classification approach, how risk assessment methodologies and applications have recently evolved toward a dynamic direction, in order to address risk issues in a continuously evolving environment. A review of existing dynamic risk assessment methodologies is followed by their application to different aspects inherent of the process industry: accident and consequence modelling, process design, implementation of safety systems, control systems, asset integrity and maintenance planning, inclusion of external factors. Section 5 presents a discussion on the advantages and limitations of dynamic approaches and, in Section 6, conclusions are drawn on the state of art of Risk Assessment and probable future developments for chemical process industries.