Journal of Integrated Security Science

Revolutionizing Safety and Security in the Chemical and Process Industry: Applying the CHESS concept

Genserik Reniers[1,2,3,]*, Nima Khakzad[1]

1. Safety and Security Science Group, Faculty of Technology, Policy and Management, Delft University of Technology, Delft, The Netherlands

2. Antwerp Research Group on Safety and Security (ARGoSS), Universiteit Antwerpen, 2000 Antwerp, Belgium

3. Faculty of Economics and Management, KULeuven, 1000 Brussels, Belgium

Received 13 December 2016
Accepted 11 February 2017

This paper argues that a new concept, summarized as 'CHESS', should be used in the chemical industry to further substantially advance safety (where we use the term in a broad sense, that is, safety and physical security, amongst others). The different domains that need to be focused upon, and where innovative initiatives should be taken are Cluster-thinking and cooperation, High transparency and efficient inspections, Education and training, Security integration, and Safety innovation. Since society has fundamentally changed over the last two decades, and ever more hazardous materials are used in chemical sites which are ever more closely situated next to highly-populated areas, revolutionizing safety via the CHESS concept is truly needed in the very near future, both from a safety and a security point of view.

Keywords: Safety history; Safety revolutions; Physical security; Safety innovation; Chemical industry

1. Introduction

Based on available literature, it is very difficult to draw unambiguous conclusions about the increase or decline in the number of accidents – occupational accidents and/or process safety accidents – in the chemical and process industries over the past decades. Nonetheless, it goes without any doubt that still too many accidents do happen in the industry (on average more than three major accidents annually). According to Mihailidou et al. (2012), who investigated 319 major industrial accidents in the chemical industry since 1917, the "number of major accidents is generally decreasing", but other authors claim differently (see e.g. Kirchsteiger, 1999; Pasman, 2016). Le Coze (2013) for instance describes similar accidents repeating themselves after 20-30 years around the 21st century. In any case, in total some 25,000 fatalities have resulted from major accidents since 1917, in which a major accident was defined by at least one of the following criteria (Mihailidou et al., 2012):

- 25 fatalities or more
- 125 injuries or more

* Corresponding author.
Email address: G.L.L.M.E.Reniers@tudelft.nl

DOI: 10.18757/jiss.2017.1.1547
ISSN: 2468-4546

- 10,000 evacuated or more
- 10,000 people or more deprived of water
- Excluded are: oil spills at sea; mining accidents; security accidents (with intention).

Besides major accidents, many occupational accidents happened in the chemical industry since the beginning of the 20th century. Nonetheless, in general, despite lacking aggregated figures, we may assume that, due to safety efforts and safety improvements of different kinds during the past decades, a decreasing trend in the occupational accidents of many chemical and process companies is present. Analyzing accident statistics as per industry type, it is well evident that there is a significant decline in accident per industry (or fatality per industry), which is still, surprisingly, way beyond public acceptance due to higher social responsibility and lower tolerance of incremental risk; this all urges a higher pressure to enhance safety.

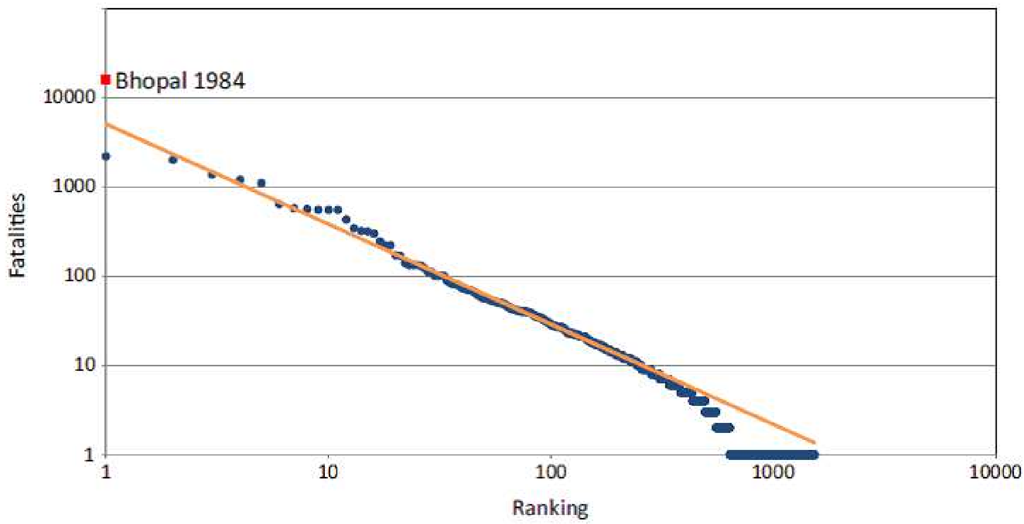

Fig. 1. Trend of the fatalities caused by major hazard incident data service accidents (MHIDAS, 2003): adopted from Paltrinieri and Khan (2016).

However, major accidents do keep happening at a steady pace (see e.g., Kirchsteiger, 1999; Pasman, 2016). Moreover, if only occupational accidents are taken into account, in industrial practice a certain threshold of the number of such accidents can be observed below which it is very hard for companies to reach. Aside from major accidents, rare accidents are usually characterized by rarity, severity, surprise, and high degrees of uncertainty. According to the nonlinear nature of rare events, small variations in causal factors can result in large deviances in severity of consequences (Bier et al., 1999). For example, consider domino effects in process plants when a primary fire or explosion in a unit can propagate to other neighboring units, triggering secondary fires and explosions whose extent and severity could hardly have been imagined. Bier et al. (1999) classify rare events into unexpected and counter-expected events. The former class refers to events that have never occurred in the past (e.g., the 9/11 terrorist attacks in the US in 2001) and thus cannot be imagined and predicted whereas the latter class addresses those events that can be imagined but due to their very low probabilities are considered impossible and are advertently ignored (e.g., the Japan triple disaster, March 2011). In recent years, the terms black swan and grey swan have been frequently used to address rare events that are quite unpredictable and predictable but with larger uncertainties, respectively (Taleb, 2007a,b; Aven, 2013).

Other authors (Knegtering and Pasman, 2009; Reniers and Amyotte, 2012) have also indicated the need for, and some pathways towards, safety improvements in the future chemical industry. Hence, the 'business-as-usual' approach for dealing with occupational safety as well as process safety in the chemical industry seems to be insufficient to truly advance safety. Actually, a paradigm shift is needed.

Such a paradigm shift should indeed provide an answer to our changing society with its own specific needs and societal expectations, including, for instance, more transparency and the inclusion of economic, moral and ethical aspects in risk assessments. In this regard, the increasing trend of new security challenges such as terrorist attacks not only throughout the world but also to the chemical industry should also not be overlooked. The recent intentional attacks to two chemical plants in France in June and July of 2015 (BBC news, 2015a,b) raised the flag about the imminent risk of security events in the chemical industry. Some other observations are that despite too many incidents and accidents in the chemical industry, (i) the chemical industry does not seem to really have learned from these accidents since still a majority of approaches toward safety are reactive and not proactive, and (ii) chemical companies in industrial areas (chemical industrial parks) are still dealing with safety issues (let alone the security issues) too individually, that is, from a "safety islands" perspective instead of a "safety clusters" viewpoint.

As for the paradigm shift, the following questions may be formulated:

- How to integrate different types of risks (e.g., domino effects, land-use-planning, natech accidents, and security risks) when making risk decisions?
- How to deal with horror scenarios (e.g. terrorism) from a sustainable viewpoint?
- How to consider moral aspects in decision-making?
- How to develop usable and inclusive dynamic risk assessment techniques, using big data and real-time monitoring?
- How to advance academic knowledge regarding physical- and cyber security?
- How to truly advance collaboration and cluster-thinking?
- How to innovate safety within the chemical industry in a sustainable way, whereby the energy transition, land-use planning, safety behavior, etc. are all considered?
- How to initiate and advance strategic proactive and reactive collaboration in chemical clusters?
- How to increase people knowledge about safety, or e.g., how to encourage students to pursue majors in chemical process safety and security?

Despite the evolution of safety over the past century which is based on Swuste et al. (2010), Swuste et al. (2014), Swuste et al. (2016a), and Oostendorp et al. (2016) (see Figure 2), no answers have been formulated so far for these questions. Hence, current approaches and contemporary thinking, mental models, technological approaches and solutions, safety implementations and (evolutionary) ways to improve safety are regretfully not sufficient either to answer these questions or to revolutionize safety and thus making it much safer in a realistic and achievable way. Therefore, a safety revolution is needed in the chemical industry.

In fact, two safety revolutions already took place (Figure 2): (i) the 'safety first movement' (1900s until 1950s) represents the first safety revolution, and (ii) the 'risk management and loss prevention' approaches (1960s until 2010s) denote the era of the second safety revolution. The third safety revolution which is desperately needed today to further advance safety in the chemical industry can be summarized by the acronym 'CHESS' (from 2020s onwards). Figure 2 shows the three safety revolutions along with the underlying theories, models, concepts and ideas per decade.

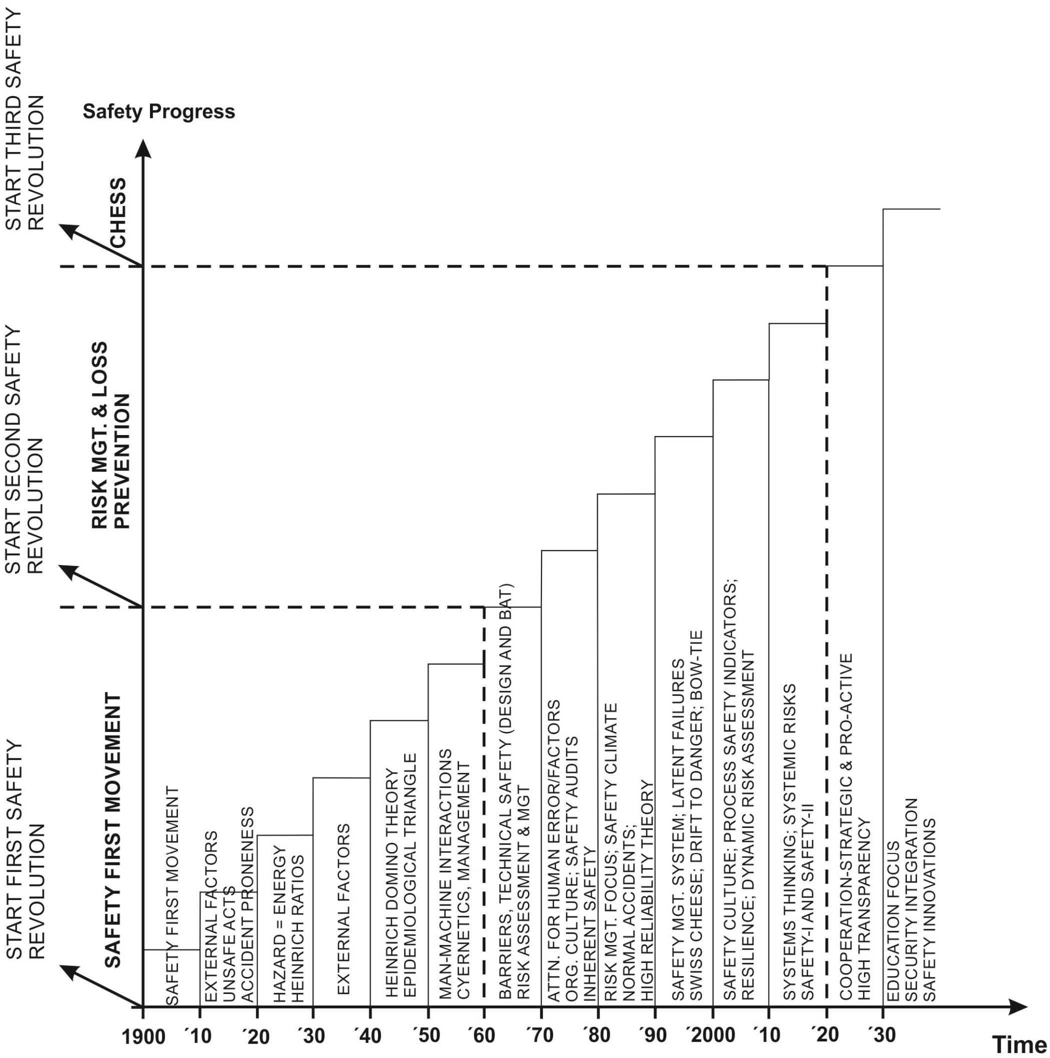

Fig. 2. Safety progress and the three safety revolutions in the chemical industry (1900-2030 and future).

The present study is aimed at identifying the characteristics of the third safety revolution and setting guidelines as to how to transition from the current safety era to the next one (where amongst others the importance of physical security is acknowledged and fully integrated with safety policies and management). Section 2 discusses the evolutionary trends currently being practiced within industrial safety and security research in academic institutions. Section 3 further elaborates and explains the CHESS concept representing the needs for the third safety revolution in the chemical industry. Conclusions and further recommendations are presented in Section 4.

2. Current evolutionary trends to improve safety (and security) in the chemical industry

The number of safety-related tasks in any organization is huge, so are the responsibilities accompanying the decisions and choices that have to be made. Well-known (technical) aspects of safety assessment and management in companies, that is, hazard identification, scenario modeling, and risk analysis and assessment, are only one part of the larger domain of dealing with risks undertaken by company safety managers. Other elements include but are not limited to safety training and education, training-on-the-job, management by walking around, emergency response and planning, business continuity planning, ethical aspects of safety, reliability engineering, learning from incidents, risk communication, risk perception, psycho-social aspects of risk, economic aspects of safety, risk governance, and many more. Meyer and Reniers (2016) define operational risk management as “the systematic application of management policies, procedures and practices to the tasks of identifying, analyzing, evaluating, treating and monitoring risks”. Figure 3 illustrates the very broad and challenging operational risk management set. Safety managers nowadays realize that this set represents their package of responsibilities. From a rather very technical approach, safety management has expanded towards an approach encompassing all these other domains, to a lesser or higher extent.

Furthermore, the scientific background and the disciplines needed to tackle the different domains and items in the risk management set are ever more diverse. Safety- and risk management are no longer the exclusive terrain of engineers, physicians, and safety scientists; in fact, sciences such as psychology, sociology, pure mathematics, chemistry and physics, philosophy, economists, communication, business and management, criminology, and law are also effectively involved in safety improvement these days.

Employing the well-known bow-tie concept (Figure 4) to explain the evolutionary trends taking place in safety improvement in the chemical industry, three areas may be discerned: the proactive phase (pre-incident), the incident phase, and the reactive phase (post-incident). In the proactive phase, a variety of trends can be observed and discussed. The first trend is that there is ever more cooperation between companies, however, mainly on an operational level and mostly concerning reactive issues such as accident investigation and evacuation exercises (Reniers and Cozzani, 2013). More collaboration among companies and academia and authorities can also be seen. The second trend is concerned with making risk assessments less static and more dynamic (Paltrinieri and Khan, 2016). Dynamic risk analyses include advanced mathematical-based techniques being developed in the academia including Markov chains (Shu and Zhao, 2014), Event sequence diagrams (Zhou et al., 2016), Petri-nets (Zhou and Reniers, 2016a,b,c), and Bayesian Networks (Khakzad et al., 2016; Khakzad, 2015; Khakzad and Reniers, 2016; Khakzad and Reniers, 2015a). Furthermore, operational economics including cost-benefit analysis and cost-effectiveness analysis are improved and employed with an increasing trend (Reniers and van Erp, 2016; Reniers and Sorensen, 2013; Reniers and Brijs, 2014). Some specialized topics have also been explored, introduced and developed in chemical corporations, such as security risk analyses (Khakzad and

Reniers, 2015b; Reniers and Audenaert, 2014), performance management science (Swuste et al., 2016b), mental models and moral or ethical principles for calculating risks (Reniers and van Erp, 2016). The attention for systemic risks, whereby one looks at the whole system rather than (analytically) looking at its parts, leads to the taking of safety barriers at a systemic level. An example is that one looks at a whole chemical plant at once instead of merely considering its installations or equipment (Reniers et al., 2012; Reniers et al., 2014). Besides, a variety of scientific disciplines (cfr. also Figure 3) are employed to invent trans-disciplinary solutions. All kinds of safety apps can further be expected to lead to optimized communication and perhaps much better safety decision-making. Innovation with respect to the so-called 'safety culture', via, for example, High Reliability Organization principles (Meyer and Reniers, 2016) or newly developed leadership styles such as Total Respect Management (Blokland and Reniers, 2013) are also being elaborated.

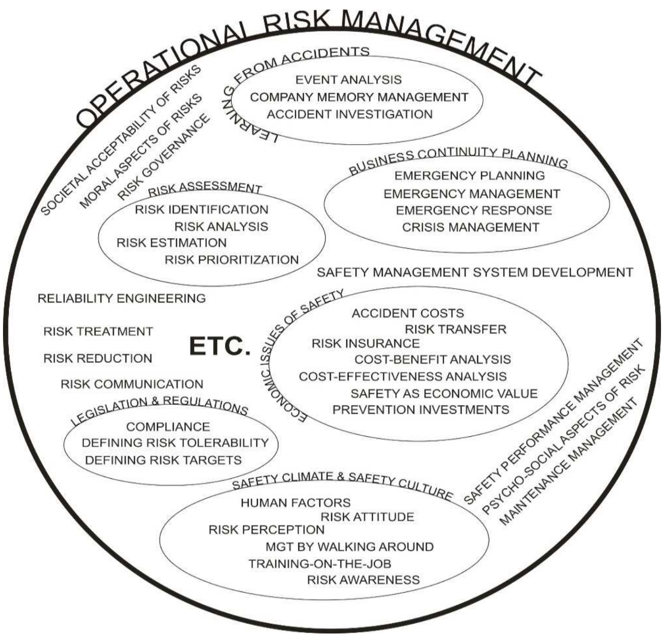

Fig. 3. The operational risk management set (based on Meyer and Reniers (2016).

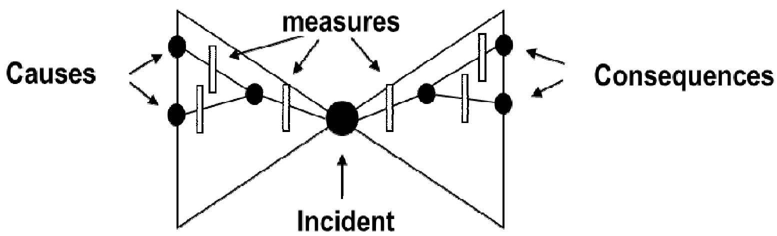

Fig. 4. Bow-tie concept with three phases: proactive, incident, and reactive.

In the incident phase, also several evolutionary trends can be observed. Real-time data and big data, as well as all progress in communication devices and possibilities have led to better and more objective risk assessments and decisions, as well as regulations such as Land-use Planning (Pasman and Reniers, 2014). Large-scale simulation exercises of disasters are made more real while serious games to exercise incident-phase decisions and tasks are elaborated. Collaboration between different actors in the incident phase is also improved with more involvement from the public and the authorities.

During the aftermath of an incident, an important evolutionary trend of improvement concerns better collaboration among rescue workers, fire-fighters, industrial practitioners, medical services, logistics services, communication experts, and academics. Moreover, the use of innovative technology (e.g., drones), certain human aspects (e.g., trauma-psychological aspects), and organizational structures to deal with problems in a post-incident phase are trends that cannot be disregarded.

Obviously, most progress is currently made in the proactive phase. The incident and certainly the after-incident phases are, however, less focused upon in current time, probably since they have a much longer history of interest by researchers in the past decades.

3. Revolutionizing safety: The CHESS concept

The previous section provided the evolutionary trends which can be discerned in current academic research and industrial practice. However, these trends represent thinking ‘within the box’, and are usually “more of the same concept/approach” or, at best, incremental improvements and optimization of existing technology, management practices, organizational arrangements, and human factors. To truly advance safety within the chemical industry, we need to think ‘out of the box’, and another revolution such as “the safety first movement” or “risk management and loss prevention” is necessary. But what should such a revolution contain, and who could realize it?

Revolutions start with radically new ideas, and not with ‘old wine in new barrels’ or ‘new wine in old barrels’. These new ideas are formed via mental models, the willingness to change things, and the understanding that changing things will lead to a better/improved situation, which in turn will result in the profitability and license-to-operate of chemical plants. Such should be the case with this third safety revolution in the chemical industrial sector.

We believe that the third safety revolution can be represented by the acronym ‘CHESS’. CHESS in fact summarizes 5 very important fields where revolutionary progress is needed:

- **C**luster-thinking and intensified cooperation
- **H**igh transparency and efficient inspection
- **E**ducation, training and learning
- **S**ecurity integration
- **S**afety innovation and dynamic risk assessments

At first sight, these fields represent well-known recipes for improving safety in any industry whereas they are nothing new. However, one should realize that the combination of these domains could indeed lead to a third safety revolution in the chemical industry if they would be addressed in radical innovative ways. The required innovation can be exemplified by a number of concrete ideas, which can only be realized if current mentality of practitioners, academics and authorities changes.

3.1. Cluster thinking and intensified cooperation

For the first revolutionary field, cluster-thinking and collaboration intensification, some thorough research has already been done (Reniers, 2010; Reniers, 2013; Reniers and Pavlova, 2013). Cooperation on a proactive and strategic level such as joint emergency management strategies and decision making tools, besides reactive and operational level cooperation such as joint evacuation drills, should form the backbone of the third safety revolution. Some chemical industrial parks have already started working together so as to strategically improve horizontal logistics, the use of energy (or utilities in general), or environmental issues (e.g. waste streams); however, they usually fail to collaborate more intensively with respect to proactively and strategically enhancing safety.

The following innovative approaches can be considered:

- Establish a multi-plant council or a cluster council (see e.g. Reniers, 2010)
- Establish proactive strategic cooperation and improvement by setting up a ‘cluster safety funding’ budget (see e.g. Reniers and Pavlova, 2013)
- Use ‘flying risk assessment’ teams and ‘flying internal audit’ teams in clusters
- Establish a cluster emergency planning matrix (see e.g. Reniers and Faes, 2013)
- Take various forms of risks such as domino effects (escalating accidents) and natech accidents into account in risk assessments
- Establish a cluster safety management system upgrade approach (see e.g. Reniers, 2010)
- Establish a ‘cluster safety culture’ (see e.g. Reniers, 2010; Reniers, 2013)

3.2. High transparency and efficient inspection

The second revolutionary field, high transparency and more efficient inspection, has already inspired the aviation sector. In this sector, a mature system of procedures and agreements is worked out to deal with the reporting of all incidents and near-misses in order to learn as much as possible in a ‘just culture’ setting (Dekker, 2012).

Accordingly, the following innovative approaches can be introduced and elaborated in the chemical industry worldwide:

- Establish a national database to report all types of incidents and accidents by chemical companies (see e.g. Meel et al., 2007)
- Establish a ‘just culture’ in chemical plants/clusters (see e.g. Dekker, 2012)
- Establish a dissemination system where companies and authorities/inspection teams can learn from all incidents happening within the industry
- Establish an understanding between cluster safety council members and inspection services to make inspections more efficient
- Use drones to continuously gather data from around the cluster

Besides efficiency improvements, inspections should evidently also be more effective. Often, the quality of inspections is below a level that might be expected in case of chemical industrial activities. Besides operating plant personnel, inspectors from the authorities should therefore also be well-educated (cfr. also Section 3.3), and physical and cyber security issues should be inspected, in one go with safety inspections of installations.

3.3. Education, training and learning

The third revolutionary field, dealing with safety education, learning and training, also deserves dedicated attention. One not only needs to learn not only from near misses and incidents but also from safety models, theories and knowledge in general. Here lies also a task for society: there should be courses on 'dealing with risk and uncertainty', or 'operational safety', starting from primary school education. If people get familiar with safety from very early ages, they can learn much more in higher education. Moreover, it can be expected that the much more thorough safety knowledge of all people through regular education will be used in daily life and business to make better decisions and reduce losses, both on private-and public working levels.
In this regard, the following innovations can be suggested:

- Knowledge management systems should be present in every chemical plant
- There should be training sessions where plant safety managers and safety inspection services are jointly present
- Safety learning should be supported by adequate/validated/scientifically investigated performance management science
- 'Basic knowledge of valuing and prioritizing safety' should be taught to children in primary schools
- 'Risk management and risk-based decision making' should be taught at high schools and universities, either as a separate course, or within existing courses
- 'Process safety' (and inherent safety) should be taught to all chemists, chemical engineers and industrial engineers, and be considered essential in the educational program

3.4. Security integration

The fourth revolutionary field, security integration, mainly concerns more effective counter-terrorism security practices in the chemical industry. At present, security efforts in chemical plants are aimed at low-impact high-frequency security risks (Reniers, 2012; Reniers, 2011) such as burglary and sabotage, or, at best, would-be (or tourist) terrorists. However, an adequate upgrade is needed towards anti-terrorist security measures (Landucci et al., 2015; Zhang and Reniers, 2016). But more in general, security should be treated in an integrated way with safety by company safety management. Safety and security both concern the avoidance and mitigation of losses of different origins (safety looks at possible unintentionally caused losses while security is about tackling deliberately caused losses).
Some innovative ways to improve this domain are:

- Carry out threat assessments, security vulnerability assessments or, in general, security risk assessments in all chemical plants/clusters (alongside safety risk assessments, and in an integrated manner)
- Use a cluster view in addition to a plant view in order to take counter-terrorism measures,
- Make a priority of hazmat transportation security (transportation risk assessments and measures based on these assessments, secure lanes, secure emplacements) within a chemical industrial area
- Establish cluster security teams (cfr. also section 3.1)
- Develop a security incident database (cfr. also section 3.2)
- Establish security inspections for chemical plants/clusters (alongside safety inspections)

- Take counter-terrorism measures seriously, preferably design-based by scientific studies

3.5. Safety innovation and dynamic risk assessments

The fifth revolutionary field, i.e., safety innovation and dynamic risk assessments, builds on the evolutionary trends of the previous section and is therefore the most evident field to work on. This field requires the least change in the mentality of practitioners, academics and authorities. Nonetheless, due to the fact that it is the most demanding field from a technological perspective, it is the highest hanging fruit. During the past decade, the attempts in the field of dynamic risk assessment have been made to address factors such as dynamic procedures for atypical scenario identification (including black swan and grey swan events), dynamic hazard identification (as a substitute for conventional static techniques such as FMEA, HAZOP, etc.), reactive and proactive approaches for probability updating using leading and lagging risk indicators, which in turn would result in a more effective uncertainty modeling, dynamic consequence analysis so as to consider temporal variations of contributing parameters such as vulnerability, economic conditions, etc., and dynamic risk management (for a detail discussion see Paltrinieri and Khan, 2016).

Despite remarkable innovations in the field of quantitative risk analysis (QRA) as a tool to improve safety, design, licensing, and operational processes, still methods for uncertainty handling and, more importantly, validation and verification of QRA results are lacking. Thus, one of the main issues as for safety innovation could be developing techniques to verify and validate risk analysis in parallel with developing techniques for safety improvement and uncertainty handling. It is thus crucial to investigate which theoretical views on validity and validation of QRA can be found, which features of QRA are useful to validate, and which frameworks can be proposed for this purpose, what kinds of claims are made about QRA, and what evidence is available for QRA being valid for the stated purposes.

Some innovations that, if applied together, would make this evolutionary trend a true revolutionary field, are as follows:

- Use big data and the Internet of Things to innovate risk knowledge and safety decision-making within chemical plants and chemical clusters
- Use dynamic risk assessment techniques (make large investments in their development and on-site application) to advance real-time knowledge and decision-making
- Invest in research for performance management science and safety/security performance indicators (should mainly be proactive) to see which indicators work and which don't (this requires large-scale longitudinal studies)
- Serious games for a large variety of safety and security major accident/terrorist attack scenarios should be developed and used for learning and exercising
- Science with respect to leadership, required mental models of employees, and the impact on safety should be developed and implemented in chemical plants and clusters
- Develop alternative risk assessment techniques whereby both ethical/moral principles and economic information are considered

4. Conclusions and recommendations

Achieving a paradigm shift for safety in the chemical industry, leading to a third safety revolution in the chemical industry, will be very challenging and ambitious for all stakeholders, yet it is achievable in industrial practice and in the long term will be very rewarding for safety and company profitability.

Such a third safety revolution would undoubtedly lead to an improved acceptability and acceptance of chemical risks in current society that is ever more risk averse and demanding for more transparency and more communication.

A strong competitive advantage for chemical clusters that would act as first-movers could probably be created, providing opportunities for large-scale investments in their industrial activities.

The third safety revolution can be achieved via five revolutionary fields denoted by acronym 'CHESS': Cluster-thinking and cooperation, High transparency and efficient inspections, Education, Security integration, and Safety innovation.

These revolutionary fields can truly and in a sustainable way change the safety landscape within the chemical and process industry. The most achievable revolutionary field is the cluster-thinking, that will also deliver the highest safety improvement. Nevertheless, all five mentioned fields should be taken up and considered to gain a third safety revolution.

Finally, better safety will also further reduce environmental risk and would give a new impetus in terms of sustainability of chemical industrial activities. In brief, bringing the CHESS concept into practice would bring the vision of resilient chemical industrial parks, encompassing the whole chain of activities of plant and cluster design, construction, commissioning, operation, and finally decommissioning, also in a sustainable sense.

References

Aven T. On the meaning of a black swan in a risk context. Safety Science, 2013; 57:44–51.

BBC. France attack: Man decapitated at factory near Lyon, available online at: http://www.bbc.com/news/world-europe-33284937; 2015a.

BBC. France Explosions: devices found near Berre Letang plant, available online at: http://www.bbc.com/news/world-europe-33537345; 2015b.

Bier VM, Haimes YY, Lambert JH, Matalas NC, Zimmerman R. A survey of approaches for assessing and managing the risk of extremes. Risk Analysis, 1999; 19(1):83–94.

Blokland P, Reniers G. Total Respect Management: Het Handboek van de "excellente" Manager (in Dutch). Leuven: Lannoo Campus; 2013.

Dekker S. Just Culture. Balancing safety and accountability. Burlington, VT, USA: Ashgate Publishing Company; 2012.

Khakzad N, Reniers G. Risk-based design of process plants considering domino effects and land use planning. Journal of Hazardous Materials, 2015a; 299: 289-297.

Khakzad N, Reniers G. Protecting chemical plants against terrorist attacks: a review. Journal of Socialomics, 2015b; 5(1): DOI:10.4172/2167-0358.1000142.

Khakzad N. Application of dynamic Bayesian network to risk analysis of domino effects in chemical infrastructures. Reliability Engineering & System Safety, 2015; 138: 263-272.

Khakzad N, Reniers G. Application of Bayesian network and multi-criteria decision analysis to risk-based design of chemical plants. Chemical Engineering Transactions, 2016; 48: 223-228.

Khakzad N, Yu H, Paltrinieri N, Khan F. Techniques of reactive frequency update: Bayesian inference. In: Khan F, Paltrinieri N (Eds.). Dynamic Risk Analysis in the Chemical and Process Industry, UK: Elsevier; 2016, 51-61.

Kirchsteiger Ch. Trends in accidents, disasters and risk sources in Europe. Journal of Loss Prevention in the Process Industries, 1999; 12: 7-17.

Knegtering B, Pasman HJ. Safety of the process industries in the 21st century: a changing need of process safety management for a changing industry. Journal of Loss Prevention in the Process Industries, 2009; 22: 162-168.

Landucci G, Reniers G, Cozzani V, Salzano E. Vulnerability of industrial facilities to attacks with improvised explosive devices aimed at triggering domino scenarios. Reliability engineering and system safety, 2015; 143: 53-62.

Le Coze JC. New models for new times. An anti-dualist move. Safety Science, 2013; 59: 200-218.

Meel A, O'Neill LM, Levin JH, Seider WD, Oktem U, Keren N. Operational risk assessment of chemical industries by exploiting accident databases. Journal of Loss Prevention in the Process Industries, 2007; 20: 113-127.

Meyer T, Reniers G. Engineering risk management. 2nd edition. Berlin: De Gruyter; 2016.

MHIDAS (Major Hazard Incident Data Service). Mhidas database. Harwell, UK: AEA Technology, Major Hazards Assessment Unit, Health and Safety Executive; 2003.

Mihailidou EK, Antoniadis KD, Assael MJ. The 319 major industrial accidents since 1917. International review of chemical engineering, 2012; 4(6): 529-539.

Oostendorp Y, Lemkowitz S, Zwaard W, van Gulijk C, Swuste P. Introduction of the concept of risk within safety science in The Netherlands focussing on the years 1970-1990. Safety Science, 2016; 85: 205-219.

Pasman H, Reniers G. Past, present and future of quantitative risk assessment (QRA) and the incentive it obtained from land-use planning (LUP). Journal of loss prevention in the process industries, 2014; 28: 2-9.

Pasman H. Disasters don't seem to disappear (in Dutch), available (in Dutch) online at: https://www.deingenieur.nl/artikel/rampen-verdwijnen-kennelijk-niet; 2016 [accessed in Dec 2016].

Paltrinieri N, Khan F. (edit.) Dynamic Risk Analysis in the chemical and petroleum industry. Oxford: Elsevier; 2016.

Reniers G. Multi-Plant Safety and Security Management in the Chemical and Process Industries. Weinheim, Germany: Wiley-VCH; 2010.

Reniers G. Terrorism security in the chemical industry: results of a qualitative investigation. Security journal, 2011; 24(1): 69-84.

Reniers G. Security within chemical process industry: survey results from Flanders. chemical Engineering Transactions, 2012; 26: 465-470.

Reniers G, Sörensen K, Dullaert W. A multi-attribute systemic risk index for comparing and prioritizing chemical industrial areas. Reliability Engineering and System Safety, 2012; 98(1): 35-42.

Reniers G, Amyotte P. Prevention in the Chemical and Process Industries: Future Directions. Journal of Loss Prevention in the Process Industries, 2012; 25(1): 227-231.

Reniers G, Cozzani V. (Edit.) Dealing with Domino effects in the Process Industries. Amsterdam: Elsevier; 2013.

Reniers G. Cluster thinking as part of sustainable chemical plants. Chimica oggi, 2013; 31(2): 30-33.

Reniers G, Pavlova Y. Using game-theory to improve safety within chemical industrial parks. London: Springer; 2013.

Reniers G, Faes R. Managing domino effects in a chemical industrial area. In: Reniers G, Cozzani V. (Edit.) Dealing with Domino effects in the Process Industries, Amsterdam: Elsevier; 2013, 272-295.

Reniers G, Sörensen K. An approach for optimal allocation of safety resources: Using the knapsack problem to take aggregated cost-efficient preventive measures. Risk Analysis, 2013; 33(11): 2056-2067.

Reniers G, Brijs T. Major accident management in the process industry : an expert tool called CESMA for intelligent allocation of prevention investments. Process safety and environmental protection, 2014; 92(6): 779-788.

Reniers G, Audenaert A. Preparing for major terrorist attacks against chemical clusters : intelligently planning protection measures w.r.t. domino effects. Process safety and environmental protection, 2014; 92(6): 583-589.

Reniers G, Sörensen K, Khan F, Amyotte P. Resilience of chemical industrial areas through attenuation-based security. Reliability engineering and system safety, 2014; 131: 94-101.

Reniers G, Van Erp HRN. Operational safety economics : a practical approach focused on the chemical and process industries. Chichester: Wiley; 2016.

Shu Y, Zhao J. A simplified Markov-based approach for safety integrity level verification. Journal of Loss Prevention in the Process Industries, 2014; 29: 262-266.

Swuste P, Van Gulijk C, Zwaard W. Safety metaphors and theories, a review of the occupational safety literature of the US, UK, and The Netherlands, till the first part of the 20th century. Safety Science, 2010; 48: 1000-1018.

Swuste P, Van Gulijk C, Zwaard W, Oostendorp Y. Occupational safety theories, models and metaphors in the three decades since World War II, in the United States, Britain and the Netherlands: A literature review. Safety Science, 2014; 62: 16-27.

Swuste P, Van Gulijk C, Zwaard W, Lemkowitz S, Oostendorp Y, Groeneweg J. Developments in the safety science domain, in the fields of general and safety management between 1970 and 1979, the year of the near disaster on Three Mile Island, a literature review. Safety Science, 2016a; 86: 10-26.

Swuste P, Theunissen J, Schmitz P, Reniers G, Blokland P. Process safety indicators : a review of literature. Journal of loss prevention in the process industries, 2016b; 40: 162-173.

Taleb N. The Black Swan: The Impact of the Highly Improbable. New York: Random House and London, Penguin; 2007a.

Taleb N. Black swans and domains of statistics. American Statistician, 2007b; 61(3): 1–3.

Zhang L, Reniers G. A game-theoretical model to improve chemical plant protection from terrorist attacks. accepted for publication in: Risk Analysis, 2016; DOI: 10.1111/risa.12569.

Zhou J, Reniers G, Khakzad N. Application of event sequence diagram to evaluate emergency response actions during fire-induced domino effects. Reliability Engineering & System Safety, 2016; 150: 202-209.

Zhou J, Reniers G. Petri-net based modeling and queuing analysis for resource-oriented cooperation of emergency response actions. Process safety and environmental protection, 2016a; 102: 567-576.

Zhou J, Reniers G. Petri-net based simulation analysis for emergency response to multiple simultaneous large-scale fires. Journal of loss prevention in the process industries, 2016b; 40: 554-562.

Zhou J, Reniers G. Simulation analysis of the use of emergency resources during the emergency response to a major fire. Journal of loss prevention in the process industries, 2016c; 44: 1-11.