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A review of the past, present and future of the European loss prevention and safety promotion in the process industries

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ABSTRACT

In 2013, the European Federation of Chemical Engineering (EFCE) celebrates its 60th anniversary. EFCE has continually promoted scientific collaboration and supported the work of engineers and scientists in thirty European countries. As for its mission statement, EFCE helps European Society to meet its needs through highlighting the role of Chemical Engineering in delivering sustainable processes and products. Within this organizational framework the Loss Prevention Symposium series, organized throughout Europe on behalf of the Loss Prevention Working Party of the EFCE, represents a fruitful tradition covering a time span of forty years. The tri-annual symposium gathers experts and scientists to seek technical improvements and scientific support for a growingly safer industry and quality of life. Following the loss prevention history in this paper, a time perspective on loss prevention and its future is presented.

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1. The origins of the Working Party and the symposia

From 1953 onwards, the European Federation of Chemical Engineering (EFCE) has continually promoted scientific collaboration and supported the chemical engineering work of engineers and scientists in thirty European countries. As an organization the EFCE was initiated in the Western part of Europe, but Central and Eastern European countries joined. As for its mission statement, EFCE will help European Society to meet its needs by highlighting the role of Chemical Engineering in delivering sustainable processes and products.

The EFCE Working Party on Loss Prevention and Safety Promotion in the Process Industries (WP Loss Prevention) began in 1971 as a group of very motivated professionals, who decided at the symposium "Major Loss Prevention in the Process

Industries", held in Newcastle upon Tyne, that in view of the safety situation at the time an international effort was necessary and found a "roof" for it in the EFCE.

The first international symposium was organized by an international committee and officially labelled "on Loss Prevention and Safety Promotion in the Process Industries" (LPS) was held on 28–30 May 1974 in the Aula of the Delft University of Technology in Delft, The Netherlands. The new approach to safety, "Loss Prevention" was originally directed to the prevention of large scale accidents and to set up measures to limit their possible consequences to acceptable levels. From the accident histories in the 1960s, much was learned (Pasman, 1998), as summarized in the following:

- the conditions that lead to an accident are often complex and difficult to reproduce;

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Table 1 – Topics at the 1st international symposium on Loss Prevention in the Process Industries 1974.

1. Emergency planning	7. Gas, vapour cloud and dust explosion
2. Guide lines for safe design	8. Transport and storage of liquefied gases
3. Hazards and operability studies	9. Vapour dispersion in the atmosphere
4. Insurance aspects	10. Explosibility, test procedures and results
5. Reliability engineering	11. Loss prevention through design
6. Safety organization	12. Case studies

- test methods were often inadequate for making reliable predictions;
- the effect potential for large mass was often underestimated;
- a system approach appeared crucial for successful prevention.

Starting from these considerations, a look at the topics of the first Proceedings, reproduced in [Table 1](#) with the original terms utilized in those days, can give an idea of the wide number of emerging issues connected to safety and loss prevention, which were relevant in the early seventies. One of the most urgent tasks was recognized to be the collection of sufficient relevant data to predict the reliability of technological systems over a given period of time. A good start was explained by [Green \(1974\)](#) presenting reliability data collected in the field of nuclear energy generation and the need of organizing a world-wide data collecting system for the process industry. In the same first symposium, while explaining how safety is good business, [Webster \(1974\)](#) commented “safety is rapidly emerging from a modest chrysalis of injury prevention to become a profit spinner supreme in the guise of damage and total loss control”. Moreover, he pointed out the need that top managers take a keen interest in accidents, so that the effort of the company are properly brought to bear on accident problems. As a matter of fact, we must remember that there was some hesitation in the 1974 LPS selection committee to accept the paper, in that talking about money should not obscure the ethics of safety. Mr Webster modified the title of his paper, which originally was called “Safety as a money spinner”. Sadly, the day after the Delft symposium, the vapour cloud explosion of the 2-years-old caprolactam Nypro plant, near Flixborough, U.K., which over the years became one of the most extensive investigated accidents ([Venart, 2004](#)), proved once again how urgent the study of safety issues was at that time.

2. The 20th Century evolution

Forty years of loss prevention and safety promotion in the process industries are well outlined by the LP symposium history, depicted in [Table 2](#) and showing the different hosting countries from the origin to nowadays, with attendance reaching over 500 delegates. Now the figure seems stable around

350–450, with shifts in affiliation and origin of the attendees. In particular, over the last years the percentage of delegates from industry decreased in favour of the number of professors, PhD students, and consultants. This shift seems in some way connected to economic reasons and possible funding cuts for basic safety research at the industrial level. The content of the different symposia reflects, at least to some extent, the evolution of Loss Prevention and the improvement in methods on risk analysis and assessment. Some milestones and examples of the ongoing evolution are summarized in the following.

Risk analysis as a methodology to describe and delimit the risk of chemical process operations was introduced in the mid-seventies to the then newly founded community of Loss Prevention in the process industry. The second and third LPS reflected this debate, focusing on what quantification is worth with definite pro's and con's, with a wide diffusion of Quantified Risk Analysis (QRA). The methodology borrowed from the nuclear industry was seen by some as a panacea but initially stirred up endless discussions and controversy based on misunderstandings on contents of concepts and differences in definitions. Also, from the start, there was an apparent qualitative versus quantitative dichotomy. The International Study Group on Risk Analysis, established within the framework of Loss Prevention Working Party in September 1980, presented the major findings of their work at a specialized session during LPS 1983, covering in a systematic and comprehensive way the up-to-date emerging issues related to risk analysis in the process industries, i.e. hazard identification procedures; consequence analysis; quantification of risk, and application of risk analysis. In the Eighties, “human factor” became an up-to-date issue and with good reason it was not believed by all people that this could ever be quantified. With equipment and single components becoming more and more reliable, emphasis is moving towards human factors not only in running the plant/process, but also in performing activities like maintenance for good quality of which ergonomics, prevention of error of omission, or lack of attention are important. Human factors must be taken into account already at the design stage.

At LPS 1986, a session on Human Factor was explicitly introduced for the first time, collecting five papers ranging from human factor and systems safety, to the incorporation of human reliability into probabilistic risk assessment. Since 1986 to nowadays, human factor represents an evergreen topic within the framework of each Loss Prevention Symposium. A report of the EFCE Loss Prevention Working Party ([Mill, 1992](#)) provides techniques for improving human behaviour within the context of Loss Prevention: motivation; social climate and environment; personnel management; instructions and procedures; avoiding stress, alcohol and drugs; adequate training; quality of provided information; discipline, and checking performance.

At the Oslo symposium the concept of loss prevention management was categorized by [Bond \(1989\)](#) by introducing the laws of loss prevention, respectively in connection with looking back at the past, thinking ahead to the future, and measurement attitudes, then established as:

Table 2 – EFCE Loss Prevention symposia.

1971 Newcastle, UK	5th LP 1986 Cannes, FR	10th LP 2001 Stockholm, SE
1st LP 1974 Delft, NL	6th LP 1989 Oslo, NO	11th LP 2004 Praha, CZ
2nd LP 1977 Heidelberg, DE	7th LP 1992 Taormina, IT	12th LP 2007 Edinburgh, UK
3rd LP 1980 Basel, CH	8th LP 1995 Antwerpen, BE	13th LP 2010 Brugge, BE
4th LP 1983 Harrogate, UK	9th LP 1998 Barcelona, ES	14th LP 2013 Firenze, IT

1. He who ignores the past is condemned to repeat it.
2. Success in preventing a loss is in anticipating the future.
3. You are not in control if a loss has to occur before you measure it.

The last one was connected to William Thomson (1824–†1907), known as 1st Baron Kelvin: “when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be” (Thomson, 1983).

According to Bond's view, the measure should be based on proactive type measurements, including actions that prevent the unwanted events from happening. And indeed, the process industry recently introduced in a systematic way the concept of “leading performance indicators”, which here was anticipated.

A milestone in the history of process safety in Europe was the foundation of the European Process Safety Centre (EPSC) in 1992. Bernard Hancock, a member of the Loss Prevention Working Party has been the leading promoter of this new competence centre, based in Rugby (UK). The Centre today has some 40 members, mostly large multinational companies, who use the Centre as a platform for experience exchange and benchmarking. Today EPSC is acknowledged by the European Commission and by CEFIC as the leading technical advisory group on process safety in Europe. EPSC has played a supporting role to the European Commission in their drafting of legislation that has relevance to and impact on process safety management. One notable example is the EU Seveso II Directive, where EPSC contributed to the Working Guidance documents produced by the Commission. EPSC also participates in the current round of mutual joint visits by competent authorities around Europe in order to best understand the issues and differences that are raised by the Seveso directives at the Member state level.

The concept of minimizing hazards or fostering inherent safety, based on the use of technologies and chemicals that reduce or eliminate hazards was reviewed at the 7th Loss Prevention Symposium by Kletz (1992) by recalling the basic principles of intensification, substitution, attenuation, and limitation of effects. Inherent safety, based on basic concepts known for more than one hundred years (Kletz, 1998), still represents a common sense approach but it is not common practice (Gupta and Edwards, 2002) and is one of the most successful topics in the symposium series. Kletz was a constant and enthusiastic speaker at several LP symposia, proposing some memorable and impressionable sentences, e.g. “what

you don't have can't leak”, “good safety is good business”, “the man in the middle” and “organizations have no memory”. His legacy (unfortunately, he recently passed away at age 91!) about the importance of inherent safety from the design stage and the need to learn and share lessons from incidents, are as true today as they have been in the past, and are the stimulus for further research on the topics, as highlighted in recent papers inspired by the above lessons (e.g. Darbra et al., 2012; Mannan, 2012; Fabiano and Currò, 2012; Tyler, 2012; Vaughan and Klein, 2012).

In 1991, 20 years after it was founded, the Working Party presented a position paper at the Achema in Frankfurt (Pasman et al., 1992), which in hindsight is a witness to how many years evolution takes. At the 1995 LP Symposium, Safety Management Systems was placed as the focal point on the programme. The past and future trends of topics that are considered within the process industry, on the basis of the lessons of the 1980s, was summarized by Visser (1995), as depicted in Fig. 1.

The following symposium, as the last one of the 20th Century (EFCE event n° 602), was held in Barcelona in 1998. Among other technical topics and case histories, the 1998 symposium focused in a more systematic way on the importance of safety as a factor in the management of business, on the harmonized occupational health, environmental, and safety management system and at last on how excellent “SHE performances” become synonymous with good business (Margetts, 1998). From a technical viewpoint, the papers on automated, highly reliable safety instrumented systems as a foundation for process protective structures, as fore-runners of the later IEC 61511 standard, are worth mentioning. Karydas and Houtermans (1998) addressed the evaluation of Safety Integrity Level (SIL) of Programmable Electronic Systems (PES) considering PES components, their failure modes and associated failure rates and utilizing appropriate tools, such as reliability block diagrams, fault trees, and Markov models.

3. Progress in the 21st Century

In the third millennium, the first symposium was held in Stockholm (EFCE event n° 620). At LP 2001, the concept of sustainability (operationally defined through the term “sustainable development” and its definition in the “Brundtland report”) was explicitly related to safety, health, and the environment as a complement and expansion of Loss Prevention, by adding design criteria that take ecological, economic, and social aspects into account (Lemkowitz et al., 2001).

The concept of Layer of Protection Analysis, LOPA, was developed in the United States in the late nineties, and was presented to the European process safety community as a

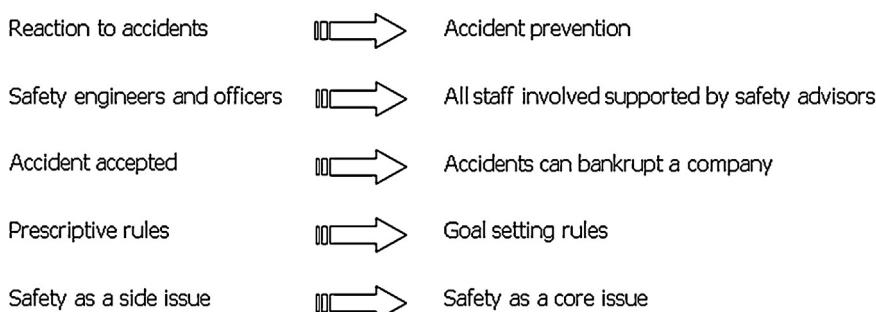


Fig. 1 – Past and future trends in process safety as formulated by Visser at the Antwerp LPS in 1995.

simplified risk assessment tool on the occasion of LPS 2004, the first symposium held in a Central European country, namely Czech Republic. LOPA became very popular and widely utilized, because it fit perfectly with the advent of risk-based engineering standards, such as IEC 61511, specifying SIL levels of reliability of Safety Instrumented Systems for reducing various categories of risk to a tolerable value. Making use of a risk matrix and defining a target line of consequence-frequency combinations permits rather simply, given the data are available, to set-up a cost-benefit assessment and to answer the question how safe is safe enough.

At the end of the Praha symposium, a number of challenges were identified:

- Too few methods, techniques, and technology exist to prevent and to rule out accidents, i.e. the loop from operational experience back to design has not been closed sufficiently.
- Few methods help to make plant operations safer, i.e. methods to identify systematically possible incident precursors in a running process, methods to analyze the installation, and operation top down risk reducing measures have not been developed.
- Development of sufficiently detailed models for emergency response planning is required to plan emergency operations and to support decision making in actual situations.

Over the years, we witnessed sharp improvements and progress in IT and computer technology, which were the subject of several papers presented at LP series. Examples included the integration of safety application tools with computer aided design (CAD) systems and with electronic permit-to-work systems, which were already suggested by Kletz. In the same LP Symposium, the concept of developing Just Culture applied to process safety was highlighted by Bond (2007), as a way of thinking that promotes a questioning attitude, is resistant to complacency, committed to excellence, and fosters both personal accountability and corporate self-regulation in safety matters. In other words, a Just Culture is all about continuously giving the right response to safety related situations and actions that can be judged from multiple viewpoints. In this context, the aviation industry provided useful indications for the development of a just culture in the process sector, adopting proper causation models based on Reason's "Swiss Cheese" approach (Reason, 2005):

- The Personal factor. It emphasizes the inadequate capability, lack of knowledge, lack of skill, condition of stress, or improper motivation leading to an unsafe act or condition and resulting in personal injury.
- The Workplace factor. It includes inadequate supervision, engineering, purchasing procedure, maintenance, and work standards. The work place factor has its origins in reliability engineering, and emerges from HazOp operations and risk analysis.
- The Organization factor. This model views human error more as a consequence rather than a cause, and it evolves from latent inadequacies and failing leadership or management systems.

In the last few years, new pressures and related safety threats have been developing rapidly, e.g., cost cutting and downsizing, plant complexity and ageing, early retirement, outsourcing, job-hopping, and complacency. Despite previous efforts, high profile process accidents still happen and

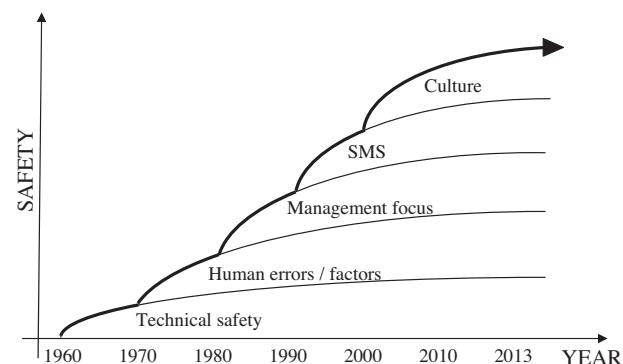


Fig. 2 – Contributions to process safety over the years as originally shown by Visser at the Antwerp symposium in 1995, but later extended by Pasman and Suter (2004).

emphasize the importance of process safety performance metrics to enable and maintain good safety management. As already been recommended before, with the publication of the Baker Report (2007), triggered by the 2005 Texas City Refinery tragedy, it became obvious to the chemical industry that process safety leadership and incorporation of process safety into management decisions cannot be achieved without measuring and reporting process safety performance. To sustainably maintain and continuously improve process safety culture, it is at the same time essential that process safety performance indicators, both lagging and leading, are meaningful and easy to understand for the entire organization from shift workers, plant engineers, and plant managers to top management. In addition, the last decade evidences the importance of culture (and consequently the value of education) as a major contributing factor to the improvement of safety performance.

The evolution, over a time span of fifty years, as clearly depicted in Fig. 2, was modified by Pasman and Suter (2004) after the evolution was originally expressed for safety management by Visser (1995). Some of these topics were presented, either as theoretical frameworks, or as applicative case-studies at the 13th symposium held in Bruges.

In detail, some challenges of process safety implementations in the process industry were here presented by Mannan et al. (2010), by showcasing the main problems still unresolved, summarized as follows:

- organizations have no memory;
- insufficient attention to leading indicators;
- increasing complexity of process operations and lack of communication;
- need for better solutions (and respective research needs).

Some illuminating new challenges were proposed in the closing keynote of the same symposium by Pasman (2010) while commenting on resilience as an aspect overarching and integrating the operability, flexibility, and controllability of a system. He proposed resilience engineering as an emerging analysis and management tool to maintain overview, discover trends, correct course, cope with transients, and provide a better grip on abnormal process states, without ending in an unsafe state.

So, while looking back, the community succeeded in getting better control over the risks of operations. Attention shifted from explaining after the fact how the accident had occurred, via designing and implementing protective measures, towards prevention by inherent safer features and

Table 3 – 14th EFCE Loss Prevention Symposium topics.

1. Risk Management and Regulatory Issues	3. Learning from Accidents and Knowledge Transfer
Hazard identification	Lessons learned from accidents
Risk assessment and evaluation	Identification of root causes
Consequence modelling	Implementation of lessons learned
Siting and land-use planning	Knowledge transfer
Regulatory issues (REACH, ATEX, SEVESO, GHS, PED)	Teaching methods and tools
Technical issues	Experience from other industries
Impact on Small Medium Enterprises	Communication and education
Regulation in developing countries	4. Process Safety Engineering
Transport risks	Safety critical systems
Security risks	Sustainability
Impact of natural hazards	Inherent safety
Novel assessment methods	Designing for safety
Risk communication	Fire and explosion mitigation
Crisis management and emergency preparedness	Plant layout and domino effects
2-Human Factors and Management Systems	Biotechnology
Human factors in the control of major hazards	Laboratory and pilot scale plants
Ergonomics, including the design and manning of control rooms	Nuclear energy safety
Competence and capability	Resilience engineering
Safety culture	Emerging technologies
Process safety performance (indicators and metrics)	5-Material Hazards
Process safety education and training	Hazards from novel or emerging technologies
Organizational change	Material hazardous properties
Outsourcing and subcontracted activities	Hazards of nano-materials
Health, safety, environment and security management systems	Chemical reaction classification (REACH, GHS)
Contract manufacture	Predicting hazardous properties (computation, QSPR)
Asset integrity	

rethinking the processes. These trends do not hold only for safety, health, and environmental protection, but of course also for product quality, energy management, and process operability (Pasman and Suter, 2004). Resilience engineering, a system approach to process safety, knowledge improvement on human interaction and reliability in complex systems can represent promising challenges for further development. On this basis, in the programme of the 14th LP Symposium, some new topics were introduced, also taking into account EFCE efforts to transmit the key messages relevant to:

- Relation between safety and economics.
- Relation between safety and customer perception.
- Importance of long term sustainability.
- Personnel safety and process safety differences.
- Importance of creating a blame-free culture.
- Importance of accident and risk communication to the public.
- Importance of senior management's role in internal safety communication.
- Importance of appropriate process safety indicators and metrics.

The papers of this 14th symposium fall into five groups relating to five major topic areas, resulting from the experience of the previous symposia and properly updated by the present scientific committee, as summarized in Table 3.

This grouping triggered a trial whether a trend over the whole history period can be observed. However, over these 40 years the degree of diversity and names of themes changed much, and no standardized indices on the proceedings exist. When a categorization of lectures is made in four groups (taking categories 4 and 5 in Table 3 together) a rough quantifiable comparison basis is found. As presented in Fig. 3, proportional changes in themes are modest, although the content of lectures varies greatly over the years.

The programme features the work of researchers, engineers, regulators, and consultants from 41 Countries, reflecting again the worldwide attention and interest in the event, even though under the present global economic crisis.

4. A future perspective on process safety/research

The final paper in the 2013 Florence symposium had a focus on future needs and new future possibilities.

4.1. Process Safety Research Agenda for the 21st Century

In October 2011 on the initiative of Sam Mannan, Director of the Mary Kay O'Connor Process Safety Center of the Chemical Engineering Department of the Texas A&M University, a group of process safety professors from various parts of the world reviewed the state of affairs and wrote the Process Safety Research Agenda for the 21st Century. To make progress in process safety concepts, approaches, and methods, the low hanging fruit has already been harvested. Further progress can only come through research in depth.

During the first day of the agenda meeting, presentations by various participants were given on their vision of the future and current problem fields. On the second day, break-out sessions were organized to discuss priorities, while the meeting was closed following reports from the sessions. The draft agenda text has been circulated to the participants for comments. The printed agenda is downloadable (PSRA, 2012). It contains beside an Executive summary and an Introduction, a chapter on the various processes considered and their safety issues, an overview of the expertise areas that can be distinguished within the field, and the achievements made in process safety with the open ends. As further preparatory work, recent developments in science and engineering relevant to process safety are summarized, as illustrated in Fig. 4.

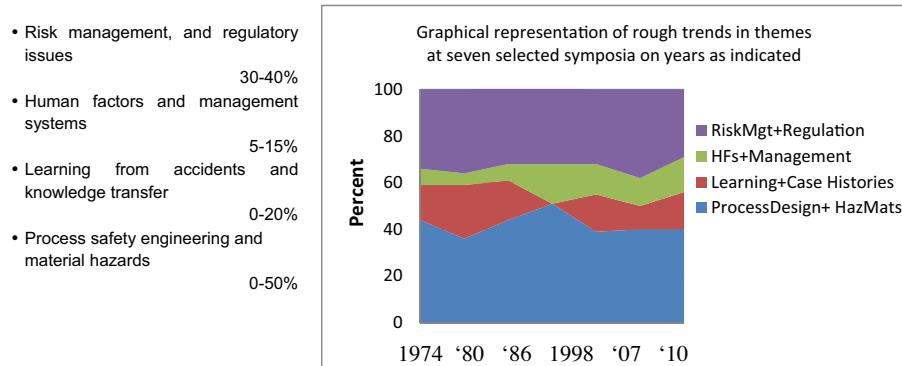


Fig. 3 – Trends in size in terms of number of papers in themes presented at the Loss Prevention symposia.

Also, the future of the process industry and the expectation of society have been discussed. Despite the products of the process industry, which are fulfilling many daily needs, the public tolerance level for acute and environmental risks remains low and a severe mishap with injuries and fatalities, certainly when these are ‘outside the fence’ can mean ceasing production or at least investment in costly, additional measures.

Venkat Venkatasubramanian of Purdue University made an important contribution to the meeting by pointing out how systemic failures in complex engineered systems occur, the challenges complexity presents to engineers, and in what direction solutions should be sought. He published about this topic separately (see Venkatasubramanian, 2011), and in the paragraphs below this relatively newly recognized problem field of complex systems control is given more attention. Systems' thinking shall be the core competence of the chemical engineer.

Venkatasubramanian's presentation covered too the neglect of process safety in chemical engineering teaching and research, despite, e.g., the Safety in Chemical Engineering Education (SACHE) programme of the Centre of Chemical Process Safety (CCPS). There are more than 100 universities in the U.S. with a chemical engineering department, but only a handful of professors are actively working in process safety. The majority of departments limit themselves to requiring

the students to write a safety report and wearing personal protective equipment in the laboratory. The National Science Foundation is not giving the subject any priority. In Europe the situation differs from one country to another, but also there in several countries process safety teaching and research efforts are on the decrease or have disappeared, as was concluded at the dedicated, two-day conference on Process Safety Competence during the 8th European Congress of Chemical Engineering in Berlin in September 2011 (ECCE-8, 2011). Due to the occurrence of numerous accidents investigated by the U.S. Chemical Safety and Hazard Investigation Board, ABET, the U.S. Accreditation Board of Engineering and Technology, has modified recently the chemical engineering curriculum requirements. Starting in 2012 the student should obtain sufficient knowledge and know-how to operate chemical process equipment not only in a technical sense but also in conformance with health, safety, and environmental regulation. In Europe, in some areas the trend is positive, e.g., the KU Leuven in Belgium developed a new thrust by establishing several chairs in aspects of process safety, and meanwhile in Delft in the Netherlands also a new spirit seems to emerge.

The meeting defined 19 research topics and prioritized these according to relevance for process safety, or more in detail according to loss prevention potential, historical losses, knowledge gap, cross-cutting benefits, multiple application,

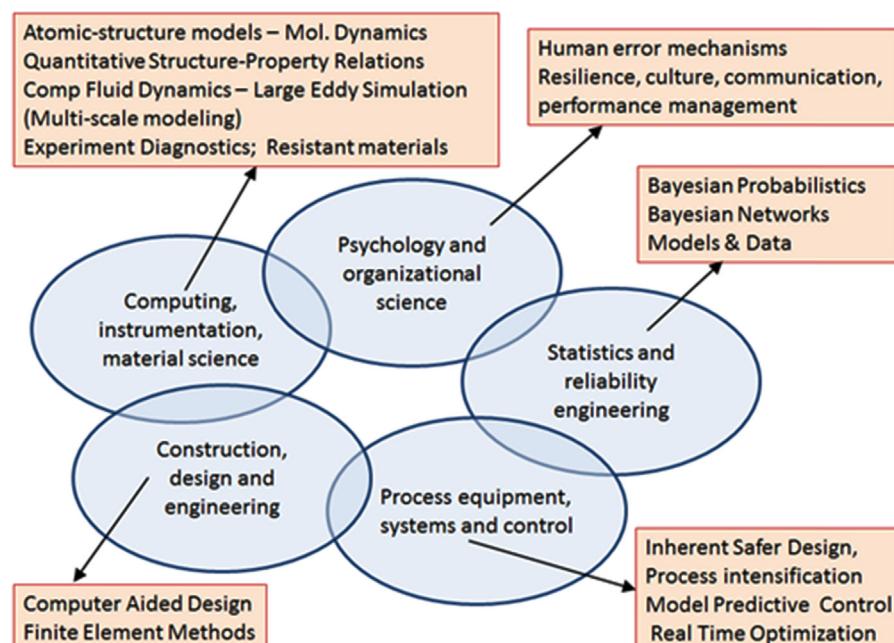


Fig. 4 – Developments in science and engineering relevant to process safety.

Table 4 – Prioritized research topics according to the Process Safety Research Agenda 21st Century.

1	Hazardous phenomena	10	Safety culture
2	Inherently safer design	11	Mechanism to import process safety into emerging technologies
3	Risk management	12	Safety technologies, layers of protection and mitigation systems
4	Consequence analysis	13	Life cycle/maintenance
5	Critical infrastructure protection	14	Process safety management knowledge: transfer, improved access; dissemination
6	Complex systems	15	Standardization of process safety methods
7	Resilience engineering	16	Integration of data bases for improvement of process safety
8	Integration of process safety with occupational safety	17	Easy-to-implement process safety methods for industry
9	Organizational/human factors: distinguish between technology and people	18	Application of process safety to drilling operations
		19	Natural hazard triggering technological disasters (NaTech)

potential for international collaboration, capacity building potential, and input/output ratio: investment incentives helping the process safety business case, and finally time-scale and cost constraints. In [Table 4](#) the 19 topics are listed.

Each topic is further elucidated in the agenda. Also, clustering of related topics is possible and also a classification in technical safety and organizational safety topics, as shown in [Table 5](#). Finally, the agenda contains an additional table of the 19 topics with their respective integrating concept and their implementation mechanism, as, e.g., for topic no. 1: 'substance property' and 'standardization'.

The last chapter of the agenda is on globalization and international collaboration, addressing such topics as the challenges with academic funding in view of the clear and global need of academic research. It makes the observation that as a 'business case' the costs of investment in education and research could easily be justified against the costs to repair the damage of a preventable accident. It also makes the observation that although many organizations are involved in process safety research, there is no global structure to coordinate the research. Objectives for a globally spanning organization are described and some actions suggested.

4.2. Shift in problems, new approaches

As can be observed from the shift in emphasis in symposium topics described in [Section 3](#) and the shift in problems mentioned in the Research Agenda as lack of overview due to complexity, misdiagnosing of abnormal situations, and risk management failures, a new holistic approach and supporting tools will be welcome. It is not coincidental that the topics at the bottom two rows of [Table 5](#) are the ones that appear both at the technical and organizational side. We must consider the system as a whole. In the present 14th LP Symposium, [Pitblado and Nelson \(2013\)](#) emphasized this in their paper with respect to barrier management. In this regard during the last few years some interesting progressive developments can be observed. Below, these are briefly summarized.

James Reason ([1990](#)) from a psychologist viewpoint, gave us insight with the Swiss-cheese model into accident causation and human error in the early nineties. In reaction, and also because of growing installation complexity and cost cutting, industry automated and installed safety instrumented systems supplemented with safety management, performance indicators, and promotion of safety culture. A drawback of more complex installations and of automation appeared to be the phenomenon of alarm flooding, while for quick fault diagnosis and suitable contingency no general cure still exists.

More recently, another psychologist, [Hollnagel \(2009\)](#), stressed that for determining failure probabilities human acting cannot be decomposed the same way as a technical system. He even uses the word 'resonance' for a sudden and not readily reproducible interaction of 'frequencies' of human acting causing errors. Accidents can therefore not be fully understood from a static, components connecting structure with expected values of probability as, e.g., a bowtie. Dynamics in couplings are involved, making an event path intractable, which increases uncertainty. He also points out that we have to act continually to balance thoroughness of decision making versus the time constraint dictated by efficiency. He calls this the ETTO or Efficiency-Thoroughness Trade-Off principle. This places in fact a person continually in decision dilemmas that adds to the variability of consequence. Where previous accident causation models such as the Swiss-cheese model, although complex, may still be called linear with respect to its cause-effect structure, we have in fact in case of systemic failures to deal with non-linearities by concurrence of multiple dependent factors. Together with David Woods of Ohio State University and Nancy Leveson of Massachusetts Institute of Technology, he took the initiative of proposing resilience engineering as a "paradigm for safety management that focuses on how to help people cope with complexity under pressure to achieve success" (cit. [Hollnagel et al., 2006](#)).

Resilience is used here as the ability to recover a process from unforeseen and unexpected disturbance that potentially leads to mishap. Risk assessment aims by its identification step at predicting all that can go wrong, but the new insight is that given prediction will be incomplete, more is necessary to avert disaster. Even if all possible routes to an abnormal situation are predicted, the non-linearity adds to the uncertainty about how often one can expect the event to occur. This is all with regard to the human factor, but if from an engineer's perspective one decomposes a technical item to a sufficiently deep level of detail, causation becomes blurred too as, e.g., with fracture mechanics at the molecular level. Anyhow, for prevention these mechanisms forces focus on flexible, timely, and adequate risk control both from an organizational as a technical point of view. It is clear that the earlier a disturbance is detected and recognized as a potentially hazardous precursor, the more effective possible recovery may be realized.

[Leveson \(2011\)](#), following [Rasmussen \(1997\)](#), stressed that for a system approach, first the system has to be carefully defined with its hierarchy, functions of the elements, and information/feed-back flows among them ([Fig. 5](#)), and further that safety is an emergent property of a system. Such properties are controlled by imposing constraints on behaviour and

Table 5 – Categorization of research topics of Table 4 according to their main character.

Topic no.	Technical safety topics	Topic no.	Organizational safety topics
1, 11	Hazardous phenomena, properties of substances	8	Process and occupational safety
2	Inherently safer design	9, 10	Human factors, safety management, safety culture
12, 13, 18	Safety technologies, protection layers, drilling	14, 15, 17	Knowledge transfer, learning, standards, easy methods
3, 4, 5, 16, 19	Risk assessment, consequence analysis, NaTech	3	Risk management, decision making
6, 7	Complex systems, resilience	6, 7	Complex systems, resilience

on interaction amongst components. Unintended releases of hazardous materials result from inadequate control, which can stem from wrong or absent (dysfunctional) interactions and not only from component failure. Causation is asking why controls fail. Organizational erosive processes following, e.g., budget pressures, may lead to decline of safety culture, maintenance quality, and operational alertness. Advancing from the system view, Leveson developed a holistic approach to identify potential failures of complex techno-social systems by the System-Theoretic Process Analysis, STPA, a kind of HazOp. This predictive method stresses in its queries not the type of deviations, their causation, and required preventive or corrective measures, but rather given a hazard to the system and the safety constraint to keep the system within the safe envelope, what risk controls must be applied, within what time window, in what sequence and duration. The method shall be applied on both the entire technical and organizational structure of a process plant from design to operation and including regulation and inspection. The accidents that her group investigated showing the features of the approach, have been of diverse nature: process industrial, aerospace, financial/economic, traffic. So far, however, it is rather top-down, the grand picture, and less on a level of the many operational and technical details to make the approach predictive in providing scenarios, which in a quantitative sense can serve to initiate a risk assessment instead of explaining an accident in hindsight. On the other hand, the approach makes clear that process safety and process control should be more closely linked.

Venkatasubramanian (2011) who performed with his group at Purdue university much research in process control and

fault diagnosis (see, e.g., Venkatasubramanian et al., 2003), mentioned three areas important to overcome the systemic failures as, e.g., with the Deepwater Horizon offshore rig disaster. The first research area is complexity science to reveal systemic failures due to dysfunctional component interactions, which come on top of the familiar component failures, which traditionally have been unrealistically assumed to be independent. This is where Leveson's STPA will help. The second is multi-perspective modelling of the system structure comprising material and information flows, predicting its behaviour under various conditions including abnormal ones and its impact on intended functioning. This is where the BLHAZID tool of Cameron and his team will become useful as explained below. Finally, the third, building on the previous two, is development of hybrid intelligent prognostic tools for decision support. On the operator level it will provide better situational awareness by real-time monitoring of a system's risk level in anticipation of mishap and suggest timely corrective actions. For this objective, process modelling and simulation will be brought together with data-driven empirical methods. It is expected also to support economic process optimization and provide management information needed for optimum decision making.

4.3. New and improved tools

A team guided by Ian Cameron (see, e.g., Seligmann et al., 2012) recognizing the implications of a socio-technical system, developed an improved process hazard identification tool called Blended Hazid or BLHAZID. It consists of the combination of function failure driven, modified HazOp (Hazard and Operability study) and component failure driven FMEA (Failure Mode and Effect Analysis) in a functional systems framework setting (Fig. 6). The approach generates synergy of the two traditional methods. A system consisting of sub-systems comprises here plant, people, procedures, and components, while their functions, which deliver the system's state, are determined by their capabilities. A delivered state should match the desired state intended by the design. For all sub-systems on the basis of available sources such as process knowledge and other design information, P&IDs, and measured variables, a limited set of so-called characterizing variables (c-vars) is defined of which deviations in value cause function failure (FF) and by its impact a hazard scenario. Capabilities, c-vars, and other quantities are quoted in computer storable semantics, e.g., a pump is capable of <increase><pressure>. The HazOp information is generated through <guide word> and <c-var> and packed as the triplet syntax: <cause><deviation><impact>, while in case of component failure (CF), FMEA leads via a <failure mode> to a <cause><failure mode><implication> triplet. Each triplet element can itself be a FF or CF, so that possible BLHAZID triplets are: (FF, FF, FF), (CF, FF, FF), (CF, FF, CF), (FF, CF, FF), (CF, CF, FF), and (CF, CF, CF). Elaboration making use of technical, human factor, and procedural knowledge sources produces even for an

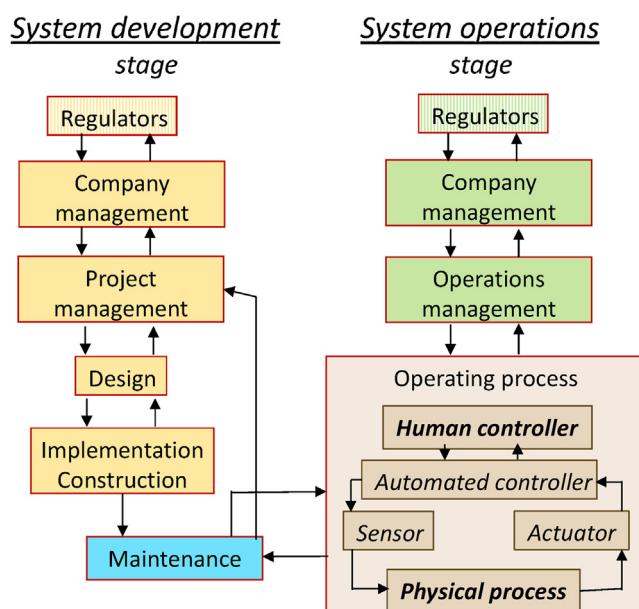


Fig. 5 – Hierarchical socio-technical system with levels connected by control flows, after Leveson (2011).

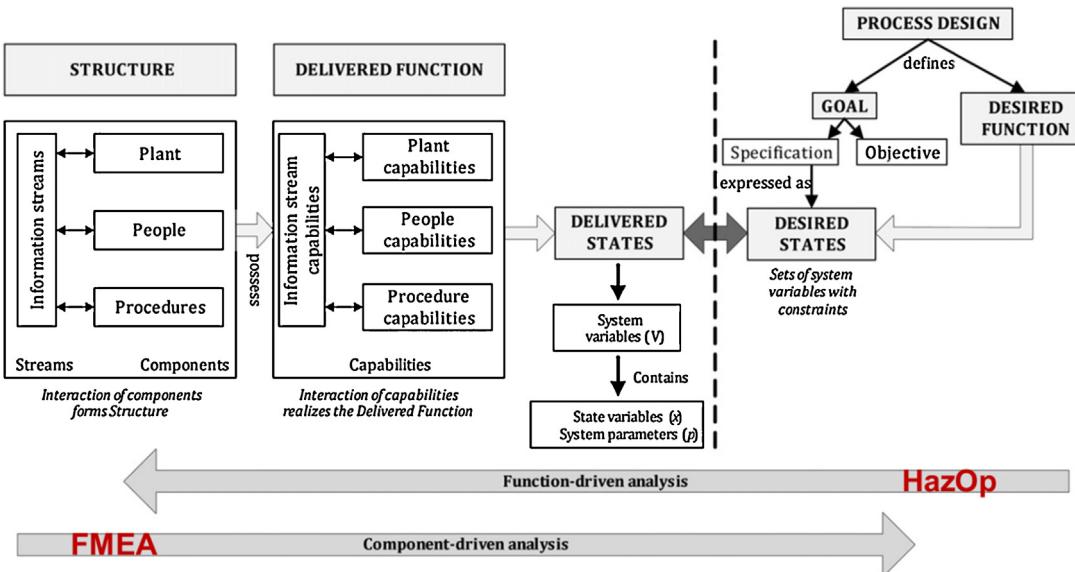


Fig. 6 – Functional systems framework for investigating impact of deviations of variable values from design intent and effect of component failures to identify system hazards, after Seligmann et al. (2012).

installation of modest size a huge number of triplets. The computerization makes it not only more practical for design, but also more easily storable and transferable. As the stored information can generate by itself cause-effect relations among parameter deviations of the various installation components, it will also be suitable for fault diagnosis as presented by Nemeth and Cameron (2013) in the 14th LP Symposium. Also, such a causal network may serve as a basis for operator training and provide the intelligence needed for effective alarm management and reduced alarm flooding. According to the developers (I. Cameron, personal communication, March 2013) the tool is close to a deployable stage.

In this connection the progress in fundamental causality theory by the work of Pearl (2009) is very helpful for developing scenario models of cause-effect chains, such as Bayesian Networks (BNs) built on the Bayesian theorem stating that prior probability can be updated by new evidence to a posterior probability. Or in other words, effect probability can be calculated conditional on the probability of its causes. Once a causal network has been formulated, BN enables predictive and diagnostic reasoning making use of physical relations, empirical data, deterministic, and probabilistic or even fuzzy quantity values, while keeping track of uncertainty. These networks, in which each node represents a (random) variable, can readily be used to optimize for instance a system of layers of protection (see Fig. 7) or perform a full risk assessment. In fact, they are more versatile and powerful than Boolean (true/false) logic diagrams, such as fault tree, event tree, or bowtie and may form a unifying infrastructure including FMEA and HAZOP. Indeed, research should be undertaken to find out how the causal graphs generated by BLHAZID can be transformed into BNs. The networks also open possibilities to model beside ‘hard’ failures of the technical system the ‘soft’ ones of the management system, as the links (arcs) between nodes can model weaker, fuzzy influences obtained in a quantitative sense by indicators or expert elicitation. Process safety performance indicators form a powerful pool of data on the functioning of an organization. BNs will be able to process the data through aggregation while keeping all information on fluctuations that otherwise by averaging would

be lost. Together with other background factor values such as management characteristics and more direct signals from plant (e.g., corrosion) or environment (e.g., weather), influences on the risk level of parts or an entire installation may be determined and checked against collected historical data and expert judgement. Because the networks can also be made to reflect the dynamics of a technical process and its organizational constellation, an overarching methodology might be developed to identify the risks, judging the adequacy of its controls, and to diagnose on the basis of the lagging and leading indicator signals trends in the performance of the management system and in overall risk control. By introducing adequate alarm thresholds, such a system can help to maintain a high process safety level on the longer term, while supporting optimum cost-benefit decision making.

While it can make use of the Bayesian Network infrastructure, now available, traditional risk analysis must perform its present tasks of assessing risk of designs and lay-outs to optimize plant safety, land use planning, and emergency response, but in addition it must support resilience analysis and the decision making support to overcome the problems of losing overview induced by complexity. To that end, the methods and the data used must be steadily improved, because accuracy of calculated risk is currently only within one or two orders of magnitude. The main causes are the variability in scenarios, certainly when one goes into details, and the assumed equipment failure rates, let alone human factors influence. In consequence analysis, continuous improvement is visible mainly thanks to computational fluid dynamic models, although large and expensive tests needed for validation have become very scarce. With better use of historical data, of more knowledge about human reliability, and again embedded in BN infrastructure, it should be possible to further improve; see also Pasman and Reniers (2013).

The methods summarized above will certainly lead to trials to develop more real-time intelligent systems either aiding designer and operator or partly further automating, although the degree of complexity should not be underestimated and where deviations of the normal occur, complexity will require more highly educated operating management. So, even if their

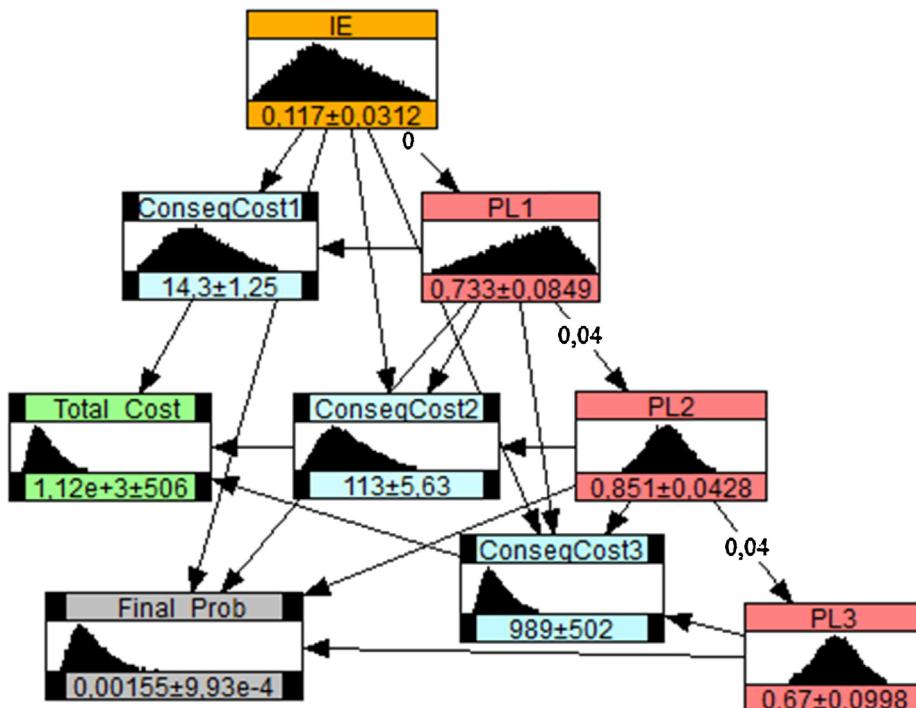


Fig. 7 – Example of a Bayesian network for calculating the annual overall failure frequency of a system of three layers of protection, the total annually expected cost of ownership, and overall damage (mean 1120 \$/yr, standard deviation 506 \$/yr) given an estimated triangular distribution of the initiating event frequency (IE), triangular distribution of probability of successful acting on demand of Protection Layer 1 (PL1), a lognormal one of PL2, and a normal one of PL3, with a common cause failure probability of the PLs, using UniNet software (see References [UniNet](#)). Information on assumed costs is given in [Pasman and Rogers \(2012\)](#). Probability data are arbitrarily chosen and can be given any distributional shape. Figures below the distributions shown are mean and standard deviation. Updating of the network on a laptop with new data (e.g., on protection layer improvements) is almost effortless.

contribution would become proven, the introduction time will be extensive, as it must be incorporated into the overall renewal of a plant's process control.

5. Conclusions

As summarized in this paper, the Loss Prevention symposia series has been successful in stimulating and sharing both theoretical and practical knowledge among the Loss Prevention community for a time span covering forty years. There have been great advances in knowledge, however, and also complexity and economic pressures have increased. In view of economic pressure, [Reniers and Sorensen \(2013\)](#), contributed a paper on optimal allocation of safety and security resources to the 14th LP Symposium. Although judging fatality and injury levels in general, the process industry can be regarded as a safe industry, the potential of major hazards is present, and risk control is certainly not guaranteed. Work on further improvements is a must and a perspective exists to help guide progress. Process safety has always been required to respond to the demands of innovations in technologies and societal developments, and the next decade will be no exception to this. Currently, there are new challenges.

New materials. Innovative materials will require new concepts in safety. In particular the broader production and application of nano-materials will cause a demand for new approaches in process safety. As an example, many standard test methods can no longer be used for these materials, either because they are not adequate or because they are not acceptable in view of work place safety in the test laboratories. The same applies also for highly active pharmaceutical

substances. Because of its higher reactivity, dust explosion properties of nano-particles are being investigated ([14th LP Symposium Murillo et al., 2013](#)).

New technologies. Numerous standard chemical processes have been transferred from Europe to Asia, in particular to China, and to the Middle-East in the past decades. New technologies and processes with a potentially higher added value were required to compensate for this industrial drain. These new processes often are carried out at very high temperatures and/or in unusual pressure ranges. Material properties under these conditions are largely unknown, and methods to evaluate them must be developed. Subsequently, new safety concepts must be derived based on the respective findings.

Examples of extreme process conditions are deep water oil drilling, shale gas processing, and process intensification (high pressures, high concentrations).

The use of new energy sources (hydrogen, LPG) not only in industrial sites but also in daily life (car fuelling) introduces new hazards that require new safety concepts, both along the supply chain, the sales points, and in the vehicles.

Hazards related to new technologies associated with Carbon Capture and Sequestration (CCS) are another upcoming challenge to process safety.

Competence sharpening-up. One of the major concerns is the loss of process safety competence in Europe. In the two decades of process transfers from Europe to Asia and the Middle-East, there was little interest in industry to invest in process safety research and development of know-how in this field. As a consequence, Process Safety Engineering was not considered to be an attractive professional career by students, with the result that today there is a lack of young safety

professionals and a lack of courses to educate. In many fields we are living from the experience of professionals at the end of their career. This issue has been identified by EFCE, and more specifically by EPSC, who organized several workshops on this topic. At the 8th European Congress on Chemical Engineering in Berlin in 2011, this issue obtained much attention in a two-day symposium specially dedicated to this problem. *ProcessNet (2012)* of DECHEMA reported about this event. UK's IChemE survey on education and the European wide equivalent organized by the Working Party are being held to further investigate the need and level of competence.

New approaches and methods as shown in Section 4. Hence, we shall welcome a new generation of process safety professionals with a broad interest in both technical and human/organizational aspects of loss prevention and process safety for the benefit of the European process industry and our economies, and we are looking forward to our next 2016 symposium in Freiburg, Germany.

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